ENVIRONMENTAL RESEARCH LABORATORIES PROGRAMS AND PLANS

FY 1985 PROGRAMS AND FY 1986 PLANS

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

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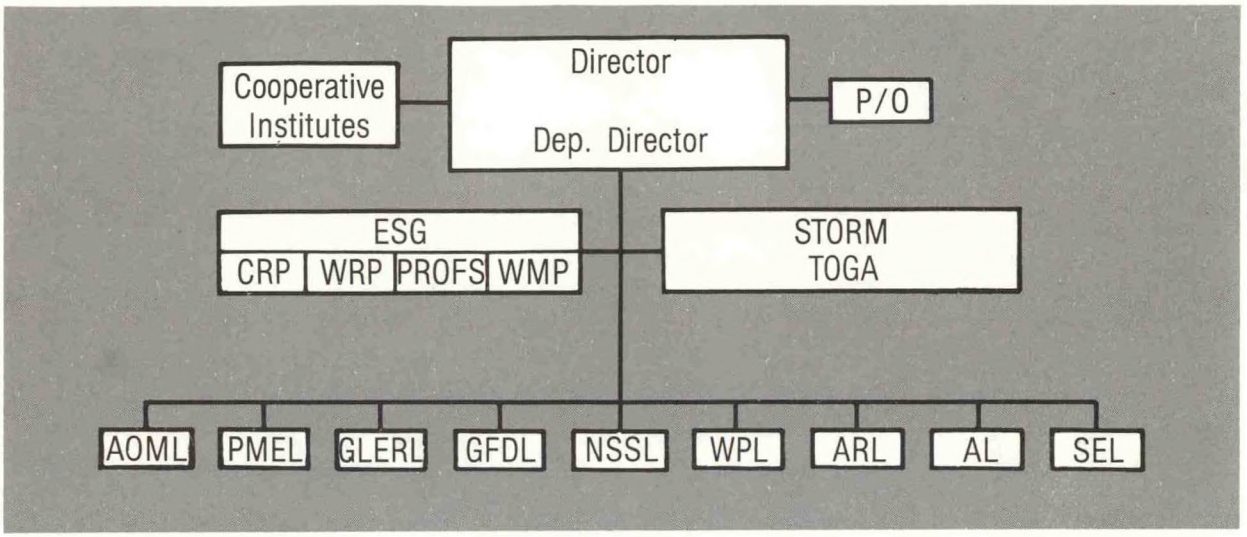


The mission of the Environmental Research Laboratories (ERL) is to conduct an integrated program of fundamental research, related technology development, and services to improve understanding and prediction of the geophysical environment comprising the oceans and inland waters, the lower and upper atmosphere, 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 Office of Oceanic and Atmospheric Research and have their headquarters in Boulder, Colo. They include major units located throughout the United States:

Aeronomy Laboratory	Boulder, Colo.
Atlantic Oceanographic and Meteorological Laboratory	Miami, Fla.
Air Resources Laboratory	Silver Spring, Md.
Environmental Sciences Group	Boulder, Colo.
Geophysical Fluid Dynamics Laboratory	Princeton, N.J.
Great Lakes Environmental Research Laboratory	Ann Arbor, Mich.
National Severe Storms Laboratory	Norman, Okla.
Pacific Marine Environmental Laboratory	Seattle, Wash.
Space Environment Laboratory	Boulder, Colo.
Wave Propagation Laboratory	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. Many ERL research efforts rely on the cooperation of other NOAA elements, including NESDIS, NOS, NMFS, and the Office of Aircraft Operations.

ERL's program includes fundamental research to develop technology and improve NOAA services to the public. Samples of outputs are Doppler radar technology (to improve tornado detection and warnings), mathematical models (to predict climate and ocean 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, National Environmental Satellite, Data, and Information 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 five subject areas:

Weather observation and prediction
Climate and air quality
Ocean and Great Lakes prediction
Marine resources
Solar-terrestrial research and services

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

WEATHER OBSERVATION AND PREDICTION

Weather Observation and Prediction includes programs of AL, AOML, GFDL, NSSL, ESG (WRP, PROFS, WMP), WPL, and the joint institutes. These programs interact directly with Ocean and Great Lakes Prediction 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. Weather programs include research on observational systems, modeling and prediction, severe storms, hurricanes, sea-air interaction, cloud and precipitation processes, mesoscale meteorology, synoptic weather, and transfer of technology.

Observational Systems

The Boulder Atmospheric Observatory 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. Smaller scale research concerns low-level winds and wind shear, of importance to aircraft operations.

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 continues on flow and precipitation fields within severe thunderstorms in support of the interagency NEXRAD Program whose goal is to produce a national Doppler radar network in the late 1980's. Also 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 NOAA 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 gather important research data in the lowest 100 km of the atmosphere. Radar systems at Platteville, Colo., and Stapleton International Airport, Denver, and three other sites in Colorado are used for real-time wind-speed and wind direction data, and are research prototypes for the Profiler system being developed, to enhance radiosonde wind-profiling capability. Microwave radiometer devices for vertical sensing of water vapor and liquid water are also part of this Colorado network and are research prototypes for

the Profiler system, also to enhance 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 efforts in ERL have several goals. In the large scale, goals include the following: to develop or improve atmospheric prediction models in the 5- to 30-day time frame (for application by 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 study of small-scale features within hurricane systems; and production of accurate numerical simulations of mesoscale processes, to understand the role of synoptic-scale parameters in severe-storm generation and evolution.

Severe Storms

Severe-storm researchers acquire data with specially developed instruments, and analyze 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.

Instrumentation developed in ERL for this research includes surface networks, 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

Hurricane research involves three major activities: (1) Hurricane field research assembles the descriptive data needed to support analytical and theoretical studies to improve the understanding of hurricane structure and behavior. The ultimate purpose is to improve operational NWS prediction of hurricanes. The field program makes use of air- and ground-based radar, aircraft, and satellite observations. Uniquely well-equipped NOAA aircraft fly for approximately 200 hours per year. 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) Hurricane modeling activities seek to develop and improve models for hurricane track prediction, mesoscale dynamics, and statistical track forecasting. (3) Hurricane prediction research 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

Sea-air interaction research 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 model predictions of waves and storm surges, to test hypotheses and understandings, and to validate or improve the models.

Cloud and Precipitation Processes

Research on cloud and precipitation processes involves numerical modeling of convective clouds to predict precipitation and phenomena such as downbursts that are hazards to aviation. To support these experiments, 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 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 non-spherical 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. In field programs, research aircraft penetrate hurricane circulations to gather data on structural characteristics, ranging from cloud microphysical to digital radar data. The observational efforts contribute to the development of numerical models of hurricanes.

A 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 four 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

Mesoscale research includes the study of atmospheric processes, with particular emphasis on meso-alpha-scale convective systems. 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 can reliably detect destructive tornadoes many minutes before they produce damage.

ERL, NWS, and NESDIS cooperate to improve local weather information service systems for NWS. System designs incorporate many advances of 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.

CLIMATE RESEARCH

Climate Research includes programs involving eight Laboratories and four joint institutes. Climate programs interact directly with other major programs such as Air Quality, Solar-Terrestrial Research and Services, and Ocean and Great Lakes Predictions, and on shorter time scales, with Weather Observation and Prediction. Climate programs include ocean-atmosphere studies; observation and analysis of solar, atmospheric, and stratospheric variability; and climate modeling.

Ocean-Atmosphere Studies

A major ocean-atmosphere program, Equatorial Pacific Ocean Climate Studies (EPOCS), is investigating the physics and dynamics of the coupled ocean-atmosphere system in the equatorial Pacific as part of the international Tropical Oceans and 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.

Another major program, Subtropical Atlantic Climate Studies (STACS), 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 measurement of electromagnetic induction from communications cables, and use of coastal tidal stations.

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.

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; recently completed 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 focus on air quality changes that might affect climate, with special emphasis on carbon dioxide. 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

Mathematical models of the atmosphere, the oceans, and the coupled fluid system are constructed to simulate the large-scale features of climate variability. The 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. Ocean circulation studies, also central to climate research, 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 and thermodynamical 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 climate 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.

AIR QUALITY

The goal of this program 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 effects 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 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.

The Atlantic Oceanographic and Meteorological Laboratory (AOML) and Pacific Marine Environmental Laboratory (PMEL) conduct research on the natural marine sources of tracer constituents and pollutants.

Ozone

In recent years, the chemistry of the stratosphere has been of great interest because of the recognition of human potential for inadvertently affecting the ozone layer, with disastrous consequences. First, the possibility of an ozone reduction from water and nitrogen oxides released in stratospheric flights of supersonic transports was considered. This problem brought worldwide attention to the potential for global air pollution problems. More recently, chlorine-containing halocarbons and nitrogen fertilizers have been labeled potential threats to stratospheric ozone. In addition to the effects on biological systems, ozone loss may also precipitate climatic changes.

The ARL monitoring program calibrates ozone measurement devices used at three ARL sites and other worldwide ozone-monitoring sites. AL is conducting measurements 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 of 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 has been 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. Depending on wind condition, the site can be used to examine the "clean air" from the west and the relatively polluted air from the Denver metropolitan area to the east. The site is being used to test current understanding of the photochemistry whereby NO_3 is formed from NO and NO_2. 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.

AOML and PMEL scientists have found natural sources of acid rain precursors in the Gulf and the North Pacific Oceans. 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. It has been found that the only natural marine source with potential significance is the Pacific Coast. In complementary 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 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 goal of ERL modeling research is to understand the formation, transport, and chemistry of atmospheric trace constituents. Such understanding requires judicious combinations of theoretical models and specialized observations. The understanding gained will be applied toward evaluating the sensitivity of the atmospheric chemical system to human activities. Ongoing chemical modeling work at GFDL includes analyses of atmospheric nitrous oxide, reactive nitrogen (natural plus anthropogenic), and tropospheric ozone. Models 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, and carbon monoxide.

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.

SOLAR TERRESTRIAL RESEARCH AND SERVICES

The solar-terrestrial program of SEL 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 for acquiring and processing data from space environment monitors on the Geostationary Operational Environmental Satellites (GOES) and the polar-orbiting TIROS-N and NOAA satellites. SESC, operated jointly 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.

OCEAN AND GREAT LAKES 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 programs. 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.

Winds and Waves

ERL conducts research to improve the observation and forecasting of hazardous winds and waves that affect homeowners, recreational boaters, the 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, increased emphasis is being placed on developing in-situ and remote-sensing techniques for directly measuring over-the-water winds.

In addition to improving the models used for wave predictions and improving the understanding of wave dynamics, ERL 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.

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.

Tsunamis

Earthquake-induced ocean waves (tsunamis) can travel great distances at high speeds and can cause extensive damage to coastal communities. A goal of ERL tsunami research is improved prediction and monitoring of these waves. Such improvements require the capability to determine in real time the expected tsunami height and runup at various coastal locations. Qualitative forecasts based on historical data are now possible, but quantitative forecasts are not. Key areas of research include tsunami generation, numerical tsunami modeling, and instrument development to monitor micro-tsunamis for analytical and numerical models and to detect tsunamis before landfall for operational warnings. 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.

OCEAN AND GREAT LAKES ASSESSMENT

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; 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.

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

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 with a variety of models.

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 is investigating the extent to which mineral and biogenic particles scrub large river-outflow systems of pollutants and bury them in deltaic sediments, and the extent to which this burial can be reversed by resuspension events such as storms. The work is focused on the Mississippi River outflow.

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

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

MARINE RESOURCES

Marine resources research 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.

Submarine Hydrothermal Venting Systems

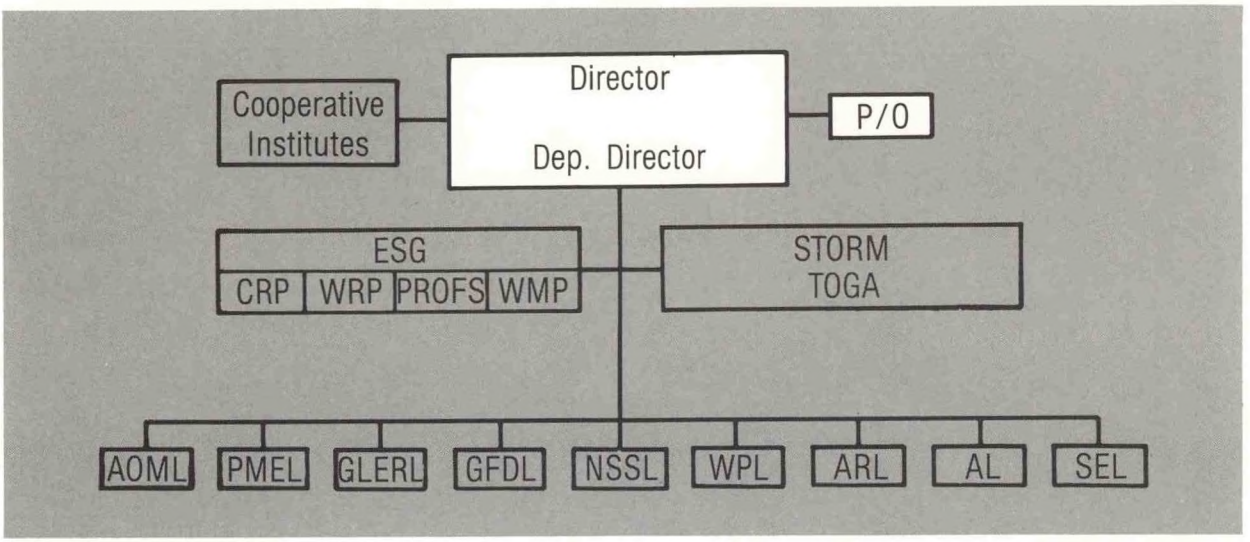
ERL increased its research on submarine hydrothermal venting systems at seafloor-spreading centers in response to the growing recognition of the environmental importance of the hydrothermal fluids. Factors such as possible economic importance of mineralized deposits have generated much of the recent interest in processes at seafloor-spreading centers. However, the basic lack of understanding of the 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.

Fisheries Oceanography

ERL conducts research on living marine resources in cooperation with NMFS. The goal of ERL is to develop an understanding of the direct and indirect effects of atmospheric and oceanic variations on fish and shellfish populations. The Fisheries Oceanography Cooperative Investigations (FOCI) program with NMFS emphasizes simultaneous interdisciplinary research aimed at understanding the variability of fisheries recruitment.

OFFICE OF THE DIRECTOR
Boulder, Colorado

Vernon E. Derr, Director
Robert J. Mahler Acting Deputy Director



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 Programs Office provides advice and services to the Director as well as to the Laboratories and ESG. The Programs Office provides advice and support in areas of policy, 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 Programs Office.

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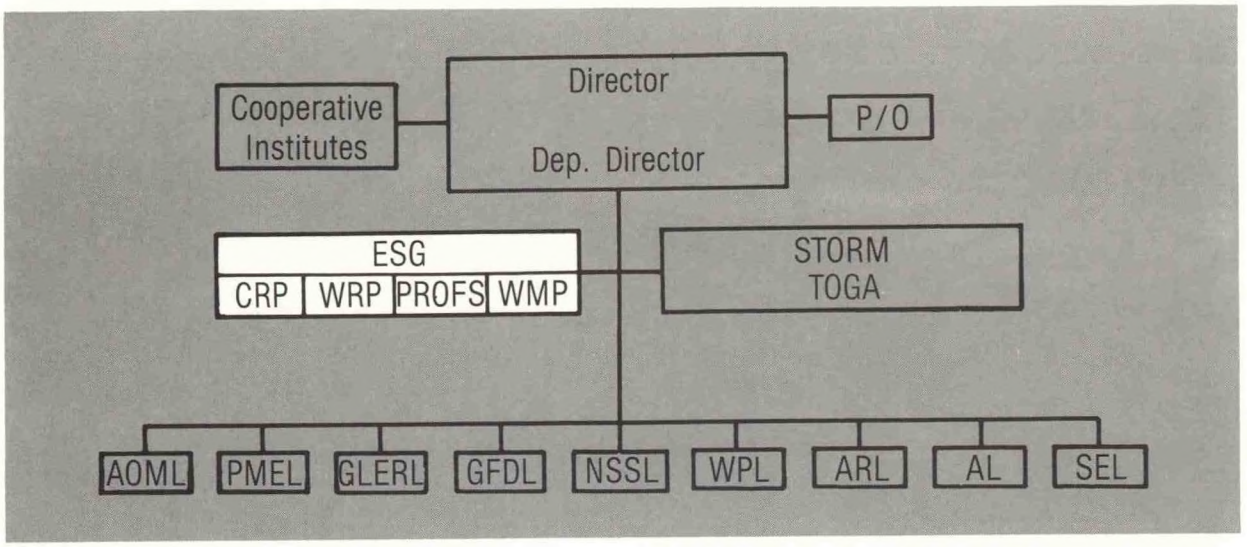
ENVIRONMENTAL SCIENCES GROUP
Boulder, Colorado

William H. Hooke
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 interlaboratory 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 Weather Research Program (WRP), the Program for Regional Observing and Forecasting Services (PROFS), and the Weather Modification Program (WMP). 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 has three broad objectives:

- Development of comprehensive climate data bases to describe climatic fluctuations during the period of instrument record.
- Interpretive diagnostic studies of those climatic fluctuations on time scales ranging from weeks to decades.
- Studies of El Niño/Southern Oscillation (ENSO) phenomena in order to improve understanding and hence the potential for prediction.

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 facilitates the participation of visiting scientists.

Accomplishments FY 1985

CLIMATE RECORD CONSTRUCTION

Marine Data Base

Work began on extending selected products from the Comprehensive Ocean-Atmosphere Data Set (COADS) through 1984. Release 1 of this global surface marine data set covers 1854-1979. Release 2 will be a continuing cooperative project among CIRES/ERL, NCAR, and the National Climatic Data Center (NCDC). It is scheduled for completion by the end of 1986.

In preparation for Release 2, a plan for continuing data acquisition and coordination was developed and reviewed by all the participating organizations. In addition, a number of software modifications were implemented to handle data for the 1980s.

COADS Release 1 data were provided to the Peoples' Republic of China (PRC) and Japan, in addition to a number of other data requests handled by NCAR and NCDC. A new data format developed to represent each statistic for each variable (e.g., the median of sea surface temperature) was installed on PRC computers, and provided to Japan.

Highly Reflective Clouds

The highly reflective cloud (HRC) data set continues to be updated and now comprises more than 14 years of data. HRC data are being distributed to the research community in the medium of magnetic tapes and in a 13-year atlas that will be available for distribution in late 1985. Work is under way on a descriptive climatology of HRC data, on the comparison of rainfall estimates derived from HRC data and the GOES precipitation index, and on the application of HRC data in studies of westerly wind/convection episodes in the equatorial Pacific.

Northern Hemisphere Land Data Base

A videotape showing color-coded monthly mean temperature anomalies for the period January 1851 to December 1980 was produced at the University of Massachusetts under a Department of Energy grant to ERL, the University of East Anglia (U.K.), and the University of Massachusetts. Work was in progress to compile a counterpart gridded data set of Northern Hemisphere land area precipitation anomalies for the similar period 1851-1980.

DIAGNOSTIC STUDIES

ENSO Variability

The differences in the sea surface temperature (SST) profile across the equatorial Pacific during the evolution of ENSO events were analyzed for classification purposes. Despite significant variability from event to event, available evidence suggests the existence of two or three types depending upon the seasonal evolution of the SST anomalies, their amplitudes and locations.

A comparative analysis of the major ENSO events of 1877-78 and 1982-83 showed that both events were accompanied by widespread and long-lived climate anomalies throughout the globe. In North America both events were characterized by warmer than normal temperatures in interior continental regions and by above normal precipitation along the Pacific coast.

Tropical-Extratropical Teleconnections

An analysis of the winter climate along the west coast of North America was completed in which the distributions of mean temperature and total precipitation during warm and cold phases of ENSO were compared with each other and with distributions in other years not classifiable into either extreme.

A statistically significant difference in the winter atmospheric circulation exists between years exhibiting cold conditions and years exhibiting warm conditions in the equatorial Pacific. However, such a difference is not unique to extreme ENSO years, and similar circulation patterns can be found during any winter month regardless of equatorial Pacific conditions.

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

CRP

A detailed analysis was conducted of various atmospheric fields associated with WWCEs that took place in the equatorial Pacific during the 1982-83 ENSO event. These WWCEs were linked to the dramatic eastward shift of Pacific equatorial convection during the last ENSO event, and appear to be modulated by a 30-60 day period of recurrence. In addition, a record of surface equatorial westerlies was analyzed for the period 1969-present. Analysis of the synoptic-scale differences and similarities between ENSO and non-ENSO years since 1969 is in progress.

Diagnostic Interpretation of the Ocean Climate Record

Work was begun to compare merchant ship observations with fixed Ocean Weather Station (OWS) records. Preliminary results indicate that merchant ship data are generally consistent with fixed-platform (OWS) data. However, prior to the 1950s the number of observations decreases fairly rapidly and the representativeness of data over large areas of the world oceans is still being assessed.

Analysis of Secular Climatic Fluctuations over the Northern Hemisphere

A new record of monthly Northern Hemisphere land temperature variations was produced in collaboration with the University of East Anglia (U.K.) and the University of Massachusetts. This record extending from 1851 to the present suggests the existence of two quasi-stable hemispheric temperature regimes, a colder one prior to the 1920s and a warmer period since then. The late 1970s and 1980s have been characterized by greater interannual variability and by a rising temperature trend.

ENSO Monitoring

A real-time ENSO monitoring system is partly in place, and additional data receipt capabilities are being implemented. Daily surface data from island stations along the equatorial Pacific from the Galápagos Islands in the east to Kapingamarangi in the west are being received at CRP on a weekly basis. The data received to date do not suggest the development of an El Niño (warm) event during fall 1985 and winter of 1985-86.

Impact of Climatic Fluctuations on Western U.S. Water Resources

The occurrence in the western United States of extremely high water flow years since 1982 has resulted in severe unaccustomed problems due to severe flooding in a number of western areas. For example, the raising of the Great Salt Lake to its highest levels in 100 years has resulted in large monetary losses for the State of Utah. In the other hand, the reservoirs of the Upper Colorado River Basin have been filled to near capacity, thus adding short-term reserve capacity to the system in case of future drought. The interplay between society, climate, and water resources has been the subject of continuing studies. A workshop was held in March 1985 in Salt Lake City, Utah, to discuss the problems and prospects for predicting Great Salt Lake levels. A consensus was reached, for planning purposes, on a probable maximum lake level elevation of 4,217 ft MSL.

Plans FY 1986

CLIMATE RECORD CONSTRUCTION

Marine Data Base

Release 2 of the Comprehensive Ocean-Atmosphere Data Set (COADS), planned for completion by the end of 1986, will extend the period of record through 1984 for the following selected products:

- Long Marine Reports (LMR)
  These individual ship reports contain the complete observational record, including quality control flags; possible duplicates will be eliminated or flagged.

- Inventories (INV)
  These are records of the number of LMRs in each year-month and 10° box, and other summary information.

- Pentad Summaries Trimmed (PST)
  These are 5-year (1980-1984) records, analogous to Monthly Summaries (see below). They include seven observed and derived variables, each described by 10 statistics for 2° latitude x 2° longitude boxes.

- Compressed Marine Reports (CMR.5)
  These reports contain 29 selected elements.

- Monthly Summaries Trimmed Timesort (MST.T)
  Nineteen observed and derived variables are described by 14 statistics for 2° boxes.

- Monthly Summary Trimmed Groups (MSTG)
  These files are an alternative to the full timesort file for studies using only a few variables and statistics.

An interim data product, consisting of CMRs for 1980-82, before duplicate elimination and quality control, is scheduled for completion by the end of 1985.

Highly Reflective Clouds

Updating of the HRC data set will continue, using an image analysis system to streamline the data-processing flow. Use of HRC data for rainfall estimation will be coordinated with the Tropical Ocean and Global Atmosphere (TOGA) program. HRC data will continue to be used in studies of the tropical Pacific being conducted at ERL/CIRES within the context of EPOCS goals aimed at improving our understanding of ENSO.

CRP

DIAGNOSTIC STUDIES

Continuing Studies of Surface Westerly Wind/Convection Episodes in the Equatorial Pacific

Work will continue on development of a synoptic model of WWCEs and a study of the role of WWCEs in the climatology of the tropical Pacific. Data from COADS will be used in extending the study of WWCEs to the past few decades.

Monitoring, Test, and Evaluation of ENSO Precursors

Enhanced monitoring of weather conditions throughout the Pacific Basin will take place, and continuing assessment and extrapolation of the monthly and seasonal evolution of meteorological conditions in the equatorial Pacific will be carried out. The aim is to develop a monitoring capability sufficient to permit accurate determination of evolving weather conditions that may con-

stitute precursors to the development of an Event and to test various indices for their usefulness as a forecasting tool.

Analysis of Secular Climatic Fluctuations in the Northern Hemisphere

A cooperative 3-year effort to study long-term climatic fluctuations was begun in FY 1985 with funding support from the Department of Energy. The research effort will include analysis of areal changes in precipitation and precipitation variability, 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, studies of regional climate variations and their relationship to large-scale hemispheric fluctuations, and comparison of the continental and oceanic records. A continuing effort will focus on assessing the magnitude of nonclimatic inhomogeneities that may be present in the oceanic record.

WEATHER RESEARCH PROGRAM

The Weather Research Program (WRP) conducts research to increase the understanding of synoptic and mesoscale weather systems. The genesis, evolution, structure, and synoptic-scale environment of convectively driven systems constitute the primary emphases of current WRP research. Attention is focused principally on moist convection; phenomena under investigation range from individual thunderstorms to large mesoscale precipitation systems. Improving the prediction of severe attendant weather, such as lightning, hail, high wind, wind shear, tornadoes, excessive rains, and flash floods, is of particular interest. WRP actively participates in planning and conducting scientific field experiments involving sophisticated research aircraft and complex networks of remote sensing and conventional meteorological instrumentation. WRP places great emphasis on transferring research results and new knowledge to the National Weather Service (NWS) and the national user community.

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

- Predictability of synoptic-scale and mesoscale weather systems and attendant significant weather phenomena.
- Characteristics of the synoptic-scale environment and their relations to the structure, intensity, and evolution of subsequent convection.
- Interactions between mesoscale weather systems and both the synoptic-scale environment and cloud-scale processes.
- Evolution of the dynamic and thermodynamic structure of Mesoscale Convective Systems (MCSs), and the nature and intensity of attendant significant weather.

- Development of airborne Doppler radar technology.

- Application of new remote sensor data for understanding and predicting mesoscale weather systems.

Accomplishments FY 1985

A major accomplishment was conduct of the Oklahoma-Kansas Preliminary Regional Experiment for STORM-Central (OK-PRE-STORM). The field program, which occurred in May and June 1985, was a cooperative one of many NOAA facilities, several NCAR groups, and a number of universities. Scientists from WRP were heavily involved in all aspects of the program from real-time forecasting, to flying, to the day-to-day operations. The goals of the program were to collect the data necessary to begin the preliminary investigation of how MCSs develop and evolve, and to evaluate new sensing systems and strategies necessary for planning the STORM-Central program. The program was very successful; special aircraft flights were flown, and upper-air regional networks were activated for 16 major operational days; one or two sensing systems were activated on several other days. Data from this program will be analyzed over the next several years by a number of groups, including scientists within WRP. A daily operational summary was being completed at the end of FY 1985.

Conceptual models were developed for generating quasi-stationary MCSs that have flash flood potential. The main requirement is that the convective system become juxtaposed with respect to the low-level mass and moisture convergence and the potential buoyant energy, in an orientation that encourages new cell growth on the rear flank of the system.

Analysis of AIMCS (Airborne Investigations of Mesoscale Convective Systems) Doppler radar data for the 3-4 July 1984 flight is under way. Preliminary results indicate the presence of a well-developed squall line circulation on horizontal scales of 100-200 km. This circulation consists of a low-level inflow branch with velocities of 10-15 m/s relative to the line motion, approaching the line from the south, as well as convective scale ascent in cumulonimbus towers organized along a 200-km east-west line, and a middle-level rear-to-front inflow jet of 10-12 m/s relative to the line motion centered about 1 km below the freezing level, and extending 50-100 km behind (to the north of) the line. Air motion estimates in the trailing stratiform region from quasi-dual Doppler synthesis of L-shaped flight patterns reveal a mean mesoscale ascent of 20-30 cm/s over a 50 x 50 km domain, with the maximum at about 7 km above the ground. **WRP**

A case study of the Cheyenne, Wyo., flash flood storm of 1 August 1985 was begun. Both conventional and special data are being studied to document some of the features of this storm.

An automated method was developed and documented to analyze characteristics of MCSs using infrared satellite temperatures. The 1985 Mesoscale Convective Complex (MCC) climatology was begun in near-real time, and because of the ease of computation compared with past manual methods, the climatology was expanded to include the hundreds of MCSs that occurred over the United States in 1985. Another convection-derived climatology, that of nontornadic severe

weather over the United States, was completed in cooperation with several staff members of the National Severe Storms Forecast Center in Kansas City.

Studies of MCSs and heavy precipitation events over south Texas (specifically the Austin flash flood, repetitive radar signatures associated with heavy-rain events, and meso-beta-scale MCSs within quasi-tropical regimes) were completed in cooperation with a staff member of the NWS forecast office in San Antonio, Texas.

Additional MCS studies reviewed the relations of the large-scale environment to the development and life cycles of MCSs, and examined the damaging MCS of 22 June 1982.

The cloud-to-ground lightning network in Oklahoma, operated by NSSL, was expanded into Kansas by the joint effort of WRP, the OK-PRE-STORM program, and NSSL. This network expansion provides a permanent benefit to ERL researchers and NWS forecasters.

An examination of the precipitation characteristics of an MCS that developed in the SESAME network on 20-21 May 1979 showed that the stratiform rainfall component of the mesoscale system produced as much as 51% of the total precipitation. This stratiform region was also found to be an area of weak upward vertical motion as diagnosed from the rawinsonde network. The growth of the areal extent of the stratiform region is evident from the vertical motion fields, as the convective component of the system was decaying. Cloud-to-ground lightning occurred primarily in the convective portion of the MCS.

The large-scale environments of dry microbursts were further identified by case studies and large-scale climatologies. In particular, the temporal evolution of the 700-500 mb lapse rate was identified as a major factor in microburst forecasting for the West. Its role in the development of MCSs and their attendant severe weather over other portions of the country were identified through studies that jointly used results from new objective moisture analyses and omega diagnostics.

Microcomputer (BASIC) software was developed to compute and plot Fourier amplitudes of wave numbers from the principal components down to the Nyquist interval. This program was applied to two-dimensional fields of pressure-height data and of omega diagnostics to determine what happens to spectral estimates after the Barnes interpolation and finite-differencing algorithms. Results indicated that height fields are represented as expected by the theory underlying the Barnes analysis technique. For the divergence of Q fields, both the finite differencing and the remaining components of noise in the weight fields spread the power to wave numbers below the rawinsonde station Nyquist interval (about 800 km), but significant amounts of meteorological signal remain at the expected wave numbers corresponding to wavelengths about 1,000 km and greater.

The life cycles of two MCSs that occurred on 21-22 June 1984 were studied, utilizing data sets from the 1984 AIMCS project. Additionally, AIMCS data were used to study (1) the spatial and temporal evolution of the Great Plains low-level jet and its relationship to MCS life cycles, (2) the possible presence of "salt fingers" over western Kansas to the northeast of a dryline,

and (3) a study of rapid, in situ, air mass destabilization over the northern Plains that led to severe thunderstorms.

A visiting meteorologist from the Australian Bureau of Meteorology worked at WRP from July through October 1985, studying the relationship of tornadic storms to shear, instability, and mass flux as derived from proximity soundings.

Work continued on improving the top boundary conditions in the WRP 2-D numerical model. Furthermore, information from the climatological documentation of MCSs was used in studies of the effect (primarily on extent and mode of organization) of the atmosphere's response to time-varying vertical distributions of latent heating.

WRP staff upgraded and updated the content of contributions to the NWS Training Center (NWSTC) flash flood course, and traveled to Kansas City to teach in all five sessions. Additionally, reviews and comments were provided on NWSTC plans and outlines for a continuing mesometeorology course for NWS forecasters.

Research nearing completion describes the application of biconstituent diffusion theory to certain mesoscale processes. In addition to Schaefer's 1975 model, which is given a simple physical explanation, biconstituent diffusion theory may be applicable, on some occasion, to the moist boundary layer.

The accuracy of computations relevant to quasi-geostrophic Omega diagnostics has been investigated. Pressure height fields were described by an analytic function, and spatial derivatives were computed using centered difference formulas. Finite difference approximations of third- and lower-order derivatives do not appreciably degrade the results for horizontal scale lengths that are adequately sampled (more than nine observations per wavelength). For wavelengths that are marginally or inadequately sampled, the finite difference approximations distort the amplitude of the Q-vector field and its derivative by amounts that increase with fewer observations. These results were obtained knowing the true height values at grid points. When grid point values must be interpolated from sparser observations, results deteriorate dramatically. Only diagnostics within a region interior to the observational network boundary (by approximately one station separation distance) are sufficiently accurate to be meaningful.

Omega diagnostics were run for the entire AIMCS period of 14 June to 16 July 1984; the diagnostics were based on 0000 and 1200 GMT soundings over the western United States. The diagnostic software was modified to output 850-700 mb and 700-500 mb lapse rates, and 850-mb mixing ratio, and to compute the geostrophic forcing in the layers 850-700 mb and 500-300 mb. The latter output, along with the forcing at 700 and 500 mb, gives some indication of the vertical distribution of geostrophic forcing. The results were assembled in one-page displays that, when viewed as a series, indicate the semidiurnal changes in the various diagnostic patterns as well as their relationships to the ongoing and ensuing convection during each 12-h period.

Water vapor data from the Profiler in Denver were examined for diurnal variability during many days in several summers. Diurnal changes were found to be stronger on days with a smaller amount of morning cloud cover (as deter-

mined from satellite imagery) than on days with widespread cloudiness in eastern and central Colorado.

Snowstorms in eastern Colorado were studied in close cooperation with the Denver NWS Forecast Office to determine large-scale conditions under which heavy snow occurs at several population centers along the Front Range. Emphasis was placed on transfer of results to operational forecasters for real-time testing of the pattern recognition methods that were formed.

Cloud-to-ground lightning flashes were analyzed for a full-summer climatology over northeastern Colorado and central Florida. The one-third of a million flashes were subdivided by location and time of day, and showed the extent to which local forcing due to mountain-plains and land-ocean topography influenced distributions. The results compared favorably with prior studies in Colorado and indicated the utility of the data in studies of convective weather. Preliminary stratifications of daily lightning activity by synoptic flow regime were also made for the Kennedy Space Center region.

Plans FY 1986

Several important scientific investigations will be carried out using the OK-PRE-STORM data. Although some will be continuations of studies already under way at WRP using AIMCS, SESAME, or other data sets, a number of new investigations will be started with the unique data set that was collected.

Wind Profiler data from OK-PRE-STORM will be analyzed for two case days when strong convective systems passed over the area, to assess the performance and utility of these data in convective studies.

New objective analysis techniques developed at WRP will be used to investigate MCS occurrence over the central United States during OK-PRE-STORM. The Omega diagnostics, middle-level lapse rate, and low-level moisture fields will be compared with the times and locations of large convective systems in this study.

The OK-PRE-STORM data sets will also be used in studies of the low-level jet stream, interactions between the convective and large scale, the forecastability of MCSs, and the refinement of conceptual models of the development of widespread "stratiform" precipitation regions.

Several new case studies will make extensive use of airborne and ground-based Doppler radar observations to diagnose internal structure and air motions, to describe various aspects of MCS structure and evolution observed during the PRE-STORM project. Cases will be identified of distinctly different MCS structure, such as fast-moving squall lines with trailing stratiform area, slow-moving lines with leading stratiform regions, and nonlinear organized systems. Relationships of MCS structure to the large-scale environment, mesoscale vertical motions, and surface convergence patterns will be investigated.

Lightning data from OK-PRE-STORM will be integrated into other data sets being studied at WRP. Cloud-to-ground data will also be investigated for

relationships to the satellite climatology of MCSs. This study will not be limited to the PRE-STORM period, as both data sets are continuous. The times and locations of positive flashes will be included in all these studies.

The utility of airborne and ground-based Doppler radar synthesis to derive three-dimensional air motions will be evaluated from the data collected during PRE-STORM. Expected errors and limitation of various flight track configurations will be documented for us in future field programs.

The case study analysis of the Cheyenne flash flood storm of 1 August 1985 will be completed.

WRP interactions with operational meteorology will be expanded along the lines of Experimental Forecast Centers as described in the planning documents for STORM. New activities will include computation of quasi-geostrophic (Q-G) diagnostics in real time. These will be made available to selected forecast offices for subjective evaluation in forecasting applications. Additionally, a 2-day training workshop will be developed that will relate Q-G theory to day-to-day weather forecasting. A portable microcomputer will be used to present concepts using real-time fields extracted from the WRP VAX computer. One member of WRP will transfer to the Oklahoma City NWS Forecast Office to work on an applied research project drawing upon the OK-PRE-STORM data sets. A member of the Oklahoma City NWS staff will also spend a 4-month tour at WRP to work on Oklahoma forecast studies. The ongoing Colorado snowfall prediction study will be completed by coupling 10-year forecast statistics for the simple pattern recognition approach.

Interactions are planned with the National Meteorological Center of the NWS so that the Nested Grid Model may be run in a research mode. This capability will provide the central focus in a new research thrust to better understand the development and evolution of intense, mesoscale weather phenomena within intense cyclonic storms--especially within wintertime settings.

Quasi-geostrophic Omega diagnostics will continue to be developed as an important new objective analysis methodology. Eventually, selected results will be reported with descriptions and discussions of the performance of quasi-geostrophic diagnostics as tools for identifying tropospheric adjustments and effects on the development and evolution of large convective storm systems. Commentary on discernible relationships of the diagnostics with more general meteorological situations will be included as a means for expanding use of these tools into the operational environment.

The automated MCS analysis method developed at WRP will be employed to develop the 1985 MCC climatology for publication. Other studies will also employ infrared satellite measurements to determine life cycles and features of MCSs over the United States during 1985.

Cloud-to-ground lightning data will be compared with radar data collected daily at Limon, Colo., and Cape Canaveral, Fla., in the summer of 1985, as well as during some case days in OK-PRE-STORM. Techniques developed at WRP will be improved to allow preliminary comparisons of flash and reflectivity data for different convective regimes as defined by flash data.

Surface convergence from the Kennedy Space Center (KSC) mesonetwork will be used to develop exploratory relationships between convergence events and subsequent lightning and rainfall. The mesonetwork was expanded prior to summer 1985, and a further increase in area late in 1985 may warrant the development of another set of relationships for improved short-term forecasting at KSC.

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 science and technology. PROFS, using the results of 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, with 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). Three NWS employees have become PROFS senior staff members to coordinate work on the NWS Advanced Weather Interactive Processing System for the 1990's (AWIPS-90).

PROFS had a number of important activities in FY 1985. From 15 May through 23 August 1985, PROFS conducted a real-time forecasting exercise involving forecasters from both PROFS and NWS. The objective of the exercise was to test, evaluate, and improve weather-warning capabilities. For the FAA, PROFS 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 coded and tested algorithms that will become a part of the new national Doppler radar system.

In a reorganization of activities, two new groups were formed: Analysis and Prediction, and Experimental Forecast Systems.

To fulfill the technology transfer part of its mission, PROFS presented information, tours, and demonstrations to about 100 visitors each month from Federal agencies, universities, private industry, and foreign countries. Furthermore, it has embarked upon the PROFS Operational Weather Education and Research (POWER) project, designed to provide the operations, education, and research communities with technology and data made accessible by recent advances in computer capabilities.

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 improvements 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 interactive workstations.

Accomplishments FY 1985

A new data-acquisition interface was developed for ingesting voice pilot reports from the FAA 604 line. Several existing data interfaces were significantly upgraded during FY 1985. The reliability of the Limited-area Fine Mesh (LFM) model data from the new National Meteorological Center (NMC) Product Service was increased to 98% or better by solving several complex communications problems. The development of software that automatically detects system failures and downline loads the Cheyenne, Wyo., and Limon, Colo., NWS radar interfaces increased the uptime of these two conventional radar interfaces substantially. The joint U.S. Air Force/PROFS lightning detection position analyzer system was moved to PROFS, and the system software and hardware were upgraded. These changes resulted in substantially more accurate and reliable cloud-to-ground lightning strike reports.

The upgrading of the computer facility continued as a new Digital Equipment Corporation (DEC) VAX-11/785 computer was installed and clustered with two already existing VAX-11/780s. The VAXcluster allows rapid transfer (at rates up to 70 megabits per second [Mbps]) of large volumes of data among the processors and the mass storage devices shared on the cluster. Also, the VAXcluster increases system availability and significantly enhances processor utilization. Practically all in-house computer communications now take place through a 10-Mbps Ethernet local-area network. Terminal servers were installed on Ethernet, enabling any one of the 100 PROFS terminals to have direct access to any of the VAX computers with a minimum of wiring. A communications server was connected to Ethernet to offload the external communication burden from the Virtual Address Extended (VAX) processors and Programmed Data Processors (PDPs). A major upgrade of data communications was accomplished by installing separate cabinets, interconnect and switching hardware, and test equipment for analog and digital telephone lines. The time required for troubleshooting and repairing malfunctions of these lines has been much reduced.

A major new release of the DEC VAX operating system, VMS V4.1, was successfully installed. The new version of Virtual Memory System (VMS) enhanced system security and introduced additional, improved cluster capabilities and data management features. The OBSERVER network-monitoring system, providing a continuous measure of DECnet traffic, network events, and errors, was also installed for the 22-node PROFS computer network. The introduction of the system Software Performance Monitor (SPM) significantly enhanced VAX system

management. SPM provides key information to the VAX System Manager on memory utilization, disk space use and fragmentation, and distribution and prioritization of processes.

The entire facility was reconfigured, and several subsystems were substantially enhanced for the PROFS 1985 Real-Time Exercise (RT85). Overall system reliability approached 100% during the hours of the Exercise from May 15 to August 23.

The demand for PROFS data by outside organizations increased significantly. To facilitate the distribution of these data, archive and output software was generated. The EDF serviced nearly 100 data requests from researchers at university and government laboratories during the year.

The real-time FAA ARTCC workstation in Longmont, Colo., was upgraded and supplied with 24-hour/day, 7-day/week data flow from Boulder. A study by the Longmont ARTCC Manager showed that aircraft delays at Denver's Stapleton International Airport were reduced by a factor of 3, owing to the availability of the PROFS workstation and data. As a result, significant fuel cost savings and improved air safety were realized.

The EDF completed a study for the Navy-NOAA Joint Ice Center (JIC), exploring the potential applicability of PROFS-developed techniques for ice analysis and forecasting. The study concluded that many PROFS capabilities would be directly applicable to the ice problem.

The EDF transferred documentation of many of its developments to outside organizations. For example, the LFM data ingest interface documentation and software were available for implementation at NASA, NCAR, and Colorado State University.

Plans FY 1986

- Continue the VAXcluster upgrade of the EDF computer facility. Generate software utilities and detailed documentation to enable users to take full advantage of cluster capabilities.

- Upgrade and expand the EDF data-acquisition interfaces. Develop a new, enhanced interface for ingesting NWS Automation of Field Operations and Services (AFOS) data to support the Denver AWIPS-90 Risk Reduction and

- Requirements Evaluation (DAR^{3}E). Re-establish and upgrade the interface to Aeronautical Radio Incorporated (ARINC) to ingest automated pilot report data.

- Develop the system for distributing POWER data and products by satellite broadcast.

- Reconfigure and operate the facility in support of a 1985-1986 Cool Season Exercise, and other projects.

- Support wind profiler Hub development by operating and maintaining the Hub VAX-11/750 computer, and by providing comparison data and systems-related consultations.

EXPLORATORY DEVELOPMENT GROUP

A portion of the Science Branch of the Exploratory Development Group (EDG) was detached and became the Analysis and Prediction Branch. The remainder of the EDG continues to pursue the acquisition, tailoring, and implementation of promising technological advances in remote sensing, such as Doppler radar and geostationary satellites for use in improved short-range forecasting.

Accomplishments FY 1985

The satellite ingest team implemented ingest of VAS Multi-Spectral Imaging (MSI) and dwell sound data. The data acquisition and processing parts of the ingest were separated, allowing a greater average throughput. Mode AAA hardware and software were completed and tested with the National Environmental Satellite, Data, and Information Service (NESDIS) simulator. For RT85, the capability to ingest Rapid Interval Scanning Operation (RISOP) data (with no operator intervention) was added to the system. Finally, documentation on the PROFS satellite ingest subsystem was completed.

The NEXRAD team continued its parameter and resolution sensitivity studies, the coding and testing of additional algorithms, and the assessment of the algorithms' formal descriptions. In FY 1985, several versions of the 11 algorithms coded the year before were reviewed for completeness and accuracy. The Mesocyclone and VAD algorithms required major recoding, and other algorithms required minor code changes. Results of resolution and parameter sensitivity studies of the Storm Sequence algorithms were published. Finally, three additional algorithms were coded: Combined Shear, Sectorized Uniform Wind, and Cross-Correlation Tracking.

The Doppler products team and the EDF operated the Phase I Doppler subsystem during RT85. This subsystem gives forecasters access to full-resolution volume-scan data at the PROFS workstation. Surveillance and high-resolution images, NEXRAD algorithms, Range-Height Indicator (RHI), and a precipitation type/intensity product based on dual-polarization, were successfully provided. The Doppler products team began addressing AWIPS-90 radar interface requirements.

The Videodisc project concluded its second year with two major accomplishments: the installation of a level-3 videodisc system and the use of that system to train meteorologists who forecasted during RT85. The level-3 videodisc system includes a videodisc player controlled by a personal computer; software on the personal computer includes an interactive demonstration course on advanced meteorological sensors. PROFS use of the videodisc system clearly demonstrates its potential as a powerful new tool for research, training, and education.

A real-time VAS assessment was conducted concurrent with the PROFS summer convective forecasting exercise. The assessment accomplished numerous goals:

- VAS workstation products were successfully created and integrated into the workstation in time for the exercise.
- Forecasters received training by the PROFS staff prior to their forecast stint.
- Products were evaluated and improved.
- Problems and new ideas for future VAS and satellite products were identified.
- Valuable data sets were archived for further evaluation and use in constructing new products.

Plans FY 1986

The major goal of the Satellite Ingest effort for FY 1986 is to implement the system on a microVAX computer, as part of a longer term goal of combining the current satellite ingest and product generation functions on one computer. Having both ingest and product generation on one small, powerful processor will allow more rapid production of finished products for the workstation, as well as providing an elegant, modular way of adding advanced satellite capabilities to the POWER system.

Planned activities for FY 1986 include the following:

- Conversion of current satellite ingest hardware to work with a Q-bus Direct Memory Access (DMA) device.
- Creation of a device driver or equivalent for ingest hardware on microVAX.
- Modification of the PROFS satellite simulator to provide mode AAA data.
- Conversion of satellite ingest scheduling software (now on PROFS1 and PDP ingest machines) to the microVAX system.
- Implementation of the entire ingest system on a microVAX, including scheduling, calibration, file formatting, arbitrary selection of desired sectors, and DECnet destination nodes of sectors.

The work of the NEXRAD team will include additional assessment of algorithm descriptions, continued parameter sensitivity studies, coding and testing of new algorithms, and meteorological assessment of selected algorithms.

The Doppler products team will begin to design and implement a Phase II radar products subsystem to use in the forthcoming AWIPS-90 evaluation exer-

cise and which will eventually become a part of the POWER subsystem. The design represents a major, expandable processing resource for PROFS high-data-rate situations. The RT85 product set will also be evaluated.

ANALYSIS AND PREDICTION BRANCH

The Analysis and Prediction branch processes surface and tropospheric data from diverse sources in order to present a clear picture of current atmospheric conditions and to make very-short-term predictions with efficient numerical models. The results of this labor appear on the PROFS workstation during real-time forecasting exercises and are expected to benefit aviation and the general public in the form of better weather information. There are two major activities in the branch: development of a Mesoscale Analysis and Prediction System and support of the FAA's Central Weather Processor Program.

Accomplishments FY 1985

MESOSCALE ANALYSIS AND PREDICTION SYSTEM

The first version of a Mesoscale Analysis and Prediction System (MAPS) was developed. A major goal of this system is to provide an experimental framework for the study of mesoscale objective analysis and short-range prediction (up to 12 h). The system was run in real time during RT85 to provide upper-level guidance for participating forecasters.

MAPS utilizes observations from rawinsondes, active (measuring wind) and passive (measuring temperature and moisture) profilers, VAS soundings, and commercial aircraft. Observations undergo gross error checks, and in the case of soundings, vertical quality control checks for reasonable wind shears and lapse rates. A horizontal quality control "buddy" check is performed in which each observation is compared with its neighbors. If the difference exceeds a prescribed limit, an inconsistency is presumed to exist, and subsequent tests are made to identify which observation is in error. All observations that are identified as erroneous in vertical or horizontal quality checks are flagged in the MAPS data base.

PROFS

A subjective quality control system using interactive graphics was also designed and implemented; this allows forecasters to review the outcome of the objective quality control procedures and to change the flags or values for any observation. Subjective quality control was performed each morning during the summer exercise. Generally, less than 1% of all observations (mostly rawinsonde) were flagged bad by objective quality control. Of these, the forecaster judged about 80% to be, in fact, not erroneous but representing some meso-alpha-scale feature such as a front, a low-level jet, or a variation in tropopause level. Thus, the combined objective/subjective quality control system effectively weeded out bad observations but retained observations representing significant smaller scale features.

The central component of MAPS is a statistical interpolation analysis scheme chosen from among several candidates. A strength of this scheme is its

ability to optimally combine different types of observations possessing different error characteristics and variable data densities with first-guess fields from an earlier forecast. Heights and winds are analyzed simultaneously in a multivariate form of the scheme using the geostrophic relationship. Temperature and relative humidity are analyzed independently. LFM model forecasts are used as a first guess, and single-level data such as aircraft reports are given a three-dimensional sphere of influence.

A barotropic forecast model was implemented to provide upper-level wind forecasts for MAPS. This model was chosen mainly because more sophisticated models require too many computations to be run operationally in the PROFS VAX environment, but despite its simplicity, forecasters found it provided helpful guidance on the timing of upper-level waves. Software was written to create contour products for the RT85 workstation from MAPS and LFM analyses and forecasts. Variable contour intervals were made available for better revolution of typical summer features, which may be quite weak yet nonetheless significant. Additional diagnostic fields such as divergence, vorticity, and advection of temperature or vorticity were also produced for the workstation, using MAPS/LFM gridded fields.

CENTRAL WEATHER PROCESSOR GROUP

The Central Weather Processor (CWP) group is responsible for designing and testing meteorological products for use in the ARTCCs, and for support to the FAA in the design of the CWP.

The following meteorological products were developed during FY 1985:

- A sounding analysis package.
- A rime icing algorithm.
- A cloud top height algorithm.
- Specific Clear Air Turbulence Risk (SCATR) Index algorithm (in conjunction with NASA and the University of Dayton Research Institute).
- An Instrument Flight Rules (IFR) Area Outline.
- Grid-to-grid resectioning.

The group sent both Program Design Language (PDL) and Fortran code to the FAA for the sounding analysis package and the grid-to-grid resectioning, and for the remapping of satellite data. The Fortran code for the latter had been written at PROFS prior to FY 1985.

Other support was given to the FAA in the form of reviewing the system specification, reviewing "CWP Data Flow Diagrams and Data Dictionaries" and participating in review meetings held by the Jet Propulsion Laboratory and the FAA.

Plans FY 1986

An improved version of MAPS will be designed and programmed. The statistical analysis scheme will be converted to isentropic coordinates, and a quasi-geostrophic forecast model that also uses isentropic coordinates will be implemented. A surface analysis will be designed and programmed. MAPS data base routines will be rewritten for greater flexibility and efficiency. Finally, a more complete objective quality control scheme will be designed to include a complex checking method in which decisions about flagging or correcting observations are made only after all vertical, horizontal, and possibly temporal consistency checks have been completed.

All the CWP algorithms developed in FY 1985 will be tested daily on a workstation during January and February 1986. In addition, some of these algorithms will be validated by comparison with pilot reports, which are now being stored and decoded automatically. Other new work will include developing an infrared satellite enhancement based on equilibrium temperatures and adding the requirements for Profiler data to the CWP specification.

EXPERIMENTAL FORECAST SYSTEMS

The Experimental Forecast Systems branch (EFS) was formed during FY 1985. Some EFS members were drawn from the Science branch of the EDG. EFS assumed much of EDG's responsibility for developing products and applications for use on the PROFS advanced forecaster workstation.

EFS is also responsible for coordinating PROFS research support activities with other ERL Laboratories and the meteorological research community in general, and for specific management of the RT85 research projects.

In October 1986, an enhanced and expanded version of the PROFS advanced forecaster workstation will be put into operation at the Denver Weather Service Forecast Office (WSFO). This workstation will physically replace the AFOS console that currently supports the public forecast function in Denver. The EFS branch has overall responsibility for the specification and implementation of this system, as well as continued support as it evolves.

PROFS

Accomplishments FY 1985

Members of EFS were heavily involved in the planning and operation of RT85. This exercise was the showcase for the latest version of the PROFS forecasting workstation. Integration of new products and application programs for RT85 was mainly the responsibility of EFS.

Several enhancements were made to the forecaster workstation for RT85. Chief among these were the addition of a second display screen, and the extension of animation capability to a maximum of 32 frames. Also, the menu interface was re-implemented to use a mouse device. EFS personnel were involved with the planning for these changes.

Data coverage was expanded to include a new scale, the AFOS North American scale. This step-up in scale for satellite data meant that the forecaster at the PROFS workstation had access to standard Geostationary Operational Environmental Satellite (GOES) Visible Infrared Spin-Scan Radiometer (VISSR) data on scales ranging from continent size for synoptic overviews down to meso-beta (20-200 km) or meso-alpha (40-400 km) for detailed local forecasting. Additionally, three images from the VAS were available on all but the largest scale.

Several new application programs were made available for use with satellite data. These included renavigation, enhancement, and data retrieval (e.g., temperatures from infrared imagery), and a program that creates imagery by combining water vapor, infrared, and/or visible data.

New radar data presentations were developed by EDG for incorporation into the workstation in keeping with the dual functions of weather radar: surveillance and severe thunderstorm analysis. For surveillance, data from the NWS radars in Cheyenne, Wyo., and Limon, Colo., were mapped to the same Lambert conformal projection used to display VISSR and VAS satellite imagery and Surface Aviation Observations (SAOs). On a smaller scale (about 200 x 200 km), the surveillance function was provided by a half-resolution display of reflectivity and Doppler velocity from the NCAR CP-2 radar. For rapid analysis of severe thunderstorms, forecaster-selectable windows within the total area covered by the CP-2 Doppler radar provided full-resolution images of both velocity and reflectivity for each of eight radar scans taken at various tilt angles. Thus, a forecaster had access to eight quasi-horizontal cross sections of any chosen thunderstorm. NEXRAD algorithms implemented by EDG to assist the forecaster in analyzing radar data included mesocyclone detection, storm tracking, and hail detection.

New mesonet data displays were developed by EFS to show insolation, precipitation, and potential temperature. Time series graphs, up to 12 h long, of any observed parameter from any station were also available. In addition, pressure changes could be plotted over 15 min, 30 min, 1 h, and 3 h on demand; insolation integrated over time since sunrise was plotted; and an accumulated rainfall plot for any specified time interval was added. Many new upgrades to the lightning location system were also installed prior to RT85.

Data from each of the Wave Propagation Laboratory (WPL) wind Profilers were assembled and presented as time-height cross-section plots, which show the presence and structure of short-lived disturbances in the troposphere above the boundary layer. The WPL radiometric (thermodynamic) profiler at Denver's Stapleton Airport was used to help detect the evolution in the temperature structure of the atmosphere in an hourly isentropic time series analysis. Time series plots of precipitable water from four Profiler sites were also generated each hour.

The MAPS developed by the Analysis and Prediction branch added many new products to the RT85 workstation. Analyses and forecasts of height, vorticity, temperature, wind, or combinations and derivatives of these fields could be selected by the forecaster. Two data sources were provided: LFM gridded data, and a local analysis and barotropic prediction model. This gave the forecaster a powerful tool to examine meteorological fields at denser space and time scales than are provided by traditional data sets.

In the area of research support, EFS served as the contact point with ESG's Weather Research Program (WRP) in arranging for data collection in support of the PRE-STORM experiment. EFS also coordinated forecasting research projects conducted during RT85.

Plans FY 1986

During FY 1986, the EFS branch will concentrate on developing the DAR^{3}E system for NWS. This system is scheduled to begin operation at the WSFO in Denver during the first quarter of FY 1987. It will functionally replace equipment used by operational meteorologists to prepare forecasts, warnings, and other products for the public. Capabilities beyond those available in the 1985 PROFS Operational WorkStation (POWS) system will be needed. They include word processing and product formatting, text retrieval and storage from the NWS AFOS system, storage and display of a large number of AFOS graphics, and new products and application programs.

The 1985 POWS system was designed primarily for the short-term mesoscale meteorological problem. During FY 1986 the workstation will be revised to accomodate traditional meteorological data sets for synoptic meteorological conditions.

The EF will be responsible for coordinating the PROFS Cool-Season Exercise during the winter of FY 1986. This experiment will be radically different from any of the convection forecasting exercises of 1982, 1983, and 1985 and will provide an opportunity to test some of the changes in the DAR^{3}E system.

The EFS branch will continue to support research uses of PROFS data. The FY-1986 objective of this project is to enhance the PROFS role in data collection, archiving, and distribution in support of the research community. A key element will be the design and installation of an interactive workstation at the National Severe Storms Laboratory (NSSL).

PROFS

SYSTEM DESIGN AND IMPLEMENTATION

The System Design and Implementation (SDI), formerly Systems Analysis and Design, branch has responsibility for the high-level system design for PROFS exercises and projects, detailed design and development of the workstation software, and system integration. PROFS exercises and projects require a thorough analysis of functional and performance requirements to specify the appropriate hardware and software configuration. SDI performs the system sizing, provides formalized high-level system design, and assists with the application of system techniques in refining designs. SDI works with project representatives to establish workstation requirements and uses these to design and develop the workstation control environment. SDI integrates data acquisition, routine meteorological product generation, and workstation functions for all system configurations.

Accomplishments FY 1985

SDI reached an agreement with the U.S. Air Force Space Division to provide meteorological enhancements to the Satellite Data Handling System (SDHS) and to develop and evaluate products for the Defense Meteorological Satellite Program (DMSP) data set. DMSP product development is to take advantage of PROFS comprehensive meteorological data and product sets.

- Computer programs were written to create surface geostrophic wind, temperature, and moisture advection products. Also, objective analysis techniques are being evaluated to select the one that provides the best performance with limited demands on computer resources.

- DMSP microwave temperature sounder data were processed to create temperature contours at standard pressure levels. These data are being prepared for analysis using the MAPS optimal interpolation scheme.

- SDHS system and application software was received from the Air Force and is being installed on a PROFS computer. Considerable effort has been invested in learning the SDHS software.

In February, a PROFS-funded data base management study recommended (1) a commercial data base management system (DBMS) and (2) a strategy for incorporating a DBMS. The SDI staff has studied the report and is waiting for funding to proceed with the purchase and implementation of a DBMS.

A major activity for SDI was the development of new workstation capabilities and the software integration for RT85. SDI performed the integration and shakedown of the acquisition, routine product generation, and workstation subsystems for the RT85 system

SDI is working closely with EFS in designing and developing the DAR^{3}E system. To date, SDI and EFS have developed a functional specifications document for the system and have defined the AFOS text product user interface.

The PROFS workstation at the FAA Longmont ARTCC was upgraded by changing some product scales and routine product sets, improving AFOS graphics product handling, and adding an application program to generate displays of pilot reports.

Plans FY 1986

SDI plans to support three major activities during the next fiscal year:

- DAR^{3}E. SDI will define the system configuration, prepare the design, and implement portions of the Denver system. Modifications will be made to the existing workstation and system software to meet the DAR^{3}E

requirements. Integration and shakedown of the system is planned for the third quarter of FY 1986.

- POWER. SDI will support development of a low-cost POWER workstation to be used by both researchers and members of the operational community. The POWER system is to be completed by the end of FY 1987. A Model I workstation, using a DEC MicroVAX II and Ramtek 9465 will be completed by spring 1986 for installation at NSSL. Initial communications with the Model I workstations will use dedicated lines. SDI and EDF will investigate techniques and available technology for a satellite data broadcast link between PROFS and POWER workstations. Initial effort by SDI will concentrate on documenting POWER functional and performance requirements and developing a preliminary system design.

- PAMSET. Efforts to help the USAF develop new products for SDHS will continue, with the implementation of an SDHS workstation at PROFS. Meteorological product software developed for the Air Force on PROFS computers will be integrated into SDHS, and additional work will be performed to develop and evaluate DMSP products.

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 1985

PROFS

The major effort was the design and implementation of RT85. Forecasts were issued for three time periods: nowcasting (0-30 min), very short-term forecasting (0-120 min), and short-term forecasting (0-6 h). Nowcasts, similar to NWS severe weather warnings, were issued for three levels of convective weather severity: significant (hail ≥0.5-inch diameter, winds ≥35 kn, rainfall ≥0.5 inch in 30 min); severe (hail ≥0.75-inch diameter, winds ≥50 kn, tornadoes ≥F0 severity, rainfall ≥1.0 inch in 30 min); and catastrophic (hail ≥2.0 inches diameter, winds ≥75 knots, tornadoes ≥F1 severity, major flooding causing considerable loss of life and damage to property). Very-short-term forecasts (up to 2 h) were termed alerts; they were issued only for significant and severe weather, with mandatory lead time of at least 30 min. The short-term forecasts were issued for a 5½-h period and were termed convective outlooks; they were issued for significant and severe thunderstorms (hail, wind, rainfall) and for tornadoes. All these nowcasts, alerts, and convective outlooks were assigned probabilities rather than being presented simply as categorical forecasts. In addition to these convective storm forecasts, regularly scheduled probability-of-precipitation forecasts were prepared every 2 h by isoplething forecast probabilities over the forecast area for two successive 1-h periods.

A series of computer algorithms available throughout the exercise also provided guidance, particularly for the nowcasts. One set of algorithms, called the NEXRAD algorithms, provided guidance on hail detection, mesocyclone detection, and storm-tracking. Another algorithm (ZDR) provided output distinguishing between rain and hail on the basis of backscatter return from vertically and horizontally polarized radar pulses.

Verification data for convective storms were obtained by vectoring radio-controlled chase cars over the forecast area, using a 1-mile-interval gridded map system. The set of visual observations obtained throughout the area during the experiment was nearly perfect.

A wide variety of image and graphics products was available for four different scales of motion ranging from the North American continent down to a local forecast area of 150 km radius centered near Boulder. In addition to the regularly scheduled products, the forecasters could call a large set of programs into play to perform diagnostic operations such as time series parameters, moisture convergence zones, and cloud-top temperatures deduced from infrared satellite images. Wind profiler data were also available for heights up to 12 or 14 km at four sites throughout the exercise, updated hourly.

In summary, the exercise included many new forecast procedures, a wealth of new data (images, graphs, and applications programs) and an excellent set of verification data for subsequent analyses. The analyses of the RT85 results are now being evaluated by the T&E staff as the major task for the coming year.

Plans FY 1986

- Evaluate RT85 nowcasts, alerts, and convective outlooks using scoring techniques based on contingency tables, Brier scores, and Signal Detection Theory.
- Develop Radar Data Processor (RADAP) hail detection algorithms modified for Colorado high plains thunderstorms.
- Evaluate the various hail detection algorithms (NEXRAD, RADAP, and ZDR) as forecast guidance tools.
- Participate in a cool-season forecast exercise scheduled for the 1985/1986 winter period.

WEATHER MODIFICATION PROGRAM

During a decade when the limitations to the nation's fresh water supplies are increasingly being realized, the NOAA Weather Modification Program (WMP) is taking a hard scientific look at cloud evolution and water budgets, and the realities of cloud-seeding technologies for enhancing precipitation. Research in this program is focused on six avenues that promise breakthroughs

in monitoring, forecasting, modifying, and understanding the effects of cloud systems on the meso-beta to meso-gamma scales:

- Testing and application of cloud remote sensors.
- In-cloud tracer technologies.
- Chemical/physical technologies to evaluate precipitation processes.
- Ice nucleant chemical kinetics.
- Modeling of cloud processes and their links to the mesoscale.
- Precipitation impacts on hydrology and agriculture.

The Weather Modification Program (WMP) office oversees the Federal-State Cooperative Program in Weather Modification Research, which began in 1979. At that time the U.S. Congress appropriated funds for a cooperative, scientific evaluation of certain ongoing operational cloud-seeding programs. Such Federal-State cooperative programs were among the many recommendations made to the Secretary of Commerce and the President 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 Board resolved that "locally controlled operational projects...offer an excellent opportunity for increasing scientific knowledge and technology development....Proper design, well-conducted operations, and careful data collection will permit useful evaluation of the effectiveness of selected multi-year operational projects. The resulting scientific gains will be sizable, and most local users, sooner or later, will appreciate Federally-sponsored scientific evaluation of the operational projects locally supported." This resolution serves as a charter for the NOAA Program.

In 1979, NOAA contracted with Colorado State University to develop a design for the conduct of the first two programs approved, those for North Dakota and Utah; various advisory groups provided recommendations for the conduct of field research programs in these two states. In FY 1983, Nevada was added to the program. In FY 1984, Illinois was added.

WMP

Currently, research in the four states is supported through cooperative agreements with the NOAA WMP. The mission of WMP is to support, conduct, and coordinate basic and applied research to understand cloud and precipitation processes and their role in the hydrologic cycle under natural influences, and with inadvertent and purposeful modification.

The summer and winter seasons and four different climate regimes are represented by the four state programs. Illinois is concerned with summer convective rain processes as they directly affect crop production in the humid, temperate climate of the Midwest cornbelt. Summer convective precipitation and hail in the sub-humid, rainfall deficient, wheat-growing regime of the northern Great Plains are the concern of North Dakota. Utah is addressing winter orographic snowfall and its impact on summer runoff and irrigated agriculture in the arid to semi-arid climate of the Great Basin, which is precipitation deficient in all seasons. Initial cloud-seeding activities in Nevada were

stimulated by requests from Native Americans who were concerned about the amount of water reaching their reservations. To assure water supplies for irrigated agriculture and urban uses, Nevada must address winter precipitation on both the windward and lee sides of the Sierra Nevada where there occurs a dramatic transition from generally abundant but annually highly variable snowfall in a sub-humid climate to deficient snowfall in a semi-arid, steppe climate.

Thus each program is of regional interest, and collectively the programs are of national interest in that they address one of a very few technologies potentially available for increasing water supplies to alleviate deficit spending of the nation's fresh water. All four programs include sizable State investments.

The long-range goals of the four cooperative programs are as follows:

- Utah/NOAA: Understand the water budgets and potential for snowfall enhancement in winter orographic clouds within the Great Basin, and physically and statistically estimate the actual effects of operational seeding.

- Nevada/NOAA: Determine the effect of winter orographic cloud seeding in California on snowfall enhancement potential and water supplies in areas of Nevada downwind of the seeded target areas.

- Illinois/NOAA: Understand the feasibility of summer rainfall enhancement in the Midwest and the agricultural effects of added rainfall during periods of water and heat stress as well as those of excessive rainfall.

- North Dakota/NOAA: Determine the potential and actual effectiveness of seeding summer convective clouds of the northern Great Plains to enhance growing-season rainfall, and determine the feasibility of hail suppression.

Accomplishments FY 1985

COOPERATIVE RESEARCH—ILLINOIS/NOAA

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), which is continuing with these specific objectives:

- Determine in a scientific manner the precipitation alterations that are obtainable.

- Determine the effects of these alterations on all aspects of agriculture.

- Determine the societal and environmental desirability of these alterations.

Top priority FY-1985 activities and corresponding accomplishments were the following:

(1) Studies of cloud and precipitation elements and systems.

- Research was initiated with radar echo data, to define experimental units, as needed in the exploratory phase of PACE.

- Satellite interpretation of precipitation systems was started.

(2) Studies of economic and environmental impacts of summer rain changes.

- Progress included installation of soil moisture tubes at four sites, acquisition of a neutron probe, and initiation of routine measurements of soil moisture at these sites for studies of soil infiltration of rainfall.

- A three-phase research effort began, to assess the agricultural economic impacts of precipitation in recent wet and very dry summers and under present farm practices.

(3) Development of facilities for PACE field operations and evaluations.

- Engineering to add computer and Doppler capabilities to a 10-cm radar was initiated under a special appropriation for instrumentation.

(4) Review, interpretation, and summarizing of all relevant past research in the Midwest.

- Results for developing scientific hypothesis and evaluation methodologies were integrated.

- An assessment of all past weather modification research in the Midwest, including an annotated bibliography of all relevant documents, was completed for use in hypothesis development. **WMP**

COOPERATIVE RESEARCH—NEVADA/NOAA

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 research seeding programs are being conducted in California, producing a potential for downwind effects in Nevada.

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

The utility of new wet-weather tracer technology is being experimentally demonstrated. The oxygen isotope ratio in snow ($^{18}O/^{16}O$), which is estab-

lished 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 ice nucleants, is being developed to distinguish between cloud nucleation and scavenging processes; a second season of field testing added data points that actually show this difference and began to confirm (1) the validity of the dual-tracer hypothesis and (2) the participation of the ice nucleant in the precipitation-forming process.

The implications with respect to effective delivery of cloud seeding material (or, e.g., to the dispersion of powerplant effluents) into cloud systems are profound. All these technologies have broad application in basic cloud studies, weather modification, and air quality.

Under a special grant for instrumentation, Nevada is building a dual-wavelength radiometer for continuous monitoring of atmospheric water vapor and cloud liquid water.

COOPERATIVE RESEARCH—NORTH DAKOTA/NOAA

In FY 1984, a preliminary field study of sulphur hexafluoride (SF_6) as an in-cloud tracer of plume transport and diffusion was successfully conducted. The pioneering results indicated that circulation within rigorously growing convective clouds was very confined; continuous cloud base seeding generated plumes of only relatively small diameters (e.g., 100 to 500 m) at a few thousand feet above the seeding altitude. The SF_6 plumes were found to spread more uniformly through the cloud volumes only at cell top, or in dissipating turrets.

These characteristics of cloud transport were examined again in an FY-1985 June-July field experiment. A new airborne SF_6 sampler developed by Washington State University (WSU) was field tested, and its samples were compared with the different SF_6 samples obtained in the previous season. The instrument was carried by the University of North Dakota Cessna Citation jet aircraft, which offered pin-point navigation and also carried a full complement of cloud physics samplers. The WSU SF_6 sampler was found to have a much better threshold of detectability and response time than earlier samplers had. Additional cumuli were treated and sampled, and calculations of averages are under way. The tracer studies represent landmark research in cloud transport; this knowledge is crucial to the fields of weather modification and air quality.

Additional radar studies were also conducted to relate cloud echo height volume to rain volume. A narrow-beam radar provided by the Bureau of Reclamation improved the resolution of the measurements.

Fast-acting ice crystal nucleants developed for North Dakota in the Colorado State University Atmospheric Simulation Laboratory were field tested. Generation modification is needed for efficient burning, but use of ice

crystals as nuclei is potentially a major breakthrough for timing treatment and precipitation growth in rapidly evolving cumulus clouds.

COOPERATIVE RESEARCH—UTAH/NOAA

The three major research challenges to the Utah/NOAA program are (1) to determine the spatial and temporal distribution and evolution of supercooled cloud water, (2) to evaluate the effectiveness of delivery of seeding materials, and (3) to determine the trajectories of natural and seeded cloud and precipitation particles.

A strong approach to these key problems was established by assembling an impressive network of instrumentation including both in-situ and remote sensors. The 1981 and 1983 field studies were, with some variations, supported by X-, K-, and C-band radars, a scanning dual-channel radiometer, a polarization lidar, rawinsondes, a mountaintop supercooled-liquid-water detector, a network of precipitation gauges, and a cloud physics aircraft.

In a very successful experiment in January and February of 1985, studies of windflow and cloud processes were emphasized, using, simultaneously, a dual-wavelength radiometer to measure liquid water content, a K-band radar to detect the conversion of liquid water to ice crystals and measure cloud top height, a polarized lidar to follow cloud base height and phase of water, a C-band (5 cm) Doppler radar to determine low-level wind fields up and along the barrier, constant-level balloons and SF_6 released to track airflow and plumes, and supporting soundings, riming sensors, and precipitation gauges.

These physical measurements provided a strong basis for evaluating the cloud water budget and will contribute substantially to the refinement of the operational technology and total assessment of the snowpack enhancement program. Intensive analyses are in progress by participants from the Desert Research Institute, University of Utah, Colorado State University, Atmospherics, Inc., and North American Weather Consultants.

Plans FY 1986

COOPERATIVE RESEARCH—ILLINOIS/NOAA

FY 1986 will be the second full year of Illinois participation in the program. Analyses of radar echo evolution, based on data previously 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 complete modification of its HOT (Hydrometeorological Operational Tool) 10-cm radar to include a Doppler capability, which, with its existing CHILL (CHicago and ILLinois) 10-cm radar (a national facility), will provide a dual-Doppler capability. Review of past Water Survey tracer work in convective clouds will be completed, as will review of the physics of all previous weather modification efforts relevant to Illinois. Use of soil moisture measurements and economic models will be continued, to assess major effects of real or hypothetical pre-

cipitation variations on agriculture production capacity and water quality. New field studies of summer convective clouds in Illinois will be initiated.

COOPERATIVE RESEARCH—NEVADA/NOAA

A field program during the winter and spring of 1986 will assist in (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) assessment of nucleation, scavenging, and precipitation processes using chemical and isotope techniques; (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. Development and construction of a dual-wavelength radiometer for shared use in the Federal-State program will be completed, and field tests will also be completed.

COOPERATIVE RESEARCH—NORTH DAKOTA/NOAA

Following are the principal activities for FY 1986:

- Continued analyses of the pioneering 1984 and 1985 preliminary tracer studies of cloud transport and correlated cloud physics to determine plume and treatment characteristics over time and space.

- Laboratory tests to improve reliability and efficiency of cloud seeding generators that produce the new fast-acting ice crystal nucleants, such as the chemical complex AgI•AgCl•NaCl.

- Continuation of a comparative exploratory field experiment on in-cloud diffusion and treatment signatures for relatively fast- and slow-reacting AgI chemical complexes, and another slow complex.

- Continued 2-D modeling of the theorized North Dakota precipitation process.

- Further analyses of radar data to complement the existing climatology of cloud echo volumes vs. rainfall, to determine the time between first and maximum echo heights for treated and untreated cells, and initial field studies to attempt to relate cloud transport and microphysics to first echo.

- Procurement and assembly of a GOES weather satellite receiving and weather analysis system, with field tests in 1986, as provided by a special appropriation for instrumentation.

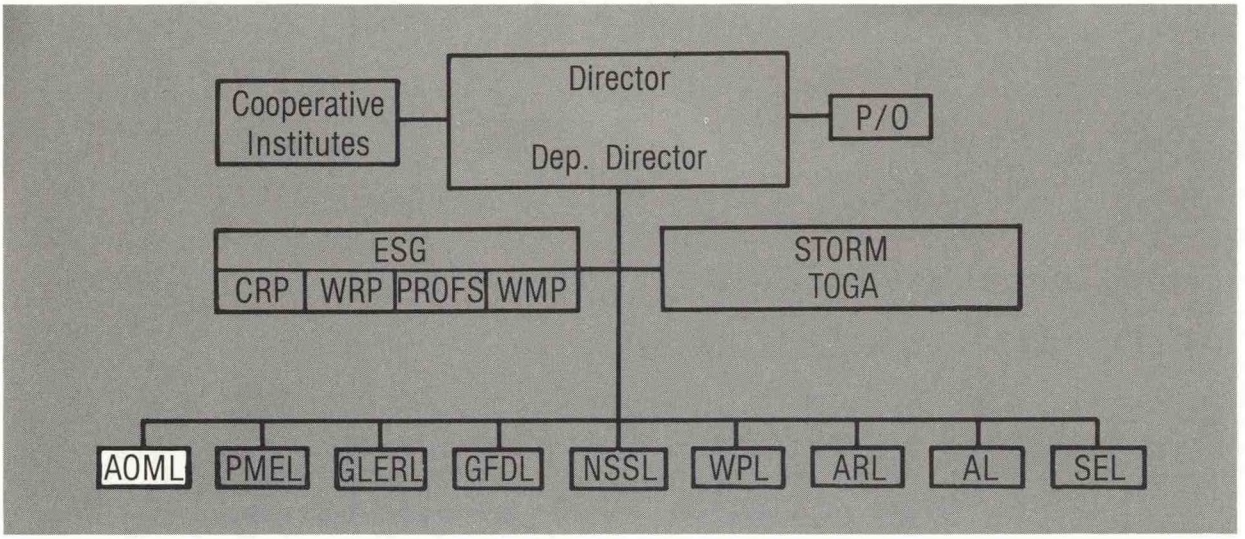
- Initiation of studies and modeling of convergence fields to improve forecasts of convective cloud activity.

COOPERATIVE RESEARCH—UTAH/NOAA

FY-1986 activities will focus on continued intensive analyses of the valuable and comprehensive data sets from the 1985 field study of orographic clouds in the Tushar mountains. These analyses of cloud motions, liquid water development, and precipitation processes will address case studies and the overall season. Limited field work focused on tracer studies of plume transport, and delivery of seeding material may be undertaken as well.

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. AOML activities in these areas are part of the NOAA contribution to national and international programs for climate research.

More and more, the scope of problems being addressed 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. The ultimate goal of the work is to improve forecasting of oceanic and atmospheric variations using predictive models. Model development per se is not a major part of the climate research program at AOML, but focus is provided by the data needs of models, model-data interaction, and observations for parameterization of physical processes in models and for evaluation of models.

The AOML program in climate research is conveniently described within the two categories of tropical ocean climate studies and subtropical Atlantic Ocean climate studies.

Accomplishments FY 1985

TROPICAL OCEAN CLIMATE STUDIES

Tropical ocean climate studies at AOML consist of participation in the continuing NOAA Equatorial Pacific Ocean Climate Studies (EPOCS) 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 Tropical Ocean and Global Atmosphere (TOGA), which has objectives very similar to those of EPOCS, but which concerns all the tropical oceans rather than just the equatorial Pacific Ocean. 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 (ENSO) phenomenon.

An investigation was completed into the physical nature and implications for modeling of prominent long waves regularly observed in the equatorial oceans. Major results are that these waves affect a remarkably large equatorward heat transfer, which could be parameterized as a Fickian diffusion process but which has an extraordinarily large coefficient, and a significant momentum transfer that cannot be parameterized in any conventional way because it is partially countergradient in direction.

An intensive investigation was conducted into the accuracy of linear models that represent the observed variations of the tropical oceans in terms of vertical modes. The principal results are that such models appear to be capable of reproducing the variations that normally occur on relatively short time scales, but that the important variations (such as ENSO events, which occur on longer time scale and whose prediction is of the highest priority) are fundamentally nonlinear, and are not likely to be quantitatively representable with linear models.

Surface meteorological data and surface and subsurface oceanographic data collected during FGGE (1979) in the tropical Atlantic and Indian Oceans were used to estimate the heat balance of the ocean surface mixed layer. Results show that surface heat fluxes account for 75% of the variations observed in many areas. In the Atlantic, addition of estimated zonal advection does not significantly improve the estimation. It was concluded that seasonal variation in the intensity of vertical mixing across the base of the mixed layer is an important process in equatorial regions.

An oceanographic atlas was published describing the El Niño event of 1982-83. This atlas contains a broad comprehensive set of observations by U.S. scientists and those of other nations. It will serve for many years as the definitive summary of oceanographic observations that will be used for testing models and diagnostic studies of this historic event.

Drifting buoy data collected from 1977 to 1983 in the eastern tropical Pacific were used to estimate the rate of equatorial upwelling from the horizontal divergence of near-surface currents. An average upwelling rate of 1.5 + 0.3 m/day was found for the region 1.5°N-1.5°S, 80°-130°W. (This is the first estimate of equatorial upwelling with attendant error bars). Substantial annual and semiannual modulation, agreeing in phase with previous analyses of isotherm depth, were also found.

The mean dynamic topography of the Gulf of Mexico was computed from all available Nansen bottle, CTD, and XBT data for investigation of the uses of satellite altimetry. More than 26,000 stations were used to determine the mean dynamic height at 25 km resolution. The dynamic topography is dominated by the 150-dynamic-centimeter high associated with the Gulf Loop Current in the eastern basin, and by a cyclone/anticyclone pair in the western basin. The standard error of the mean is less than 2 dynamic cm.

A new design was completed for a drifting buoy for measuring sea surface currents and temperature in the tropical oceans. This buoy is characterized by improved (and better documented) Lagrangian performance. It can be constructed and transported for less than one-third the cost of previous buoy designs and can be deployed easily from smaller vessels. It also is designed to take advantage of recent progress in development of data processing procedures which is expected to reduce the cost of data collection by at least one-half. It is anticipated that this drifting buoy will be used extensively in the EPOCS and TOGA programs.

Further progress was made also in development of ocean sampling, in cooperation with research institutions in Latin America. Subsurface thermal sampling was begun from an Ecuadorian vessel operating between South America and Japan, and the equipment now used aboard two Ecuadorian vessels was upgraded to provide capability for real-time transmission of data for use in evaluating predictive models of the El Niño phenomenon. **AOML**

SUBTROPICAL ATLANTIC CLIMATE STUDIES

Analysis of data collected during the 2-year intensive observing period in the Straits of Florida indicates that variability occurs on many spatial and temporal scales. Variability at periods ranging from days to several weeks occurs in both the baroclinic and barotropic components of the flow and frequently takes the form of continental shelf waves. These waves are generated by local and/or regional wind forcing. The phase of the annual signal in total transport closely resembles the phase of the annual signal generated by a wind-driven numerical model of the North Atlantic. The observed amplitude of the annual signal is approximately twice the amplitude of the model annual signal. The amplitude of the interannual signal in transport as derived from sea level observations calibrated for transport is less than one-half the annual signal.

In two cruises to the western North Atlantic Ocean, over-the-side observations were taken, and in situ recording instruments were placed, following the philosophy adopted in the Straits of Florida of using direct observations of transport to calibrate indirect observations. The North Atlantic Deep Undercurrent was observed directly for the first time at 26.5°N. Geostrophic observations show that this equatorward flow, which apparently has a large role in meridional heat flux, exists as far south as San Juan, P.R.

Particular success was achieved also in implementing a system for acoustic remote sensing of currents from the R/V Researcher. Both the hardware and the data-processing software place this system at the fore, in both reliability and accuracy, of the several similar systems that exist throughout the world. It is notable that development of this system was not implemented primarily as an engineering task at AOML, but rather was driven by scientist-users who interacted with the engineering staff. Unprecedented views of the three-dimensional ocean current structure have already been obtained using this device, and it is serving as the model for installation on other NOAA ships, and even research vessels of other nations.

Plans FY 1986

TROPICAL OCEAN CLIMATE STUDIES

The main focus of these studies will continue to be with the EPOCS and TOGA programs. A closer association with model developments is planned. Strategy will be developed for four-dimensional data assimilation in models; that is, an investigation will be made of the use of observations to "update" model simulations in optimal ways. AOML has detailed a senior research oceanographer to the NOAA National Meteorological Center to participate in implementing and evaluating a general circulation model of the tropical Pacific Ocean for simulation and experimental predictions of El Niño phenomena.

Collection of surface current and sea surface temperature data by means of satellite-tracked drifting buoys will be substantially increased, using the new drifting buoy design. An intensive program for observing and mapping the surface currents in the region of the South Equatorial Current and North Equatorial Countercurrent will be conducted in the eastern tropical Pacific Ocean as part of EPOCS. Deployments of drifting buoys are planned also in the western Pacific Ocean in association with United States/Peoples' Republic of China for the TOGA cooperative agreement program, and in the Arabian Sea and Bay of Bengal as part of the TOGA program in the Indian Ocean. Initial deployments will be used to explore the nature of these regions. Plans for future work will be based on results from initial deployments.

Two research cruises are planned to investigate the currents and hydrographic conditions in the southeastern tropical Pacific, farther offshore than heretofore studied in the EPOCS program. This is the region in which precursory indications of El Niño are seen in some historical data, and from which some of the anomalous conditions observed near the coast during El Niño are presumed to be derived. Cooperation with scientists in oceanographic institutions in Latin America will continue, with the objective of assisting them to

improve the quality and quantity of their observing projects for mutual benefit.

If an El Niño event occurs during the year, AOML scientists will be intensely involved in augmentation of observations, using the NOAA research aircraft as well as all the observing systems mentioned above.

SUBTROPICAL ATLANTIC CLIMATE STUDIES

The program for long-term monitoring of the Florida Current using the methods developed during the first phase of the work will be continued. The major emphasis for research during Phase 2, however, is to develop knowledge of the currents along the topographic rise on the eastern side of the Bahama Islands and in the Antillean passages. Continued observations of currents, sea level, pressure, and water properties will be made with shipboard and in situ instrumentation

It is planned that in the more distant future this work will evolve into a substantial part of the NOAA contribution to the World Ocean Circulation Experiment (WOCE). Although the particulars of the objectives and observing strategies for WOCE are still undecided, it is certain that measurements such as those currently being changed to operational status on the Straits of the Florida will be critical.

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 uses NOAA research aircraft to acquire unique data sets. AOML interacts with the National Hurricane Center (NHC) and the National Meteorological Center (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 the Geophysical Fluid Dynamics Laboratory (GFDL) in the area of hurricane modeling.

Accomplishments FY 1985

OBSERVATIONAL STUDIES OF HURRICANES

Microphysics

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

An analysis that correlated particle type and concentration with the PPI radar display for Hurricanes Allen (1980) and Irene (1981) showed that regions of high (>30 dBZ) radar reflectivity above the 0°C isotherm were positively correlated with strong updrafts and with the presence of liquid precipitation. Strong radial gradients of radar reflectivity in the outer edge of the eyewall were frequently associated with downdrafts and high concentrations of ice particles.

Convective-Scale and Mesoscale Features

Analysis of airborne Doppler radar data from Hurricane Alicia (1983) neared completion. It was possible to map the secondary circulation in the eyewall, including the radial inflow at low levels, the updraft along the inside edge of the eyewall, and the radial outflow at the top of the eyewall. The radial outflow was concentrated in a relatively narrow layer, 2-3 km thick, at the top of the storm.

The airborne Doppler system provided direct measurements of the mesoscale verticle motions in the nonconvective or stratiform region surrounding the eyewall. Both updraft and downdraft air motions were found to originate at the 0°C level. This is consistent with recent modeling results obtained at AOML. The magnitude of these mesoscale vertical motions was 30-80 cm s^{-1}, which is comparable with those in other tropical systems.

AOML's land-based radar project is concerned with analysis and interpretation of digital land-based radar data recorded at NWS offices during the landfall of hurricanes. The emphasis is on the description of important changes in the patterns of rainfall that are caused by land influences, the statistical properties of the convective-scale and mesoscale features of hurricane rainbands, and the life history and three-dimensional structure of the convection. During FY 1985, the project produced a color time-lapse movie of the digital radar data that were recorded during the landfall of Hurricane Alicia (1983). A second movie of landfalling Hurricane Diana (1984) neared completion.

Detailed observations of supercell activity were obtained in eastern Pacific Hurricane Norbert (1984). Doppler radar data, lower fuselage reflectivity data, cloud microphysical data, aircraft wind and thermodynamical data, and remotely measured surface wind data were obtained. Preliminary analysis reveals a remarkable similarity with a previous supercell case--Hurricane Gladys (1975). Supercell locations (with respect to the low-level circulation center), as well as horizontal scales and magnitudes of reflectivity features, were nearly identical. Both cases were characterized by intense downdrafts (>15 m s^{-1}) downwind of the convective cores (some with reflectivity >50 dBZ) extending through 500- and 700-mb levels. This resulted in relative humidities of less than 30% and temperature anomalies of nearly 20° C at 700 mb.

Synoptic Environment

The steering currents on the periphery of mature hurricanes are determined by Omega dropwindsondes (ODWs), which are deployed from NOAA P-3 aircraft. The ODWs measure temperature, relative humidity, and pressure, and transmit

data to the aircraft. They also receive and retransmit Omega navigational signals, which allow horizontal winds to be computed. With the ODW observations, the synoptic-scale flow around a hurricane can be determined from the surface to 400 mb more accurately than is possible with the current operational data sources.

Experiments were conducted on three days during flights in the periphery of Hurricane Josephine in October 1984. The spatial scale of Josephine's circulation was slightly larger than 1000 km. The operational objective analysis at NMC, however, is able to resolve only scales that are generally greater than 1500 km. The analysis resolved the larger scale aspects of Josephine's circulation but did not respond well to ODW observations within 500 km of the storm center. Differences between the analyses computed with and without the ODW data were very small. Track forecasts computed by the Movable Fine-Mesh (MFM) model were also not changed significantly by the ODW data.

The MFM errors in the track forecasts at 12 h were particularly large in comparison with climatology-persistence forecasts made by the CLIPER model. Since the MFM became operational, its 12-h track forecasts have consistently been worse than those made by CLIPER. It was previously thought that poor performance of the MFM forecasts at 12 h was the result of the lack of data near the center of hurricanes. It now appears that the insensitivity of the MFM track forecasts to the ODW data and the consistently poor track forecasts at 12 h are a result of the inability of the operational objective analysis to adequately resolve the hurricane circulation.

We are attempting to develop an objective analysis scheme for the large-scale environment of hurricanes which incorporates ODW and other available data such as rawinsonde, NOAA P-3, and Air Force reconnaissance data. A set of horizontal analyses of winds, temperature, relative humidity, and geopotential height for Hurricane Debby (1982) was completed. The analyses are at 50-mb intervals from 100 mb to the surface. Data input for the analyses comes from ODWs, Caribbean and U.S. rawinsondes, NOAA P-3 and Air Force reconnaissance aircraft, surface ships, commercial aircraft, University of Wisconsin satellite data and derived products, and NMC operational analyses. The raw data were carefully edited to promote consistency between the various data sources before input to the analysis package. An iterative scheme was developed to couple the horizontal analyses vertically by creation of bogus data where the analyzed fields are noisy. This occurs most often in data-void regions. Results of the first tests were very encouraging.

AOML

Air-Sea Interaction

Two hurricane air-sea interaction experiments were conducted in 1984. Systematic measurement of ocean currents, using airborne expendable current probes (AXCPs), was carried out in Hurricane Norbert. Ocean current profiles were obtained which enabled patterns of mixed layer and sub-thermocline currents to be mapped. Vertical wind profiles in the Hurricane Planetary Boundary Layer (HPBL) were obtained using airborne Doppler radar; surface winds were obtained using the University of Massachusetts stepped-frequency microwave radiometer (SFMR).

The experiment was repeated in Hurricane Josephine, where three drifting buoys were also deployed by USAF aircraft immediately ahead of the storm. Measurements of surface winds and pressures, sea temperatures at four depths, and data obtained from AXCPs and research aircraft during Hurricane Josephine made it one of the most thoroughly observed storms from an air-sea interaction viewpoint.

SFMR data were taken in Hurricanes Norbert, Josephine, and Isidore. Data quality was excellent for all cases. Calibration constants for converting output voltages to microwave brightness temperatures and surface wind speed are being derived.

HURRICANE TRACK PREDICTION

Research to improve the barotropic hurricane track forecast model (SANBAR) used operationally at NHC has been in progress for several years. In FY 1985, a revision was made to the method by which the model calculates the vorticity and the stream function in the vicinity of the hurricane. The revision reduced discontinuities in the fields near the storm and produced a definite improvement that resulted in reduction of average forecast errors when a fine-grid version of the model was used. The average errors showed a statistically significant reduction for the 12-48 h forecast intervals.

HURRICANE VORTEX DYNAMICS

Data collected in Hurricanes Diana (1984) and Alicia (1983) offer substantial confirmation for the convective ring model in which tropical cyclones undergo cyclic changes of intensity and eye size. The observations also document Diana's intensification from a tropical storm to a category-four hurricane.

Research to understand the nonhydrostatic convective dynamics of hurricanes is in progress. A fine-resolution (2 km horizontally and 1 km vertically) axisymmetric model is being used to examine factors that affect the structure and evolution of the simulated storm. Recent emphasis has been on the role of ice-phase microphysics. Statistical analyses of four versions of the model with different microphysical parameterizations show a definite "ice-phase signature" in the strength and horizontal scale of downdrafts near the melting level. Frequencies of stronger downdrafts with larger horizontal scales increase at and below the melting level, whereas no vertical variation is present when the ice phase is not included.

QUASI-SPECTRAL HURRICANE MODELING

To achieve substantial improvement over existing operational models, it is necessary to understand various physical and dynamic factors affecting the motion of a hurricane, and to test new ideas with a quantitatively accurate numerical model. A general-purpose base model on nested grids is under development, utilizing an accurate and flexible numerical method, QSTING (Quasi-Spectral Time Integration on Nested Grids).

Spectral representation of field variables by cubic B-splines is the basis of QSTING. It combines the numerical accuracy of spectral methods with the freedom of specifying boundary conditions to a finite domain. To nest a series of finite domains of differing resolution is a modeling assumption that forces compromise on the obtainable mathematical solutions. Our concern is to reduce the compromise to a physically acceptable level. The acceptable level depends on the physical problem. Its achievability depends on numerical techniques.

The problem of wave propagation across an interface, from a fine-resolution domain to a course-resolution domain and vice versa, was solved earlier by dynamically matching spatially variable filters at the interface. We were aware of another problem with the Gibbs phenomena, which arose from a strong stationary disturbance in a fine-resolution domain when the disturbance was projected on the same area embedded within the next larger domain. The projection entails spectral truncation due to a change in resolution. By carefully designing projection filters, we reduced the error to a level that we had once thought to be acceptable. However, as soon as the plane QVADIS was tested with a balanced free-spinning hurricane-like vortex, we were shown to be wrong. Although the error at each time step was small, it accumulated, and after 8 h (2880 time steps) the vortex was noticeably out of the original shape and definitely unacceptable.

A solution to the problem is to eliminate the projection entirely. That is, we accept each nested domain with a hole in the middle where no information exists. (Earlier, there was no hole of information, since the area was filled with the projection, or "shadow", of the subdomain fields.) The new procedure technically implies performing spectral transforms in a domain with a hole, without knowing the explicit inside boundary conditions. Because of this and other technical complications associated with holed domains, we had stayed with the projection method too long. When proper algorithms were developed and the new QSTING-anumbra (meaning "without shadow") was reprogrammed, the model worked beautifully. The free-spinning vortex now keeps spinning with very little change.

OBJECTIVE ANALYSIS OF TROPICAL WINDS

AOML

NHC has archived twice-daily objective analyses of ATOLL (Analysis of the Tropical Ocean Lower Layer) (nominally about 900 mb) and 200-mb winds over the tropical Atlantic for June through November since 1975 and for the entire year since 1981. Spectra of selected locations in the tropics show substantial variation in the 3-5 day "easterly wave" band. In the "data-rich" subsection of the grid from 40°W to 100°W and 10°N to 30°N, the analyses were sampled on an approximate 3° grid, and filtered in time to isolate energy in the 3-5 day band. Complex tensor covariance statistics were used to analyze the spatial structure and temporal (month to month) variability within the band. Complex Empirical Orthogonal Functions (EOFs) were used to extract the dominant spatially coherent signal. The complex EOFs include information on the three-dimensional structure, including phase propagation, for the individual modes.

Considerable temporal variability and spatial inhomogeneity were found in the monthly statistics. In July-September of 1975-1977, only July 1975 and one month in 1976 had dominant EOF modes that were statistically distinct from

the lower ones. In July 1975 there was a series of strong easterly waves in the Atlantic and Caribbean that were well defined over a large portion of both the 200-mb and ATOLL analyses. The first EOF, explaining 25% of the total variance, had large amplitude at both levels. The phase lines of the dominant meridional wind component sloped somewhat from southwest to northeast at the ATOLL level and tilted westward with height against the mean westerly wind shear. The zonal wavelength at both levels was about 3500 km, corresponding to a westward phase speed of about 9 m s^{-1}. Vorticity amplitude and phase were also computed. The extension of the mode to the west showed vorticity phase propagation continuing across the Atlantic, the Caribbean, Central America, and Mexico, and into the region of tropical storm formation in the eastern Pacific.

GALE

The Genesis of Atlantic Lows Experiment (GALE) should provide new information on coastal frontogenesis and cyclogenesis and the mesoscale structure and evolution of cyclones. The field experiment is scheduled for the Carolina coastal region from 15 January to 15 March 1986. During 1985, AOML's portable radar recorder was taken to the NWS office in Wilmington, N.C. Weather Service personnel operated the recorder and recorded data in four weather events between 30 January and 22 March. PPIs were recorded every 6 min. The data were processed and a color time-lapse movie was completed and distributed to interested GALE scientists. The movie is being used to plan observing strategies for the field experiment.

STORM

Mesoscale convective systems (MCSs) produce significant rainfall and severe weather in the Midwest during the spring. Two of the main goals of the Stormscale Operational and Research Meteorology (STORM)-Central research program are to improve understanding of the genesis, evolution, and structure of MCSs, and to improve forecasts of MCSs. The field phase of the Preliminary Regional Experiment, PRE-STORM, took place in Oklahoma and Kansas (OK) in spring 1985. The goals of OK-PRE-STORM were to investigate mesoscale convective systems. One of the sub-goals was to observe microphysical characteristics and radar characteristics of mesoscale convective systems. AOML participated in the field phase of PRE-STORM by recording digitized radar reflectivity at the Wichita NWS WSR-57 radar, and by collecting microphysical data on the NOAA P-3 aircraft. These data, and the data collected by the NCAR Doppler radars and the portable automated mesonetwork (PAM), will be used to study the initiation and evolution of the stratiform precipitation region, the precipitation mechanism(s) in the stratiform region, and feedbacks into the dynamics of the mesoscale convective systems.

Plans FY 1986

OBSERVATIONAL STUDIES OF HURRICANES

Microphysics

A study of the melting layer in Hurricane Alicia (1983) will be completed. Data taken in stratiform regions of hurricanes and PRE-STORM data from stratiform regions in MCSs will form the basis for a comprehensive study of stratiform precipitation. The analysis and interpretation of the microphysical data from the Hurricane Norbert (1984) water budget experiment will continue.

Convective Scale and Mesoscale Features

The primary emphasis will be on analysis of the water budget in Hurricane Norbert (1984). The airborne-Doppler analysis will be completed and integrated with the analysis of the flight level and microphysical data. The water budget equations will be formulated and the terms evaluated. Analysis of the visual and radar-derived characteristics of Hurricane Diana's (1984) eyewall will be completed. The three-dimensional structure of the convective-scale and mesoscale features in Hurricane Alicia (1983) will be examined with both land-based- and airborne-radar data.

Synoptic-Scale Environment

Cooperative studies with NHC and NMC will continue to examine the effect of the ODW data on the operational analyses and hurricane track models. The data will be used in diagnostic and prognostic studies of hurricanes and in the evaluation of remote atmospheric soundings.

Air-Sea Interaction

AOML

It is planned to acquire additional color photographs of sea state for use in developing color descriptions of sea state corresponding to Beaufort categories 3 through 19. Photos will be compared with SFMR measurements. This study will also use Inertial Navigation System flight level wind measurements made near cloud base, and planetary boundary layer (PBL) models,to reduce flight level winds to the surface. Airborne Doppler radar measurements in the PBL will also be used for estimating surface winds. It is planned to develop a surface wind speed algorithm for use with SFMR data in real time.

HURRICANE VORTEX DYNAMICS

Work will be directed toward preparation of the confirmatory concentric-eyewall observations for formal publication and toward exploration of additional aspects of Hurricane Alicia (1983), Arthur (1984), and Diana (1984) that relate to vortex motion and banded structure. Theoretical vortex-motion work will focus on detailed exploration of a barotropic model from which preliminary results indicate that it may be possible to explain trochoidal motion of

the vortex through resonance between a normal mode oscillation and periodic forcing by rotating steering currents.

QUASI-SPECTRAL HURRICANE MODELING

It is necessary to understand, and extend, the concept of nonlinear diffusion. Some form of nonlinear diffusion that responds to in situ needs for diffusion is desirable. The deformation-dependent diffusion, as originally proposed by Smagorinsky, is too indiscriminately diffusive. The need for diffusion depends on both the spectral resolution of the model and the physical problem to be solved. Therefore, the question straddles the border of numerics and physics. We must also examine inertial instability in the hurricane upper-outflow layer. Upper-level outflow jets associated with organized cumulus convection have attracted many diagnostic studies. We would like to provide a better theoretical explanation of these features.

It is hoped that QVADIS can be converted by October to the extent that it will run on the CYBER 205. However, vectorization of the program under the 205 rules requires extensive changes using nonstandard special routines of the 205. Also, the conversion of QVADIS's interactive output program must also be accomplished as soon as possible.

OBJECTIVE ANALYSIS OF TROPICAL WINDS

Analysis of the characteristics of the disturbances in the 3-5 day band will be completed for 1975-1977. Statistical analyses of rawinsonde station profiles will be made to describe the vertical structure of the disturbances. Spectral and EOF techniques will be used to investigate the long-term inter- and intra-annual variability in the wind data since 1975. The relationship of the wind variability to climatic fluctuations, such as the El Niño/ Southern Oscillation, the 30-60 day global oscillation, and hurricane cycles will be examined. Work to provide a climatology of the winds, including monthly means, will be started.

GALE

AOML's existing radar recorder and two new recorders will record data at Weather Service stations during GALE. Five or six AOML scientists will participate in the field experiment for periods ranging from 2 weeks to a month. They will operate instruments on the NOAA P-3 during flights, ensure that the portable radar recorders are operating properly, and provide advice in the design of Omega dropwindsonde flights. Plans are being developed for cooperative research on coastal fronts with Pennsylvania State University and the State University of New York at Albany and on the mesoscale structure of oceanic rainbands with the University of Washington.

STORM

The PRE-STORM data set contains 1000 tapes of Doppler data from the two NCAR radars and 200 tapes of digitized radar data from the Wichita WSR-57. A

necessary first objective for 1986 is to produce an overview of eight or nine notable weather events, using the digitized WSR-57 data. This overview is expected to help focus the subsequent analyses of the Doppler, the surface, and the aircraft data sets.

OBSERVATIONAL STUDIES OF THE SOUTH FLORIDA SEA BREEZE

The field phase of the sea-breeze experiment, carried out in previous years, was designed to provide a description of the mixed layer, the cloud layer, and the evolution of the sea-breeze circulation from shortly after sunrise until midafternoon when deep convection is normally present. The role of the sea-breeze in organizing the development of deep convection is being examined. Airborne Doppler radar data, collected on two days, are being used to specify the kinematic structure of mesoscale precipitation lines that were initiated by the sea-breeze circulation. Analysis of the aircraft data will be completed as will analysis of airborne Doppler radar observations of the development of deep convection in the sea-breeze convergence zone.

AIR QUALITY

Air quality research at AOML has two focuses. One is to develop an understanding of the geochemical cycles (horizontal and vertical distributions, sources, sinks, and transformation processes) of major trace constituents of the atmosphere. The second component concerns studies of the role that marine biological processes have in determining the composition of the atmosphere. At present, both programs are addressing those species (excluding carbon dioxide) that are significant in determining the Earth's radiation balance. The overall objective of this research is, in conjunction with AL, ARL, GFDL, and PMEL, to develop a validated diagnostic and prognostic ability to assess climate alterations resulting from observed or projected changes in the radiatively important trace species (RITS).

Accomplishments FY 1985

ACID RAIN

AOML completed its interim assessment of the role of oceanic processes in determining the acidity of precipitation. This assessment was called for in the National Acid Deposition Assessment Program plan and was based on 3 years of research cruises to study chemical and biological processes in oceanic regions. Though emphasizing the biogeochemistry of sulfur, the research studied a wide variety of precursors of acidic species, such as the precursors of organic acids, and processes that transform precursors into acidic species, such as oxidation. The major findings of the assessment were that the combined fluxes of reduced sulfur from marshes, estuaries, and oceanic regions to the coterminous 48 states were insignificant (<10% and most likely only 1-5%) compared with the anthropogenic fluxes. On a regional scale, however, such natural sources could be significant to the sulfur budget of the west coast. It is also possible that marine sources of reduced sulfur may affect the immediate

Gulf Coast but are rapidly removed within 100 miles or so inland. Marine sources are not significant on the east coast. On a global scale, no evidence was found indicating that published data on levels of reduced sulfur over oceanic regions are in error and, consequently, that fluxes derived from those measurements are incorrect. However, we cannot balance these fluxes on the basis of what we have learned about the biogeochemistry of sulfur. A large flux of biogenic sulfur from the marine environment to the atmosphere cannot be substantiated by our experimental evidence on inorganic sulfate assimilation by marine organisms and the subsequent partitioning within biochemical systems.

RITS

AOML continued its marine tropospheric chemistry program as part of the ERL RITS effort. Equipment and apparatus were built and acquired. Spectrometers, chromatographs, sampling systems and chemical standards were accumulated.

Work continued on the analyses of the volatile organic components in a suite of samples collected over the Pacific in 1984. These reactive and radiatively important trace substances have very large variability in concentration in both space and time. The different compositions of the mixtures are probably related to their biogenic source. Vertical profiles of the volatile organics, collected from the NOAA P-3, show that the chemistry of many of the components is confined to the lower few hundred meters over the sea surface. Other, more stable, constituents mix throughout the boundary layer. Ozone concentrations were measured constantly throughout the organic sampling on shipboard and on the aircraft. It is not clear from the data in hand whether the organics evaporating from the sea surface are sources or sinks of ozone. High concentrations of many organic oxidation products were identified in the boundary layer. These observations will be investigated in more detail in FY 1986.

Plans FY 1986

ACID RAIN

AOML's research into the role of oceanic processes in determining the hydrogen ion content of precipitation ended in FY 1985. The principles and approaches developed in that program will continue to be applied within our overall research program into biosphere, hydrosphere, geosphere, and atmosphere interactions. Much of this will occur within the scope of our RITS program. Some specific questions that arose in the course of our acid rain research, such as balances between biological and geochemical cycles of atmospheric trace species, are generic components of biogeochemical research programs and are likely to be addressed within the RITS program.

RITS

The AOML tropospheric chemistry effort will concentrate on the tropical Atlantic. More chemical species will be measured synoptically along with all relevant meteorological data. Methane, carbon monoxide, ozone, nonmethane hydrocarbon gases, and the volatile organic liquids will be measured at the sea surface. In addition, detailed vertical profiles, up to cloud base, of ozone and the volatile organics will be determined with a new tethersonde sampling package. Finally, if funds are sufficient, the biogenic origin of the reactive and radiatively important organics that evaporate from the sea surface will be investigated. The very large qualitative and quantitative differences observed in time and space indicate that the release of this broad array of compounds is intimately associated with biological cycles and ecological microcosms. The relationships between these living systems and the chemical/physical environment of the sea should be quantified.

MARINE RESOURCES

The AOML contribution to studies in Marine Resources is directed toward determining the chemical and thermal effects on the ocean of hydrothermal venting from representative sections of the slow-spreading Gorda Ridge and Mid-Atlantic Ridge. These efforts are central to the program objectives of the NOAA VENTS program.

Accomplishments FY 1985

GORDA RIDGE

The objective of the FY 1985 program was to determine the state of hydrothermal activity on the Gorda Ridge. Toward this end, a number of investigators participated in a cruise of the NOAA Ship Surveyor (May 1985). Selected accomplishments are as follows:

- All existing NOAA and USGS geological and geophysical data on the Gorda Ridge were reviewed and applied to selecting target sites for the May 1985 VENTS Program cruise, in close collaboration with USGS scientists (Marine Geology and Geophysics Branch, Menlo Park).

- AOML participated in the May 1985 Surveyor cruise to the Gorda Ridge, to collect suspended particulate matter, sediment cores, interstitial water, near-bottom water temperature profiles, seafloor imagery, and SEABEAM profiles at preselected target sites, in close collaboration with participating scientists from NOAA/PMEL and Oregon State University.

- Preliminary energy dispersive analysis (EDA) of the suspended particulate matter showed enrichment of particulate iron, manganese, calcium, and sulfur, suggesting the presence of anhydrite; the iron enrichment is in the form of relatively large (~10 μm) subhedral to euhedral particles, in contrast to iron particles in suspended particulate matter (SPM) of the Mid-Atlantic Ridge, which are in the colloidal range.

- Initial extractions of metals (Cr, Cu, Fe, Mn, and NiO) indicated distinct variations in concentration, which are being interpreted in terms of remobilization under changing redox conditions and variations in hydrothermal input to the sediment column. Copper, Fe, Mn, and Ni exhibit a strong positive correlation in their distribution; Cr is negatively correlated with these metals.

- Three camera-temperature profiles were run with SEABEAM bathymetry at sites where water chemistry indicated intermediate levels of hydrothermal activity on the central Gorda Ridge; review and reduction of these data are being coordinated with heat flow measurements (Oregon State University) and seismic reflection profiling (USGS) to determine relations between hydrothermal activity, heat transfer, and crustal structure.

- Shipboard analyses of interstitial water revealed high redox states and consequent remobilization of metals, particularly manganese, related to relatively high contents of organic matter in the sediments; this result indicates that remobilization of metals and expulsion of the metal-rich water during sediment compaction may have a significant effect on ocean chemistry, in contrast to the Mid-Atlantic Ridge where oxidizing conditions were found to prevail in the sediments and metal remobilization was negligible.

MID-ATLANTIC RIDGE

The objective of the FY-1985 program was to locate and characterize the actual venting zone at a site where active venting was identified on the VENTS Program FY-1985 cruise of the NOAA Ship Researcher. Accomplishments of the cruise (9 July-7 August 1985) are as follows:

- High-temperature black smoker-type venting was discovered at the Trans-Atlantic Geotraverse (TAG) Hydrothermal Field in the rift valley of the Mid-Atlantic Ridge at latitude 26°N. This is the first high-temperature black smoker venting found on a slow-spreading oceanic ridge. Slow-spreading oceanic ridges constitute more than half the globe-encircling, 55,000-km oceanic ridge system. The implication of the discovery is that hydrothermal venting from slow-spreading oceanic ridges, including the Gorda Ridge, has a significant impact on the chemistry and heat budget of the oceans and offers potential for the occurrence of polymetallic sulfide deposits.

- In the search and discovery process, the FY-1985 cruise collected multidisciplinary data sets at far, intermediate, and near fields with reference to the black smokers. The data sets comprise water samples (suspended particulate matter, dissolved manganese, dissolved rare earth elements, dissolved gases), water properties (salinity and temperature and particulate light-scattering profiles), near-bottom temperature profiles, moored oceanic current meter arrays, bottom sediments (cores, grabs, sediment traps), rocks, imagery, and some biological material.

Plans FY 1986

GORDA RIDGE

A NOAA cruise will be organized to examine a hydrothermal venting zone at what appears to be the most promising site or sites on the Gorda Ridge (an evaluation based on prior NOAA, USGS, OSU, and other work); the cruise will be a collaborative effort of NOAA (AOML, PMEL), USGS, OSU, and others. The objective of the FY-1986 cruise is to observe the active vents at close range and to characterize their effluents, building on findings from prior cruises.

MID-ATLANTIC RIDGE

The possibility of a modest series of dives with the submersible Alvin is being explored to follow through on the discovery of black smokers at the TAG Hydrothermal Field on the Mid-Atlantic Ridge. The scientific objective of the dives would be to sample the hydrothermal effluents and precipitates, measure their temperatures, and make related detailed investigations to determine chemical and thermal fluxes, mineralization, and associated geologic setting of the venting. A multidisciplinary, multi-institutional group to carry out the dive series and subsequent data reduction would include NOAA scientists (AOML, PMEL) with NOAA funding support, and MIT and WHOI scientists with outside funding (e.g., NSF).

MARINE OBSERVATION AND PREDICTION

AOML research in Marine Observation and Prediction is concentrated in the following areas: (1) Improving the definition and measurement of the ocean bottom depth for charting, navigation, and bathymetric purposes; (2) determining optimum measurement system configurations for flux of volume, heat, particulates, and other parameters as they are used in NOAA Climate Programs and Marine Assessment Programs; (3) potential operational system evaluation and demonstrations. This research is aimed at improving the observational equipment and techniques that are used to collect data on the marine environment; particular emphasis is placed on the use of new, advanced, high-technology systems.

AOML

Accomplishments FY 1985

ECHO FORMATION MODELS

AOML personnel developed an initial bottom-echo-formation model. When given a set of input parameters characterizing a bottom environment, the model will produce the echo signal to be expected from such a bottom. The signal thus produced is extremely detailed and is used to evaluate different methods of echo signal processing and displays. Thus far the model has indicated that the identification and classification of different bottom types is feasible.

OPERATIONAL SYSTEM EVALUATION

Establishment of an initial theoretical basis for optimum flux and other measurement systems and arrays was carried out. The theoretical framework produces the basis for determining an optimum set of instruments and their placement in strategic regions in order to achieve specific measurement goals.

An experiment to evaluate the performance of the AOML transverse Doppler current-profiling technique in a highly turbulent channel, the entrance to the Port of Miami, was carried out. Data from this equipment are being evaluated.

A plan for AOML to participate in an operational demonstration of Coastal Ocean Dynamics Applications Radar (CODAR) in the Straits of Florida between Miami and Fort Lauderdale was approved by the directors of AOML, WPL, NWS, NOS, and the USCG. A contractor was hired by NOS to refurbish, update, install, and operate the NOAA-furnished equipment for the first 2 months.

FLORIDA ATLANTIC COAST TRANSPORT STUDY (FACTS)

Field measurements of satellite-tracked Lagrangian drifters and inverted echo sounder/pressure gauges (IES/PGs) near Cape Canaveral were completed in May. Three areas west of the Gulf Stream were identified as locales where drifters tend to come ashore: south of Cape Canaveral, Fla.; near Jacksonville, Fla.; and near Charleston, S.C. Data from two of the three deployed IES/PGs were recovered; the linear correlation with the STACS cable transport was 0.83, and as in the Subtropical Atlantic Climate Study (STACS), most of the signal was on the western side of the Gulf Stream. IES/PG pairs are useful indicators of volume transport when cables and/or surface tide gauges are not available.

Plans FY 1986

ECHO FORMATION MODELS

AOML intends to continue the development of the bottom-echo-formation model. A field experiment for model validation is planned. It will probably be conducted within Chesapeake Bay, and will be designed to obtain actual data on echo formation by different bottom types. A comparison will be made between the echos recorded in the field and the echos predicted to exist by the AOML echo-formation model.

OPERATIONAL SYSTEM EVALUATION

Research into optimum measurement system configurations will continue, using a mixture of local, integral, and remote measurement systems. Application of empirical orthogonal function theory to climate and other program-dictated measurement sections is planned. Continued reduction of sediment and particulate transport data, obtained using acoustical systems, is anticipated. Routine operation of the CODAR at Straits of Florida sites will be turned over to NOAA by the contractor in February. AOML will transfer the day-to-day pro-

cessing and public information broadcasts to NWS, and will continue to conduct verification tests jointly with the USCG. Research into the use of operational CODAR data for monitoring the Florida Current and for nowcasting of sea state will begin at AOML.

FLORIDA ATLANTIC COAST TRANSPORT STUDY (FACTS)

Analysis of the AOML-obtained Lagrangian drifter data and the IES/PG data will be completed. In addition to the AOML data, information from 44 moored current meters, numerous Pegasus casts, sea level/weather gauges, and a submarine cable are available for multi-input linear and spectral analysis. In addition to an assessment of the impact on Florida of mineral-mining operations between Palm Beach and Jacksonville, the FACTS section will be subjected to a synergistic systems analysis to determine the optimum combination of measurements for an initiative in monitoring critical ocean regions.

MARINE ASSESSMENT

The ocean, particularly the coastal ocean, is an invaluable environmental resource. Among its many uses, it is at one time a source of food and a receptacle for anthropogenic wastes. It is vital to our national interests to ensure maximum compatibility of our various uses. We believe that trace metal speciation processes in environments receiving waste inputs may play a major role in determining what, if any, ecological cost will be associated with pollution. The most economically significant living resources in coastal waters are fisheries; however, owing to the time and space scales of actual and probable pollutant inputs, the most critical ecological events concern phytoplankton. Perturbations once initiated, however, can cascade through the food web and indirectly affect fisheries.

It is important to recognize that stress from pollution may not be inherently pernicious. We have reason to believe that it will be possible to develop effective strategies not only to minimize bad effects but perhaps to optimize desirable ecosystem transformations. Because of the potential impact on the coastal zone environment, we are faced with a need for developing intelligent choices for waste disposal; one option is ocean dumping. However, problems at active bulk dump sites like those in the New York Bight have turned many people against the ocean disposal alternative. We hypothesized that major rivers with high suspended sediment loads can adequately handle a significant pollutant burden and that river deltas are a reasonable choice for controlled, passive waste disposal. Rivers are the major pathway by which the products of natural geological erosion processes and the pollutant inputs of mankind are added to the oceans. Since most river-borne chemical pollutants are favored to partition onto suspended particulates, pollutant pathways are likely to vary with the particle pathways. Study of pollutant dispersal into the marine environment thus becomes very much a study of particle-pollutant dynamics on river deltas. Furthermore, when massive sediment deposition occurs on a river delta, anthropogenic inputs may be obscured and diluted to innocuous levels. If these sediment pollutants are not reintroduced into the water column by chemical, physical, or biological processes prior to "deep"

burial, then delta sediment depositories become permanent reservoirs for enormous annual burdens of industrial and municipal wastes.

Accomplishments FY 1985

FISHERIES OCEANOGRAPHY

Catch data from Japanese longline bluefin tuna fishing in the Gulf of Mexico during 1979-1980 were analyzed relative to in-situ oceanographic data and satellite remote-sensing data. A threefold increase of catch per unit effort in 1980 compared with 1979 appears to be associated with the area fished, and seems to reflect a change in fishing strategy. The higher catches were made primarily in proximity to the surface thermal front of the Gulf Loop Current. Correlations with other environmental factors such as sea surface temperature, temperature differences, and current patterns, and with age of the fish, were generally inconclusive.

FISHERIES OCEANOGRAPHY COOPERATIVE INVESTIGATION (FOCI)

For the past several years, AOML has conducted research in cooperation with the National Marine Fisheries Service with the long-term goal of understanding direct and indirect environmental controls on the year class strength of commercial fisheries. Research cruises with this specific objective have been conducted aboard the F/V Oregon II and the R/V Researcher in the Northern Gulf of Mexico, particularly in and near the frontal plume of the Mississippi River. In this last year, a series of publications and presentations resulted, detailing the relationship between larval fish growth and abundance and the concentration of their planktonic food resource by physical process. Preparatory to renewed field studies extending this work to new areas and fish species, a project was initiated through CIMAS to improve sampling technology in regard to synopticity, real-time feedback, and the integration of physical and biological sampling. AOML investigators led a team of ONR-funded university investigators in a physical/biological study of the Gulf Stream core and western wall. Systems developed previously were substantially re-engineered for this effort, particularly in regard to the incorporation of fluorescence sensors and computer interfacing capability. For the first time, zooplankton data were gathered by traditional, acoustic, and optical methods in conjunction with continuous acoustic records of current shear.

TAP

AOML continued studies of the mechanisms of metal/organic interactions in seawater, especially metal chelation by naturally occurring organic ligands. The objective was to develop interactive biological/chemical models of metal speciation as it affects ocean planktonic populations that serve as food sources to larval fish. Results of the work include the following:

- Zooplankton samples collected in the northern Gulf of Mexico were analyzed for species composition in areas where AOML has characterized the chelation capacity of near-surface seawater.

- Chemical analyses showed that some marine organics can chelate metals strongly enough to compete with artificial chelators, thereby impacting so called "total" metal determinations.

The above discovery on chelation suggests that models of the thermodynamic equilibrium speciation of a trace metal important in biological processes may, therefore, incorrectly assess the potential impact of the introduction of a trace metal contaminant to an ecosystem. These results suggest that future work in the field must assess such an impact, in order to correctly model this process, through a thorough evaluation of the stability constants of naturally occurring organic ligands with metals.

P–PRIME

The P-PRIME (Pollutant-Particle Relationships in the Marine Environment) program was completed in FY 1985 with publication of the following information:

- P-PRIME data from the Mississippi River and adjacent shelf (tables and illustrations detailing station locations, summaries of data types and amounts thereof including dates of collection and geographical position, depth, etc., suspended particulate matter size distributions, concentrations and trace metal analysis results).

- Compelling evidence that over the last decade a measurable decline in lead transport and deposition in and around the Mississippi River and Delta is related and proportional to the decreased consumption of lead in the United States resulting from environmental regulations such as the deleading of gasoline.

Plans FY 1986

FISHERIES OCEANOGRAPHY

AOML

Continuing work will require identification of new funding.

FISHERIES OCEANOGRAPHY COOPERATIVE INVESTIGATION (FOCI)

Data analysis will occupy much of FY 1986. Publications will continue to result from the Gulf of Mexico data, albeit at a reduced rate. The results of the sampling technology cruise will have to be assimilated so that they may be taken into consideration in designing the new field studies. Two separate field studies are being planned in cooperation with the National Marine Fisheries Service. The first will be aboard the F/V Oregon II in February 1986, in collaboration with the Beaufort Laboratory of the Southeast Fisheries Center. The second will be in the Shelikof Straits in May 1987, in collaboration with PMEL and the Northwest and Alaska Fisheries Center.

TAP

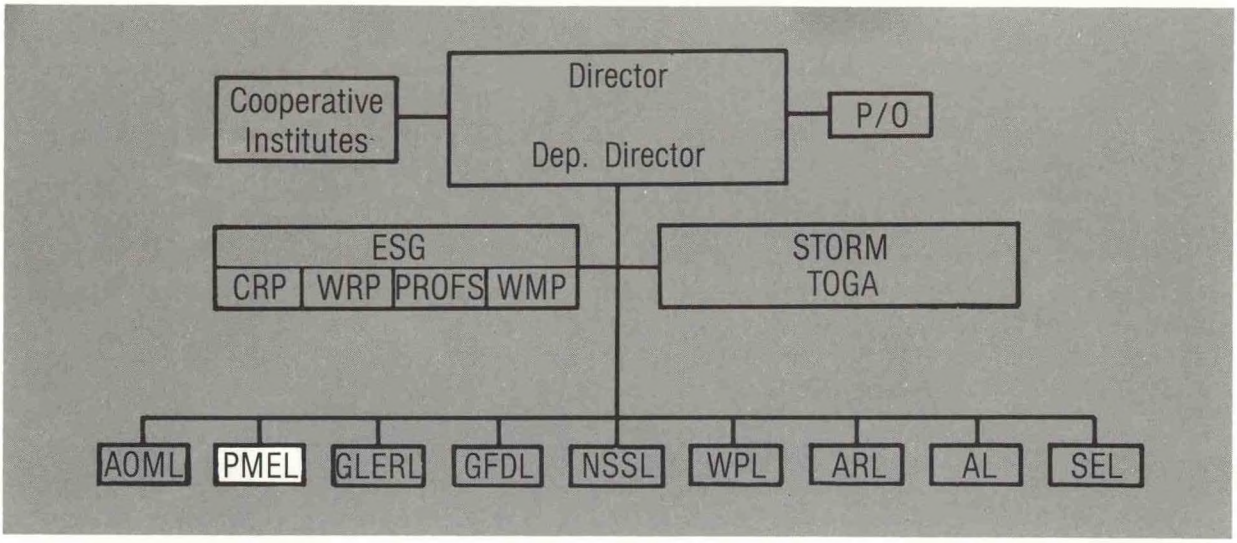
No additional activity is anticipated in this program unless new funding is identified.

P–PRIME

No additional activity is anticipated in this program unless new funding is identified.

PACIFIC MARINE ENVIRONMENTAL LABORATORY
Seattle, Washington

Eddie Bernard
Director



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 the Study of the Atmosphere and Ocean (JISAO) and the Joint Institute for Marine and Atmospheric Research (JIMAR), established between NOAA and the Universities of Washington and Hawaii, respectively, provide a bridge between the academic community and PMEL scientists working in climate dynamics, environmental chemistry, tsunami propagation, 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 dynam-

ics. 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 hypothesis that ocean surface temperature anomalies in equatorial regions have a pronounced effect on atmospheric circulation in both equatorial and temperate 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, is also postulated to have an important effect on world climate. Studies at PMEL continue to focus on the Florida Current as part of the Subtropical Atlantic Climate Studies (STACS).

PMEL also conducts 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 anthropogenic 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 1985

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 that 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 analyzed. A numerical modeling program was begun during FY 1985, which focuses on increasing our understanding of the dynamical processes responsible for changing the heat content of the tropical Pacific.

Equatorial Dynamics During 1982-83 ENSO Event

During the El Niño of 1982-83 there were large changes in the north-south distribution of the depth of the thermocline as well as changes in the temperature of the surface layer. These changes imply significant changes in the strength of the zonal current systems. During 1979-81, there was a decrease in the transport of the North Equatorial Countercurrent (NECC) in the northern summer. In 1982 the transport of the NECC increased in the summer to a strong peak in November 1982. This peak was followed by very low values the following summer. These variations were due primarily to shifts in the thermocline depth; a shallower than normal thermocline at 10°N combined with a deeper thermocline at the Equator, creating a strong downslope to the south and a high transport. The very strong NECC eastward transport in the latter part of 1982 contributed substantially to the accumulation of warm surface water in the eastern Pacific that occurred at the end of 1982. In the period before the 1982-83 event, the South Equatorial Countercurrent (SECC) transport typically increased in the first part of the year, while the NECC transport decreased. In 1982 the SECC transport peak did not develop, but it was present in 1983. Studies of the seasonal cycle of the SECC transport have shown that it is primarily a response to the variation in the north-south gradient of wind stress. The 1982 SECC transport perturbation presumably is due to the change in the Southern Hemisphere wind stress pattern, which preceded the marked changes that occurred in the summer north of the Equator in the central Pacific.

Long-time series of current mooring data in the eastern equatorial Pacific were examined to delineate the seasonal cycle of the upper ocean's circulation. To define the normal conditions that serve as background for El Niño anomalies, analysis was restricted to non-El Niño time periods. During the northern spring. the South Equatorial Current (SEC) is replaced by eastward flow near the surface between 95° and 150°W in response to the annual weakening of the trade winds at the Equator. The intensity of the near-surface flow lags the climatical surface winds, but has the same westward propagation observed in the wind field. The dominant features of the non-El Niño annual cycle have been reproduced by a three-dimensional linear model of the equatorial Pacific forced by the annual component of the climatological winds. **PMEL**

In October 1982 near the onset of the ENSO event, a two-ship survey in the eastern Pacific was used to study water mass characteristics and circulation in the 10° square centered near the Gálapagos Islands. Sea surface temperature during this period was 3°-5°C above normal, and Galápagos sea level was about 30 cm above normal. Surface temperature showed no indication of the Galápagos Front, which is usually pronounced this time of year. However, since the Front was still present in surface salinity, southward advection of

warm water across the Front was ruled out as a mechanism for producing the anomalously warm water. Rather, zonal advection appeared to be the dominant cause. Estimates of warm water transport in the study region showed an influx of about 21 x 10^6 m^3s^{-1} across 95°W. Eastward near-surface flow was found all along this section except for a narrow band just north of the Equator. Water mass characteristics indicated that flow in this band represented a return of NECC water rather than Equatorial Undercurrent (EUC) water. Along the northern and southern boundaries of the study area, relatively weak poleward flow of the warm water layer was observed. The net outflow along these boundaries was only about 6 x 10^6 m^3s^{-1}. Thus, about 15 x 10^6 m^3s^{-1} appears to be continuing eastward across 85°W and must either escape in a narrow coastal current along South America or accumulate in this eastern region. Little evidence for the former is seen in coastal sections taken in December. Assuming the latter leads to a predicted sea level rise of about 0.5 cm d^{-1}, an amount close to the observed rate of sea level increase at the Galápagos from September to December. This result suggests that zonal advection of warm surface water from the west is the dominant mechanism leading to the initial warming in the eastern Pacific.

Studies such as the one discussed above are hampered by the lack of continuous records of upper ocean thermal structure. In addition, such measurements are required in order to monitor the ocean variability and, in the future, assess the likelihood of subsequent El Niños. To provide such information in real time, PMEL has developed the ATLAS (Automated Temperature Line Acquisition System) moored thermistor chain, which telemeters, via satellite, temperatures to a maximum depth of 500 m. Time series data from an ATLAS mooring, deployed at 2°S, 110°W since December 1984, have shown the seasonal cycle of warming during spring and cooling during summer of 1985. The warming is confined to the upper 50 m; there is little participation by the thermocline. Such a record demonstrates the importance of local heating in generating the seasonal temperature variability. Measurements from ATLAS moorings at 165°E, 140°W, and 110°W will be used to monitor the thermal variability in real time.

The velocity structure of the equatorial Pacific has been studied using NOAA vessels equipped with acoustic Doppler current profilers. The data are collected while the ship is underway, providing continuous and spatially high-resolution ocean velocity sections. The variations in these velocity sections are being analyzed in terms of the effect on the heat content of the upper ocean in the tropical Pacific.

Radiant Heating of a Wind-Roughened Sea

In a general circulation model of the coupled atmosphere-ocean climate system, the heating terms describing the conversion of solar radiant energy into potential thermal energy drive the motions of the system. In the ocean part of the model, the albedo of the air-water surface is a key factor for defining the heating rate in the upper ocean layer. By combining physical optics and water wave statistics the dependencies of the albedo, over the visible electromagnetic spectrum, on various wind speeds, wind directions, and solar altitudes have been found. In general, the radiant flux across the air-water interface increases with increasing wind speed. Both theory and experi-

ment show that capillary waves, rather than gravity waves, are the dominant determinants of the sea surface's albedo.

Tropical Modeling and Analysis Program

The Tropical Modeling and Analysis Program (TMAP) was established to add a theoretical and numerical modeling balance to PMEL's climate observational program. Procurement of the needed computer hardware and hiring and training of staff was a major part of this effort during FY 1985. Model studies of ENSO phenomena were begun through analysis of a hindcast of the 1982-83 ENSO event done at GFDL. Attention was focused on the evolution of surface currents and sea-surface temperature (SST). During the initial phase of the event, when central Pacific equatorial SST warmed rapidly, the model hindcast indicated that anomalous zonal advection of heat from the west was the primary warming mechanism. Later in the event the processes are more complex.

STACS

Measurements of voltage differences using submarine cables have been shown to be valuable for continuously recording the transport variations of ocean currents such as the Florida Current. In addition to cable voltages induced by ocean currents, there are voltages induced by time-varying ionospheric and magnetospheric electric currents. Robust methods have been developed whereby the geomagnetic variations can be removed by using magnetic data obtained at remote magnetic observatories and therefore free of ocean-induced variations. This method has been used to correct voltages from a cable spanning the Florida Straits between Jupiter Inlet, Fla., and Settlement Point, Grand Bahama Island. The geomagnetically induced voltages in submarine cable data can be reduced by using shore-based magnetic data even if the shore site is remote, since geomagnetic variations are coherent over global scales. This data processing technique has also been applied to magnetotelluric survey data where it has proved to be very effective in removing noisy values and yielding superior response estimates to the commonly obtained band-averaged estimates.

In order to expand the cable measurement program, 140 days of hourly mean cable voltages from the telephone cable that spans the Florida Straits between West Palm Beach, Fla., and Eight Mile Rock, Grand Bahama Island (about 20 mi south of Jupiter) were collected with the cooperation of AT & T. These cable voltages represent the voltage difference between the sea-water contacts at West Palm Beach and Eight Mile Rock and can be corrected for fluctuations in the cable power supply since the power supply electric current was also measured. Measurements of temperature at the power station and a comparison with the Jupiter Inlet/Settlement Point cable voltages established that the power separation filter has a temperature-induced variation, and a temperature coefficient approximately that of copper.

CARBON DIOXIDE/RITS RESEARCH

Since about 1850, human activities, including the burning of fossil fuels and deforestation, have raised the atmospheric carbon dioxide (CO_2) level from about 280 ppm to 345 ppm in 1985. This CO_2 increase is thought to affect the

Earth's radiation balance, leading to an increase in 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 CO_2, 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 act both as a source and as a sink for atmospheric CO_2, particularly in upwelling and downwelling areas, PMEL scientists continued an interdisciplinary study of the CO_2 system in the surface and intermediate waters of the eastern North Pacific during the summer and winter of FY 1985. The purpose of these investigations was to study the dynamics of the CO_2 system and gas exchange along a meridional transect that includes major frontal systems in the North Pacific.

During February and July 1985, on two cruises in the eastern North Pacific, measurements were made of total CO_2, pCO_2, alkalinity, freons, suspended matter, calcium, salinity, temperature, oxygen, and nutrients. In addition, atmospheric and surface ocean measurements of CO_2 and CH_4 were made in cooperation with scientists from ARL's Geophysical Monitoring for Climatic Change (GMCC) Division. The preliminary data for July indicated significant variations of seawater pCO_2 concentrations along the transect, with near-saturation values near the Subpolar Front, and supersaturated values in the Subpolar Gyre. The winter values were significantly lower than the summer values. The high values in the Subpolar Gyre are probably due to seasonal heating of the surface waters. These results suggest that the waters near the Subpolar Front are sinking faster than the time required for equilibration with respect to CO_2, or significant uptake by marine phytoplankton.

The fluorocarbon tracers F-11 and F-12 were also measured on both the winter and summer cruises. The F-11 distribution for the summer cruise revealed maxima in the mixed layer in the Gulf of Alaska near station "P", slightly above saturation equilibrium with respect to the overlying atmospheric burden (as observed for CO_2 as a result of seasonal heating). A subsurface freon maximum was traceable southward across the Subpolar Front and Subtropical Gyre nearly to Hawaii. The fluorocarbon signal was detectable to a least 800 m at 35°-40°N, the deepest penetration along the section. A comparison with previous F-11 profiles taken near "P" in December of 1980 reveals that the near- surface freon concentration has risen in direct proportion to the 20% atmospheric increase during this 4½-year interval. However, below the mixed layer the F-11 burden within the upper thermocline (σ_T = 26.5-27.0) has at least doubled since 1980. Although a gradual deepening of tracer profile was to be expected as a result of the slower rate of atmospheric increase since the late 1970's, the very rapid fluorocarbon accumulation suggests that this period (1980-85) has been one of unusually efficient thermocline ventilation. Local vertical overturning and/or lateral advection from source regions to the west are the major ventilation mechanisms, but whether the observed increase in freon in the thermocline has been gradual or the result of a particular overturning event cannot be determined from the limited sampling.

Plans FY 1986

EQUATORIAL DYNAMICS

- Implement an array of 12 ATLAS thermistor chains spanning the equatorial Pacific from 165°E to 110°W. The data obtained will be used to provide real-time information on thermal structure variability and to study the low-frequency variability.

- Use the ship-of-opportunity thermal data set to assess the role of variations in wind forcing in changing the thermal field; carry out numerical model verification studies with the data.

- Complete tropical Pacific island surface wind analyses and prepare results for publication.

- Conduct a variety of hindcast studies of the 1982-83 ENSO event, using the GFDL model and surface wind stress fields prepared by different groups, and determine the model mechanisms responsible for the evolution of near-surface currents and SST. Compare model results with ocean data as possible.

- Study the prediction of El Niño and related global atmospheric events, using a new statistical technique based on the discriminant method.

STACS

- Investigate the upstream variations of the Florida Current and the origin of the occasionally large monthly transport bursts by expanding the cable voltage recording system to include telephone cables between Key West, Fla., and Havana, Cuba, and between St. Thomas, Virgin Islands, and Maiguetia, Venezuela, and compare the voltages with those being collected from the Jupiter Inlet/Settlement Point cable.

CARBON DIOXIDE/RITS RESEARCH

PMEL

- Continue North Pacific time series of fossil CO_2 increase.

- Begin measurements of radiatively important trace species (RITS) in the North Pacific.

- Develop kitetoon atmospheric boundary layer sampling capability.

MARINE ENVIRONMENTAL ASSESSMENT

Marine environmental assessment at PMEL emphasizes understanding the complex physical and geochemical processes 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 1985

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 (L-RERP), 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 pollutants 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 1985, PMEL scientists continued to make significant advances in our understanding of the physical and chemical processes controlling the distribution and fates of toxic trace metals and hydrocarbons in coastal areas and estuaries. Following are descriptions of accomplishments in related theoretical, observational, and modeling research efforts.

Theoretical work on modeling the long-term, two-layer circulation in fjords uses freshwater and salt as convenient tracers to deduce the recirculation, or refluxing, of water between outflowing and inflowing layers at mixing

zones where fjord reaches intersect. However, if such an intersection involves more than two reaches, more tracers are necessary to resolve the mathematical indeterminacy. Unfortunately, long-term data sets for other tracers are not usually available. Therefore, a technique based upon entropy maximization has been developed to yield a solution that is maximally noncommittal with regard to the missing tracer information. An application to Puget Sound indicated that less than 1/2 of the seaward-flowing surface water is recirculated landward because of mixing at the Admiralty Inlet sill; this is somewhat lower than earlier estimates of 2/3. Dissolved copper concentrations were used in conjunction with the refluxing model to both test and improve it. Given estimates of copper inputs to Puget Sound, the model predicts copper concentrations, which in turn have been compared with actual observations. Theory and observation show similar trends and agree to within error limits. An advantage of the maximum entropy technique is that new tracer information can be incorporated readily to produce improved reflux coefficients. The model has been run with and without anthropogenic inputs to evaluate the effect of human activities on Puget Sound copper concentrations.

A theoretical index based on the estuarine Richardson number was developed to predict the occurrence and intensity of intrusions of new water into estuaries controlled by sills. For Puget Sound this index was computed from predicted tidal currents in Admiralty Inlet for the period 1970-1989. It shows that the strongest intrusions should occur during 4-month periods centered on the spring and fall equinoxes with gaps during the winter and summer solstice periods. An apparent 4-5 year cycle in the intrusion index is being compared with observations.

Acoustic observations are being used to deduce the degree of mixing during the onset of intrusions. Once initiated, dense bottom water propagates 70 km up-estuary, replacing water existing below the 65-m sill. Five episodes of deep-water renewal were observed at approximately fortnightly intervals in response to enhanced gravitational circulation and reduced turbulent mixing during neap tides over the entrance sill. At mooring sites along the estuary, renewals were characterized by a sequence in which there occurred a rapid change in temperature followed by a 2-10 day up-estuary pulse of deep currents and maxima in salinity and density. The renewal characteristics were phase lagged with distance from the sill; this lag indicated up-estuary velocities of 7-14 cm s^{-1}. The observations of the advance and vertical structure of the deep intruding water are interpreted as a turbulent gravity current that spreads linearly with a constant mean velocity and a density difference that varies inversely with distance due to entrainment. A classical two-layer box model used to estimate flow during various stratification and runoff conditions indicated a possible seasonal cycle in transport with a maximum in winter and a minimum in summer. Evaluation of long-term observations of flow at one location are now beginning to confirm the predictions. Transports in January-March are about double those in June-August. The exact monthly intervals, however, would vary for any particular year. Thus, replacement rates for water will obviously vary throughout the year, and incorporation of these ideas with the intrusion index concept is under way. Observations across the section of the long-term measurements are being used to improve calibration of transport estimates.

PMEL

Investigations are also continuing on the vertical transport of particles and pollutants through the water column. Because of the uncertainties regard-

ing sediment trap efficiency in estuarine environments where current flow may exceed 100 cm s^{-1}, a field experiment was designed to compare the trapping characteristics of drifting traps and moored traps. A special trap that divides the vertical flux into four discrete samples representing different flow regimes was designed and built. Results of the experiment showed that cylindrical sediment traps are efficient collectors of the "true" vertical flux (as measured by drifting traps that sense no relative flow) at current speeds up to approximately 100 cm s^{-1}. Total flux varied by 10% between drifting and moored traps. More importantly, the particle population, as defined by size and density distributions, was the same for drifting and moored traps. This latter result held even during intervals of much higher current speeds when moored traps under-sample the total flux. The success of this field experiment indicates that the vertical particle transport can be measured accurately under most estuarine flow regimes.

Sediment trap investigations have also been valuable in quantifying the transport and fate of toxic metals in Puget Sound. Comparisons of metals in sediment trap particulates and metals in sediments indicate that for many metals, including Fe, Cr, Ni, Zn, and Pb, retention in estuarine waters is enhanced by scavenging processes in the water column. Only a small fraction of the total metal flux is recycled at the sediment-seawater interface and, consequently, most of the toxic metals are retained within the fine-grained sediments of Puget Sound. Trace metals that are rapidly scavenged by particulates are subsequently enriched in the surface layer of the sediments.

Polycyclic aromatic hydrocarbons (PAH) are toxic hydrophobic compounds and are also generally associated with particulates. Particulate hydrocarbon concentrations in the main basin of Puget Sound decrease with depth in the water column and with distance from Seattle. The residence time of these pollutants in the water column is not sufficient for mixing to take place throughout the estuary or out of the estuary. Although these compounds are rapidly transported to the bottom sediments, resuspension and lateral transport in the bottom nepheloid layer disperse the compounds throughout the fine-grained sediments in the center basin.

During the past year, PMEL also began, for EPA, multidisciplinary field studies of pollutant transport in the two main urbanized embayments of Puget Sound, Elliott Bay, and Commencement Bay. Earlier PMEL studies of transport processes in Elliott Bay had shown that pollutant-bearing particles are added to the surface waters by river inflow, combined sewer outfalls, atmospheric precipitation, and other routes. Those particles that remain suspended above the pycnocline are advected out of the bay by the estuarine circulation. Particles that rapidly settle out of the surface layer contribute to pollutant accumulation in the bottom sediments. Bottom sediments may be a new sink for particles rather than a source to the main basin.

Bottom Boundary Layer Processes

In the bottom boundary layer, active processes determine much of the transport and deposition of sediment and particulate-borne pollutants. Tidal and other currents resuspend material from the bottom; the material is then diffused upward by turbulence into the overlying water. There, this material reacts with dissolved and suspended chemical constituents before settling back

to the bottom. Entering the layer from above and upstream are new sediment and dissolved constituents. Manganese and iron ion particles, for example, scavenge toxic metals from the water column and carry them down to the bottom sediment. Some of the manganese and iron are chemically reduced in bottom sediment and diffuse back into the water column. Boundary layer processes help determine the extent and duration of the exposure of biota to pollutants on and near the bottom.

A boundary layer model using turbulence closure was implemented to simulate chemical, sediment, and flow processes near the bottoms of estuaries. Obtained from the Swedish Meteorological and Hydrological Institute, this model supplements the high-resolution boundary layer models that have been developed at PMEL. One result of the investigations was the finding of undulating patterns in the eddy viscosity profiles, due to tidal currents. The effects of the undulating pattern on sediment and trace metal processes are now being studied. The distributions of dissolved and particulate manganese are found to be strong functions of the time constants for chemical reactions relative to the time scales of diffusion and tidal currents. The model played a central role in the planning of a near-bottom experiment in Puget Sound that was carried out in FY 1985.

One focus of the L-RERP sediment transport work has been on erosion rates, their characterization and prediction. A critical review of the literature and a match of a high-resolution model to laboratory observations indicated that erosion of abiotic, fine sediment occurs at bottom stresses well below those often cited as critical stresses. This can be seen from a statistical point of view in which the turbulent currents produce random concentrations of stress over a bed of particles with randomly varying exposures to the flow. This line of research is continuing through intensive modeling and field experiments. A two-dimensional model under development will simulate the erosion and transport of sediment down the major axis of Puget Sound.

Pollution Accumulation In Sediments

Recent sedimentation in estuaries is of special interest because it is one important way anthropogenic particulate-borne contaminants are isolated from the estuarine biosphere. In the past year, work was completed on the analysis and interpretation of 210-Pb data from cores taken along the axis of the main basin of Puget Sound. The results suggest that a zone of rather high deposition is off Elliott Bay. The results also show that biota within the upper part of the sediment column can be churning surface-deposited material to a depth of 35-40 cm. This rather rapid mixing helps bury newly deposited contaminants, but it also exposes much older sediments and contaminants to the sediment-seawater interface. **PMEL**

The sediment column also provides a historical record of the usage of materials indicative of industrialization. The record is blurred by the stirring of sediments by the infauna but 210-Pb profile analysis allows us to quantify the pattern of mixing. Historical records of pollutant sources can then be related to the pollutant profile of the sediment column. By using as source history the sum of tetraethyl lead in the Puget Sound area and a steady contribution from industrial sources that began in 1890, the profiles of stable Pb within the sediment column were determined. The result compares

favorably with the measurements of stable Pb made on a core near Meadow Point, Seattle, for which coincident 210-Pb data were acquired. PAH profiles are being similarly compared.

ACID RAIN RESEARCH

Reduced sulfur compounds are produced biologically in the photic zone of the ocean. Our initial studies showed that dimethylsulfide (DMS), the most abundant volatile sulfur compound in surface ocean waters, contributes significantly to the global atmospheric burden of sulfate. Our recent efforts have stressed the coastal ocean and its potential impact on regional sulfur budgets. Regional sulfur budgets are necessary to assess the relative importance of natural and anthropogenic emissions on the chemistry of precipitation, since the tropospheric residence time of sulfate is thought to be insufficient for this species to be well mixed on a global or even hemispheric scale.

DMS concentrations were measured in ocean waters along the West Coast of the United States on four cruises from May 1983 to May 1985. Concentrations in surface waters ranged from 13 to 380 ng S L^{-1}, with a summer average of 60 and a winter average of 20 ng S L^{-1}. By use of the stagnant film boundary layer model, the flux of sulfur from the ocean to the atmosphere was calculated to be 30 mg S m^2 yr^{-1}. Based on average surface zonal wind velocities and an assumed non-sea-salt sulfate atmospheric residence time of 5 days, the calculated net flux of biogenic sulfur to the West Coast of the United States is 0.05 Tg yr^{-1}. Because of the many assumptions, the net flux is known only within a factor of 2-3.

The depositional area for this marine sulfur is more difficult to estimate. The principal mechanism by which sulfur is removed from the atmosphere is cloud scavenging and precipitation. Much of the rainfall in the western United States occurs on the western slopes of the mountain ranges. We pose two continental regions of potential deposition for this oceanic sulfur, the region west of the Cascade/Sierra Nevada Mountains and the region west of the Rocky Mountains. The estimated oceanic biogenic sulfate is 13% of the anthropogenic emissions in the first region and 4% in the second region. It is possible that the oceanic sulfur is largely deposited in an even smaller region, such as the area west of the Olympic/Coastal mountain ranges.

Plans FY 1986

LONG-RANGE-EFFECTS RESEARCH

- Complete analysis of selected 1984 cores to determine the along-channel and cross-channel patterns of organic pollutant accumulations in Puget Sound.

- Continue the development of one- and two-dimensional models of chemical, sediment, and flow processes in the bottom boundary layer.

- Carry out an experiment in Puget Sound to calibrate and test models of bottom boundary layer processes.

- Obtain reliable, first-order estimates of the relative scale of pollutant transport paths (surface plume vs. bottom nepheloid layer) in Elliott Bay.

ACID RAIN RESEARCH

- Refine flux estimates by measuring DMS and its precursors in the ocean and DMS and its oxidation products in the atmosphere.

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, 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 1985

SEA ICE RESEARCH

The Arctic Polynya Experiment

The Arctic Polynya Experiment (APEX) was conducted in the vicinity of St. Lawrence Island in the northern Bering Sea during the winter of 1984-85. The purpose was to investigate physical processes in the atmosphere, sea ice, and ocean and to observe the interaction of a wind-driven polynya with regional dynamics and thermodynamics. The relative importance of baroclinic currents due to brine rejection during the freezing of ice in the polynya, barotropic currents due to set-up on the shelf (particularly differences between the Anadyr Strait and Sphanberg Strait), internal ice stress due to presence of St. Lawrence Island, wind stress, and Coriolis force on sea ice motion are being considered. The measurement program included a variety of field measurements from ocean moorings, from the sea ice, and from St. Lawrence Island. **PMEL**

Nine ocean moorings, 15 Argos position buoys, 2 GOES shore meteorological stations, and 2 GOES ice stations were deployed in and around the Bering Sea. Weather conditions during January over the eastern Bering Sea and western Alaska were anomalous with the warmest air temperatures on record and the least ice ever recorded for a January, both due to prolonged southerly winds throughout the month. During the last three weeks in February, the winds shifted to northerly, air temperatures dropped, and the ice recovered its previous minimum both by freezing in situ and by the return of Bering Sea ice

from the Chukchi Sea. The Argos buoys initially drifted south-to-southwestward. In February the buoys turned and drifted northward. This is consistent with the idea that reversals in Anadyr Strait (periods of southward flow) are of shorter duration than in Sphanberg Strait, although this was certainly one of longest reversals ever observed for Anadyr Strait. The eastern array lost two Argos buoys on the southward transit past the island and one on the northward transit from crushing or shear, and both arrays exhibited greater deformation than the MIZEX-West array had while passing St. Matthew Island during 1983. The buoys in the western array melted out at the ice edge between 18 March and 2 April and in the eastern array between 17 May and 16 June.

The data from the over-winter current meter moorings, the arrays of drifting ice buoys, and the regional meteorological stations should provide new information on high-latitude sea/ice/air interactions and contribute to our understanding of Arctic heat, salt, and ice budgets.

Vessel Icing

Ability to forecast icing is one of the most important marine meteorological problems in high-latitude waters because rapid accretion on superstructure creates an extreme hazard. Icing conditions require the presence of subfreezing air temperatures, strong winds, and sea surface temperatures not more than 6° above freezing; thus, it is not always obvious which way a vessel should head to mitigate a situation. Actual icing rate is a characteristic of each vessel, depending on its design and sea-keeping ability.

During FY 1985 a categorical algorithm was completed that related vessel icing to meteorological parameters. An initial set of 195 icing incidents from Alaskan waters during 1980-1983 was reduced to a data set of 85 observations verified by interviews with the observers. Meteorological information in these reports was compared for consistency with the Anchorage Weather Service Forecast Office meteorological analyses. Fifteen icing rates were greater than 2.0 cm h^{-1}, substantially higher than those in the Alaskan observation base available for our previous icing rate nomogram.

A major feature of the algorithm development is the use of a robust statistical procedure to relate icing rates to meteorological parameters. The method is considered robust because the influence of inaccuracies in any individual observation in the data set is minimized by basing the algorithm upon icing and predictor categories. This contrasts with standard regression techniques in which extreme observations either have undue weight or are excluded from the data set as outlying values.

The new algorithm predicts icing rates greater than three times those of the previous NOAA nomogram. The new results will be incorporated in National Weather Service guidance products issued from the Marine Products Branch of the National Meteorological Center, and the Alaskan Region.

HAZARDOUS WAVES

On October 12, 1984, during a flight of the U.S. Space Shuttle Challenger the Shuttle Imaging Radar-B (SIR-B) system acquired imagery of the ocean sur-

face near Hurricane Josephine, which had a peak maximum sustained wind speed of approximately 90 kn. Such wave data--large-scale, synoptic, directional, and near a hurricane--are rare. Imagery, taken over a period of about 2.5 min, covered an area 25 km wide by 600 km long and had a resolution of about 33 m. Surface wave patterns were clearly evident. Sub-areas of the imagery were subjected to two-dimensional fast Fourier transform analysis, from which estimates of the dominant wavenumber vectors could be derived. A primary wave system was evident that moved away from the storm track and was distinguished by a smooth and continuous variation in wavelength and direction along the entire 600 km length of the radar swath. The system underwent a 90° rotation in direction. and displayed a decrease in wavelength of more than 30% from >300 m to <200 m. Also evident were secondary systems that displayed considerable variation in wavelength and direction.

TSUNAMIS

The Agency for International Development (AID) awarded PMEL a contract for a project titled THRUST (Tsunami Hazard Reduction Using System Technology). THRUST's purpose is to demonstrate the effectiveness of a regional early warning system for an underdeveloped country. The pilot project will take place in Chile. The major efforts this year were the development of a Pacific basin tsunami data base and the development of instrumentation for the THRUST system. The system uses existing seismic instrumentation connected to satellite communication to establish a warning system. With this system, Chile will have rapid data acquisition and analysis, and quick information dissemination.

Time series analyses were performed on data collected at six coastal tide stations during a low-amplitude, Pacific-wide tsunami that occurred on 3 March 1985 just offshore of Valparaiso, Chile. All records were characterized by significant energy in the 50-60 min period band. Higher frequency energy, though dominant at the two southernmost stations, decayed rapidly away from the source in a northerly direction. Initially, low-frequency energy also decayed northward. but then increased monotonically after reaching a minimum at Caldera.

Bottom pressure recorders were deployed in the equatorial Pacific to record the characteristics of passing tsunamis in the open ocean. Several small tsunamis have been recorded, as well as signals from distant storm events. **PMEL**

Plans FY 1986

SEA ICE RESEARCH

- The second phase of the APEX experiment ice buoy deployments will be conducted in the northern Bering Sea to study sea ice drift in the vicinity of Bering Strait, to provide a scientific basis for extending the sea ice forecasting model to this region.

- A two-dimensional, coupled ice/water model for the Bering Strait region will be developed as the first phase of a complete Bering/Chukchi ice forecasting model.

HAZARDOUS WAVES

- Further studies of the Challenger SIR-B imagery will focus on the dynamics of hurricane wave generation and propagation, and the influence of fundamental hurricane parameters such as the radius to maximum winds, the maximum sustained wind speed, and the hurricane forward velocity.

TSUNAMIS

- Additional numerical simulations are planned of long-wave propagation along the entire west coast of South America for a variety of tsunami-generating mechanisms. More detailed studies of the response of the Valparaiso harbor to nearby sources will be carried out on a relatively fine-scale grid.

MARINE RESOURCES

Hydrothermal venting, which occurs along seafloor-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 called VENTS (not an acronym). 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.

In PMEL's second major area of research in marine resources, fisheries oceanography program development and preliminary field experimentation continued in anticipation of future funding of the Fisheries-Oceanography Cooperative Investigations (FOCI) initiative. FOCI, which combines the expertise of PMEL and of NOAA's Northwest and Alaska Fishery Center, has the primary research objective of understanding the influence of variability of North Pacific meteorology and physical oceanography on commercially important fisheries.

Accomplishments FY 1985

VENTS PROGRAM

VENTS conducts research on seafloor-spreading processes to assess the consequences of high-temperature hydrothermal venting at geologically active ridges. Hydrothermal venting systems are thought to have a significant effect on the oceanic thermal and mass budgets. They are a major source for mineralization of seafloor 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 constitutes an important element in NOAA's ongoing research in marine living resources.

One of the principal goals of VENTS is to quantify the effects of hydrothermal venting on the biogeochemistry and physics of the oceans. Materials and heat hydrothermally cycled between the Earth's crust and seawater along mid-ocean-ridge spreading centers, at hot spots, and in back-arch basins are known to play an important role in the global distributions of many elements. Localized deposits resulting from hydrothermal venting may provide significant reserves of economically important metals. VENTS investigators examine the composition and flux of venting materials and study the biogeochemical and physical processes that occur as these materials are mixed and dispersed by induced and ambient ocean motion.

During FY 1985, three major field experiments were conducted in support of VENTS: three Surveyor cruises to the Gorda and Juan de Fuca Ridges, a Researcher cruise to the Mid-Atlantic Ridge, and an Atlantis II/Alvin submersible cruise to the Galápagos Ridge.

On the Gorda Ridge, hydrothermal indicators showed a strong along-strike variation consistent with the known variation of spreading rates. Stations on the slowly spreading (~1.5 cm yr^{-1}) southern and central portions of the ridge exhibited no enrichment in dissolved or particulate hydrothermally derived material. At the two most northerly stations, where the spreading rate is ~5.5 cm yr^{-1}, plumes of almost certain hydrothermal origin were identified on the basis of increased particle concentration anomalous hydrographic properties, and increases in dissolved and particulate trace metals. The plumes were found between 2700 and 3000 m and were as much as 600 m above the floor of the axial valley, suggesting that the vent sources are located somewhere on the adjacent valley walls as has been observed for the similar topography of the Mid-Atlantic Ridge. The Gorda Ridge is the only known section of hydrothermally active ridgecrest that lies within the Exclusive Economic Zone (EEZ) of the United States.

Hydrothermal plumes from three tectonically dissimilar regions of the Juan de Fuca Ridge were sampled from Surveyor in June to provide the first internally consistent data representative of several different plume types. A metal-dominated, high-exit-temperature plume was found over the southern Juan de Fuca Ridge whereas a sulfur-dominated plume was found above the Endeavour Ridge segment of the northern Juan de Fuca Ridge. On the central Juan de Fuca, a low-exit-temperature-type plume was mapped within the caldera of an axial seamount.

PMEL

Short-term current observations at the southern Juan de Fuca site in 1984 showed predominantly northward flow for about 20 days. However, there was an indication of some westward flow during the first 5 days, which could have carried the observed plumes to the west. A year-long mooring on the west rim of the ridge showed 2 months of northward flow, followed by 8 months of westward flow, and then a return to northward flow for 3 months. Low-frequency speeds were typically 1-2 cm s^{-1}. Tidal oscillations of 4-10 cm s^{-1} are also evident in the data.

Vent particulates from the southern Juan de Fuca and Endeavour Ridge sites were studied for their chemical and mineralogical composition by X-ray

diffraction and X-ray microanalysis procedures. Samples from the southern Juan de Fuca Ridge consisted mainly of sphalerite, pyrite pyrrohitite, barite, elemental sulfur, and two unidentified Fe- and Ca- silicate phases that have not been observed in other hydrothermal systems. These phases are the result of mixing intermediate-temperature (200°-270°C) hydrothermal fluids enriched in Fe, Si, Zn, Ca, and S with seawater. The major phases emanating from the Endeavour Ridge vents included chalchopyrite, anhydrite, pyrite, sphalerite, pyrrohitite, marcasite, barite, and elemental sulfur. These phases are characteristic of reactions involving the mixing of high-temperature (290°C) hydrothermal fluids with ambient seawater.

Microbial geochemistry studies focused on the role of bacteria in the precipitation and transportation of metals such as Mn and Fe within the plumes. Transmission electron microscopy with X-ray micro-elemental analysis was used to identify, count, and analyze individual microparticles. Other microbiological parameters under study include bacterial number (direct epifluorescent microscopy) and two independent and complementary measures of biomass (ATP and lippopolysaccharide). Additionally, radiotracer experiments were performed at sea in order to examine rates of Mn-54 and Fe-59 precipitation under biologically controlled conditions.

Early results indicate that the metal encrusted capsules of certain bacteria are significant contributors to the plume particulate Mn loads. These encapsulated bacteria are very abundant (10-25% of total bacterial numbers) and represent the only microparticles, so far, that contain detectable Mn. Though Fe deposits are always associated with the capsules, the capsuled bacteria's relative contribution to total plume particulate Fe is variable.

Sampling and shipboard analytical capabilities were further enhanced through the acquisition of a sea-going Zeeman modulated atomic absorption spectrophotometer and several high-resolution CTD systems. A four-chamber, remotely activated plume sampler was designed to accompany the horizontally towable CTD system (SLEUTH) which included integrating nephelometers and high-resolution transmissometers. These tow-systems provide continuous and real-time sensing and sampling of hydrothermal plumes and allow scientists to adjust operational strategies to use ship time most efficiently.

High-resolution deeptow side-scan sonar images were obtained at Axial Seamount on the Juan de Fuca Ridge. Ground-truth data were obtained by numerous camera tows and provide the first physiographic map sufficiently detailed for submersible navigation.

The Atlantis II/Alvin cruise was specifically designed to survey the surficial extent of the massive sulfide deposits associated with an extinct vent site on the Galapagos spreading center as well as to conduct state-of-the art magnetics and electrical experiments to define the subsurface extent of the sulfide enrichment. This experiment marked the conclusion of a series of NOAA-sponsored diving programs at this site and provided information on the duration and volume of vent activity during the entire life cycle of vent systems.

A VAX 11/750 computer system was brought on line for the primary purpose of processing digital SEABEAM bathymetry to produce detailed maps within areas of VENTS interest. All previously existing NOAA software to accomplish bathy-

metric data processing was reconfigured to operate on the PMEL system. The unique capability for large-scale plotting, in color, of bathymetric maps became operational approximately 6 months ahead of schedule, and initial map products were used in FY-1985 VENTS field expeditions.

FISHERIES-OCEANOGRAPHY RESEARCH

The Fishery-Oceanography Experiment (FOX) was funded jointly by PMEL and the Northwest and Alaska Fishery Center (NWAFC) to study the effects of the biotic and abiotic environment on early life stages of pollock in Shelikof Strait, Alaska. Field operations for FOX were conducted between August 1984 and August 1985. They provided initial research for FOCI, which will examine interannual variations in the environment and relate them to fluctuations in recruitment of commercially valuable fish and shellfish stocks. The paradigm that guides this research is that year class strength is primarily determined by interactions with predators and prey during early life stages and that variability in these interactions is a function of fluctuations in the abiotic ocean climate, which in turn are driven by atmospheric variability.

For the stock of pollock in Shelikof Strait, our primary hypothesis is that larvae and juveniles remaining near the coast of the Alaska Peninsula are more likely to survive than those that are transported off the shelf. Exchange of mass with adjacent slope waters of the Alaskan Stream affects water properties and the composition of plankton communities. These factors can also affect survival at early life stages. Thus, the key process in the physical environment is transport, and the factors that influence its variation must be understood.

The two major activities of the 1985 fishery-oceanography program were to conduct field operations and to synthesize existing data and knowledge regarding the abiotic environment of the Gulf of Alaska. On six oceanographic cruises, operations included deployment and recovery of ten current and bottom pressure moorings; collection of 563 water samples for nutrient analyses, 344 samples for estimation of chlorophyll concentration, 449 zooplankton samples, and 144 micro-zooplankton samples; acquisition of CTD data at 324 stations; and 40 atmospheric radiosonde observations. Nine flights were made with the NOAA P-3 research aircraft, to study the unique meteorological conditions in Shelikof Strait and along the coast of Alaska. Ancillary meteorological data were collected from the ship's weather logs and three land-based platforms southwest of the strait.

The 1985 pollock egg survey in April indicated that abundance was similar to that in previous years (1980-84). Spawning occurred at a similar time and in about the same location in lower Shelikof Strait. Results of the survey of larvae in early May, however, were markedly different from those for previous years. Few larvae were found, even after the search pattern was expanded to cover all areas where larvae might conceivably have drifted, an area four times larger than originally planned. Four possible causes for the unexpected absence of larvae are under investigation: (1) unusually strong off-shelf transport, (2) mass starvation due to low food abundance, (3) excessive predation, and (4) poor condition of the eggs. Wind and current meter data will be used to address the question of transport. The other causes will be evaluated from biological samples collected during FOX.

Preliminary examination of weather and CTD data indicated that anomalous conditions existed in early 1985. Throughout January and in early February a ridge of high pressure existed over the Gulf of Alaska, resulting in a westward displacement of the Aleutian Low. As a result, the primary storm track was northward into the Bering Sea rather than into the Gulf of Alaska. In late winter and early spring, a winter storm pattern rather than a typical spring pattern was established with anomalously persistent northerly winds in the region. There was an unusually large number of storms that passed through the western Gulf of Alaska. Although the ramifications of this perturbation are not yet fully known, CTD data indicate significant differences between 1985 and 1981 (a year when the number of larvae collected was several orders of magnitude larger than in 1985). During 1985, surface waters were about 1.5°C colder, the mixed-layer depth was approximately 25 m deeper, and bottom waters were 0.3°C warmer and 0.4 g kg^{-1} more saline than in 1981. It appears that this condition continued through May. The changes in surface temperatures and mixed-layer depth suggest the action of increased storm activity; the changes in bottom water characteristics may be related to enhanced transport in the upper layer with compensating flow of slope waters into the Shelikof sea valley.

Plans FY 1986

VENTS PROGRAM

- Field work will continue within specific areas along the Gorda Ridge, to survey what appear to be hydrothermally active vent sites discovered during the FY-1985 field season.

- Time-series sampling of vent-associated waters will continue at several known active hydrothermal sites along the Juan de Fuca Ridge, in order to begin quantification of the long-term variations in vent fluid output.

- The detailed photogeologic, seismic, and high-resolution side-scan sonar mapping of the Axial Volcano vent fields will be completed in anticipation of the arrival of Alvin in FY 1987.

- A series of Alvin dives will be requested to follow up the discovery of the active mid-Atlantic vent fields and bring to a successful close the VENTS field work on the Mid-Atlantic Ridge so that full concentration of program resources can be allocated to the Gorda and Juan de Fuca Ridges.

- The high-resolution data (e.g., bathymetric and side-scan sonar) processing capability at Newport will be augmented with interactive high-resolution graphics capability.

- Efforts will begin, to plan and implement the capability for submersible-based long-term monitoring of selected geological, biological, and oceanographic variables at the seafloor within and close to the active vent systems.

FISHERIES-OCEANOGRAPHY RESEARCH

- Analyze field observations obtained during the 1985 FOX experiment.
- Prepare a coordinated FOCI planning document with NWAFC.
- Conduct field operations in the vicinity of Shelikof Strait to study slope/sea valley water exchange processes.
- Assess new measurement techniques for field operation in the Bering Sea (e.g., bottom-mounted Doppler acoustic current profilers, satellite-tracked drifters, and CTD systems).

PMEL

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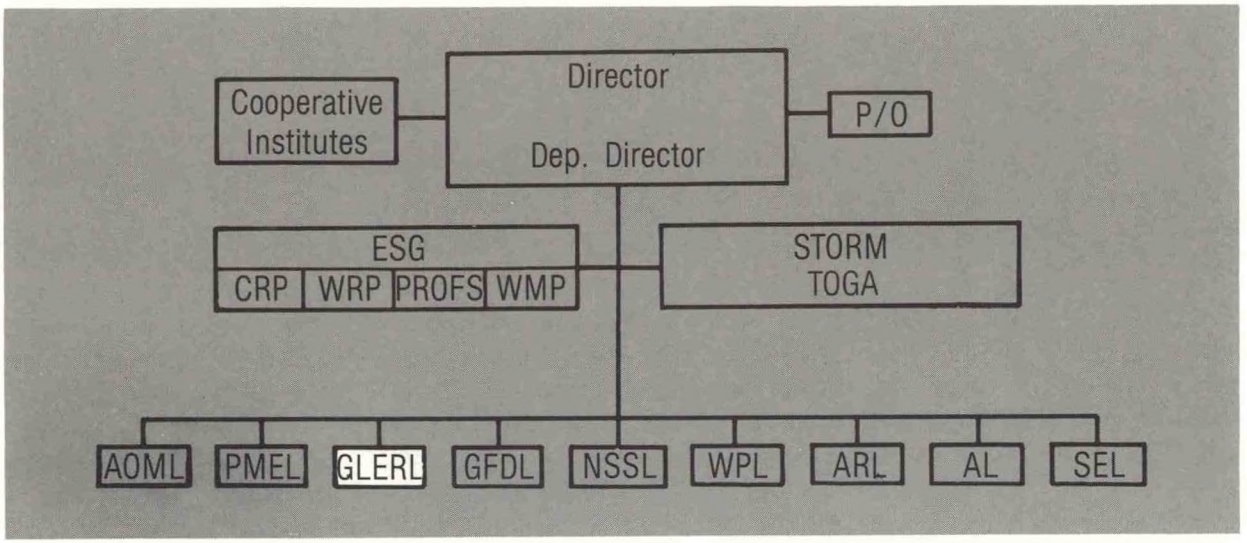


The Great Lakes Environmental Research Laboratory (GLERL) conducts integrated, interdisciplinary environmental research in support of resource management and environmental services in coastal and estuarine waters, with special emphasis on the Great Lakes. The GLERL program includes both basic and applied studies and combines experimental, theoretical, and empirical approaches. Field, analytical, and laboratory investigations are performed to improve understanding and prediction of environmental processes and their interdependencies with the atmosphere, land, and sediments in coastal and estuarine areas. GLERL places special emphasis on a systems approach in problem-oriented research to develop environmental service tools. The products of GLERL research are used by government and private organizations to facilitate planning and decision making in water resources management. GLERL also provides end-user assistance to resource managers and others who wish to apply the information, tools, and services it develops.

Research is carried out by five groups: Synthetic Organics and Particle Dynamics, Ecosystem and Nutrient Dynamics, Lake Hydrology, Physical Limnology and Meteorology, and Environmental Systems Studies. Staff specialties include aquatic chemistry, aquatic biology and toxicology, applied mathematics, meteorology, geology, hydrology, physical oceanography, ecology, computer systems applications, instrument design and development, and experimental design and analysis.

GLERL's multidisciplinary program supports the Ocean and Great Lakes Prediction Research Program of NOAA. Decision makers at all levels of government require access to predictions that improve impact assessment, resource management, and safety and economy of operations in the coastal marine environment. With most of the U.S. population residing near the coasts, the ability of the adjacent bodies of water to accomodate wastes, and the ability of people to us those water bodies and the surrounding shorelines safely and effectively for housing, transportation, and recreation, must be given increased attention.

The Great Lakes are the largest reservoir of fresh surface water in the United States, but are also sinks for domestic and industrial wastes. Major cities, including Buffalo, Cleveland, Chicago, Detroit, Milwaukee, Rochester, and Toledo are located along the shoreline, and more than 30 million people in the United States take their drinking water from the lakes.

Ocean and Great Lakes Prediction Research at GLERL is designed to improve our understanding of the Great Lakes and to provide precise scientific information about the processes that occur within them. GLERL's program addresses (1) the need for new and improved simulation and prediction models of ecosystem structure and function, and of the effects of stresses and proposed remedial options, and (2) the need to assess other options while taking system metrics into account.

Biogeochemical studies of the cycling and dynamics of nutrients and toxic contaminants provide precise, sophisticated information relevant to the management of wastes, water quality, and fisheries, and form a basis for models that simulate and predict the transport and fate of these contaminants as a function of human input to the lakes. Such models are needed to support decisions related to waste management and regulation, dredging, shoreline use, and siting of facilities. More precise scientific information on lake water levels, connecting channel flows, and ice distribution is critical to those involved with erosion control, shoreline development, transportation, recreation, and power generation. Studies of the lakes' physics lead to better understanding and prediction of the circulation, the thermal structure, and the transport and dispersion of chemical and biological constituents of the ecosystem; numerical forecast tools result in products applicable to water quantity management, pollution transport, and dispersion. Research on physical phenomena such as surface waves, seiches, and surges provides a better understanding of these phenomena and results in improved numerical prediction methods that are applicable to shipping activities, recreation, shoreline flooding, and erosion.

GLERL's programs focus on two elements of the Ocean and Great Lakes Prediction Research Program: Marine Ecosystems Assessment, and Marine Hazards and Lake Hydrology. To ensure that its research products reach the usercommunity in a timely manner and are responsive to user-community needs, GLERL maintains an Information Services Group. In FY 1985, GLERL research products included 69 scientific articles, reports, and books, 85 talks presented at scientific and public meetings by GLERL staff, and responses to approximately 1,100 requests for information, providing more than 1,350 items to service those requests.

MARINE ECOSYSTEMS ASSESSMENT

The Marine Ecosystems Assessment research program at GLERL is designed to (1) improve our understanding of, and predictions related to, natural marine ecosystems, physical phenomena and the impact of human-induced stresses on the ecosystem, and (2) help provide a sound scientific basis for management decisions pertinent to marine resources, marine pollution, and environmentally sensitive marine activities. GLERL projects in support of these program elements include investigations into 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); the structure and function of aquatic ecosystems and the effects of human activities on those ecosystems; measurement, analyses, and prediction of physical phenomena such as currents, river flows, and air-water-sediment interactions; and sedimentary fluxes and processes, especially sediment-contaminant interactions.

Accomplishments FY 1985

Sediment traps are an integral part of GLERL's field research, as they provide data on bulk sediment mass flux, as well as samples for analysis of individual component mass fluxes. Sediment traps of different size and design from GLERL and Canada's National Water Research Institute (NWRI) were deployed in tandem at multiple depths on a mooring in Lake Michigan to determine and compare their relative collection efficiencies.

Winter resuspension of bottom sediments provides recoupling of previously removed contaminant-bearing particles with lake water, and can buffer the Great Lakes system against significant short-term response to reductions in new contaminant loading. Sediment traps were recently retrieved from winter moorings in Lakes Michigan, Superior, and Huron. Traps from multiple depths at two sites in Lake Michigan revealed a year-to-year variability in the winter downward mass flux of suspended material. The 1984-85 winter mass flux ranged from 1.2 to 2.5 times the winter mass flux during 1983-84. All trap samples are being analyzed to determine the downward fluxes of carbon, nutrients, radionuclides, total mass, and organics.

Bottom currents and topographic controls focus sediment deposition in the Great Lakes, resulting in areas characterized by high sedimentation rates. Measurements in cores from such high sedimentation (Hi Sed) areas provide a basis for testing comprehensive time-dependent diagenetic models of contaminant deposition and history. ^{137}Cs and ^{210}Pb profile analyses and dating were completed for more than 20 cores from Hi Sed areas in the Great Lakes. The signal associated with the large decrease in atmospheric lead flux since 1973, reflecting the introduction of "no-lead" gasoline, shows clearly in the profile analyses. In collaboration with a University of Wisconsin-Milwaukee scientist, a comparison was made of sediment deposition focusing in Lake Michigan in 1982 and 1972, as shown by the ^{137}Cs record. Results show that the majority of lake suspended load is rapidly transported and focused to the "final" depositional basins within the lake, and within the last decade there have been small changes in the locations of the Hi Sed depositional basins.

In relation to the radionuclide measurements, a regional fallout source function for long-lived radionuclides (a contaminant surrogate) was constructed and documented.

A coupled Lakes Model, which predicts the long-term response of the lakes to time-dependent contaminant loads, was developed. A sensitivity analysis of the Lakes Model to sediment resuspension, sediment mixed-layer thickness, and contaminant partitioning coefficient (between solid and dissolved phases) was completed and documented. Partitioning between dissolved and particulate

(solid) phases was found to have the most significant effect on the half life of organic contaminants in the system.

The form in which organic contaminants such as polycyclic aromatic hydrocarbons (PAH) are present in the ecosystem affects the availability of the contaminants to the biota. Complementary field and laboratory experiments showed that for particulate matter indigenous to the Great Lakes, there is a seasonal variation in sorptive capacity for radiolabeled organic compounds. Initial results from kinetic studies indicate that the adsorption process is more rapid than the desorption process. The bioavailability of PAH added in the dissolved form to water decreased when natural dissolved organic material (DOM) was also present in the water. A large fraction of the PAH operationally defined as "dissolved" was actually weakly bound to natural DOM and was not available, for example, to the common benthic amphipod Pontoporeia hoyi. Additional experiments revealed that the partitioning of organic contaminants to DOM is related to differences in the characteristics of the DOM, including molecular weight but not compound solubility.

In related studies the bioavailability to P. hoyi of PAH in sediments exhibited considerable variability, the following parameters being most significant: sediment composition, amount of material ingested, and characteristics of the organic compound. On the other hand, the bioavailability of PAH to Mysis relicta (another small shrimp-like freshwater invertebrate) through contaminated food sources was found to be significant, indicating that food is the single most important pathway for contaminants entering that organism. However, contaminant accumulation in the organism was variable and may depend upon the nature of the food source.

The availability of 20+ years of limnologic data from Lake Washington provided a basis for developing and testing a series of general lake ecosystem models. Results of a heat-diffusion model for Lake Washington revealed that the time required for vertical transport of near-surface phytoplankton by turbulent diffusion is highly dependent on nocturnal convection events and heat input from the Sun. This affects diurnal phosphorus utilization and therefore the phosphorus budget. The ecosystem models developed for Lake Washington are now being applied to Lake Michigan, using data obtained from the comprehensive Lake Michigan Ecosystem Experiment.

Data from the Lake Michigan Ecosystem Experiment are also being used for studies of community and species-specific primary production and zooplankton grazing rates. Analysis of a 10-year ecological data set from southern Lake Michigan revealed a gradual improvement in water quality over the last decade; two years showed particularly clear water and low chlorophyll concentration. These are thought to be caused, respectively, by heavy ice cover and ecological shifts associated with a decline in alewife abundance.

Studies of bacterial dynamics are necessary to understand and quantify the transfer of energy and nutrients through the food webs of the Great Lakes ecosystem. Completed analyses of the 1983-84 field data from the Lake Michigan Ecosystem Experiment indicate that bacterial growth rates range from 0.05 to 0.24 h^{-1} and appear to be balanced by grazing losses. Experiments in Lake Superior demonstrated the importance of microorganisms in ecosystem energy transfer. Cyanobacteria less than 1 μm in size were responsible for

approximately 24% of the total primary production and are consumed by small (5-20 μm) heterotrophic protozoans.

An understanding of the mechanisms of zooplankton feeding is necessary to predict the effect of zooplankton on food web dynamics, ecological succession, and particle transport in the Great Lakes. 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. Last year, a high-speed microcinematography facility at the Skidaway Institute of Oceanography was used by a GLERL scientist to make the first direct observations of these processes for a freshwater copepod. During FY 1985, a microcinematography laboratory was established in a prefabricated temperature-controlled environmental room at GLERL. A high-speed microcinematographic study showed that the water flow field created by the copepod Diaptomus sicilis while feeding, and Diaptomus general feeding behavior, differ from those of marine copepods. Diaptomus behavior is apparently a specialization for capture of small particles, which are more abundant in freshwater than in marine waters. The effects of feeding history on zooplankton food selection adaptation were also studied. Results showed that Diaptomus exposed to small-diameter algae for 4 days had a much greater selectivity (preference) for small cells in a mixture of small and large cells than did animals exposed to large cells for 4 days.

Late summer "whitings" occurring on a lake-scale and produced by autogenic precipitation of calcium carbonate have been reported for Lake Michigan since at least the mid-1960s. A GLERL study of calcium carbonate in Lake Michigan seston revealed that calcite constitutes 20-56% of the particle volume during such whitings. Potential ecological effects, which are a function of calcite particle size, include decreased light intensity, increased sinking rate of fecal pellets, and decreased zooplankton feeding rates. The projected two- to three-fold increase in atmospheric CO_2 over the next century may drastically decrease or eliminate this seasonal event, making it important for study now.

Phosphorus uptake by microorganisms was investigated to determine the major pathways of organic and inorganic phosphorus flux through the lower food chain. Kinetic studies on nutrient uptake in Lake Michigan showed that bacteria utilize organic phosphorus whereas phytoplankton utilize inorganic phosphorus. These findings provide an improved basis for modeling aquatic phosphorus dynamics.

Model simulations of the effects of silica limitation on phytoplankton species succession were performed to determine if limitation of this nutrient causes the observed shift from diatoms to blue-green and green algae in Lake Michigan. Analysis of nutrient-uptake kinetics showed that silica limitation affects the ability of diatoms to utilize phosphorus, and thus triggers the shift to blue-green algae during summer.

Modeling of phosphorus cycling in lakes has been impeded because orthophosphate cannot be measured accurately. A new kinetic procedure to quantify low-level orthophosphate concentrations in Lake Michigan was developed. The method is a bioassay procedure that uses natural microbial populations.

The final set of microcosms for determining phosphorus release rates in Lake Michigan sediments was completed. These data will complement sediment trap data in providing information needed to develop phosphorus transport models for Lake Michigan.

A method to determine ammonium excretion by zooplankton in suspensions of their food, using heat-killed algae, was developed and tested against the flow-cell method. The results validated the flow-cell method and provided information about the relationship between nitrogen excretion and feeding history.

The potential importance of P. hoyi to remineralizing nitrogen (i.e., converting organic nitrogen to inorganic ammonium) in recently deposited detritus was estimated by comparing the areal excretion rate of P. hoyi in southern Lake Michigan to inputs of organic nitrogen in particles collected in sediment traps. This calculation suggested that P. hoyi excretion could account for remineralization of up to 40% of the organic nitrogen settling into the hypolimnion and implies the importance of benthic invertebrate excretion.

Denitrification (conversion of ammonium and nitrate to nitrogen gas) rates are needed to quantify the relative importance of invertebrates and microbes to the remineralizing of nutrients in detrital material in sediments. Techniques were developed to measure denitrification rates in lake sediments, and a field program was initiated to quantify this process in Lake Michigan sediment.

The lipid (fat) content of an organism is a measure of its stored energy; studies of the lipid content of lower-food-chain organisms are necessary to follow and understand energy transformations and flow up the food chain. Measurements of the seasonal lipid content of four species of benthic invertebrates in Lake Michigan showed that animals feeding on suspended material or surface detritus and microbes tend to have higher and more variable lipid contents than do those feeding on subsurface material. The invertebrates with relatively high lipid content are desirable prey species for small fish.

The data base from a study of the long-term trends in benthos populations in Lake Michigan was checked, verified, and formatted for publication along with data gathered from previous surveys. Statistical tests indicated that a significant general increase in the population of several benthic groups occurred between the mid-1960's and 1980-81. P. hoyi was shown to be the predominant benthic macroinvertebrate, constituting about 65% of the benthic macroinvertebrate biomass in southern Lake Michigan.

Studies of gut contents of P. hoyi indicated that individual P. hoyi often have only partially filled guts, implying that feeding by this organism may be periodic rather than continuous. Lipid extracts of P. hoyi and Stylodrilus heringanus, obtained by microextraction techniques developed at GLERL, indicated that most of the lipids in P. hoyi, but not those in S. heringanus, are present as the energy-storing triglycerides. The ability of P. hoyi to store energy as lipids may help to explain its ability to thrive in low-nutrient systems such as the upper Great Lakes and to withstand long periods without food. In a related study, the areal caloric contents of the major benthic organisms in southern Lake Michigan were calculated. The

results revealed that P. hoyi constitutes about 70% of the total caloric content of benthic invertebrates in southern Lake Michigan.

A GLERL biologist participated in a series of submersible dives during the first exploration of the Great Lakes (Lake Superior) with a research submersible.

The seasonal cycle of thermal stratification in Lake Erie was described, including thermocline formation and the intermittent progression of thermocline deepening associated with the passage of storms. The persistence of a near-bottom thermocline was also demonstrated, and the physical basis for oxygen depletion of bottom waters associated with the water quality issue of nutrient overenrichment was examined.

The seasonal cycle of Lake Erie circulation was determined. One circulation cell often dominates the flow in the central basin, in contrast to the prediction of two-cell circulation by several numerical models. Seiche currents are important over the whole lake, but are strongest in the passages between the islands that separate the western and central basins.

Analysis of the records from current meter moorings in Green Bay showed that during the stratified season, inflow of bottom water from Lake Michigan and outflow of near-surface (above the thermocline) water to Lake Michigan contribute substantially to the flushing of Green Bay. A one-layer model would significantly underestimate Green Bay flushing.

With the development and testing of user interface subroutines for Great Lakes physical data bases and the publication of a user's manual, the GLERL Data Acquisition System is now essentially operational and available for storage and retrieval of research data sets in GLERL's VAX 11/780 computer. Further testing of this system is under way using water level data, current meter data, and climatological weather data.

Analyses of the records from a network of 13 current meter moorings deployed in Lake Michigan from July 1982 to July 1983 indicate that rotational waves are confined mainly to the southern basin. Comparisons between data analyses and a one-layer numerical prediction model showed some disagreement; e.g., a predicted strong oscillatory current across the midlake topographic ridge was not observed. Analyses of the data for the mean flow field revealed a very weak circulation during early summer and during the stratified season; organized large-scale circulation prevailed only during the fall and winter and was cyclonic.

A vertically integrated model that incorporates Ekman layer sediment transport was developed and is now being applied to Lake Michigan's southern basin and to Lake St. Clair, the latter as part of the Upper Great Lakes Connecting Channels Study (UGLCCS) (see below).

Numerical methods to compute finite difference currents and to estimate the numerical accuracy of trajectory calculations were developed.

The new spill model PATHFINDER was formally released for use by the National Weather Service, U.S. Coast Guard (for search and rescue operations),

and the Canadian Weather Service. Spill model verification studies will continue by comparing drifter tracks with PATHFINDER predictions.

A comparison of Eulerian and Lagrangian current data from Lake Michigan showed good agreement in both speed and direction.

Data from 1984 tests of new acoustic current meters (ACMs) deployed in tandem with older, reliable vector-averaged current meters (VACMs) close to the bottom of Lake Michigan revealed defects in the ACMs, which were returned to the manufacturer for repairs. VACM data collected in the lower 7 to 10 m of the water column showed an Ekman veering of the velocity with height and suggested that deployments in the lower 10 to 20 m would be rewarding during winter, when the velocities are larger.

Analyses of the data from the 1983 and 1984 drifter-slippage experiments using Rhodamine-B dye were completed. Results verify that drifter trajectories can be explained by the vector sum of a fixed fraction of the wind added to the surface current. These results are applicable to the light wind and small-amplitude wave conditions that existed during the experiments.

GLERL scientists began work as part of UGLCCS, an international (U.S.-Canada) and interagency [U.S: Environmental Protection Agency (EPA), NOAA, U.S. Army Corps of Engineers (COE), Department of the Interior Fish and Wildlife Service (FWS), and Michigan Department of Natural Resources; Canada: Department of the Environment (DOE)/Environmental Protection Service, DOE/NWRI, Inland Waters Directorate, Department of Fisheries and Oceans, Ontario Ministry of the Environment] multi-year water quality research and monitoring study of the St. Clair River, Lake St. Clair, the Detroit River, and the St. Mary's River. GLERL's primary task in this 3-year program is to model the behavior and fate of nutrients and trace contaminants in the upper Great Lakes connecting channels. The U.S. lead agency is EPA, from which GLERL receives partial support by interagency agreement.

As part of UGLCCS, GLERL and NWRI (Canada) have developed collaborative plans for a shallow water wave experiment in Lake St. Clair. Towers, wave staffs, and other instrumentation are being fabricated and assembled for deployment this fall along a WNW-ESE transect. Data from this experiment will be used to develop and test models of wave growth, propagation, and decay in shallow water. Sediment cores were collected by hand (scuba) from 60 sites in shallow Lake St. Clair and returned to GLERL for radionuclide processing. A significant cooperative research effort in support of the GLERL part of UGLCCS was initiated with the University of Michigan and Argonne National Lab (ANL), using funds from the NOAA/EPA interagency agreement. A bottom-mounted tripod belonging to ANL was equipped with sensitive instruments to measure transparency, current, temperature, and pressure and was deployed in Lake St. Clair. The objective is to develop data sets to describe sediment resuspension, which include measurements of near-bottom suspended material as well as current velocity (from wave action or other causes).

A total phosphorus mass balance model for Lake St. Clair is under development to support UGLCCS. Tributary loads and rough budget calculations were performed, and studies began, to assess the importance of internal phosphorus regeneration in Lake St. Clair. Major mechanisms being evaluated include phosphorus release from sediments and phosphorus excretion by mussels.

Microcosm experiments, similar to those done on Lake Michigan sediments, are being conducted to assess the importance of sediment release.

Three significant technology transfers of GLERL products in Marine Ecosystems Assessment took place:

- Method of Amino Acid Analysis of Natural Waters
  User: Michigan State University (MSU)

- Track Autoradiography Procedure
  Users: University of Southern California and MSU

- Methods of Measuring Primary Production in Lakes and Rivers
  User: Georgia EPA

Plans FY 1986

Equilibrium partition coefficients (the concentration associated with the particle phase divided by the concentration in the dissolved phase) will be measured seasonally for a selection of radio-labeled synthetic organic compounds in lake water samples. These data are needed for contaminant models.

Sediment trap work will continue at a station 35 km offshore in southeastern Lake Michigan. Data from this station were obtained for each of the past five years, in order to quantify the natural variations in particle (and associated chemical) fluxes.

Laboratory studies have indicated that hydrophobic synthetic organic compounds form stable associations with naturally occurring organics, decreasing their bioavailability. Field/laboratory studies will be conducted to determine the magnitude of this process.

The rate of synthetic organic uptake, depuration, and metabolic transformation will be measured for Hexagenia sp., a major component of the Lake St. Clair benthos. These data will be used in the UGLCCS modeling program.

Whether Lake St. Clair is a source, trap, or a temporal integrater of materials being transported from the upper lakes to Lake Erie will be studied through the collection and analysis (radiotracers, contaminant organics, selected metals, and nutrients) of an array of diver-collected sediment cores. **GLERL**

Data analysis and non-steady-state modeling will continue on sediment cores from the Hi Sed regions of all the Great Lakes. Results will be used to reconstruct the contaminant history of the Lakes.

In-situ measurements of sediment resuspension will be made from remotely deployed bottom-mounted instrument arrays in Lake St. Clair. Data will be used in calibrating sediment transport models.

The long-term monitoring of benthic trends in Lake Michigan will continue. Emphasis will be on changes in benthic communities in response to shifts in predation pressure.

The abundance and distribution of benthic macroinvertebrates determined during periods of ice cover of Lake Michigan's Grand Traverse Bay will be compared with abundance and distribution immediately prior to and following ice cover. Since few studies have examined macroinvertebrate distribution in Great Lakes sediments during the winter months, results will provide greater understanding of overall changes occurring in benthic macroinvertebrate populations throughout the year.

Benthic production in Lakes Huron, Michigan, and Superior will be estimated by measuring oxygen consumption of biota in intact sediment cores. Results will be compared with pelagic production estimates as part of an effort to document energy cycling through both benthic and pelagic components.

Phosphorus release rates from sediments in Lake Michigan and Lake St. Clair will be assessed in relation to other input sources. Also, the role of benthic invertebrates in the release process will be evaluated.

A study will be initiated to determine changes in the physiological and nutritional state of the amphipod P. hoyi in response to seasonal changes in food availability.

The use of benthos by fish as a food source will be examined in predator exclusion experiments in deep-water areas of Lake Huron or Lake Superior.

The importance of metabolic excretion by freshwater mussels as a source of nutrients (phosphate and ammonium) will be evaluated in Lake St. Clair by seasonally measuring excretion rates and estimating abundance of these dominant invertebrates in the lake.

The organic carbon and lipid content of sediment trap material will be determined seasonally to trace energy flow patterns from phytoplankton to the benthos in Lake Michigan.

The intermittent feeding strategy of P. hoyi will be examined to evaluate the importance of discontinuous feeding in estimates of the sediment recycling rates of P. hoyi. Throughput estimates will be included in future models of contaminant bioaccumulation by P. hoyi.

Sediment trap and core samples from Lake Huron will be analyzed for zooplankton remains. Changes in relative abundance and morphology of pelagic cladocerans will be used as a basis for reconstruction of food webs.

Predation rates by stock salmon and trout will be estimated for alewife as the primary prey. The resulting empirical estimates of predation rates will be employed in development of a Lake Michigan food web model.

A combination of high-speed microcinematography and traditional feeding experiments with algae isolated from the Great Lakes will be used to evaluate the importance of algal size and shape in regulating zooplankton feeding.

Data on the contribution of calcite to the total particle-size spectrum of Lake Michigan seston will be summarized for 1978-85. Experiments assessing

the impact on the plankton of this autogenically precipitating calcite will continue.

A project to assess the rates of primary production in the Upper Great Lakes will be initiated. Previous rate measurements have been limited to short-term ^{14}C experiments. This project will compare several different methods for measuring the primary production.

Measurements of the effects of diel stratification on primary production within the epilimnion of Lake Michigan will be analyzed.

The relative influences of nutrient regulation and food web control on water clarity will be explored by use of a suite of models designed to simulate long-term ecosystem behavior of Lake Michigan.

Field measurements of the vertical and horizontal, short (diel) and long, (seasonal) temporal distributions of bacteria production will be analyzed. Estimates of grazing loss rates of the bacterial population and preliminary data on pathways of autotrophically forced carbon will also be summarized and analyzed.

Estimates of grazing impact by the zooplankton assemblages on the phytoplankton community, determined during the 1983 and 1984 field seasons of the Lake Michigan Ecosystem Experiment, will be summarized.

Population dynamics (growth, grazing loss, and sinking) of key phytoplankton species of the epilimnetic assemblage, determined during the Lake Michigan Ecosystem Experiment in 1983-84, will be analyzed.

A comparative study of bacteria production and grazing losses is tentatively planned for the 1986 field season in Lakes Michigan, Superior, and Huron.

A hypothesis that bacteria in Lake Michigan are often grazer controlled, rather than substrate limited, will be tested by examining kinetic results from substrate (amino acids) addition experiments.

The ammonium excretion rates of two species of estuarine copepods will be measured. Influences of food type (detritus vs. algae) and season (winter vs. summer) on excretion rates will be examined. **GLERL**

Experiments on the kinetics of phosphate and silicon uptake by phytoplankton will be evaluated to determine how silicon limitation affects phosphate uptake by diatoms.

Experiments on species-specific growth rates, phytoplankton biomass, and the kinetics of nutrient uptake will be analyzed to test the hypothesis that microscale nutrient plumes from zooplankton provide a significant phosphorus source for algae. Preliminary results, based on experimental measurements and stimulated phosphorus uptake, suggest that plumes provide a significant nutrient source.

Experiments on the kinetics of phosphorus uptake by Lake Michigan microorganisms will be assessed to determine the primary forms of phosphorus prefer-

red by phytoplankton and bacteria and how these two types of organisms compete in natural environments. Preliminary results indicate that both microbial groups can coexist because they use different phosphorus sources.

The potentials for using immunochemical techniques to determine how microbial populations are affected by organic contaminants will be explored.

A three-dimensional numerical circulation model developed at the Geophysical Fluid Dynamics Laboratory will be tested for applicability to the Great Lakes.

Numerical simulations of the development of vertical thermal structure in Lakes Erie and Michigan will be carried out and compared with observations from thermistor chains.

Rotary spectra and cross spectra of current meter vector time series from Lake Michigan will be compared with conceptual models of rotational waves in closed basins.

Models for predicting current patterns and sediment transport in Lake St. Clair will be coupled and applied to UGLCCS data, and an experiment to measure shallow water effects on the growth and dissipation of the wave spectrum in relation to sediment resuspension will be carried out in Lake St. Clair in collaboration with NWRI (Canada).

The PATHFINDER spill model will be tested against GLERL's extensive collection of drifter buoy tracks.

Synoptic observations of currents in Lake St. Clair will be analyzed to determine the spatial variability of the circulation.

Measurements of bottom boundary-layer velocity profiles in southern Lake Michigan will be completed and examined for evidence of an Ekman layer. Theoretical calculations suggest that sedimentation patterns and sediment resuspension in deep lakes may be strongly controlled by transport in a bottom Ekman layer.

Models for Lake St. Clair will be developed, including an ecological model, a generic contaminant model, contaminant mass-balance and management models, and an ecosystems management model.

Stochastic optimization models will be developed for Great Lakes policy issues.

MARINE HAZARDS AND LAKE HYDROLOGY RESEARCH

Marine Hazards and Lake Hydrology research focuses on (1) improving prediction of environmental phenomena associated with the National Weather Service (NWS) marine warning and forecasting services and the U.S. Army Corps of Engineers regulation of Great Lakes water flow, and (2) providing better tools and methods for short- and long-term assessments of water resources of large lakes. GLERL research in these areas includes field and analytical in-

vestigations to develop simulation and prediction models of over-water wind and wind-waves, water surface oscillations, storm surges, and flooding; lake ice formation, growth, movement, and break-up; and hydrologic lake levels, water supplies and balance, and flows in the connecting channels. GLERL staff work closely with colleagues at the forecasting and warning service agencies to assure that GLERL products meet the needs of the operational forecasters. Products released to the user community continue to be improved by GLERL researchers, either by fine tuning or by the addition of new tools and capabilities.

Accomplishments FY 1985

A water supply and lake level forecast model for Lake Champlain was developed from the GLERL Large Basin Runoff Model, and operational software was transferred to the NWS River Forecast Center (RFC), Hartford, Conn., for use on its minicomputer. Model studies indicate that net groundwater flux to the lake is significant. The package supplied to NWS generates distributed parameter deterministic or probabilistic water supply and lake level outlooks on a near-real-time basis.

A data acquisition and reduction system was integrated with a numerical outlook/forecast system for Lake Superior water supply and was transferred to the U.S. Army Corps of Engineers (COE), Detroit District, for its use. A study of total basin supplies, comparing results from the GLERL model with those from a water balance approach, suggests that further model improvements of equal amounts could be obtained by improving runoff estimates or by improving evaporation and precipitation estimates. Procedures for rapid determination of areal averaged snow water equivalent from gamma radiation snow surveys were developed in cooperation with the NWS North Central RFC and the COE. These procedures were incorporated with the software package; they are used for the winter and spring water supply forecasts, and were included in the package installed for the COE, Detroit District.

Continuous electromagnetic and acoustic current meter measurements are being made in the St. Clair and Detroit Rivers to develop a data base in support of improved river flow modeling for winter ice conditions. A case study of the record ice jam of April 1984 in the St. Clair River was completed and demonstrated that existing river flow models are inadequate for winter ice conditions.

The water levels in the Great Lakes reached record highs during spring 1985, causing shoreline flooding and hazardous conditions for riparian owners. This resulted in many information requests to GLERL from the news media and others on the cause of this phenomenon and the outlook. An analysis indicated that the primary cause was high precipitation in December 1984 and much higher than normal precipitation during winter and early spring 1985, combined with a sudden thaw in early February. GLERL participated in special briefings organized by the International Joint Commission for the Great Lakes public, the U.S. Congress, and State legislators.

Spectral reflectance was measured for different types of snow and ice on Saginaw Bay during March 1985, using a programmable band radiometer mounted on

a helicopter. These measurements characterize the visible and near-infrared reflectance (and thus transmission/absorption) under clear sky conditions. The data will be analyzed and summarized for specific snow and ice types.

Analysis of data for Lake Erie ice motion from four satellite-tracked buoys deployed in the ice during winter 1983-84 revealed much greater motion than was expected. The data showed that Lake Erie ice motion is usually small (0 to 5 cm s^{-1}), but on occasion ice movements at speeds of 20-46 cm s^{-1} were observed.

Marine weather forecasters at the NWS Great Lakes Weather Service Forecast Offices (WSFOs) continued to use the GLERL Interactive Wave Prediction Model with favorable comments. At the request of the Cleveland WSFO, an air-sea temperature difference parameter was added to the forecast program; the usefulness of this additional parameter is being evaluated.

An evaluation of the GLERL Numerical Wave Prediction Model showed that it will not be feasible to include shallow water effects by modifying the existing model, because the wave momentum equations in that model do not provide an adequate theoretical framework for that purpose. Collaboration was initiated with a scientist at Woods Hole Oceanographic Institution to apply his shallow water wave model to the GLERL shallow water data from Lake Erie. If preliminary tests are encouraging, this model may be applied to Lake St. Clair.

The GLERL Wave Rider Information Processing System (WRIPS) wave buoy, which sends data via satellite, was successfully deployed during September, October, and November 1984 in western Lake Erie. It was moored near a National Data Buoy Center (NDBC) NOMAD buoy to determine the comparability of wave measurements from the two types of buoys, WRIPS being a small (approximately 1 m diameter) sphere and NOMAD having a large (6-8 m) boat-shaped hull. The results from more than 1,000 paired measurements indicated that the NOMAD buoy significantly under-reports waveheights of less than 0.5 m; otherwise, reported waveheights compared extremely well (correlation coefficient 0.99, rms error 7 cm).

With 1981 NDBC data from the Great Lakes, a generalized wave spectrum representation was developed as a function of significant waveheight and average wave period. The result is free from any empirically derived coefficients and exponents, and may be used for coastal and marine engineering applications.

Five significant technology transfers took place:

- PATHFINDER Trajectory (spill) Model
  Users: NWS-National Meteorology Center and WSFOs in Chicago, Ann Arbor, Cleveland, and Buffalo
  USCG and Canadian Weather Service

- Lake Champlain Water Supply Model
  User: NWS-RFC in Hartford

- GLERL Interactive Wave Prediction Model
  Users: NWS-WSFOs in Cleveland, Ann Arbor, Buffalo, and Chicago

- Lake Superior Water Supply Model
  User: COE (Detroit District)

- Procedure to Estimate Snow Water Equivalent from Gamma Radiation Measurements
  User: COE (Detroit District)

Plans FY 1986

A procedure will be developed to derive lake-wide reflectance values, and techniques will be developed for ice type identification/classification from satellite imagery.

Under a pilot program, a catalog of pertinent meteorological parameters and associated ice cycle types based on the variation of annual ice cycle characteristics for a major subbasin of one Great Lake will be developed to assess the usefulness of this technique in improving NWS ice forecasts.

The GLERL Great Lakes Basin Supply Forecast package will be implemented for the entire Great Lakes system, and integrated with the Hydrologic Response Model. It will include improved lake evaporation forecasts and estimates of net groundwater flux to the lakes.

Capabilities will be developed for the system-wide assessment of the impacts of major new diversions, increased consumptive uses, and climatic changes on Great Lakes levels.

The flow variability and characteristics of the St. Clair and Detroit Rivers will be determined, and an unsteady flow model of the total St. Clair River will be tested against data collected during FY 1985.

GLERL will continue to provide support for the Interactive Wave Prediction Model.

Wind, wave, and temperature data recorded by NDBC NOMAD buoys in the Great Lakes will be analyzed and used to develop climatological information on Great Lakes waves. **GLERL**

Theoretical predictions of the shape of the wave spectrum in shallow water will be compared with data from the LEX-81 Coastal Boundary Layer Experiment.

INTERNATIONAL AND INTERAGENCY ACTIVITIES

GLERL staff participated as members (unless noted otherwise) of the following International Joint Commission boards, committees, and task forces:

- International Great Lakes Technical Information Network Board
  Systems Evaluation Committee
  Hydrology Committee

- International Great Lakes Levels and Flows Advisory Board (U.S. Co-Chairman)

- Great Lakes Water Quality Board, Surveillance Work Group
  - Upper Connecting Channels Task Force
  - Lake Michigan Task Force
  - Lake Erie Task Force
  - Task Force on In-Place Sediment Contaminants, Workshop on Monitoring in Areas of Concern

- Great Lakes Science Advisory Board
  - Great Lakes Levels Task Force (Chairman)
  - Great Lakes Research Strategy and Toxic Contaminants Committee
  - Health and Aquatic Communities Workgroup (Advisor)
  - Task Force on Great Lakes Modeling

GLERL staff participated as members (unless noted otherwise) of other interagency and international activities:

- Upper Great Lakes Connecting Channel Study (UGLCCS)
  - Management Committee
  - Activities Integration Committee
  - Modeling Task Force (Chairman)

- Coordinating Committee for Great Lakes Hydraulic and Hydrologic Data
  - Riverflow Subcommittee

- U.S.-Canada Ice Information Working Group (U.S. Co-Chairman)

- Journal of Great Lakes Research (Associate Editors)

- International Association for Hydrologic Research
  - Section on Water Resources Systems (U.S. Representative)

GLERL staff participated in an interagency Great Lakes planning activity with NOAA/NMPPO and Great Lakes representatives of EPA, FWS-Great Lakes Fisheries Laboratory, and COE to develop an "Action Plan for Federal Research and Monitoring Related to Great Lakes Water Quality and Water Quantity."

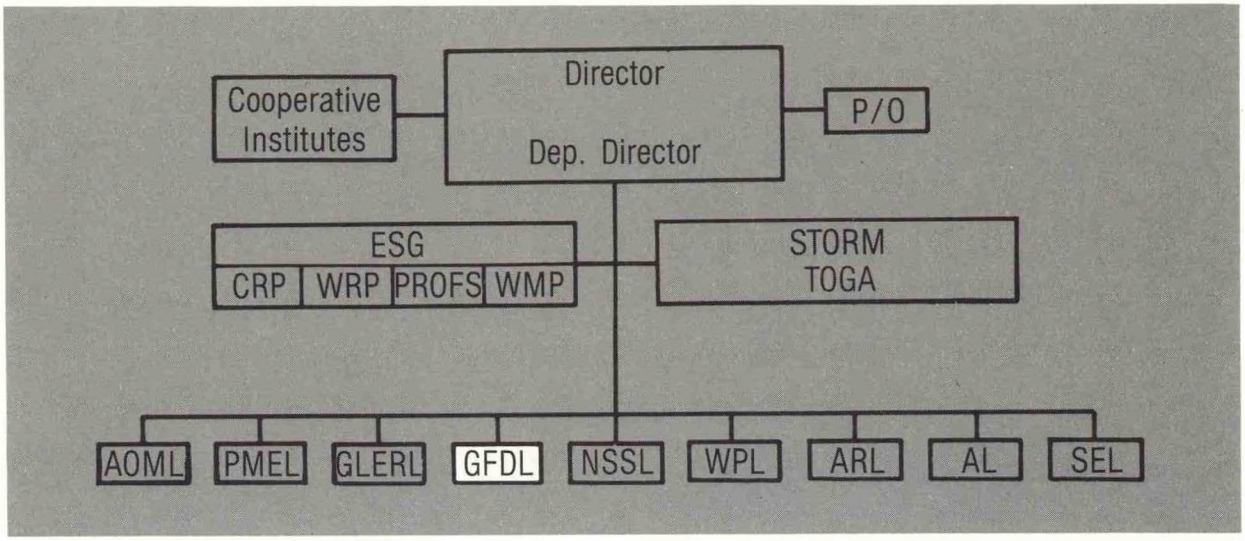
Activities involving participation with other NOAA units included the NOAA Marine Environmental Quality Task Force (OAR Technical Representative), the Synthetic Organics Research Subcommittee (Chairman), the Habitat Modification Research Subcommittee (Member), the Nutrient Overenrichment Research Subcommittee (Member), and the NOAA Technical Subcommittee, New Bedford Superfund Action (Member).

GLERL scientists participated on the Executive Board of IAGLR as President and Secretary. IAGLR is the primary Great Lakes research professional society and is involved with coordinating programs and disseminating results.

One GLERL scientist was a member of the National Research Council Conference on Review of the Great Lakes Water Quality Agreement, and another presented a 2-day short course on Toxic Substances in the Great Lakes in conjunction with Michigan Sea Grant at MSU.

GEOPHYSICAL FLUID DYNAMICS LABORATORY
Princeton, New Jersey

Jerry D. Mahlman
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.

GFDL

The scientific work of the Laboratory encompasses a variety of disciplines: meteorology, oceanography, hydrology, classical physics, fluid dynamics, chemistry, applied mathematics, and numerical analysis. Research is facilitated by the Geophysical Fluid Dynamics Program, which is conducted collaboratively with Princeton University. Regular Princeton faculty, visiting scientists, and graduate students participate in theoretical studies, both analytical and numerical, and in observational experiments, in the laboratory and in the field. The program is supported, in part, by NOAA funds. Visiting

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

WEATHER SERVICE

During the past two decades synoptic-scale weather forecasts have improved considerably because of the development of numerical models that include more of the physical processes of the atmosphere, have high spatial resolution, and parameterize turbulent processes more accurately. Successful forecasts for periods up to 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 1985

An extended series of 30-day forecasts using numerical models was completed for evaluating the feasibility of long-range prediction. The score statistics for eight January cases show an encouraging degree of predictive skill for the time-averaged flow in the 20-30 day range. To attain usable skill levels, however, it has been necessary to subtract the model's known climatic bias from the forecasts. This study marks the first quantitative demonstration of predictive skill by numerical models in the monthly forecast range.

A new National Meteorological Center (NMC) spectral medium-range forecasting model was developed by including the GFDL subgrid-scale physics package. In quasi-operational runs launched during January 1985, the useful forecast range was extended from ~4.5 days to ~6 days. This represents a breakthrough in forecast accuracy, as compared with the existing operational model. The new model has become the NMC operational model.

An analytical theory of the distribution of eddy fluxes along storm tracks was developed. The theory is based on baroclinic instability of zonally varying flows, and reproduces many of the features in the observations.

It was shown that the response of a baroclinic atmosphere to a pulsating localized forcing consists of a baroclinic wavetrain that amplifies with distance downstream of the source, in addition to the more familiar equivalentbarotropic Rossby wavetrains. The amplification rate is appreciable even at quite low frequencies. This spatial instability has implications for the nature of low-frequency atmospheric variability.

The effects of mountainous islands on the behavior of tropical cyclones were investigated. Three regions of high tropical cyclone frequency were selected: Caribbean Sea region, Taiwan, and Luzon, Philippines. Results show that the storm's track and speed can be significantly affected by island mountains. The intensity change upstream of islands can be caused by the advection of relatively dry air from the land. These and other results suggest that inclusion of detailed topography and accurate treatment of boundary layer processes are important for the prediction of tropical cyclones.

A forecast study of the genesis of Hurricane David (1979) is in progress. The analysis shows that latent heat release is a necessary process even at the storm genesis stage. The distribution of computed rainfall intensity compares favorably with the cloud satellite imagery. Also, the movement of the model storm for 72 h is in fairly good agreement with the observed track. These preliminary results provide encouragement for further exploration of the forecasting skill of the hurricane model.

A study of the evolution of mesoscale disturbances on a mean baroclinic state demonstrated the importance of localized surface heating in producing the rapid development of short baroclinic waves. These waves have a depth on the order of that of the boundary layer and horizontal scales of a few hundred kilometers. In the presence of moisture, release of latent heat will cause the waves to develop explosively into an intense meso-cyclone.

The Presidents' Day snowstorm (18-20 February 1979) was successfully "predicted" using a limited-area model nested in a global spectral model. Starting from coarse initial conditions, a mesoscale disturbance developed with the aid of strong surface sensible and latent heating. This disturbance rapidly intensified through latent heat release. Varying the initial and boundary conditions had only minor effects on the model solutions. However, a higher model resolution was required in order to produce accurate forecasts of the storm's structure, intensity, and position.

GFDL

The stability analysis of a linear representation of a convectively unstable cloud region and its stably stratified subcloud layer indicates some of the parameters that determine the structure of low-level updrafts associated with convective systems. A simple relationship was found between the vertical convergence field and characteristics of the stable lower layer, which allows one to predict whether a single (vertical) or dual (upshear sloping) updraft will occur in the subcloud layer.

Four-hour numerical simulations were carried out for a north-south squall line observed on 22 May 1976 in west-central Oklahoma. In this calculation a line of precipitation extended in a nearly unbroken form across the 32-km north-south domain of the model. The propagation speed of the line, the surface cooling behind the gust front, and the point values of precipitation

were in reasonable agreement with the observed values. In all simulations a significant down-gradient vertical momentum flux was found in regions with strong shear in the zonal wind component. This preliminary result suggests that parameterizations of moist convection, in general circulation models, should include the effect of vertical momentum transfer.

Plans FY 1986

A variety of approaches to the wave amplification and cyclogenesis problem will be tested, using analytical and numerical techniques.

Numerical models will be under continual development to improve forecasting of the large scale, the mesoscale, hurricanes, and squall lines, with emphasis on improved parameterizations.

Diagnostic analysis will be employed to improve understanding of these shorter range processes.

CLIMATE

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

Accomplishments FY 1985

The geographical distribution of soil moisture change in response to an increase of atmospheric CO_2 was investigated by use of an atmospheric general circulation model (GCM) coupled with a simple model of the mixed-layer ocean. The results of this study indicate that, during summer, soil moisture is expected to be reduced over extensive regions of the North American and Eurasian continents in middle and high latitudes.

The climate of the last glacial maximum was simulated using two versions of a coupled atmosphere/mixed-layer ocean model with fixed and predicted cloud

cover. In both versions, the reduced glacial CO_2 concentration as inferred from ice core measurements was incorporated. A comparison of these experiments with a variety of paleoclimatic data indicates reasonably good agreement in simulating the ice age cooling over both oceans and continents, suggesting that these models may be used with increased confidence.

The atmosphere/mixed-layer ocean model was used to study the individual contributions of expanded continental ice, reduced atmospheric CO_2, and vegetation-induced changes in land albedo to the maintenance of the cold climate of the last glacial maximum. The expanded continental ice sheets were found to make the largest contribution to the ice age cooling on a global basis, and the reduced CO_2 made an important additional contribution, especially in the Southern Hemisphere.

Linear simulations of the interannual variability produced by a GCM suggested that anomalous transient eddy fluxes are of greater importance than anomalous heating or orographic forcing in generating the anomalous extratropical stationary waves in El Niño years. These results reveal that the transient disturbances portray a much more dominant role in atmospheric interannual variability than had heretofore been speculated.

Space-time spectral analysis of a spectral general circulation model (GCM) indicated that the tropical 40-day oscillations are qualitatively well simulated, although the simulated amplitude is somewhat smaller than that based on FGGE IIIb data. Further statistical analyses indicate that this tropical phenomenon is linked to circulation features in the wintertime extratropics, as well as to the summer monsoon over South Asia.

Experiments using a GCM with a zonally uniform surface indicated that wave-wave energy transfer is an important source of energy for transient ultralong waves in their growing stage, but plays a less important role in their mature stage.

A global coupled ocean-atmosphere model with realistic topography and annual mean insolation was time integrated to an equilibrium solution. The simulation of the coupled system by this model was found to be substantially superior to a previous simulation by a model with relatively lower resolution and higher subgrid-scale viscosity.

GFDL

The new experimental 1° latitude version of the SKYHI troposphere-stratosphere-mesosphere GCM achieved some important advances in simulation capability in all regions of the atmosphere. These advances have allowed planning for future applications in climate and in atmospheric chemistry. The most notable improvements include stratosphere winter polar cold bias, tropospheric jet stream location, tropical zonal winds, surface pressure, eddy kinetic energy and planetary wave amplitudes, cyclone dynamics, tropical tropopause temperatures, the mesoscale energy spectrum, and interaction between gravity-wave and planetary scales.

The first large-scale modeling attempt to evaluate directly the effect of gravity waves on planetary scale flows was completed. Using a 3° latitude version of the SKYHI model, the analysis shows that gravity waves moving with phase speeds similar to the large-scale flow are strongly absorbed in the lower stratosphere. The remaining waves propagate to the upper stratosphere

and lower mesosphere where they are absorbed mainly by turbulent dissipation. This absorption acts to produce strong decelerations of both easterly and westerly flows, in addition to providing a strong damping on the planetary waves Preliminary testing with the 1° latitude SKYHI model shows yet larger effects, suggesting that these effects are even stronger in the actual atmosphere.

A coupled ocean-atmosphere model indicated a new feedback mechanism in the response of the climate system to an increase of greenhouse gases. For large perturbations from equilibrium, a climate warming produces a partial collapse of the ocean's thermohaline circulation. This allows the ocean to sequester more heat than would be possible for a normal circulation, augmenting the delaying effect of the ocean on climate response to a CO_2-induced warming.

An equation capable of describing all scales of geostrophic motion and the interactions between such motions in high and low latitudes was obtained. This formulation has proved useful for defining and describing oceanic and Jovian eddies and currents on planetary, intermediate, and synoptic scales.

Solitary coherent vortices resembling Jupiter's great Red Spot were simulated for periods in excess of a century, and some of the factors controlling their genesis were isolated. These factors include the inhomogeneity of the initial perturbation, the width and criticality of the shear zone, and the history of the interactions.

On the basis of the observed semidiurnal tidal radiances, the presence of a strong middle-latitude jet at about 75 km in the Venus atmosphere was deduced from theoretical considerations for the first time. This is very significant because it is impossible to observe the mean wind structure of Venus directly with existing instruments.

Global computations of the observed divergence of water vapor show that the strongest source of water vapor is located over the eastern Arabian Sea during the summer months. The evaporation over this region (with maximum values of up to 100 cm/month) must be a very important source of water vapor for the Indian monsoon, probably exceeding the supply of Southern Hemisphere water vapor carried toward India by the Somali jet system.

Plans FY 1986

Detailed analyses of important budgets for an Earth warmed by a greenhouse gas and an Earth during the ice age will be under way.

Model development will continue on a number of climatically significant topics. These include a coupled atmosphere-ocean system, the stratosphere, higher computational resolution, radiative transfer, subscale closure, and sources of remaining climatic biases in the various models.

Many diagnostic and theoretical analyses will be undertaken on transient and standing flows and on their interaction. Diagnostic analysis will continue with emphasis on global dynamical climatology, as well as an increased

emphasis on regional problems such as those of the Southern Hemisphere, polar regions, southeast Asia, and the central Pacific.

The GFDL work on dynamical aspects of ocean climate will continue.

ATMOSPHERIC QUALITY

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

Accomplishments FY 1985

A series of model experiments that explore the global impact of the North American combustion sources of reactive nitrogen (NO_x) was completed. This problem is of special concern because of its possible impact on the chemistry of ozone in the "unpolluted" troposphere, in addition to its well recognized role in the "acid rain" problem. Preliminary conclusions from this work suggest that about 50% of the combustion source returns directly to the source region as dry deposition, 25% returns through rainout, and about 25% is exported to more remote regions.

For the first time, a two-dimensional (2-D) tracer transport model successfully reproduced zonally averaged results from its "parent" 3-D transport model. The transport coefficients and meridional circulations were derived from the 3-D model in a completely self-consistent manner. These data sets were then used to assemble a 2-D model capable of running completely independent of the 3-D model. This process has provided fundamental new insights into the transport mechanisms acting in the 3-D model. A number of 2-D model comparisons with the 3-D model yield generally excellent results. This methodology is already being widely used throughout the chemical modeling community.

GFDL

The vertical mixing of passive tracers initially confined to the boundary layer was examined. Calculations with a moist convection model were carried out for a fully insoluble tracer and an infinitely soluble tracer. Present results indicate that significant amounts of the insoluble tracer can be advected into the upper troposphere by convection, whereas rainout prevents all but a small fraction of the soluble tracer from reaching the upper atmosphere. Also, there is an indication that much more of the insoluble tracer is advected above the 6 km level by line convection than by isolated cells.

Plans FY 1986

Work will continue on the regional/global transport, chemistry, and removal of chemically and climatically important trace gases. A self-determined ozone chemistry will be inserted into the SKYHI GCM.

Moist chemical removal parameterization processes will be developed for use in convective and large-scale models.

MARINE QUALITY

Research at GFDL related to the quality of the marine environment has as its objectives the simulation of oceanic conditions in coastal zones and in estuaries, the modeling of the dispersion of geochemical tracers (e.g., tritium, radon) in the world oceans, and the modeling of the oceanic carbon cycle and trace metal geochemistry. For regional coastal studies, two- and three-dimensional models of estuaries 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. Basin and global ocean circulation models are being developed for the study of the carbon cycle and trace metal cycling.

Accomplishments FY 1985

The important role of persistent salinity anomalies in generating asymmetric interhemispheric ocean flows in the presence of symmetric forcing about the Equator was demonstrated in a sector ocean general circulation model. This result is part of an ongoing study to understand what factors control the deep ocean circulation, how this might be affected by climate changes, and how ocean circulation changes will affect the carbon cycle.

A seasonally driven model of the Atlantic Ocean developed for tracer studies showed a dramatic change in oceanic heat transport associated with the cycle of the North Equatorial Countercurrent. The model is being used to study the role of seasonality in thermocline and deep ocean ventilation.

Studies of oceanic nutrient measurements demonstrated the importance of diapycnal mixing processes in the Equatorial region and beneath the Mediterranean Sea salt tongue. The observations are being analyzed in order to develop a data base for carbon cycle models.

An observational and numerical modeling study of the Delaware Estuary started, in collaboration with National Ocean Service scientists. It was found that most but not all of the sea level variability due to winds can be calculated, even though the alongshore extent of the model shelf is limited.

Plans FY 1986

An effort will be initiated to incorporate biological effects in a coupled carbon-cycle/ocean GCM.

A wide range of analyses of ocean tracer data relative to ocean dynamical structure will continue.

OCEAN SERVICES

Various models that can be used for the prediction of oceanic conditions are being developed at GFDL. The simpler models are capable of predicting relatively few parameters. For example, 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 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 1985

A simple coupled ocean-atmosphere model indicates that El Niño conditions --high sea surface temperatures over the entire tropical Pacific Ocean, and weak trade winds--cannot persist indefinitely because the coupled system is unstable in this state. Perturbations will amplify and will restore horizontal sea surface temperature gradients, and intense tradewinds.

A model of an idealized subtropical gyre circulation with steady external boundary conditions exhibits large scale, internally generated pulsations in the gyre structure on the time scale of years. These pulsations are accompanied by complex changes in the intensity and spatial distribution of convection and ventilation. Unexplained multi-year time dependence observed in ocean and climate systems may be related to this model-simulated phenomenon. **GFDL**

Plans FY 1986

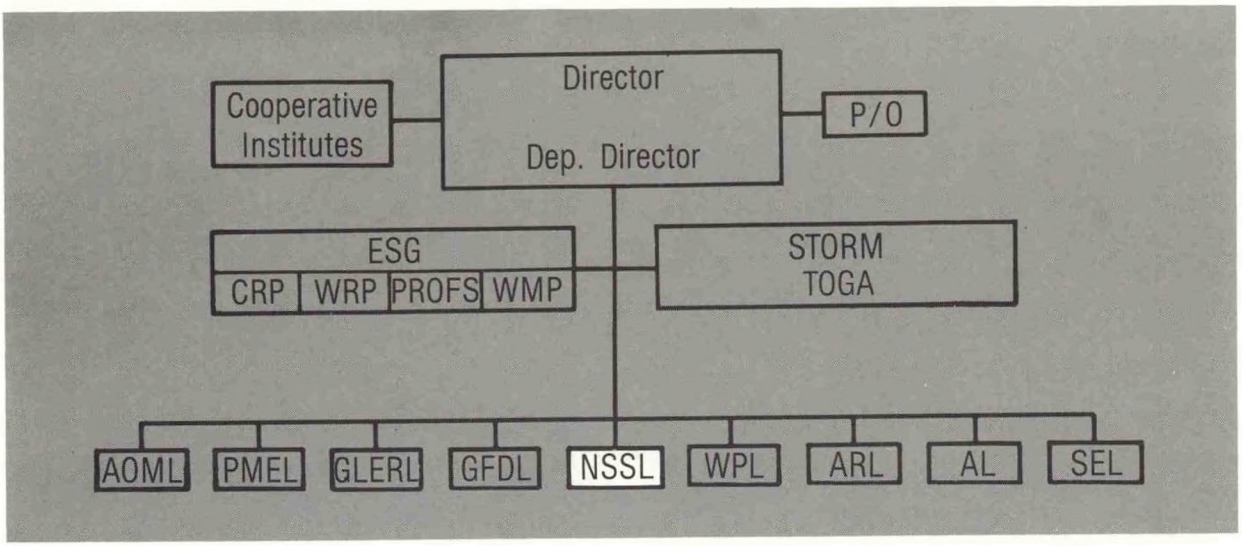
Detailed analysis of the behavior of ocean models will be under way with special emphasis on the new higher resolution models.

Work will continue on ocean model development with emphasis on ice dynamics, turbulent closure, and isopycnal coordinates.

Detailed comparisons of estuary model behavior against observations will be carried out.

NATIONAL SEVERE STORMS LABORATORY
Norman, Oklahoma

Edwin Kessler
Director



The National Severe Storms Laboratory (NSSL) develops improved means for weather observing and forecasting through studies of storm processes, numerical and conceptual modeling of storm phenomena, and applications of new technologies in remote sensing. New technological developments, new scientific discoveries, and new requirements are reflected in changing approaches to goals of accurate precipitation forecasts and storm warnings well in advance of events. Recent studies have drawn heavily on observations by Doppler radar and lightning-mapping systems, and we have developed more effective methods for utilizing Doppler radar and lightning data for forecasts and warnings of severe storms.

The last several years will be seen as a watershed for research and development activities at NSSL. The work at NSSL, probably the most substantial precursor of the major national initiative NEXRAD continues to support that program in critical ways. Other work at NSSL is providing a base in understanding to support deployment and use of national networks for lightning sensing. During two decades NSSL has examined individual storm cases to garner significant bits of knowledge about physical processes in the storms. These case studies continue, but we are now seeing significant maturation of both our knowledge and our tools. We now understand the processes by which initial spinup occurs in tornadic storms, we know how fields of wind and water substance are interrelated, and we have good methods for interpreting three-dimensional detail observed by modern sensors and for communicating essential information rapidly to forecasters. Means are within our grasp to extract substantial new meteorological information from radar data through utilization of diversely polarized transmissions and advanced capabilities in data processing. The Laboratory now has access to a state-of-the-art computational capability, and fine numerical models for both analysis and forecasting. There is a plan of action to bring edge-of-the-art capabilities for data synthesis to the Laboratory during the coming year, and our tools are starting to address the important problem represented by forecasting precipitation in the 0-12

hour range. For example, during 1985, an important mesoscale numerical model was brought to operational status at NSSL and applied to a classical cyclogenetic situation with gratifying results.

The Laboratory has a 50-station capability for digital recording of surface meteorological parameters, and maintains instrumentation on the tallest tower in the United States that is equipped for recording boundary layer parameters. Two 10-cm Doppler radars on a 41-km baseline provide unique capabilities for recording atmospheric circulations both in precipitating weather systems and in the optically clear boundary layer. A comprehensive range of instrumentation for 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 about 20 different organizations.

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 Oklahoma. During FY 1985, NSSL staff participated in experiments involving lightning strikes to aircraft near Wallops Island, Va., assisted in interpreting Doppler radar returns from orographic thunderstorms during experiments in New Mexico, consulted in a multi-agency program on aviation safety at Memphis, Tenn., and had a major role in the multi-agency Preliminary Regional Experiment for Stormscale Operational and Research Meteorology (PRE-STORM) during spring 1985. A major effort in the Laboratory is directed toward establishing an effective national weather radar network for the late 1980s and beyond, in support of the NEXRAD Joint System Program Office, Silver Spring, Md.

In all these activities, the Laboratory cooperates with a host of other capably staffed organizations around our country.

METEOROLOGICAL RESEARCH

The Meteorological Research Group seeks to improve thunderstorm forecast and warning capabilities by developing conceptual, numerical, and laboratory models of major thunderstorm phenomena and of the prestorm atmosphere. Analysis and interpretation of storm flow fields expand our understanding of external and internal forcing, thermodynamics, cloud physics, electrification, 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 1985

TORNADIC STORMS

Theoretical studies of storm rotation, when combined with Doppler radar and storm intercept information, enhance understanding of tornadic thunderstorms. It was established that veering of the storm-relative environmental winds with height (i.e., storm-relative streamwise vorticity in the environment) causes updrafts (downdrafts) in supercell storms to rotate cyclonically (anticyclonically) on average. Also obtained from linear theory was a formula for the correlation coefficient between vertical vorticity and vertical velocity in terms of storm motion, environmental winds, and the growth rate and horizontal scale of convection.

A model of Beltrami flow, in which vorticity is everywhere parallel to velocity, was initialized to provide insights into the pressure field around a rotating updraft. As an exact solution of the Euler equations of motion, the Beltrami model serves as a test case for conceptual models that "define" main features of dynamic pressure fields around updrafts. It also explains why the mesolow at the Earth's surface is often observed to be several kilometers away from the circulation center in mesocyclones, and may help to explain the characteristic size and rotation rate of mesocyclones. Several results from linear theory are also applicable when nonlinear effects are included.

Observational data also play a major role in our understanding of the generation and intensification of vertical vorticity within severe thunderstorms. Studies of several major tornadic storms during the past decade support recent numerical simulations showing that production of vertical vorticity begins at the very roots of an updraft as horizontal vorticity in low-altitude inflow regions is tilted toward the vertical. Then, as the flow passes through the updraft, the tilted vorticity and preexisting vertical vorticity are amplified by convergence to create the tornado parental circulation (mesocyclone). The low-altitude mesocyclone intensification that heralds tornadogenesis seems to result from interaction between spreading rainy downdraft air and inflow air from the storm's right flank. Vertical vorticity is amplified by surges of convergence in the region of interactions. Rear downdrafts, which develop at approximately the time of tornadogenesis, do not transport significant vorticity; rather, their divergent character reduces vertical vorticity. Rear downdraft formation reverses the horizontal gradient of the vertical wind across the low-level mesocyclone and increases vorticity generation by twisting within the mesocyclone; but the generation rate is less than half the amplification rate by convergence. Thus, tornadoes are most likely to be triggered by the vorticity amplification that follows from outflow-inflow interaction. During dissipation, updrafts and rainy downdrafts weaken, and rear downdraft air fills the mesocyclone. Vertical vorticity rapidly dissipates as air diverges near the ground, and the association between the mesocyclone and updrafts ends. **NSSL**

The retrieval of pressure and buoyancy information from the basic three-dimensional wind field is improving our understanding of dynamic forcing within severe thunderstorms. For example, the structure and evolution of the Del City, Okla., tornadic storm of 20 May 1977 were clarified through an investigation into coevolving structure of velocity, pressure, and buoyancy. The pressure field near the storm updraft includes higher pressure on the up-

shear side and lower pressure on the downshear side. This orientation of pressure centers rotates with the shear vector with height. The buoyancy distribution in general shows warm updrafts and cool downdrafts, and a potential relation between low-level vertical vorticity production and horizontal buoyancy gradients.

On rare occasions, a tornadic storm that produces an unusually large and intense tornado is positioned close to an NSSL Doppler radar. In such situations, exceptional details about the radar reflectivity and Doppler velocity signatures in the vicinity of the tornado can be obtained. The storm that produced the violent (F4) Binger, Okla., tornado on 22 May 1981 was such a storm. During a portion of the tornado's lifetime, high pulse repetition frequency (PRF) measurements were made by NSSL's Norman Doppler radar; this special radar channel permits unambiguous velocities up to ± 91 m s^{-1} to be measured within the radar sampling volume. Analyses of the skirts of the Doppler velocity spectra revealed wind speeds of 90 m s^{-1} within the tornado.

Using the normal PRF (± 35 m s^{-1}) with the NSSL Doppler radars along with the pulse pair processer does not permit examination of the Doppler velocity spectrum; instead, only the mean velocity in the sampling volume is available. However, a large and/or intense tornado produces a unique tornadic vortex signature (TVS) among the mean Doppler velocity values as the radar scans past the tornado. The TVS associated with the Binger tornado had unprecedented vertical extent--extending from the ground to within about 1 km of storm top. Colocated with the TVS was a significant reflectivity minimum that became a weak echo hole at middle altitudes. The diameter of the minimum was ~750 m near cloud base and gradually increased to ~2 km at 9 km elevation. Calculations for microphysical retrieval (see Microphysical Processes below) led to the speculation that low reflectivities in a narrow tube-like region were due to strong tangential velocities that prevented graupel from entering the tornado. This hypothesis is being tested with a finely resolving numerical model.

Direct observation of tornadoes is another means by which understanding of tornadic storms is achieved. A portable instrument, TOTO (TOtable Tornado Observatory), was first developed in the Wave Propagation Laboratory to make direct measurements of meteorological variables in tornadoes. Measurements of wind speed and direction, temperature, and pressure were made with this device near tornadoes and beneath a rotating wall cloud. Data from damage surveys and Doppler radar are used in conjunction with TOTO measurements to obtain estimates of wind speeds in and near tornadoes. On 29 April 1985 an NSSL intercept team successfully deployed TOTO in the path of a tornado for the first time. Subsequent damage surveys revealed that the tornado was of minor intensity (F0 classification) and that TOTO was located near the edge of the damage path. Wind speeds of 30 m s^{-1} and a pressure drop of 1 mb in 1 s were recorded with the tornado, and a pressure fall of 5 mb in 2 min with the mesocyclone. However, wind tunnel tests and recent calibrations suggest some uncertainty in measurements of significant variations over such short periods.

One channel of NSSL's Norman Doppler radar is able to measure large unambiguous velocities (± 91 m s^{-1}), making possible nonaliased velocity spectra for sample volumes that include tornadoes. From spectral skirts, the maximum sampled velocity components were inferred as tornado wind speeds. A moderate tornado (F2 damage) in 1977 produced winds of 65 m s^{-1}, and the violent Binger

tornado (F4 damage) in 1981 was associated with winds of 90 m s^{-1}. Special analysis methods are required to deduce accurately the velocities of tornado targets whose distance renders them small compared with the radar beam.

THUNDERSTORM EVOLUTION AND STRUCTURE

Radar observations, both conventional and Doppler, are continuing to provide important information concerning the evolution and structure of convective systems. The mechanisms whereby intense convection was maintained on the leading edge of a large squall line occurring on 19 May 1977 were examined. Observations revealed that at certain locations along the line new convection formed in short shower lines that were perpendicular to the principal squall line. Showers within the short lines, initiated by convergence not connected with outflow boundaries, sustained convection in the most intense portion of the squall line.

The characteristic lifetimes of particular thunderstorm features are important to operational meteorologists and to those engaged in aviation activities. A data set obtained on 19 June 1980 shows reflectivity core growth rates of 4 to 5 dBZ min^{-1} and updraft growth rates of 3 to 7 m s^{-1}. Typical cells persisted 40 to 60 min. A related experiment, with important implications for scanning strategies with operational radars in NEXRAD, investigated the influence of data resolution on automated storm analysis and tracking algorithms. Results indicate that interlacing of consecutive volume scans (i.e., odd-numbered tilt elevations from one data collection are mingled with even-numbered tilt elevations from the next collection) produces a gain in the detectability and predictability of severe weather phenomena, because the collection interval for each scan is reduced significantly.

Other investigations of the structure and evolution of severe thunderstorms continued. A storm on 19 June 1980 slowly evolved from a multicellular state into a supercell storm, owing to the formation of a large region of "background updraft" in which individual cells were represented by updraft perturbations. As the storm intensified, individual perturbations (updraft and reflectivity) became more difficult to identify. In the cell's reference frame, environmental vorticity was not significantly streamwise and, hence, individual updraft perturbations did not acquire strong rotation. However, the larger scale region of background updraft moved to the right of the individual cells, and in this reference frame there was an appreciable streamwise component of vorticity. Thus, the supercell structure and the presence of mesocyclones in the 19 June storm were attributed to the development and motion of the background updraft region.

NSSL

Scale interactions are prominently exposed in data sets collected on 26 April 1984. During the afternoon, isolated supercell storms formed and produced weak tornadoes; these were followed by formation of a solid squall line during the night. Violent tornadoes occurred when breaks developed within the line. It seems likely that an approaching shortwave trough aloft altered the mesoscale environment, creating greater instability and a vertical wind shear profile more favorable for tornadoes.

A study of mesocyclone evolution, downbursts, and the differential motion of mesocyclones occurring in the Lahoma and Orienta storms of 2 May 1979 was

completed. As in many other cases, mesovortex formation and intensification seem tied to the tilting of horizontal vorticity and the subsequent amplification of tilted vorticity by convergence. Periodic regeneration of mesocyclones corresponded with updraft pulsations within background regions, while new mesocyclones developed as new updrafts formed along gust fronts. Of two downbursts, one seemed to be triggered by heavy water loading (radar reflectivities >55 dBZ); the second downburst involved weak reflectivity (<45 dBZ) but was probably enhanced by the entrainment of potentially cold environmental air at higher levels. Principal mesocyclones within the two coexisting storms tended to approach and rotate cyclonically around each other. Observed rotation rates of 60-100° h^{-1} are in approximate agreement with computed value from a simple model for two interacting potential vortices.

MICROPHYSICAL PROCESSES IN STORMS

Documentation of numerical models for identifying microphysical processes in storms was completed. The work proceeds from description of the motion field by Doppler radar in three space dimensions and in time. Microphysical retrieval is applicable to studies of thunderstorm dynamics, microphysics, and electrification. Future efforts to initialize a dynamic cloud model with real data and to evaluate weather modification experiments will rely heavily on such a method.

A study of the sensitivity of microphysical output to the model representation of microphysical processes is being documented. Accuracy of the model output is most strongly dependent upon the formulations of warm cloud and hail processes and on the detail represented in the hail size distribution.

The microphysical retrieval model was applied to several types of deep moist convection. Relationships among the airflow, electrification, and cloud and precipitation development in an isolated New Mexico mountain thunderstorm are being studied with single Doppler radar and sailplane data and a one-dimensional cloud model. Non-inductive charge transfer accompanying collision and separation of ice crystals and riming graupel is calculated by the model. Total space charge, accumulated by the non-inductive ice-ice mechanism plausibly explains the observed lightning flash rate in this storm.

Diagnosis of the newly developed dynamic and microphysical retrieval models can be rigorously verified and extended through abundant in situ aircraft measurements made in New Mexico during the summer of 1984. Preliminary analyses of storm morphology began, using highly resolving data from four Doppler radars, three aircraft, and a number of electric field and charge measurement instruments.

The thermal and microphysical structure of an African squall line was analyzed using dual Doppler derived airflow and a two-dimensional version of NSSL's microphysical retrieval model. This study, in collaboration with French scientists at the Centre de Recherches en Physique de l'Environnement Terrestre et Planetaire, provides expanded knowledge of squall line structure and permits a comparison of the performance of contrasting diagnostic methods.

MESOSCALE MODELING

Some forecasters have noted that weak frontal boundaries on the elevated terrain of the Texas Panhandle and western Kansas are favored sites for growth of disturbances. Growth seems to be synchronized with afternoon heating of high terrain; a typical disturbance resembles a thermal depression located on the front. The net result is a backing of winds in the moist air eastward from the low center, and convergence is focused northeast of the disturbance. This northeastward location is thus a favorable area for severe thunderstorm development.

In collaboration with the Cooperative Institute for Mesoscale Meteorological Studies (CIMMS), a mesoscale model was formulated to address this and other problems. In the first comprehensive study, the model was initialized with a weak front and moderate southerly flow. The bottom (sloping) terrain was heated with a variable rate, decreasing eastward. The solution, 4 h into the simulation, indicates development of a vortex, backing winds in the east, and convergent tendencies northeast of the low. An intriguing feature of this development is the tendency of the vertical wind shear in this area to exhibit large directional shears below 700 mb, characteristic of tornado proximity soundings. The 850-mb fields at 8 h include increased vorticity values and falling geopotential tendencies toward the south-southwest of the low position.

FORECASTS AND WARNINGS

Much of NSSL's research related to improved forecasts and warnings involves preparation for the implementation of the next-generation Doppler weather radar system (NEXRAD). The search for single Doppler signatures for certain weather phenomena continued. Currently, wind and reflectivity fields from a simulated hurricane model are being used to construct Doppler radar signatures for these storms. We need to learn how changes in hurricane intensity are manifested in the radar observations.

A joint project (DOPLIGHT) with the National Weather Service (NWS) Forecast Office at Oklahoma City completed its second year. Single Doppler velocity data with cloud-to-ground strike locations are transmitted in real-time to the forecast office. An NWS forecaster coordinates display selection from the NSSL radar site. The real-time Doppler velocity signatures are incorporated into the forecast office's weather warning decisions.

The attenuation of radar signals at short wavelengths has import for the detection of severe weather phenomena. A comparison of reflectivity patterns at 5 and 10 cm wavelength for the 2 May 1979 data set illustrates the problems that can occur. When the Orienta and Lahoma storms became radially aligned with respect to a 5-cm radar, signal attenuation exceeded 30 dB. The attenuation distorted the reflectivity structure of the Lahoma storm as observed by a 5-cm radar, and the expected association of mesocyclone and reflectivity maxima was not evident; i.e., the mesocyclone appeared in the weak reflectivity gradient on the left flank of the storm instead of the right flank. A forecaster would not have concluded this to be a hazardous storm.

NSSL has been aiding the National Weather Service in evaluating new Doppler radars at Montgomery, Ala., and Marseilles, Ill. The Montgomery 5-cm radar seems effective for ranges <130 km. The radar was found to be limited by a small velocity measurement interval and problems in velocity interpretation, but a net improvement was nevertheless realized in local warning capability.

DATA ACQUISITION AND PROCESSING

We constantly search for better data acquisition methods and improved techniques for analyzing data. The utility of surface observations in multiple-Doppler objective analysis schemes is related to distance. Storms scanned by radars are typically 50 km or more distant. In this situation the observations are no lower than 0.25 km AGL with scanning at 0° elevation. This leaves the researcher with the choice of establishing the lowest level of the wind field analysis at the height of the lowest scan or using downward extrapolation to obtain an estimate at ground level. Downward extrapolation may suffer in accuracy since tall-tower data show that winds over large regions in the lowest half kilometer of a thunderstorm turn substantially clockwise with height. Since vertical velocity determination requires accurate boundary conditions, a method of analysis was developed for drawing on both Doppler radar and surface data to produce a more representative surface wind field.

A recent study showed that errors in wind field analyses can have large, far-reaching consequences, but also that these effects can be minimized by careful selection of analysis techniques.

Airborne Doppler radar can collect data on target storms that are quite widely dispersed. However, the relatively long time required to sample an individual storm in detail, particularly with a single aircraft, and the amplification of statistical uncertainty in radial velocity estimates when Cartesian wind components are derived, suggest that errors in wind fields derived from airborne Dopple radar measurements would exceed those from a ground-based radar network better located to observe the same storm. Error distributions for two analysis methods (termed Overdetermined and Direct methods) were applied to data collected on a sea-breeze-induced storm in western Florida on 28 July 1982. Application of the direct solution not involving the continuity equation, and the overdetermined dual Doppler method, which requires use of the continuity equation, produced similar fields. However, since the magnitudes of all errors are unknown and the response of each method to errors is different, further study is required.

An extremely important component of the 1985 PRE-STORM Program was acquisition of rawinsonde data with 1.5 to 3 h time resolution from 12 supplemental sites and 15 National Weather Service sites. A routine was developed at NSSL to bring data from the supplemental sites to the PRE-STORM control center for processing in near-real time. The processed data were then transmitted through the national system by the NWS System for Automation of Field Operations and Services (AFOS). Users of AFOS thus had unprecedented access to upper-air data with fine temporal and spatial resolution.

Along a related line, objective analysis algorithms are being developed to read and analyze mesoscale rawinsonde data. The analysis package will be used to produce fields suitable for use in NSSL's version of the Warner-Anthes mesoscale numerical model.

Plans FY 1986

- There will be a substantial effort to integrate observations with theoretical investigations and mesoscale numerical modeling. Among specific topics to be examined are cyclogenesis on mesocyclone scales and larger multi-dimensional cloud modeling, and model initialization and verification studies. These studies will be pursued in cooperation with CIMMS.

- An initialization package will be developed, suitable for interfacing the objective analysis package with NSSL's mesoscale model.

- Processing of rawinsonde data from all 27 PRE-STORM sites will be completed.

A number of studies will begin, using data collected during the 1985 PRE-STORM program:

- A case study of scale interaction on 12 May 1985.

- Mesoscale modeling experiments utilizing multi-release rawinsonde data as initial conditions for two excellent situations (10-11 May and 10-11 June 1985).

- Extensive studies of cell-storm and storm-environment interaction for understanding mesoscale convective system morphology and evolution.

- Generation of a statistical data base for algorithm development to aid design of sensing networks.

Analysis of the following storm cases will continue:

- Thunderstorm Research International Project (TRIP) 1984 case.

- 22 May 1981 Binger storm, for microphysics and dynamics; 19 June 1980 for reflectivity and electrical data.

Documentation of the following studies will be completed:

- The sensitivity of microphysically retrieved variables to details of the microphysical formulation.

- Severe storms on 8 June 1974, 9 May 1977, and 6 June 1979.

- Training manual for interpretation of single-Doppler color displays.

- Compilation of mesocyclone statistics.

Among the case studies to be initiated (other than PRE-STORM cases) are the following:

- Microphysical retrieval/electrification on 19 June 1980.
- Dynamic retrieval on 19 May 1977.

DOPPLER RADAR AND STORM ELECTRICITY RESEARCH

NSSL has major facilities to observe electrical and kinematical processes contemporaneously with precipitation phenomena. The 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 data from Doppler radar as well as a multitude of other sensors. The Storm Electricity Group concentrates its analyses on data simultaneously obtained with Doppler radar and our many storm electricity sensors.

Accomplishments FY 1985

DOPPLER RADAR

Prestorm Environment and Storm Initiation

We explored means for diagnosing changes in temperature profiles from single Doppler wind data. The geostrophic wind, and hence the thermal wind, is estimated by solving the equations of motion for the Doppler-defined fields of actual wind in various layers, with an assumption or two about vorticity. Horizontal temperature advection is then estimated from the thermal wind. Temperature change due to subsidence or rising motion is computed from averaged vertical Doppler velocity and initial temperature profile. A boundary layer model was incorporated to account for diabatic heating and vertical mixing. Tests performed on actual data were used to assess the accuracy of the method. The results with radar data from clear air are interesting and warrant continued investigation. Horizontal temperature advection appears to be the most uncertain element in the model.

Comparison of divergence measured with two Doppler radars and divergence estimated by volume-velocity processing (VVP) from a single Doppler radar showed that agreement is much better when the radar data are filtered. This is because small-scale nonlinearities that bias the VVP divergence are removed. Analysis of the 17 May 1981 data revealed areas of convergent flow near and ahead of the dry line. The variance of radial velocities from a single radar is not well related to the intensity of convergence and convective clusters (see NSSL Annual Report, 1984).

A Uniform Wind Algorithm was used to derive the wind field in the vicinity of a front, from single Doppler radar data. The derived wind was shown to be consistent with rawinsonde wind data. Furthermore, the measured slope of the front is consistent with the average divergence, deformation, and vertical air motion derived from Doppler VAD (velocity-azimuth display) analyses.

Data from a solar eclipse and other clear days revealed an effect of insolation and ground wetness on radar reflectivity near the ground. The results are consistent with expected relations, thus warranting more quantitative comparisons.

Lidar Investigation of Storm Environments

Features of special interest in windfields derived from Doppler lidar data were waves and vortices at the leading edge of a gust front marked by an arcus cloud formation and clearly delineated wind shifts in cloudless regions.

Also seen by the Doppler lidar were clear air flows just below the base and sides of an isolated cumulus congestus circumnavigated by a NASA aircraft. Analyses of winds above cloud base suggested that the cloud was entraining environmental air, therefore causing a net convergence of environmental air into the cloud above its base.

Solitary Wave Research

The steady-state solitary wave solution of the Benjamin-Davis-Ono (BDO) equation in a two-layer deep fluid was compared with Doppler radar and tower observations of a boundary layer solitary wave. The results indicated that the BDO theory provides an adequate explanation for this observed large-amplitude solitary wave. The BDO theory was extended to the case in which the upper layer has a weak stable stratification. The extended theory showed that the solitary wave amplitude should decrease with time, owing to upward radiation of wave energy, a loss not present when the upper troposphere is neutrally stratified. The theory of Maslowe and Redekopp was applied to estimate the solitary wave attenuation; theoretical results suggest an attenuation rate about twice that observed. We also initiated a joint research project with the Australian National University (ANU) to make cooperative observations with ANU's microbarograph array and NSSL's Doppler radars and tall-tower instruments. Simultaneous data were collected on at least two well-defined wave packets that propagated through the network during the 1985 PRE-STORM period.

Wind Profilers (50/405 MHz)

In cooperation with ERL's Wave Propagation Laboratory and the University of Oklahoma, a 50-MHz wind-profiling radar was installed on a gently sloping hillside about 30 km SSW of NSSL. The radar began preliminary wind observations in mid-May and has operated automatically since. The wind fields observed with radar are being compared with wind data from rawinsondes launched by the Weather Service Forecast Office in Oklahoma City. WPL and NSSL are also cooperating to test wind-profiling capabilities of a 405-MHz radar. (See Facilities Development section, below.)

Doppler radar wind profiling within storms was studied. A limited data set acquired over 2 days showed comparable differences between each of the three pairs defined by single radar, two radars, and rawinsonde.

A real-time VAD program was set up to support the DOPLOON (Doppler-balloon) project (intended to automate balloon tracking for determination of winds by Doppler radar). Refinements of the computer program were made for improved acquisition and tracking of a target balloon. From the limited number of experiments we concluded that DOPLOON winds compare well with rawinsonde observations.

Clear-Air Reflectivity

A few data sets of clear-air echoes were collected after winter cold front passages. Measured values of the structure constant were 10^{-14} to $10^{-15} m^{-2/3}$, which were also the values calculated from theory, using rawinsonde data and assumed eddy dissipation rates as inputs. However, similar calculations (i.e., assuming turbulent breakdown of shear layers) for 27 May 1983 underestimate the C_n^2 values by one to two orders of magnitude. On the other hand, the theory based on temperature fluxes in a mixed layer gave results in good agreement with observations. But vertical profiles of reflectivity on that day can also be accounted for with typical distributions of insects in the atmosphere.

Downdrafts and Gust Fronts

Thunderstorm downdrafts (downbursts) in Oklahoma can be highly asymmetric, with shear along the maximum shear axis more than five times the shear along the minimum shear axis. Furthermore, downbursts in Oklahoma are significantly different from those observed around Denver, Colo., during the Joint Airport Weather Studies (JAWS). For instance, the majority observed during JAWS were "dry" with little or no rain that reached the surface; they were driven by evaporative cooling below cloud base, which occurred when precipitation fell into a deep, dry, nearly adiabatic boundary layer. Lower cloud bases, and a moister and slightly more stable boundary layer reduce the incidence of downbursts in the Oklahoma area. Instead, observed Oklahoma downbursts were associated with intense convective storms, and the initiation mechanisms probably include low-level melting and evaporation of precipitation, precipitation loading at low levels, and evaporational cooling at middle levels due to entrainment of dry air.

Comparison of surface-measured horizontal shear and that measured by Doppler radar was completed. For 41 comparisons of gust front shear, shear measured by Doppler radar (at heights 50-600 m) averaged 1.6 times that measured at the surface. Conclusions were that the Doppler radar is able to estimate shears that may occur below the radar beam, and in fact may overestimate those shears.

Polarization Studies

NSSL's engineering group installed a fast polarization switch on the NSSL Doppler radar at Cimarron, and first data collection began in the spring of 1985. Theoretical investigation of polarization parameters produced the following conclusions: (1) Acquisition time for differential reflectivity (Z_{DR}) can be significantly reduced by simultaneously sampling the vertical and horizontal electric fields. (2) Such a scheme does not compromise spectral moment estimation and allows scan rates of 3 rpm if correlation between simultaneously received horizontally and vertically polarized echoes is better than 0.995. A theoretical investigation of all the factors that contribute to the decorrelation established that simultaneous sampling does indeed reduce acquisition time in rain media. A scheme for Z_{DR} measurement was suggested which uses +45° and -45° polarized transmissions alternately with simultaneous reception of horizontal and vertical signals to compensate for bias error due to propagation. Further, a method of nearly eliminating bias error due to receiver mismatch was suggested.

We described a new method based on differential phase ϕ_{DR} (i.e., the difference in phase shift accompanying propagation of vertically and horizontally polarized waves) to estimate rainfall rate. We showed that differential phase is relatively insensitive to drop size distribution variations and thus can yield more accurate estimates than methods based on Z_{DR}. Standard errors in ϕ_{DR} cause large inaccuracies at low rain rate (<30 mm h^{-1}), thus limiting its usefulness to estimating higher, potentially more severe rain rates. It was also shown that ϕ_{DR} can be used as a third remote measurable to determine a three-parameter drop size distribution.

Enhanced Observing Capabilities

We found additional hardware (more memory, parallel interfaces) for the FPS AP120B array processor to facilitate real-time spectral processing. A program was written for the Perkin-Elmer data processor to use the array processor for computing Doppler spectra. We developed a program to facilitate processing of raw Doppler tapes. This program lists housekeeping, skips records, and searches for time, elevation angle, azimuth angle or step number, etc., so that the data can be inventoried and processed quickly.

NSSL

A statistical classification approach to editing clear-air radar data was studied. Echo-power- and noise-biased spectral width estimates were selected for use as classification variables. The power and width space was divided into four regions for clutter, meteorological data, outliers, and noise. Boundaries for the regions were drawn by a mixture of theoretical and observational considerations. An application of the classification to PRE-STORM data for 22 April 1981 showed good performance.

A method for whitening sidelobes of linear array antennas was developed. The method requires switching of a small number of elements (2 to 4) and uses an unequal spacing between them.

Algorithms for Next-Generation Weather Radar (NEXRAD)

We completed the development and analysis of three NEXRAD algorithms. The first algorithm is a sectorized uniform wind algorithm using single Doppler data. It requires evaluation of azimuthal derivatives of radial velocity to estimate the transverse wind components. For a uniform wind, the relationship is exact. Application of this technique to Doppler data to estimate wind fields in the vicinity of frontal boundaries and in uniform wind situations showed good results. With the help of this algorithm, it will be possible to locate frontal boundaries with resolution much superior to that afforded by surface stations. These boundaries often trigger severe storm formation.

The NEXRAD Tornado Vortex Signature (TVS) algorithm is similar to the NEXRAD Mesocyclone algorithm. Its purpose is to search for regions of very high cyclonic shear associated with TVSs. In testing on eight tornadic thunderstorm cases the algorithm detected 84% of the actual number of TVS features, and there were no false alarms other than those caused by dealiasing problems. It was observed that all violent tornadoes produce a TVS signature; thus our algorithm should enhance the tornado warning process.

Testing of the divergence algorithm continued; comparison of observed divergence and fluxes showed general quantitative agreement with those generated by a simple updraft model, having the observed diameter and an estimated updraft speed. An increase in estimated divergence precedes a reflectivity buildup by 5-10 minutes.

A fourth NEXRAD algorithm being developed is meant to detect and trace gust fronts.

STORM ELECTRICITY

Lighting Strikes to Aircraft

Results of the analysis of data obtained during low-altitude storm penetrations by the NASA F106-B research airplane included the following:

- The probability of direct strikes to the airplane increases both during the decaying stage of storm cells and with decreasing natural lightning flashing rates.

- At low altitude within the storm cell the airplane can either trigger a strike to itself or intercept an existing flash; strikes at high altitude are nearly always triggered.

- The directions of channel development inferred from lightning radar echo propagation agree with those determined from actual television

(TV) recordings of the same flashes that show their propagation, a physically reasonable expectation now confirmed.

Positive Cloud-to-Ground Lightning and Synoptic-Scale Conditions

We analyzed synoptic conditions for 13 May 1983 when an unusual number of positive cloud-to-ground (+CG) flashes occurred. Synoptic-scale analyses were performed in cooperation with NASA/ Marshall Space Flight Center. The occurrence of +CG flashes does not appear to have been uniquely related to sea level pressure tendencies, moisture convergence, or vertical temperature profiles, but may have been linked to vertical shear in the horizontal wind.

Facility Upgrades and New Instrument Development

Modification to our very-high-frequency (VHF) lightning-mapping system was completed, to allow mapping of the entire hemisphere continuously with data collected at rates of 16,000 lightning impulses per second. This modification was tested and calibrated and then used to acquire data during the spring program.

For the PRE-STORM program, coverage of our network for locating lightning ground strikes was expanded to Kansas and southern Nebraska, and to contiguous parts of Colorado, Arkansas, Missouri, and Colorado.

The storm electricity mobile laboratory and the vehicles used in NSSL's storm intercept program were deployed in highly successful coordination, which will be continued.

We designed and fabricated a new instrument to measure the velocity of return strokes propagating between the ground and the cloud. Optical sensing elements, placed behind a 35 mm camera lens system, are coupled to high-speed circuits to record the optical waveform in eight narrow horizontal slits along the channel. We hope that our instrument will eventually replace the very expensive, cumbersome, and low-data-rate cameras now used to estimate return stroke velocity. Uses of the data will include determination of currents and other physical features of return stroke channels. We hope to resolve the question raised several years ago as to whether lightning currents and velocities in Great Plains severe thunderstorms are different from those observed in Florida tropical storms.

NSSL

Continuing Currents in Intracloud Lightning Flashes

Analysis of data from our vertically pointing Doppler radar and the VHF lightning-mapping system for about 70 intracloud flashes showed horizontal progression of the lightning through our observational areas, lightning echoes generally having intensities stronger than precipitation echoes seen at radar wavelength of 10 cm. The lightning echo in an intracloud flash is apparently a result of a current surge that produces ionization detectable by radar. The life cycle of these lightning echoes clearly shows thermal decay after the initial ionization. Theoretically, decay of slow echoes could be related to large size of ionized channels or to continuous current. However, observa-

tional indications are that thermal decay is slowed by continuous current in the intracloud channel. Continuous current in intracloud lightning has been inferred by others, but it was not known to be as frequent as our preliminary analysis indicates. There are practical implications for this finding in the area of aviation hazards.

Lightning channels were observed to accelerate vertically immediately after their formation. It seems probable that this acceleration is a combined effect of Earth's magnetic field and buoyancy acting on the hot plasma channel through which a current flows.

Using lightning as a tracer, we inferred vertical air velocities from $\pm$2.0 to 17.5 m s^{-1}. The observations thus far suggest that lightning is usually within updraft regions.

Lightning and Storm Studies

In cooperation with NASA/Marshall Space Flight Center, we are analyzing cloud-to-ground activity during periods of several mesoscale convective systems (MCSs).

We are seeking to evaluate the ratio of intracloud to cloud-to-ground lightning, to relate this to storm development and to apply it to use of certain sensors in NWS operations.

We are in the final stage of preparation of an improved national climatology of lightning strikes.

A completed analysis verified that +CG flashes tend to have continuing current in the return stroke channels.

Plans FY 1986

DOPPLER RADAR

To develop improved operational capabilities for forecasting the locations and intensities of storms, we shall continue in-depth examinations of the PRE-STORM radar data with other data sources and theory.

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

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

Aspect dependency of Doppler spectrum width will be studied.

The wind-profiling capability of weather radars will be examined both theoretically and experimentally. The accuracy of the 50-MHz wind profiler will be evaluated. Wind profiles derived from simple Doppler radar observations within storm velocities will be examined. We shall continue to pursue

the capabilities of Doppler radar to track reflecting balloons from which wind profiles could be derived.

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

We will analyze our first polarization data obtained in the spring of 1985 in order to determine the quality of rain rate estimates and the capability to identify hydrometeors remotely in storms.

A joint NSSL/Australian National University analysis of solitary wave data will be conducted.

STORM ELECTRICITY

- Perform a side-by-side comparison of the two commercially available cloud-to-ground strike-locating systems (dependent upon installation of the second system by its distributor) under funding from NWS.

- Continue our involvement with the National Interagency Coordinating Group (NICG) both in terms of coordinated research and as vice-chair of the 1986 International Conference of Ground and Static Electricity.

- Participate in the development of a National Plan for Lightning Data.

- Participate in the planning and data analysis of a multi-agency program utilizing a least two instrumented airplanes to measure lightning strikes to aircraft.

- Expand the data base of the characteristics of positive cloud-to-ground flashes and their relationships with storm and environmental parameters.

- Continue to address the need for and uses of a satellite-based lightning-mapping system.

- Replace the NSSL mobile laboratory, which is no longer reliable, and increase the parameters that we record by adding meteorological sensors.

- Analyze lighting channel plasma properties from dual radar observations of lightning, and continue development of software to analyze ground strike data and VHF lightning-mapping data. **NSSL**

- Acquire additional measurements of return stroke velocities.

- Complete evaluation of +CG detection capability of the NSSL lightning strike-locating system and study CG lightning evolution in mesoscale convective systems.

COMPUTER AND ENGINEERING SUPPORT AND DEVELOPMENT

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

Accomplishments FY 1985

COMPUTING AND DATA PROCESSING

The NSSL VAX 11/780 was installed and became operational. It consists of 12 megabytes (Mb) of memory, 1778 Mb of disk storage, three magnetic tapes, and a RAMTEK color graphics workstation. The system is used for interactive editing of Doppler radar data and for editing and archiving of other NSSL-collected data, and serves as a remote job entry link to the CDC 855/205 in Gaithersburg, Md.

A MICOM telecommunication system was installed. It provides communication to the CDC 855/205 by means of two dedicated 9600-baud phone lines as well as a multiplexor and electronic switch for interconnection of all NSSL terminals to the VAX, CDC/205, and to the NSSL Perkin-Elmer computer connected with the Norman Doppler radar.

NSSL supplied data sets to these users:

Lassen Research Manton, Calif.	(R. Lee)
MIT Lincoln Laboratories Lexington, Mass.	(J. Evans)
NASA Goddard Space Flight Center Greenbelt, Maryland	(G. Heymsfield, R. Blackmer, I. Hakkarinen)
National Weather Service Weather Service Forecast Office Oklahoma City, Okla.	(D. Devore)
National Weather Service Techniques Development Laboratory Silver Spring, Maryland	(W. McGovern)
Purdue University West Lafayette, Indiana	(D. Klingle)
Texas Tech University Lubbock, Texas	(K. Mehta)

University of Oklahoma
Norman, Okla.

(H. Bluestein, G. Byrd)

FACILITIES ENGINEERING

The Sperry Corporation established a ground-based facility for its airborne Doppler radar developed for the commercial carrier market. Data from the system were compared with data from the NSSL Norman Doppler to evaluate system performance. This was the third airborne Doppler radar system evaluated at NSSL.

Transfer of quasi-real-time data from the Doppler radar at Norman to the Weather Service Forecast Office at Will Rogers Airport was done routinely during the PRE-STORM program. These data proved useful to the duty forecaster and provided an opportunity for gradual technology transfer and examination of minimal Doppler radar products by the operations office.

Some NSSL facilities, particularly the Norman Doppler radar, were maintained operational from January into September in support of multiple programs: Winter Storm, during January through March, PRE-STORM from April through June, and Special Research during July and August. This schedule represented a substantial extension of the Laboratory's normal observational season.

Systems engineering for an antenna dual polarization capability on the NSSL Doppler radar at Cimarron (CIM) was completed, and routine operations began with the PRE-STORM program. Data were acquired for meteorological research, engineering evaluation, propagation studies, and real-signal statistics.

The in-house research program to examine the feasibility of upper-air wind measurement by balloon tracking with a NEXRAD-type radar continued. Experiments to determine balloon cross section and radar system performance were successful, and we are designing electronic circuits to facilitate automatic balloon tracking.

The National Acid Deposition Assessment Program site operation continues since its institution in 1983. Sample collection is both wet deposition (rainfall) and dry deposition (dust) at a local farm. Sample pre-analysis consisting of a pH and conductivity measurement is done at NSSL. Detailed composition analysis is done at the Illinois State Water Survey.

NSSL

FACILITIES DEVELOPMENT

Long-needed improvements in the CIM radar real-time display and data recording were begun with the design and fabrication of a radar signal preprocessor and second-generation color display. Fabrication of the preprocessor and display terminal was completed, and system software is being written.

An expanded data acquisition and recording terminal for the NSSL tall-tower facility was designed, built, and commissioned. Program demands in

recent years have exceeded the capability of the original system placed in service in the late sixties.

Work began on the establishment of a 405-MHz Profiler at the NSSL. This is a joint program with WPL whereby NSSL is to build a steerable parabolic antenna system and WPL is to provide the transmit/receive terminal. A parabolic reflector and positioner have been acquired from surplus and modified to suit our needs. Current goals are to determine the suitability of the 75-cm wavelength for central Oklahoma applications and the electrical performance of the parabolic antenna system.

System engineering for a microwave data link between the NSSL Cimarron and Norman radars is complete. Hardware is scheduled for delivery in late 1985. Initially the system will be an L-band simplex link consisting of a transmitter at Cimarron, a repeater on the KTVY tower, and receiver at Norman. It will carry the full data from Cimarron and interface to a remote display terminal and to the Perkin-Elmer 3242 computer terminal at Norman. Among other things, it will provide NSSL with the data needed to synthesize the observations from two Doppler radars in real time.

Plans FY 1986

COMPUTING AND DATA PROCESSING

Upgrades to the VAX 11/780 will include the installation of a seven-track tape and/or an electrostatic plotter and laser printer. Graphics software now operational on the CDC 750 will be converted for use on the CDC 205 and the NSSL VAX. New graphics software will be designed to use unique features of the RAMTEK color graphics system. Additional support will be given to scientists in the optimization of computer programs for use on the CDC 205.

FACILITIES ENGINEERING

The microwave engineering phase of dual polarization development is complete. During FY 1986 we will complete a study of signal statistics and preliminary evaluation of meteorological utility. Initial data examination indicates that the technique has good potential for meteorological research and we should proceed with the development of processing techniques and hardware needed to realize this potential.

It is planned to design and fabricate a microwave transmitter and receiver to service a vertical antenna at the Norman radar site. Data will be recorded on a wideband analog recorder and processed through the Norman terminal. This will provide a vertical-looking radar capability without conflict with the Norman radar.

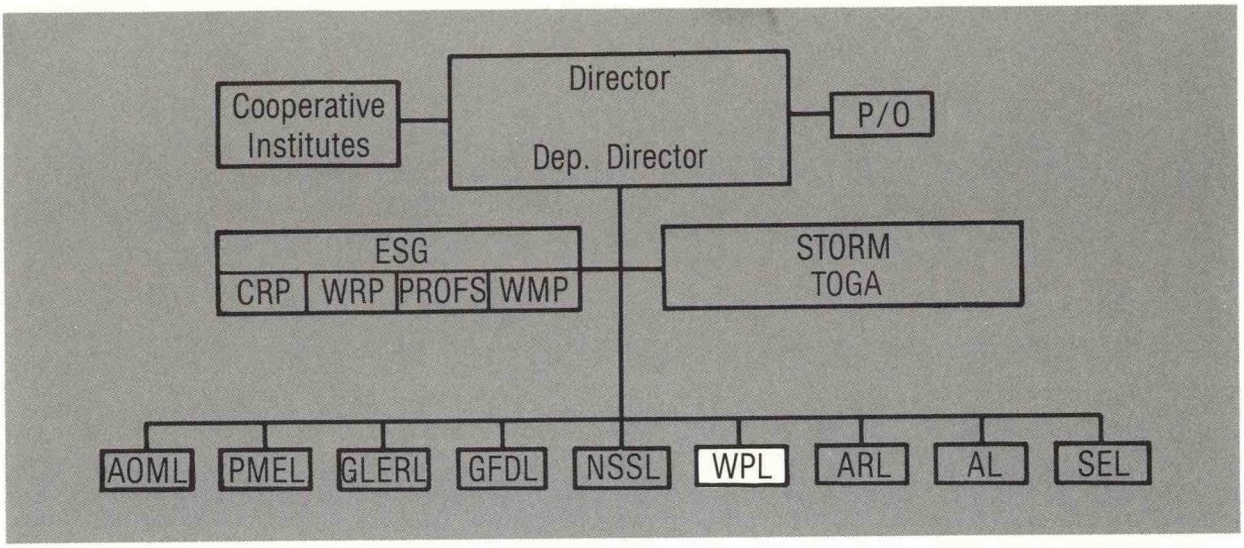
NSSL has need of a high-quality wide-bandwidth data distribution system in and around the central Laboratory. It is planned to establish a data distribution network using fiber optics technology.

The microwave portion of the Cimarron/Norman data link will be established in early FY 1986. The Cimarron radar interface is incorporated into the radar preprocessor and display terminal for this system and will be commissioned with this terminal in FY 1986. Development of remote data processing for analysis and display at Norman will continue.

It is planned to complete a 405-MHz antenna terminal and to begin experimentation. A preliminary evaluation of the system should be available by the end of FY 1986.

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.

In summary, then, the WPL mission is to improve the Nation's geophysical research and services, through the development, demonstration, and dissemination of cost-effective remote measurement systems. To achieve this goal, WPL must successfully perform the following functions: **WPL**

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

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

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

- Improvement of the Nation's atmospheric and oceanic research, and forecasting and warning 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-1985 programs and FY-1986 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. WPL's remotesensing R&D program includes contributions on all scales from the micrometeorological to the global.

MICROMETEOROLOGICAL 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 1985

SENSOR DEVELOPMENT

A technique for extracting second moments of the wind from measurements made with multibeam monostatic sodars was developed and tested. The technique is based on theoretical evaluation of the effects of the spatial and temporal separations on measurements obtained from the sodars.

New hardware and software for operating a four-axis Doppler sodar system in a simulated VAD mode were developed and tested. An experiment was conducted to determine if, as predicted by theory, this approach yields dependable values of stress in the lowest 500 m of the atmosphere.

New software was developed to process and analyze Doppler lidar data from the Brush Creek experiment of the Department of Energy's Atmospheric Studies in Complex Terrain (ASCOT) program. The software utilized spatial averaging and terrain gating techniques to generate contour plots of the radial flow field.

The fifth and final phase of the Flatville, Ill., millimeter wave propagation experiment, sponsored by the Army Research Office, was completed. Amplitude, phase difference, and angular fluctuation data were taken at a range of frequencies from 140 GHz to 230 GHz in clear air, rain, fog, and snow, over the horizontal, 1.3 km path. 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. Preliminary millimeter wave data indicate agreement with theoretical predictions based on the weak-scattering theory.

The recently completed Flatville data set contains the first combined measurements of infrared, millimeter, and visible wavelength scintillations. These measurements 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.

The theoretical basis has been developed for a synthetic-aperture spatial filtering device that will provide high-resolution vertical profiles of turbulence quantities (refractivity and microscale) from a single, aircraft-mounted light source.

A method was developed to compute errors for frequency estimators that use spectral peaks; the technique has broad application to Doppler radars, lidars, and acoustic sounders.

RESEARCH

The infrared Doppler radar was used to obtain real-time displays of drainage flow in a straight, narrow, mountain valley. Wind flow contour analysis was completed for three cases, including the transition from night-time down-valley to daytime up-valley conditions.

WPL

Convective plume fields were mapped using the Doppler lidar; spectral analysis shows a mean plume size of 1 km.

The convergence triangle of WPL's optical crosswind sensors at its Boulder Atmospheric Observatory (BAO) was used in the Meso-Gamma '85 experiment, and showed ground-level signatures characteristic of microbursts and strong updrafts.

Turbulent velocities in the daytime boundary layer, measured by 3-cm-wavelength Doppler radar using the velocity azimuth display (VAD) technique, were analyzed, and momentum flux profiles derived from variances of the radial velocity.

Cloud droplet size distributions in lenticular clouds were obtained by inverting the backscattered radiation, using three lidar wavelengths (from ruby, doubled-ruby, and CO_2 lasers) and the Backus-Gilbert technique.

A study was completed for the Environmental Protection Agency, demonstrating the accuracy to which the mean and turbulent structure of the convective boundary layer can be estimated by using simple and readily available measurements.

Plans FY 1986

SENSOR DEVELOPMENT

WPL will continue analysis of the Flatville data set to relate millimeter wave and optical scintillation data to simultaneous meteorological data. We will perform a preliminary test of a path-averaged flux measurement technique using these data. We will continue to refine our ability to make path-averaged measurements of turbulent microscale, and hence momentum flux, on longer atmospheric paths.

In connection with our high-resolution, vertical profiling of turbulence parameters using an aircraft-to-ground propagation path, we will conduct the first experimental tests of the concept on horizontal paths during FY 1986. This work could have a significant impact on predicting outages of clear air radar echoes at different radar wavelengths.

The new Doppler minisodar will be tested using BAO data to determine limitations in accuracy and resolution. This sensor is designed for easy deployment in future field experiments, and is primarily intended for use in complex-terrain environments, and in wind-energy studies.

Potential for use of the VAD technique for Doppler sodar measurements of stress will be explored through field experiments and intercomparisons with turbulence sensors on the BAO tower.

A portable instrument package for measuring atmospheric conditions beneath microbursts and in critical regions of downslope wind storms will be developed to aid in the study of those events during Meso-Gamma '86.

RESEARCH

A major study of microbursts will be undertaken at the BAO during Meso-Gamma '86, using the infrared Doppler lidar and microwave radars in addition to standard BAO instrumentation (meteorological tower, optical convergence triangle, microbarograph array).

Analysis of Phoenix II (summer 1984) data will continue to determine momentum flux in the boundary layer. Research into the use of temperature differentials derived from wind fields in combination with radiometrically derived temperature profiles will continue.

A field experiment will be conducted at BAO to compare the structure of C_n^2 in the lower atmosphere with simultaneous measurements of echo intensity profiles from vertically pointing FM-CW radar and sodar. Findings from the experiment are expected to improve our understanding of the effects of layered structures on echo parameters measured by volume-averaging remote sensors. The effect of inhomogeneous echo layers on Doppler wind estimation using variable pulse length sodars will be examined in tests at the BAO.

Studies will be completed, summarizing gravity wave statistics collected during FY 1984 and FY 1985.

R&D ON MESO-BETA AND -GAMMA SCALES

A single ground-based scanning 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 1985

MESOSCALE SENSOR DEVELOPMENT

A new CO_2 laser, designed to provide a 100-fold increase in average radiated power, was received from the manufacturer. After testing and modification in the laboratory, the new laser was installed in the Doppler lidar van, and the first atmospheric echoes were obtained using the most powerful coherent infrared pulses ever used for atmospheric research.

A 3-cm-wavelength Doppler radar was implemented with dual circular polarization; this new feature will permit X-band depolarization measurements on dispersed chaff to provide a well-distinguished signature for study of entrainment. **WPL**

Design of a 90-GHz radiometer to incorporate with an existing dual-channel (20/30 GHz) radiometer was completed; this additional channel is expected to improve significantly the capability of remotely sensing both water vapor and liquid.

RESEARCH ON MESO-BETA AND -GAMMA SCALES

An analysis of observations from the BAO tower, acoustic echosounder, PROFS mesonet, satellite imagery, and research aircraft was completed, demon-

strating the formation of 1-km-scale hydraulic heads at surface fronts, and their relationship to the triggering of intense mesoconvective weather systems.

Data taken during the NOAA-sponsored Arctic Cyclone Experiment (ACE, 1984) were analyzed, and provided the first description of Arctic mesoscale frontal structure and polar lows.

The Texas Dryline Frontal Zone Experiment was conducted during May 1985. Doppler lidar, dual-channel radiometer, rawinsonde, and research aircraft measurements were used to describe the structure and evolution of dry lines, cold fronts, boundary layer jets, upper-tropospheric jet streams, and boundary layer turbulence. Of special note was the demonstration of the unique capability of the Doppler lidar to measure the wind field of shallow fronts, and dryline discontinuities prior to the onset of severe thunderstorm activity. The dual-channel radiometer clearly measured water vapor discontinuities at the dryline.

Analyses of conventional rawinsonde soundings and total columnar ozone data from an ozone-mapping polar-orbiting satellite (TOMS on Nimbus-7) showed the relationship between the southward migration of a polar vortex and its associated tropopause fold from northern Greenland to the Great Lakes, and the record-setting cold temperatures associated with the arctic outbreak of January 1985.

Two highly successful long-term field programs in mountainous winter-cloud environments were performed at Steamboat Springs, Colo., and Beaver, Utah. A dual-channel radiometer and an 8.6-mm-wavelength dual-polarized Doppler radar were used to observe supercooled liquid and ice particles in primarily orographic cloud situations; several agencies (e.g., Desert Research Institute, Colorado State University, University of Utah, Environmental Sciences Group of ERL) are also analyzing the data.

Data obtained using the NAVSTAR satellites and two receivers of the Global Positioning System located on a 22-km baseline near Boulder, Colo., showed that steerable dual-channel radiometers, located at the baseline terminals, provided corrections for apparent path length changes introduced by variations in tropospheric water vapor. The corrections improved the rms precision of the 22-km baseline measurements from 4.7 cm to 1.3 cm.

Variability of pressure heights and layer thicknesses were measured by the six-channel Profiler radiometer at the Denver WSFO; the time series and spectra of these pressure heights and thickness variations correlate well with independent measurement of gravity waves.

A statistical study of the ability to predict icing of aircraft used pilot reports for an area surrounding Denver, Colo. Analysis of independent predictors such as surface temperature or cloud cover showed that cloud liquid water, measured by dual-channel radiometry, has by far the strongest correlation with icing, especially during winter months.

A Front Range boundary layer mesoscale model was developed, capable of simulating two basic features of the flow in the Denver area: the "Denver cyclone" for southerly winds and the "Longmont anticyclone" for northerly

winds. The Palmer ridge south of Denver was shown to be the main topographical feature, aside from the Front Range, responsible for the formation of the Denver cyclone. The Cheyenne ridge plays a similar role in the formation of the anticyclone. The associated convergence lines, which are preferred regions for thunderstorm development, are also predicted by the model.

A meso-gamma-scale experiment (Meso-Gamma '85) was conducted at the BAO during June and July of 1985 to study events on that scale occurring along the Colorado Front Range. Of particular interest were terrain-induced mesocyclones and anticyclones and associated convergence lines. Data collected with the BAO sensors, aircraft, rawinsondes, FM-CW radar, profilers, and the PROFS Mesonet, documented several mesocyclones that spawned severe weather (rain, hail, lightning, high winds, and tornadoes). These data will be used to evaluate the performance of WPL's Front Range boundary layer mesoscale model. In addition, eight microbursts and two gust front passages were carefully monitored at the 300-m BAO meteorological tower. The microburst and gust data are providing unique and essential information for the design of wind shear prediction and detection systems to be used at airports.

Simultaneous measurements at the BAO and along the Rocky Mountains have revealed a double-structured boundary layer at the BAO. The double structure results from an upper-level mountain boundary layer advecting over and capping the underlying plains boundary layer. This observation, made during the MesoGamma '85 experiment, has important implications for studies of the daytime boundary layer along the Front Range.

All wave events occurring during one month in the spring and one in the winter were documented to develop a climatology of gravity/shear waves in the Front Range region. Studies are under way, in collaboration with Georgia Institute of Technology, to examine the pressure-velocity correlations in such events.

Preliminary modeling of flow in the Santa Barbara, Calif., area was completed for the South Central Coast Cooperative Aerometric Monitoring Program (SCCCMP) experiment. The model shows strong topographical channeling of the flow by offshore islands and coastal mountains. These model results compare favorably with the limited wind observations now available.

WPL

Analyses of the Doppler lidar data from the Brush Creek experiment demonstrated the ability of the lidar to measure volume flux divergence accurately over 300-m intervals within a channeled nocturnal drainage flow. Doppler minisodar flux estimates confirmed lidar-measured volume flux divergences arising from tributary flows.

An experiment to measure aircraft response to orographically perturbed flows along the Colorado Front Range was completed. The aircraft response data will be compared with ground-based in situ and remote sensor data. This experiment was conducted in support of the FAA aircraft vertical separation program.

Plans FY 1986

MESOSCALE SENSOR DEVELOPMENT

The new Doppler lidar will be tested alongside the BAO meteorological tower to determine the accuracy of its wind measurements. New data systems, including computers and color displays, will be installed on the 8.6-mm and 3-cm-wavelength pulse-Doppler radars.

The three dual-channel humidity Profilers of the Colorado Plains Triangle Network will be calibrated by individual side-by-side tests with the mobile dual-channel instrument, which will serve as a reference standard.

WPL's radar wind Profilers were designed primarily for use at the synoptic and meso-alpha scales. A study will be made to determine if the 405-MHz Profiler can be modified to produce wind profiles with better temporal resolution (~5 min) and 150-m height resolution to a maximum height of 6-8 km MSL for meso-beta-scale applications.

RESEARCH ON MESO-BETA AND -GAMMA SCALES

Chinook wind profiles will be measured with the Doppler lidar in observations coordinated with the PROFS winter exercise.

The analysis of dryline fronts observed at Midland, Tex., will be completed.

Analysis of data from observations taken at Beaver, Utah, and Steamboat Springs, Colo., will continue, to obtain an improved understanding of winter orographic clouds, with emphasis on the behavior of supercooled liquid.

Observations of summer clouds, using several remote sensors such as radars, radiometers, and lidar (Project Echoes), will be taken using the BAO as the central site.

Analysis will start on data collected during Meso-Gamma '85. Various aspects of mesoscale cyclones, anticyclones, convergence lines, microbursts, and gust fronts will be studied.

Improvements in the mesoscale model developed for the Santa Barbara area will be made on the basis of wind observations obtained from the SCCCMP experiment.

A second meso-gamma-scale field experiment, designated Meso-Gamma '86, is planned for the summer of 1986. In addition to the sensors used in the 1985 experiment, it will deploy Doppler radars and Doppler lidar to explore the three-dimensional structure of convergence lines and microbursts. The primary objective of the experiment is to explore and demonstrate the potential of WPL's complement of remote sensors for studying atmospheric motions on the meso-gamma scale.

In a separate experiment following Meso-Gamma '86 the structure of drainage winds at the BAO will be observed using Doppler lidar, sodars, and the tower instrumentation.

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-radiometer 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 1985

A 405-MHz radar wind Profiler was completed and tested. It was installed at Platteville, Colo., to avoid interfering with radiosonde research by NCAR in Boulder. Data are available in the Profiler data base starting with January 1985. The radar operated with pulse widths of 1, 3, and 9 μs and two antenna pointing directions during 1985. Outage times, due to lack of sufficient echo strength, have been computed for each height, pulse length, and month.

The Colorado Profiler Network was restructured to provide wind profiles, total water vapor, and liquid water along a zenith path, and surface data at four stations on the high plains of eastern Colorado (Fleming, Flagler, Platteville, and Stapleton Airport). This network supplied real-time data for PRE-STORM (Preliminary Regional Experiment for Stormscale Operational and Research Meteorology) and for PROFS. It continued to supply data for use by operational and research meteorologists at NWS and the FAA. Improvements were made to protect the radars from lightning and to allow remote restart after long-term power outage. **WPL**

The Colorado wind Profiler network was shown to provide temporally and vertically consistent vorticity and divergence profiles. The procedure was adopted by PROFS for real-time application during the PROFS Warm Season Experiment.

A statistical evaluation of the 50-, 405-, and 915-MHz radar wind Profilers was performed to characterize the height coverage and data outage of various-wavelength wind Profilers. Height coverage for a given radar depends on the characteristics of the particular air mass that is overhead; longer

wavelength radars generally perform better at upper tropospheric and lower stratospheric altitudes than shorter wavelength radars with comparable sensitivity.

WPL wind Profiler technology was transferred to NSSL/Oklahoma University with the installation of a VHF radar near Norman, Okla. This radar was constructed using spare parts from the Colorado network.

WPL assisted Penn State University (PSU) in setting up its first VHF wind Profiler radar near College Station, Penn. The PSU radar uses the WPL-designed radar controller/data preprocessor and WPL's data processing and software.

The WPL Profiler Technology Transfer Group (PTTG) was formed to design and implement a network of wind Profilers across much of the midwestern United States. The network will include 30 wind Profilers (both 50-MHz and 405-MHz versions) and a Hub for data collection and distribution.

Documents essential for Profiler network planning and procurement were written:(1) the network's functional requirements, (2) the Hub design, and (3) definition of the work to be done by the contractor selected to build, install, and maintain the network of Profilers. The National Data Buoy Center was chosen to handle the procurement. In March, a technical symposium on the structure and uses of Profilers was held in Boulder; representatives from 24 interested companies attended. The standard data exchange format of the Office of the Federal Coordinator for Meteorological Services and Supporting Research was adopted for network data transmission; PTTG suggested some additions to that format for Profiler data and these were accepted. Working closely with the National Weather Service, PTTG began writing a plan for the assessment of the network in general and wind Profilers in particular as potential operational tools. Work began on a WPL 405-MHz Profiler prototype that will be integrated into a mini-network to begin operating in FY 1986. In August the network radar procurement plan was approved by the NOAA Administrator, and requests for proposals to build the 405-MHz wind Profilers were sent out to industry by the National Data Buoy Center.

Plans FY 1986

Research will be conducted on the theory and application of the colinear-coaxial antenna for UHF and VHF wind Profilers. This type of antenna is used at VHF and could perhaps provide a lower cost UHF antenna than the Yagi antenna array that is now used.

The performance of various-wavelength wind Profilers at upper tropospheric and lower stratospheric altitudes will be compared with meteorological conditions to determine whether the height coverage of wind Profilers can be predicted from conventional meteorological parameters.

Wind measurements from a wind Profiler with five antenna-pointing positions will be studied to determine whether radar wind measurements using two and three beam-pointing directions have systematic differences that depend on

the beam positions used. Comparisons will be made to investigate differences between hourly-averaged winds and winds measured every 5 minutes.

Research will be conducted on improving the data processing algorithms used to operate wind Profilers. The data archived for analysis will be expanded so that different processing techniques can be tested.

Case studies, based on observations made with the Colorado High Plains network of wind Profilers, will be conducted.

Numerical simulation of wind and radiometric temperature-profiling networks will be conducted to provide guidance for the design of future regional and national upper-air observing networks. This is a cooperative effort of WPL, CIRES, and NCAR.

The study of Arctic synoptic and mesoscale weather systems will continue, using NOAA-7 and -8 satellites, and NOAA P-3 aircraft observations.

WPL scientists will also participate in the Arctic Gas and Aerosol Sampling Program (AGASP II, 1986), and in the Genesis of Atlantic Lows Experiment (GALE).

The assessment plan for the 30-station network of wind Profilers will be completed.

A mini-network of already existing wind Profilers in Colorado will continue operation, sending data into the Hub in Boulder. The data will be sent from the Hub to assessment teams, to local research scientists, and to PROFS.

A link to AFOS (Automation of Field Operations and Services) will be completed, and data from the wind Profiler mini-network will go out on that NWS system.

The WPL 405-MHz wind Profiler will be completed and integrated with the mini-network.

A contract will be awarded for the commercially built 405-MHz wind Profilers.

Requirements and other significant documents for procurement of 50-MHz wind Profilers will be completed; requests for proposals will be sent out by the National Data Buoy Center. **WPL**

Site for the 30 wind Profilers will be selected. Staff from the Central Region of NWS will begin the process of leasing and preparing the sites.

A wind Profiler site communication system will be designed that uses both satellites and telephone lines.

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 1985

A network of 13 WPL-developed optical crosswind sensors was used in the ASCOT '84 field experiment in western Colorado. These sensors quantitatively assessed the contributions of tributary canyon and canyon sidewall slope flow to canyon air drainage, and have shown the diurnal pattern of mountain-valley winds.

Software was developed for real-time processing of stratospheric turbidity profiles measured using the ruby lidar. Stratospheric lidar echo intensity profiles were measured weekly, throughout the year.

The processing of lidar plume data taken during the EPA Hogback Ridge and Tracy Power Plant field experiments was essentially completed. Lidar observations of meandering plumes during the BAO Convective Dispersion Observed by Remote Sensor (CONDORS) experiment were processed, and passed to ARL for use in air pollution model testing. Analysis of data collected during the 1984 EPA Tracy Experiment in Nevada demonstrated the ability of sodars to measure the vertical extent of mixing layers, with confirmation from simultaneous lidar plume mappings.

The field phase of the DOE ASCOT Brush Creek drainage experiment was brilliantly successful, primarily because of the presence of the infrared Doppler lidar; analysis of the data continues.

Papers on ASCOT experiments conducted between 1979 and 1982 documented the use of acoustic remote sensors in complex terrain studies, and the importance of (1) internal waves to the production of intermittent katabatic flows, (2) inertial rotation of sea breeze to valley circulation, (3) sidewall heating to inversion descents in basins, and (4) interfacial mixing to transport and diffusion problems.

Plans FY 1986

Analysis of drainage flow in a narrow mountain valley will be completed, using multi-sensor data from the 1984 Brush Creek experiment.

The multi-year EPA-supported studies of transport and diffusion in complex terrain will be completed with summaries of the results of the program.

CLIMATE

Accomplishments FY 1985

WPL simulated the propagation of acoustic waves across the Florida Straits for the SubTropical Atlantic Climate Studies (STACS) program. Results showed that in modeling the performance of acoustic sensors of heat flux in that area, which covers most of the northward heat flux in the North Atlantic, continuous models of the geometry of the bottom reflections are crucial.

MARINE OBSERVATION AND PREDICTION

Accomplishments FY 1985

WPL completed the documentation of its three-dimensional, Hamilton-based, ray tracing program for the ocean. The program, called HARPO, is available for propagation modeling, which is essential in the analysis and interpretation of tomographic experiments.

WPL developed an objective method for inverting vertical-slice tomography data and extended the method to asymmetrical sound-speed profiles and transmitters and receivers off the sound-channel axis. This new result will enhance the value of existing and future tomographic data sets.

WPL demonstrated experimentally the feasibility of measuring path-averaged transverse currents in turbulent channels, using observations of both phase and amplitude scintillations as flow estimators. A patent was applied for.

Plans FY 1986

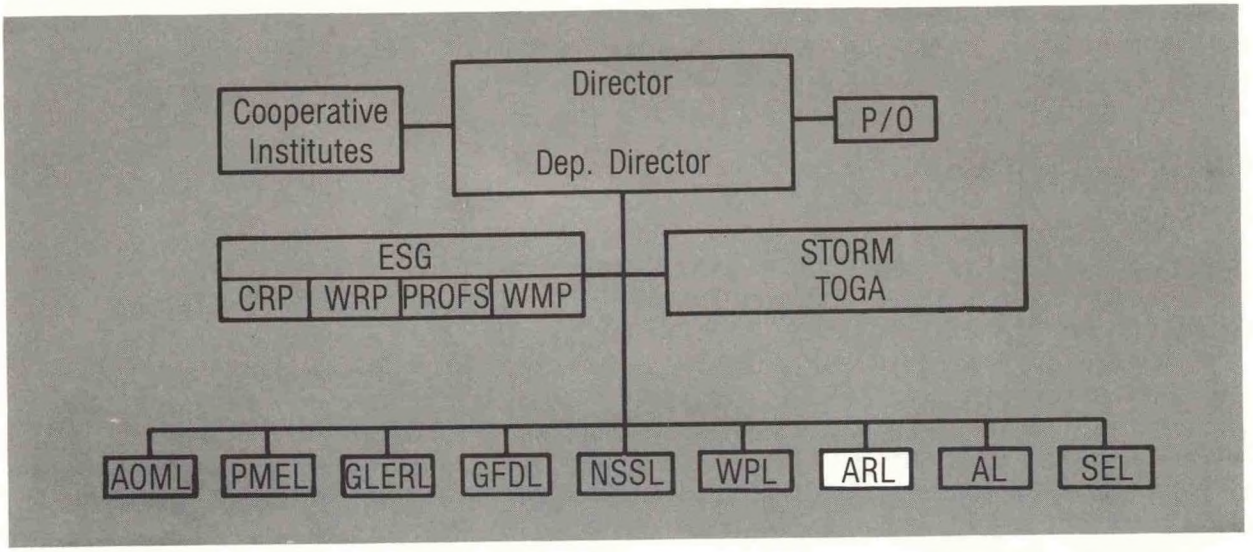
WPL will deliver to the Scripps Institution of Oceanography's tomography group a documented version of the 3-D propagation code HARPO for use with the group's objective mapping methods for tomography modeling. WPL and Scripps will jointly perform research to reconcile discrepancies between measured sound speed fields and measured pulse arrival sequences in past tomography experiments, and set up propagation models with real 3-D data fields to model planned tomography experiments. **WPL**

WPL will investigate the possibility of obtaining ocean wave-directional spectra using a bottom-mounted, acoustic, CODAR-analog device.

WPL will extend the theoretical basis of the scintillation technique to include measurement of currents and internal wave spectra in the presence of an internal wave field and on long acoustic paths in the deep ocean.

AIR RESOURCES LABORATORY
Silver Spring, Maryland

Lester Machta
Director



The Air Resources Laboratory (ARL) includes a headquarters group in Silver Spring, 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 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 ARL groups, ARL research activities are described here under two main headings, Air Quality and Climate. Many of these activities involve cooperation among the Divisions.

HEADQUARTERS GROUP

The research group in Silver Spring 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 to evaluate the environmental effects of various types of energy production. Air-sampling programs and other field experiments are con-

ducted to provide data for model verification. Major funding for this work is provided by the Department of Energy (DOE) Office of Health and Environmental Research. Research on total-ozone and ozone-profile data and on the sources, transport, and deposition of acid precipitation is also being carried out. 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 the Environmental Protection Agency (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 to verify transport and diffusion models

ATMOSPHERIC TURBULENCE AND DIFFUSION DIVISION

The Atmospheric Turbulence and Diffusion Division in Oak Ridge, Tenn., is generally concerned with air quality. ATDD conducts 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 models using the results of this research. Research is directed toward practical issues important to both NOAA and DOE's Oak Ridge Operations Office; the largest single source of support is the DOE Pollutant Characterization and Safety Research Division. Additional sources of support include NOAA, EPA, the Department of Defense (DOD), and NRC. The research program is divided into four main areas: plume transport and diffusion in the planetary boundary layer, complex topography, atmosphere-canopy interactions, and dry deposition. A fifth component makes use of wind-tunnel modeling to address questions of near-field dispersion and deposition arising in the four main areas of research. Studies are conducted in close collaboration with Oak Ridge National Laboratory and with atmospheric science units at other national laboratories, universities, and Federal agencies.

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 of air pollutants on weather and climate; and

studies to define the relationships between air quality and meteorological quantities.

The Meteorology Division also provides operational support to various EPA groups. 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; preparation of technical staff reports and documents.

SUN-CLIMATE STAFF

The Sun-Climate Staff conducts fundamental research on the cause 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 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. Research on the temporal variations of solar ultraviolet (UV) radiation, their stratospheric effects, and possible coupling to the troposphere and climate is conducted using measurements from the SBUV/2 instruments aboard NOAA satellites and other sources, and using theoretical models of the stratosphere and stratosphere-troposphere coupling.

A ground-based system to measure the secular characteristics of solar spectral changes in UV, visible, and near infrared wavelengths has been under development since 1980. The effects of atmospheric attenuation on these surface-based measurements are also being studied.

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. In 1986 this work will be done in the GMCC Division.

GEOPHYSICAL MONITORING FOR CLIMATIC CHANGE DIVISION

The mission of the GMCC Division is to measure, over a long period of time, atmospheric greenhouse gases and the long-range transport of aerosols in the atmosphere. The measurements, at NOAA's four GMCC baseline observatories and other locations, are used to determine whether these gases and aerosols are changing with time and to identify natural and anthropogenic sources and sinks as well as temporal and hemispheric gradients and global budgets. Greenhouse gases and aerosols interact with solar and terrestrial radiation and thus trends and gradients of these substances can alter the Earth's climate.

AIR QUALITY

ATMOSPHERIC TRANSPORT

Accomplishments FY 1985

Data obtained in the Cross-Appalachian Tracer Experiment (CAPTEX) have been made available on magnetic tapes for the use of air pollution modelers and other atmospheric scientists. CAPTEX was a U.S.-Canadian effort, led by ARL, to study long-range transport and dispersion. A perfluorocarbon tracer gas was released at Dayton, Ohio, and Sudbury, Ontario, and concentrations were measured in thousands of air samples collected at 80 sites in the United States and Canada, some as far as 1100 km from the source. CAPTEX data are being used by ARL and other researchers to test and improve the transport and dispersion modules of air pollution and acid deposition models.

During January-April 1985, the Air Quality Division participated in the Western Atlantic Ocean Experiment (WATOX). The objective of the project was to estimate the eastward flux of air pollutants emitted in the United States. In addition to the ARL aerosol- and gas-analyzing equipment carried aboard the King Air C-90 aircraft, instruments were provided by scientists from several universities and research institutions. Gaseous pollutants analyzed were SO_2, NO, NO_2, O_3, dimethyl sulfide (DMS) and C1-C4 hydrocarbons. Measured aerosol variables included SO_4^{-2}, NO_3^-, trace metallic elements, and size distributions. In addition, meteorological quantities and flight data were recorded.

Flights were conducted over the Atlantic Ocean approximately 100 km east of Newport News, Va., during February and March 1985, and in the vicinity of the Bermuda Islands during April 1985. The measurements indicated that the flux of SO_2 eastward across the coastline between 33° and 38°N was on the order of 1 Tg (S) yr^{-1}. This value is consistent with previous estimates based on climatological data. DMS was detected only within the planetary boundary layer; the observed concentrations were 278 ppt near the U.S. coast and 5620 ppt in the vicinity of Bermuda. The DMS concentrations decreased significantly as altitude increased, but there was no observable diurnal variation.

Atmospheric measurements of natural sulfur compounds were performed over the northern Gulf of Mexico during the late summer months of 1984. Air and aerosol samples were collected with an instrumented aircraft at elevations of 30-3500 m, during both day and night. Most air samples were representative of the clean maritime atmosphere, although some were from continental contaminated air during periods of offshore flow at the coastline. In all samples carbonyl sulfide concentrations were within the range of 400-500 pptv, but DMS concentrations showed significant variability. During "clean" atmospheric conditions the mean concentration was 2730 pptv, whereas under polluted conditions it was 73 pptv. In all cases where DMS concentrations were measured at more than one altitude during the same flight at the same location, a strong vertical gradient was detected within the boundary layer. Dimethyl sulfide

was not detected above the boundary layer. This suggests that atmospheric DMS concentrations are surface derived, have a lifetime commensurate with the boundary layer mixing time, and are very sensitive to the presence of trace atmospheric pollutants. Aerosol sulfate concentrations in the clean marine atmosphere boundary layer, together with the DMS data, in a simple model indicated that upper and lower limit estimates of the sulfur flux northward from the Gulf of Mexico are 0.25 and 0.04 Tg (S) yr^{-1}. During March and April 1985, air samples were also collected over the Atlantic Ocean approximately 100 km offshore from the Delmarva coast and in the vicinity of Bermuda. As in the Gulf samples, a strong gradient was evident within the boundary layer.

A computer model for the marine atmospheric chemistry under both clean and polluted conditions was developed and validated using WATOX data from both sampling sites. The model calculations indicate that the trace gaseous content of the air masses sampled in Bermuda can be predicted on the basis of the analysis of samples collected near the East Coast, thus supporting the assumption of direct, long-distance transport of air pollutants over the ocean.

Aerosol size distribution data from the 1983 Whiteface Mountain experiment were re-examined to evaluate the aerosol-scavenging process during cloud formation, and the release of aerosols upon cloud evaporation. Clouds observed at the summit were found to have absorbed particulate matter predominantly through nucleation scavenging. Approximately 10% of the initial aerosol population was not activated as condensation nuclei, and remained in the cloud interstitial space. Following evaporation of the cloud, the resulting particle concentration was double the pre-cloud concentration, and the aerosol mass was greater by a factor of 4 or 5. This was interpreted to mean that new aerosol mass was being created by oxidation of the sulfur and nitrogen oxides to sulfate and nitrate within the cloud drops.

The King Air research aircraft was used in a study near Oklahoma City, Okla., during June 1985. This study, the Processing of Emissions by Clouds and Precipitation (PRECP) was conducted cooperatively with Battelle Pacific Northwest Laboratories, the University of Maryland, and the University of Denver, and had as its goals (1) explicating mechanisms by which acid precursor gases and aerosols are processed by convective cloud systems, (2) determining the extent to which boundary layer aerosols were vented to the free troposphere, and (3) determining whether new aerosols were being created. Preliminary analyses suggest that nitrates and sulfates in boundary layer concentrations were being transported to altitudes as high as 10 km.

ARL

A field research project in the Grand Canyon was carried out by the Air Quality Division in cooperation with the National Park Service and the Cooperative Institute for Research in the Atmosphere. During two field periods in autumn 1984 and three in spring, an instrumented Cessna T207 research aircraft and ground observations were used to measure vertical and horizontal wind profiles in the canyon and to measure radiation from the canyon floor and walls. The purpose was to describe the dynamics of air flow in the canyon, and thus to enable Park Service personnel to burn understory vegetation without impairing visibility in this Class I area. Preliminary evaluation of the accumulated data indicates that thermal radiation is the driving force for air exchange between the Grand Canyon and the free troposphere.

During July 1985, cloud and aerosol composition-versus-altitude measurements were conducted with the King Air in the vicinity of Whiteface Mountain, N.Y. Cloud water samples collected at four levels in a deep stratus deck indicated a greater loading of dissolved substances per unit volume of atmosphere in the lower part of the cloud layer, but the pH and loading of dissolved substances per unit mass of cloud water were fairly uniform through the cloud.

Plans FY 1986

A CAPTEX model evaluation workshop will be held in November 1985. It will provide an opportunity for researchers 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 importance of using more frequent meteorological data in long-range transport calculations will be evaluated by comparing output of an NWS boundary layer forecast model with 6-hourly rawinsonde observations taken during CAPTEX.

The second, third, and fourth phases of the WATOX project are scheduled for FY 1986. The second phase will include a series of King Air air-sampling flights 100 km offshore in the vicinity of Boston, Mass., during January-March 1986. Research flights in January will be performed concurrently with a NOAA P-3 aircraft. The King Air will be used for vertical profiles of gas and aerosol parameters, and the P-3 will conduct measurements over long distances at constant altitude. The detailed vertical and horizontal profiles obtained will provide a high quality data base for flux estimations. During February and March the King Air will measure horizontal and vertical profiles during periods of offshore airflow. The fourth phase, scheduled for May 1986, will include a similar series of horizontal and vertical profiles measured in the vicinity of Bermuda during episodes of airflow from all four geographical quadrants. In addition to the WATOX objectives, measurements of naturally derived sulfur-containing substances will continue, to evaluate further their contribution to precipitation acidification.

Plans are being formulated for a possible continuation of the PRECP effort in northeast Colorado during summer 1986, in cooperation with Battelle Pacific Northwest Laboratories and NASA.

The Grand Canyon project will be terminated in March 1986.

Two alternatives are being considered for a field study to estimate the rate of oxidation of sulfur dioxide to sulfate in clouds. These are the measurement of sulfur dioxide, sulfurous acid, and sulfate in clouds at various distances downwind (1) from a point SO_2 source such as a coal-fired powerplant where the smoke plume discharges into a stratus cloud, or (2) from the release of sulfur dioxide into a cloud from a helicopter, along with SF_6 as a plume tracer. The analyses would be on cloud water and air within the cloud as sampled with the King Air.

ATMOSPHERIC TRACERS

Accomplishments FY 1985

The Field Research Division participated in a flight test program of the helicopter vortex wake/downwash flowfield; it supplied the meteorological profile instrumentation and turbulence instrumentation in support of the tests. The first phase of the tests was run during July 1985, for the T-34B/Vortex wake probing. The measurement techniques were similar to those used in the Federal Aviation Administration (FAA) superjet wake vortices study. FAA sponsored this research as part of its S-76 helicopter test program.

A preliminary study was conducted at Whiteface Mountain in upper New York State to measure the oxidation rate of SO_2 in clouds by introducing SO_2 concentrations into clouds. SF_6 was also introduced to identify the appropriate air mass. This research was carried out in cooperation with the Atmospheric Science Research Center of the State University of New York at Albany.

Extensive measurements of low-altitude winds, temperatures, and balloon trajectories were performed during the DOE tests for transient fuel damage at the Power Burst Facility and Loss-of-Fluid Test nuclear reactors. Post-test model calculations of trajectories, diffusion, and exposure from postulated airborne radionuclides were prepared and critiqued with DOE scientists.

Nuclear powerplants are required to have Atmospheric Transport and Diffusion (ATD) models capable of making dose assessments in the event of an emergency. Under an NRC contract, the Field Research Division developed methods of evaluating ATD models. Data cases have been assembled that test a model's performance under a variety of situations. Reference models were selected to compare model results from these test data sets. Evaluations were performed on ATD models used at two operating nuclear powerplants.

EPA-sponsored developmental research continued on an advanced operational system for tracking multiple Lagrangian markers (tetroons) on a regional scale. An experimental prototype has been developed of a miniaturized tetroon transmitting and receiving system employing Loran-C and Omega systems and capable of providing continuous real-time data on longitude/latitude, ambient pressure (altitude), and temperature. Field testing was accomplished during FY 1985 to ranges of 1000 miles.

Gaseous tracer and sampling support was provided during the South Central Coast Cooperative Aerometric Monitoring Program field study covering the area from the Los Angeles Basin to Santa Barbara. **ARL**

Thermal, remotely sensed data were analyzed to show how urban land areas within the Salt Lake City area interact with the lower atmosphere to determine the urban climate of the area. Field Research Division meteorological instruments provided ground level meteorological conditions and solar radiation data, and analyzed the data. NASA sponsored this research project.

The Field Research Division contributed to and supported a test by the University of Michigan, Department of Environmental and Industrial Health Cyclotron/Positron Emission Tomography Facility, by measuring dispersion of emissions from a cyclotron vault and laboratory hot cell and hoods by releasing tracers and having air samplers positioned around the facility. Analysis will be done in conjunction with the University of Michigan.

Gas chromatography laboratory hardware and software were modified to permit processing of more than 2000 tracer samples per day, along with calibrations and quality assurance checks. Initial tracer analyses were performed and supplied to EPA within 48 h of data collection. Feedback of results allowed in-the-field review and modifications of field measurement programs. This project was sponsored by EPA.

Plans FY 1986

A report to NRC will describe the methods and data cases used to evaluate atmospheric transport and diffusion models. Reference models will be compared. Nuclear powerplant atmospheric transport and diffusion models will be evaluated upon request by the NRC.

The South Central Coast Cooperative Aerometric Monitoring Program will continue with a minimum of five tests.

A prototype gas chromatograph will be developed and tested as part of the automated gas chromatography laboratory. This prototype will analyze the next-generation types of gaseous tracers suitable for regional and larger scale studies.

ARL will carry out, in cooperation with the U.S. Army, a project on the dispersion of military smoke over rolling terrain and flat terrain. It will consist of meteorological instruments and sample and tracer releases.

Continued long-range tracking and a new digital design transponder will be tested during FY 1986.

The FAA helicopter study will continue through FY 1986.

Prototype samplers will be adapted from existing units for extended-period sampling of next-generation gaseous tracers. Alternate designs will be assessed.

PLUME DISPERSION

Accomplishments FY 1985

ARL's year-long Metropolitan Tracer Experiment (METREX) in the Washington, D.C., area was completed in January 1985. The experiment was 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 were released at two sites every 36 hours.

Average monthly tracer concentrations were measured at about 90 sites, and continuous 8-h samples were collected at three sites.

A model to simulate the airflow over an urban heat island was developed. Various simulations showed that the low-level heating of the rural air as it passed over the city enhanced the vertical mixing. Preliminary tests of other pollutant dispersion models over an urban area indicate that simple models are not satisfactory, except for long-term average concentrations.

An improved model of the dispersion and deposition of trace gas and primary and secondary aerosols emitted in an urban area was completed under EPA spon-sorship. The model was tested using field data obtained in an intensive experimental program conducted by EPA in Philadelphia.

Work on the theoretical aspects of model evaluation has led to a number of related activities. In particular, an assessment is being made of errors associated with the assumption of straight-line Gaussian dispersion at distances up to 500 miles, under sponsorship of NRC.

An evaluation of near-field Gaussian plume dispersion models developed for assessing the effects of accidental releases of reactive heavy gases was completed for DOE. This work is of special interest to the operation of uranium-processing facilities, which use large quantities of uranium hexafluoride.

The behavior of the nocturnal planetary boundary layer has become the major focus of ATDD research on plume dispersion. An acoustic sounder was set up and is now in routine operation at the Stone Mountain, Atlanta, observatory of the Georgia Institute of Technology. The records obtained will be used with air quality data to investigate the nature of nocturnal turbulence intermittency.

Plans FY 1986

Investigations will continue, to develop relatively simple models to simulate the effects of complex urban wind fields on pollutant dispersion.

The collaboration with Georgia Institute of Technology will be extended to apply the automatic video digitization techniques developed earlier at ATDD. The methodology will be used to reduce and interpret observations of arctic haze to be obtained during aircraft missions conducted in collaboration with GMCC. **ARL**

The benefits of coupling direct observations of atmospheric turbulence with air quality data to investigate nocturnal intermittency will be further explored. Turbulence data obtained in the operation of monitoring stations under the Dry Deposition component of the ATDD research program will be used.

DISPERSION IN COMPLEX TERRAIN

Accomplishments FY 1985

ARL participated in the DOE Atmospheric Studies in Complex Terrain (ASCOT) dispersion experiments in September-October 1984 in Brush Creek Valley, Colo. Three perfluorocarbon tracers were released during the night to delineate nocturnal drainage flows and early-morning flow reversal and venting of pollutants out of the valley. The data will be used in developing dispersion models for these flows, which have a high potential for producing unacceptable air pollution levels. A three-dimensional katabatic flow model has been developed and tested against ASCOT data.

Reduction of field data obtained in the September-October 1984 ASCOT field experiment was mostly completed. ATDD provided considerable organizational input, a role that is of increasing importance as management of the ASCOT program is gradually moved from Lawrence Livermore National Laboratory (LLNL) to Los Alamos National Laboratory (LANL), with ATDD managing field operations of the program. In addition, considerable attention was given to quality control and quality assurance of the data generated, with the assistance of the EPA Meteorology and Assessment Division and personnel from LLNL and LANL.

The Complex Terrain Model Development Program is a multiyear effort to examine and model the effect of powerplant plumes in mountainous terrain. The prime contractor, the Wave Propagation Laboratory (WPL) and ARL's Field Research Division have participated in the three field programs over several years, at Cinder Cone Butte in Idaho, Hogback Ridge in New Mexico, and the Tracy Power Plant near Reno, Nev. In the Hogback Ridge and Tracy Power Plant field studies ARL disseminated a visible oil-fog and two invisible tracer gases and analyzed up to 1100 dual tracer-samples for each experiment-day. ARL also measured wind and/or temperature, using radars, tethersondes, and small towers.

The Meteorology Division computed and placed on magnetic tape the meteorological and tracer gas data base from the Hogback Ridge study, and documented descriptions of the data tape files. The data base is available on tape or by interactive computer access.

The latest ERT reports indicate that the basic modeling concept, that of a dividing streamline height, developed initially for an isolated hill, is also essentially valid for flow over long ridges and mixed complex-terrain features. The current version of the Complex Terrain Diffusion Model (CTDM) divides plumes into elements that go around and/or over terrain obstacles. Tests of the model against measured tracer concentrations demonstrate improved performance over contemporary models and the need for on-site meteorological measurements. The current version of CTDM has been adapted to run on a microcomputer, making a useful and convenient tool for further model development and evaluation.

The Green River Ambient Model Development Program was completed with the delivery of two initial air quality models. One model is designed for application when pollutants are carried in locally developed circulations within a

deep valley flow decoupled from the flow above the valley. The other model is designed for application to mesoscale transport of air pollutants over the complex-terrain region of the Green River oil shale formation of Colorado, Utah, and Wyoming. Both models are initial working versions for very complicated situations, and there is a continued need for model evaluation and improvement.

Eight complex-terrain dispersion models were reviewed. An outside contractor calculated and tabulated a uniform set of performance statistics. Three Meteorology Division reviewers then evaluated each model, using the standard performance data and technical information from the User's Guides. Under a cooperative agreement, the American Meteorological Society reported the results of the Meteorology Division scientific reviews.

Plans FY 1986

Responsibility for planning and organizing large, multilaboratory field experiments for the ASCOT program now resides with ATDD. Plans for the next major field study will be drafted during FY 1986, and exploratory investigations will begin.

The ASCOT program also encourages smaller single-laboratory field studies designed to test specific features of models. Plans will be prepared to conduct such a study at a coastal location of practical importance, suitable for testing the three-dimensional models already developed under this program. Wind tunnel investigations of enhanced dispersion due to the presence of large buildings will be completed. The results will be incorporated in the heavy-gas puff dispersion and transport model being developed under ASCOT's Plume Dispersion component.

Work will continue on the development and evaluation of the Complex Terrain Diffusion Model, using the field data collected at Cinder Cone Butte, Hogback Ridge, and the Tracy Power Plant, and data collected during physical modeling experiments in the Fluid Modeling Facility. A study will be initiated on the evaluation and improvement of dispersion models for use on the Alaskan North Slope.

AIR QUALITY DISPERSION MODELING ARL

Accomplishments FY 1985

Technical assistance was provided to the People's Republic of Chin (PRC) through the sponsorship of the United Nations World Health Organization. This program consisted of reviewing PRC environmental monitoring and research programs, and providing lectures on measurement principles and practices, state-of-the-art sampling technology, and current dispersion concepts and models, with emphasis on dispersion in complex terrain and on regional-scale problems associated with coal-fired powerplants. The primary host was the Atmospheric

and Environmental Research and Monitoring Center, the major research arm of the PRC's Ministry of Water Resources and Electric Power.

The Regional Oxidant Model (ROM) was applied to a series of hypothetical problems whose exact solutions are known. Model predictions and known solutions were compared, to assess the accuracies of numerical algorithms. For ozone, the solutions of the model's numerical algorithms are within 10% of the corresponding solutions of differential equations that describe the chemical and physical processes that the model simulates.

An improved first-generation ROM was applied to data for a 2-day period, to demonstrate the model's usefulness in evaluating the effect of urban control strategies on rural ozone concentrations. The base case results, which used the 1979 Northeast Corridor Regional Modeling Program emission data, were compared with control strategy results in which the 1979 emission rates were modified on a country basis. The results were used to make a preliminary assessment of the impact on ozone concentration of projected 1987 hydrocarbon and NO_x emission reductions (about 32% and 8%, respectively) over the northeastern United States. It was found that ozone concentrations in the control case were everywhere lower than those in the base case, but the percentages were not uniform in space. In urban and suburban areas the maximum hourly average was about 35% lower; in rural locations the predicted peak was only about 20% lower. Emission control reduced peak concentrations by considerably larger percentage than it reduced the median or mean values.

A major portion of the oxidant modeling of the New York Metropolitan Area was completed, including (1) transfer of air quality and meteorological data bases to the New York State Department of Environmental Conservation; (2) selection of five candidate modeling days; (3) development of ambient and emission inputs; and (4) application of the Airshed Photochemical Model (APM) for the first base-case simulation. An interim report described the procedures employed for deriving the air quality and meteorological inputs necessary to apply APM to the tri-state New York Metropolitan Area. The results of this project will be used to determine the need for further emission controls, to attain the ozone National Ambient Air Quality Standard in this area.

Two feasibility modeling studies were conducted to provide preliminary information on regional-scale ozone predictions in support of the EPA Ozone Regulatory Impact Analysis. The two studies included an example application of the Regional Transport Model and initial simulations with the first-generation ROM. Specific applications of the second-generation versions of both models are planned, to provide estimates of the change in regional ozone concentrations for alternative volatile organic chemicals and NO_x emission control scenarios for various regions of the United States.

A cooperative agreement with the Microelectronics Center of North Carolina was funded to explore ways of implementing large model codes such as the ROM and the Regional Acid Deposition Model (RADM) in custom computer chips. The research is directed toward operation of large, complex, dispersion models on mini- and microcomputers, thereby reducing the running time of the codes substantially.

Operations manuals were produced for the Airshed Model, a numerical three-dimensional grid model for photochemical air quality applicable to urban

scales. The manuals include a User's Guide and a Systems Manual. The theoretical framework of the model was documented.

The final version of the Regional Lagrangian Model of Air Pollution (RELMAP), formerly ENAMAP, was applied on a monthly basis for 1980. Monthly, seasonal, and annual concentrations and depositions were submitted as part of the International Sulfur Deposition Model Evaluation.

A preliminary particle-size-discriminant emissions inventory was prepared for initial testing of RELMAP for particulate modeling. Extensive data processing and quality control were performed on the National Acid Precipitation Assessment Program (NAPAP) version-4 emissions inventory for application in the ROM and the RADM.

The Meteorological Processor for Dispersion Analysis and associated user's guide were completed. The Branching Trajectory Model was enhanced to produce overlays of geographical features on trajectory maps; it was applied for April through October 1982 and 1983 for several sites, to assist Maine's Air Bureau in a critical ozone analysis. A parameterization of mixing-depth statistics and analysis of the structure of the turbulent boundary layer was completed for the Tennessee plume data.

Several studies were completed evaluating a Gaussian air quality model known as RAM and the Climatological Dispersion Model (CDM) with the Regional Air Pollution Study data base. The RAM model was found to have a bias toward underpredicting concentrations during the day and overestimating values at night. Although area-source emissions constituted only 3.5% of the total SO_2 emission, the CDM estimates of area-source contributions to the annual average range from 14% to 67%.

To assist EPA's Office of Air Quality Planning and Standards in developing revised stack height regulations, a short research note was prepared summarizing calculations of expected maximum ground-level pollutant concentrations, together with frequencies with which higher concentrations might occur. Calculation were made for conditions of normal dispersion, building wake effects, inversion breakup fumigations, limited mixing layers, and plume looping events.

The 1980 guideline for determining Good Engineering Stack Height was revised. The revision incorporates (1) recent regulatory requirements; (2) results from recent studies and tests on the applicability of the Good Engineering formula; (3) treatment of portions of terrain that may induce downwash in a wind tunnel simulation; (4) application of air quality modeling when there is high terrain, multiple source impacts, or venting from multiple flues.

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Models MPTER, CDM, CRSTER, ISC, and RAM, developed and recommended by EPA, are being revised to reflect improvements in modeling techniques and to improve technical consistency among the models. The changes include (1) consistent formulations of plume rise; (2) treatment of terrain (where appropriate); (3) buoyancy-induced dispersion; (4) revised wind profile exponents; and (5) addi-tion to CRSTER and ISC of the urban dispersion coefficients now in the RAM model.

Three published methods to calculate the standard deviation of wind direction, sigma-a, were tested, both on tower data and on synthetic data containing extremes. The method of Yamartino produces results with maximum errors of 1.2° or 1.5%.

The experimental and theoretical work on vehicle wakes was completed. A user's manual for the model ROADWAY is being prepared.

A position paper concerning models of diffusion in atmospheric boundary layers was completed.

Plans FY 1986

Direct meteorological research support to EPA will continue with development and evaluation of air quality dispersion models for inert and reactive pollutants and the associated meteorological models on all temporal and spatial scales. An important area of continued concern will be the problems associated with model uncertainty and model evaluation procedures. Emphasis in FY 1986 will be on development of a regional-scale particulate-matter dispersion model; development and evaluation of a second-generation ROM; examination of the effect of mesoscale convective precipitation systems on ozone transport and haze dispersal; and development of custom computer chips for use in running large, complex models on mini- and microcomputers.

FLUID MODELING

Accomplishments FY 1985

The Fluid Modeling Facility continued studies using a water channel/towing tank and one large and several small wind tunnels, in support of EPA research. Studies involved flow in complex terrain, flow through wind screens, building wake effects, and stack height.

A wind tunnel demonstration study on good-engineering-practice stack height was conducted in response to a request from the EPA Office of Air Quality Planning and Standards in conjunction with a Federal Appeals Court Mandate requiring EPA to revise the Stack Height Regulations. A 326-m stack was demonstrated as necessary to avoid wakes, eddies, and downwash caused by the terrain upwind of the Clinch River Power Plant in southwestern Virginia.

Under a cooperative agreement with the North Carolina State University, a wind tunnel study to examine the effectiveness of screen in reducing wind speeds near storage piles was completed. 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 for each of two basic shapes of storage piles--a cone shape and a flat-topped pile of roughly elliptical cross section. Application of simple particle-uptake models suggested that screens could be

highly effective in reducing fugitive dust emissions; 90% reductions were fairly typical.

An initial feasibility study of methodologies for analyzing videotaped images of smoke-visualized plumes was successfully completed. Through video image analysis, short-time-scale building wake effects on plume dispersion can be studied. The information obtained, along with conventional point measurements of tracer concentrations and fluid velocities, is being used to evaluate the overall effects of buildings on plume dispersion.

A cooperative project was initiated with the Los Alamos National Laboratory to examine the conditions under which flushing of a valley between two ridges will occur, i.e., to answer the question of when a stable crosswind will sweep the valley clean and when the flow will separate from the top lee side of the first ridge, reattach at the top windward side of the second ridge, and thus form a nearly stagnant region in the valley beneath. The first phase of a series of towing-tank studies examined the effect of Froude number (characterizing the stability of the cross wind) and the separation distance between a pair of ridges, where the maximum slope of the valley sidewalls was quite steep (40°). The results strongly suggest the need for further studies with valley sidewalls of smaller slope.

A large set of streamline trajectories over an axisymmetric hill was measured in the stratified towing tank. Three-dimensional coordinates of the streamlines were determined through stereographic analysis of photographs of streak lines of dye released at a matrix of source positions (heights and lateral offsets from the hill/flow centerline), and at stabilities ranging from strongly stable to neutral.

Previous towing-tank and wind-tunnel measurements of concentration distributions on the surface of a hill when a plume impinges from an upwind source were published. The major results were that (1) when the source is below the dividing-streamline height (HD), the plumes impact on the windward hill surface and yield maximum surface concentrations nearly the same as would be observed at the plume centerline in the absence of the hill; (2) when the source is above HD, the plume surmounts the hill top, but if it is only slightly above HD, the maximum surface concentrations can again essentially equal those at plume centerline in the absence of the hill; (3) the location and value of the maximum surface concentration is extremely sensitive to slight displacements of the source from the stagnation streamline when the source is below HD.

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Terrain amplification factors were measured for a large matrix of source positions (locations and heights) both upstream and downstream of each of two idealized hills: an axisymmetric hill, and a two-dimensional ridge. The results showed that "windows" of 40% excess concentration extend to 1.8 hill heights (h) in the vertical, 14h upstream, and 10h downstream for the three-dimensional hill, and 2.2h in the vertical, 8h upstream, and 15h downstream for the two-dimensional ridge. Maximum terrain amplification factors were found o the downstream sides of the hills; values were 6.8 and 5.6 for the 2-D and 3-D hills, respectively.

Under an interagency agreement with the Oak Ridge National Laboratory, wind tunnel measurements were conducted to examine the flow fields and concen-

tration patterns resulting from sources upwind of a series of ramps (followed by plateau) of various slopes and crosswind aspect ratios. Data reports and preliminary analyses were completed.

The flow fields around moderately steep hills of triangular cross section and varying crosswind aspect ratio were examined using models immersed in a simulated atmospheric boundary layer in the wind tunnel. Concentration patterns resulting from sources placed upwind of each of these hills showed strong plume deformations, and terrain amplification factors generally increased with decreasing aspect ratio.

A cooperative project with the Los Alamos National Laboratory was concluded with the preparation of a report on Monte Carlo simulation of two-particle relative diffusion using Eulerian statistics. Detailed measurements of low characteristics downstream of a turbulence-generating grid were used as a basis for calculating particle diffusion. Results of the calculations were compared with total diffusion measured by a hydrocarbon tracer technique and with relative diffusion determined from analysis of near-instantaneous photographs of smoke plumes. Comparisons between a one-particle diffusion model and the present two-particle model showed that the two-particle model provided a more accurate description of plume meandering and relative diffusion.

Plans FY 1986

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 and around buildings and other obstacles.

ACID DEPOSITION

Accomplishments FY 1985

The acid rain problem has continued to be a very important area of research and a major concern of the U.S. public. Evidence of forest and lake damage in both North America and Europe is still being evaluated, and research indicates that the environmental attacks are not limited to acid precipitation but include dry deposition of aerosols and gases, particularly ozone. ARL has a leadership role in the Federal acid rain program, to study all aspects of problems involving the atmosphere. International cooperation, especially with Canadian and European scientists, has been maintained at a high level.

Research in precipitation chemistry made notable progress:

- Aerosol and gas measurements were made along the mid-Atlantic coast and at Bermuda during a major WATOX field experiment. (See Atmospheric Transport for details.)

- The Global Trends Network showed that seasalt corrections in precipitation chemistry involve several complex assumptions, and that

appropriate reference species (e.g., Mg^{+2}, Na^{+}) must be selected using objective criteria.

- Two meetings with representatives from the People's Republic of China resulted in plans for the establishment of a precipitation chemistry station in western China during FY 1986.

- A special study was carried out to evaluate inflow of dimethyl sulfone, a naturally occurring sulfur compound from the Gulf of Mexico. (See Atmospheric Transport for details.)

- Special studies at the atmospheric research sites included con tinued application of isotropic trajectory modeling to precipitation data bases, and the evaluation of evaporation losses from the automatic precipitation collectors used in the NOAA/EPA/World Meteorological Organization (WMO) precipitation chemistry network between 1972 and 1980.

- The NOAA precipitation data for both remote and continental U.S. locations, collected between 1972 and 1982, were published.

- Routine operation of 15 National Trends Network precipitation chemistry stations continued. A full year of data from two pairs of colocated stations in Texas and Maine has now been collected.

Plans FY 1986

Ongoing activities will be supplemented by the following new activities:

- A major WATOX field experiment during January 1985 will obtain measurements with the King Air and the NOAA P-3 along the central Atlantic and New England coasts.

- In cooperation with EPA, a remote station in western China will begin operating as part of the Global Precipitation Chemistry Program.

DRY DEPOSITION

ARL

Accomplishments FY 1985

Several new stations were added to the dry deposition pilot monitoring network, at Champaign/Urbana, Ill. (in collaboration with the Illinois State Water Survey), Panola State Park, Ga. (in support of watershed studies by the U. S. Geological Survey), and Borden, Ontario (in cooperation with the Canadian Atmospheric Environment Service). Data obtained in the first year's operation of the original five sites were reduced. These preliminary data indicate that at most locations dry deposition rates of sulfur exceed wet deposition rates.

The computer analysis routine by which deposition velocities are derived from measurements of selected meteorological and surface properties has been exercised routinely as a part of the pilot dry deposition monitoring program. This computer model is viewed as a first-generation development, to be upgraded as more results become available from the ongoing field programs conducted under the Core research program.

The series of comparison studies involving the laboratories of the Core research program continued, recent attention being directed to the problem of deposition to snow and to mature corn. Periodic site-specific investigations of dry deposition fluxes are now routine at each of the Core sites (Oak Ridge, Tenn.; Argonne, Ill.; and State College, Pa.), so as to provide "benchmarks" for evaluating the estimates of dry deposition obtained using simpler techniques.

In March 1985, an intensive field study of sulfur eddy fluxes was conducted over a grass field and subsequently over a spruce forest in West Germany. For the first time two nearly identical sets of sulfur-sensing apparatus were operated side-by-side for an extensive period. The data obtained show good agreement between the two systems. A procedure for directly quantifying the error associated with individual half-hour averages of eddy fluxes was tested and is now part of the routine eddy flux measurement program a applied by ATDD. The opportunity was also taken to evaluate the effect of artifact signals on determinations of sulfur eddy fluxes. Several reports have described the results of this field study, conducted in conjunction with studies in the state of Baden-Württemberg, in southwestern Germany.

Plans FY 1986

The model now in place for deriving deposition velocities from measured meteorological and surface information will be further tested and improved. The series of Core station comparison experiments will continue with a major multilaboratory study at the forest meteorology research facility in Oak Ridge. Two dry-deposition pilot stations will be added. The Core network will also be expanded slowly with support from EPA.

ACID RAIN MODELING

Accomplishments FY 1985

A major effort continues, in support of the EPA research program, to develop and evaluate regional and mesoscale acid deposition models. As part of this program, under an agreement with the National Science Foundation, a comprehensive regional model is being developed at the National Center for Atmospheric Research (NCAR). Development of component modules, under agreements with several DOE National Laboratories, continued with both field studies and numerical modeling activities.

A preliminary version of the Regional Acid Deposition Model (RADM) being developed at NCAR was completed and received favorable peer review. The RADM is being subjected to extensive sensitivity analyses and preliminary evaluation.

In cooperation with the U.S./Canadian Technical Committee for Eulerian Acid Deposition Modeling, a conceptual plan for performance evaluation of regional acid deposition models was developed and favorably reviewed. The plan proposes a major field program consisting of a 50-station long-term surface wet deposition and ambient air quality network and four 1-month intensive field programs starting in the spring of 1987.

The acid precipitation mesoscale project has shown that urban-industrial areas make significant contributions to the acidity of downwind precipitation. Preliminary results from the May 1985 field study confirm that there can be large differences in this contribution on an event basis, especially for nitrates. The sulfate contribution appears to be due to aqueous conversion of SO_2.

A standard set of 1980 model input and output data was created and used to compare and evaluate the performance of 13 regional long-term acid deposition models for seasonal and annual wet deposition amounts across eastern North America. Preliminary results suggest that these models, all of which use simple linear parameterizations of acidic processes, reasonably replicate wet deposition patterns; however, maximum deposition appears to be displaced several hundred kilometers eastward

A statistical study demonstrated similar trends in the monthly SO_2 emissions from the electric utility industry and monthly average ambient SO_2 concentrations in the northeastern United States from 1975 through 1982. The study also investigated the correlation between seasonally adjusted emissions and ambient concentrations at the local, state, and regional levels.

Statistical techniques, including Kriging, were used to analyze spatial patterns of wet deposition data from Canada and the United States for 1980-1983. Maps of concentration and deposition of SO_4, NO_3, and H ions were prepared and examined for significant temporal trends.

Field experiments for VENTEX (Venting Experiment) were conducted to study the transport and transformation of acidic compounds by nonprecipitating cumulus convective processes, and to provide the observational bases for the developmentof parameterized models for inclusion as process computer modules for the RADM. Vertical exchange between the mixed layer and the overlying free troposphere was found to be enhanced by the presence of cumulus convective clouds, especially those having significant vertical development. This conclusion was reached through the analysis of inert tracer data, which showed significant concentrations of the tracer at the surface and in the mixed layer soon after release at the altitude of the prevailing cumulus cloud tops. A firstgeneration cumulus transport module was developed for inclusion in the RADM.

The release of fluorescent dye particles and subsequent tracking by an airborne two-wavelength backscatter lidar system was demonstrated to be feasible and useful as a marker for air parcels in transport and transformation

studies on local and regional scales. This method was first tested by SRI in 1983. This year it was successfully used in VENTEX summer field studies of vertical transport processes by cumulus convective clouds, as well as regional-scale transport studies.

Plans FY 1986

Work on the development of the RADM and its module will continue. Detailed design development and other preparation will continue for a major field program in 1987 to obtain a data base for evaluating regional models. With the assistance of NASA and Brookhaven National Laboratory, development and evaluation of the mesoscale acid deposition and assessment model will continue. The International Sulfur Deposition Model Evaluation (ISDME) will be completed.

ATMOSPHERE-CANOPY INTERACTION (FOREST METEOROLOGY)

Accomplishments FY 1985

Climatological monitoring and data reduction at the forest meteorology research site continued, with some modification due to the need for additional data for other program components.

The seasonal variation in the statistics of radiation penetration into the canopy was analyzed and used to evaluate several canopy phytoactinometric models. Under partial sponsorship of DOD, intensive studies of the thermal radiation distribution above and in the forest canopy were completed.

Irregular radiative heating of the surface results from the different exposures imposed by terrain complexity (slopes with a southern exposure receive more radiation then do those facing north, for example). The consequences were detected as apparent imbalances in the surface heat energy budget as deduced from eddy fluxes measured at the forest meteorology research site.

A multilevel canopy stomatal conductance model was developed as an initial step toward generating an advanced atmosphere-canopy exchange model. Such a model would be suitable for describing details of the source/sink distributions within the canopy, and for guidance in studies of surface parameterization. In this regard, it is becoming increasingly clear that a balanced parameterization scheme is required, coupling aspects of biology with surface physics and chemistry as well as involving atmospheric turbulence.

Field data on the eddy fluxes of heat, momentum, and mass obtained in intensive studies conducted periodically at the forest meteorology research site were used in the development of the sub-canopy model. Particular success was attained in the case of carbon dioxide (CO_2). A collaborative experiment with the University of Nebraska successfully demonstrated that CO_2 fluxes can be measured at the forest floor as well as above it. The CO_2 exchange rates

between the canopy and the atmosphere were much as expected from other measurement programs. These data are being used to evaluate the overall surface-interaction model which, when proved, will provide the desired capability to extend such single-surface eddy flux observations to other situations.

Plans FY 1986

The multilayer subcanopy photosynthetic model already in existence will be coupled with a detailed subcanopy turbulence model, in order to provide a first-generation simulation of pollutant movement through canopies and into plant tissue.

Further experimental investigations of turbulent statistics and flux parameterizations above and within the forest canopy will be conducted. The penetration of gusts into the canopy and the resulting subcanopy flow fields will be addressed in field experiments.

Measurement programs will continue; the data obtained are also of interest to workers at Oak Ridge National Laboratory and to those involved in the dry deposition research programs at the Core site in Oak Ridge.

OZONE

Accomplishments FY 1985

With funding from the National Environmental Satellite, Data, and Information Service (NESDIS), the GMCC Division began ozonesonde, Umkehr, and total-ozone monitoring programs late in 1984 to provide NESDIS with ground- and balloon-based ozone data for use in validating SBUV-2 ozone data obtained aboard the NOAA-F satellite. The work is expected to continue during the next several years as other NOAA satellites carrying SBUV ozone instrumentation are launched.

NESDIS has identified 16 select Dobson spectrophotometer stations whose total-ozone data will be used for the validations. GMCC has agreed to help maintain calibration of the Dobson instruments at these sites to ensure that total-ozone observations are of high quality. The stations are in Arosa, Switzerland; Boulder, Colo.; Edmonton, Canada; Goosebay, Canada; Huancayo, Peru; Haute Provence, France; Invercargill (or Lauder), New Zealand; Mauna Loa, Hawaii; Melbourne, Australia; New Delhi, India; Perth, Australia; Poker Flat, Alaska; Pretoria, South Africa; Sapporo, Japan; Tateno, Japan; and Varanasi, India. In December 1984, GMCC conducted an International Intercomparison of Dobson ozone spectrophotometers at Melbourne under the auspices of the WMO, at which time the Melbourne, Invercargill, New Delhi, and Tateno Dobson instruments were calibrated relative to World Standard Dobson instrument No. 83 maintained by GMCC. Of the remaining select total-ozone stations, only Arosa, Sapporo, and Varanasi require Dobson instrument calibrations in 1986. **ARL**

Apart from the stations named above, total-ozone observations with Dobson spectrophotometers continued during FY 1985 at Bismarck, N. Dak.; Caribou, Maine; American Samoa; Tallahassee, Fla.; Nashville, Tenn.; South Pole; Wallops Island, Va.; and Fresno, Calif.

The GMCC Dobson spectrophotometer Central Laboratory in Boulder continued to upgrade and calibrate Dobson instruments in the global total-ozone station networks. In addition to the instruments calibrated at Melbourne, two Australian instruments and one United Kingdom instrument were calibrated.

Weekly observations of ozone vertical distribution to about 40 km altitude with electrochemical concentration cell (ECC) ozonesondes commenced at Boulder and Hilo, Hawaii, in early 1984. A third station, at Edmonton, was added to the network in August 1985 in a cooperative effort between GMCC and the Atmospheric Environment Service of Canada.

Umkehr observations with automated Dobson ozone spectrophotometers were continued during FY 1984 at Boulder, Haute Provence Observatory, Poker Flat, Mauna Loa Observatory, and Perth. A sixth automated Dobson instrument became operational at Huancayo in September 1985.

Total-ozone and ozone-profile data for the world were updated through the autumn of 1984. Ground-based and satellite measurements show that total ozone returned nearly to average following anomalously low values in early 1983. In the north temperate zone where most of the ozone stations are located, total ozone was 1% above average in 1984 compared with 4% below average in 1983. In the 16-24 km layer of the low stratosphere where the ozone reduction was most pronounced, the ozone amount was 6% below average in 1984 compared with 13% below average in 1983. In the 32-48 km layer of the high stratosphere, Umkehr data indicate an ozone amount 8% below average in 1983 and 3% below average in 1984, but the 1984 data may still be biased by the aerosols from the El Chichón volcanic eruption in the spring of 1982. Ozonesonde data suggest only a 1% increase in tropospheric ozone between 1983 and 1984. It is still uncertain whether the anomalously low ozone values in early 1983 were due to atmospheric circulation changes induced by the 1982-83 El Niño or, directly or indirectly, to volcanic aerosols injected into the atmosphere by El Chichón.

Plans FY 1986

Dobson ozone spectrophotometers operated at Sapporo and Varanasi will be reconditioned and recalibrated. A program carried out in 1981 to check the calibration status of Dobson spectrophotometers in the network, using traveling, calibrated standard lamps, is being repeated. Test results from all stations are expected to be received in Boulder by late 1986. An automated Dobson instrument will be installed for Umkehr observations at Lauder in January 1986.

Umkehr measurements will be analyzed for information on ozone profile variations and tendencies on much shorter time scales, using automated Dobson data. The results of the Umkehr analysis will be compared with SBUV profiles, observed concurrently with the Umkehr, to determine the agreement that is now achievable with the two systems. This study will include an investigation of

Umkehr measurement noise from thin clouds, and possibly aerosols, in the zenith-sky field of view.

Stations at Poker Flat and South Pole will be added to the ozonesonde network. Research will be conducted to couple ECC ozonesondes to hypsometer radiosondes in a manner that will permit real-time, automated processing of the ozonesonde data. Use of substantial numbers of ECC ozonesondes is envisioned for tropospheric ozone studies.

The total-ozone data and ozone-profile data will continue to be updated to confirm that the recent ozone decrease was indeed temporary and does not, in part, reflect anthropogenic influences on stratospheric photochemistry.

CLIMATE

SUN- AND MOON-CLIMATE RELATIONSHIPS

Accomplishments FY 1985

The University of Arizona, under an ARL grant, has been testing a solar spectrometer at Mt. Lemon and at the University of Arizona campus in Tucson. This device is designed to measure, from the Earth's surface, variations in the "solar constant" after adjustment for intervening atmospheric effects.

Analysis of solar UV spectral irradiance measurements from the Nimbus-7, SME, and AE-E satellites identified three time scales of UV radiation variations important to the stratosphere and caused by solar activity variations: (1) short-term variations (days, weeks), caused by the solar rotation of solar active regions distributed nonuniformly in solar longitude, that are quasi-periodic, having periods near 13 and 28 days; (2) intermediate-term variations (4-8 months) caused by episodes of major activity, and (3) long-term variations (years) caused by the buildup of solar active regions, their long-lived remnants and/or the active solar network over a solar cycle. The annual variation in all solar radiation caused by the Sun-Earth distance variations is a little less than 7% above the minimum value, and that of the observed variations in the total solar irradiance is a few tenths of 1%. Using the long-term relation of the 205-nm flux with respect to the 1083-nm He I line observations, we estimate that the 205-nm flux increases by about 8% from the minimum to maximum for solar cycle 21 for annual average values, by about 10% for monthly mean value (including long- and intermediate-term variations), and by about 13% for daily values (including short-term variations). The largest 27-day short-term increase was about 7%, comparable with the annual variations. **ARL**

The intermediate-term variations of the solar UV and the 1083-nm chromospheric-line fluxes were shown to rise slower, peak later, and decay slower than those of the classical indices of solar activity, namely the sunspot number and Ca-K plage index. This is because the photospheric and chromospheric plages and plage remnants have a slower evolution than their associated sunspots, coronal active regions, and initial major plages.

The SBUV/2 measurements of solar UV spectral irradiance were analyzed for April 1985, the only month of data released by NOAA-NESDIS.

Solar UV flux variations are a routinely monitored quantity. The ozone variations caused by these variations were identified, measured (mainly by scientists outside of NOAA), and shown to be in good agreement with theory, where the main point of controversy is the timing in the upper stratosphere brought about by the interplay of increased ozone production through UV-induced increases in atomic oxygen combined with delayed temperature increases that cause increased ozone destruction.

The main calibrations of the solar UV spectroradiometers were completed in collaboration with scientists at the National Bureau of Standards (NBS) in Gaithersburg, Md. These spectroradiometers were then used in laboratory experiments to show that the NBS tungsten-lamp radiation standards, which are normally used at visible wavelengths, and measurements from the NBS Synchrotron Ultraviolet Radiation Facility (SURF), which is normally used at ultraviolet and extreme ultraviolet wavelengths, agree within about 1% at middle-UV wavelengths.

An analysis was completed of the sensitivity of U.S. summer precipitation to the position of the Moon in its orbit. Prior studies have shown that a maximum in precipitation occurs about 4 days after new moon and a minimum occurs about a week later, considering the United States as a whole. The present analysis shows that in summer these effects do not occur simultaneously but rather appear first in the northwest and, over a 2-week period, propagate to the southeastern United States. The maximum frequency of occurrence of summer precipitation occurs in the northwest about 5 days before new moon, and reaches the southeast about 6 days before full moon. The minimum occurs about a week after maximum in most regions of the U.S., except the portions of the southwest that receive little or no summer precipitation.

The fact that lunar modulation of precipitation does not occur simultaneously over the United States suggests that a previous theory explaining lunar effects on precipitation through modulation of galactic cosmic ray is either incorrect or must be modified. Our tentative hypothesis is that lunar position affects summer precipitation in the United States through changes in tropospheric circulation--induced either in the Gulf of Alaska by modulation of synoptic-scale systems, or by modification of large-scale convection in the tropics and subtropics.

The change in precipitation over the lunar period is, in some regions, relatively large. Summer precipitation in Colorado and Wyoming varies by a factor of 2 over the lunar synodic period. Analysis confirmed the published evidence of additional systematic variation in precipitation over the lunar synodic period, delayed by about 2 weeks relative to the indicated cycle.

Studies are in progress on solar and lunar effects on tropospheric variables such as vorticity area index, zonal atmospheric angular momentum, and tornado frequency.

Plans FY 1986

The University of Arizona plans to deploy the solar spectrometer at Mauna Loa Observatory in late 1985 for support of ARL research.

Analysis of solar UV spectral irradiance in the 160-400 nm range from the SBUV/2 monitor aboard the NOAA-9 satellite will continue. Analysis of Nimbus-7, SME, and AE-E satellite measurements of solar UV flux variations will be completed except for future comparisons with SBUV/2-NOAA-9 measurements.

Two special sessions will be held at the fall meeting of the American Geophysical Union: Stratospheric, Mesospheric and Thermospheric Effects of Solar Variability; and Solar Variability. Research on coupling of the stratospheric effects of solar UV variability into the troposphere will be increased.

Research will continue on solar/lunar forcing and changing conditions in the troposphere. Specifically, a tentative hypothesis will be tested explaining lunar effects on summer precipitation over the United States in terms of effects 2n tropospheric circulation. The statistical significance of the relationship between lunar position and tropospheric variables will be evaluated. Discussions will continue with the National Weather Service (NWS) Techniques Development Laboratory on the possible application of these analyses to prediction of precipitation over the United States.

SOLAR RADIATION FACILITY

Accomplishments FY 1985

Funding was obtained for upgrading data acquisition and solar tracking units at 31 U.S. weather stations. NWS purchased computers for data acquisition, and ERL issued a Request for Proposals for automatic solar trackers that will be maintained by GMCC's Solar Radiation Facility.

There are now 40 two-wavelength sunphotometers either in operation at U.S. stations and GMCC observatories or on loan. Approximately 24 station years of data have been acquired since the upgrade of the turbidity network. The procedure for calibrating these instruments has been tested and deemed feasible. It consists of calibrating precision sunphotometers at Mauna Loa Observatory and using this instrument at Boulder to calibrate the U.S. network instruments. **ARL**

Plans FY 1986

Two five-wavelength precision sunphotometers will be tested and placed into service to calibrate the two-wavelength U.S. network sunphotometers. These instruments will also be used as reference standards at Mauna Loa Observatory when the site is used for special testing and calibration of

instruments from sources outside NOAA. WMO has recommended Mauna Loa Observatory as one of two world facilities for testing and calibrating turbidity sunphotometers.

The new data acquisition and tracking instrumentation for the U.S. Solar Radiation Network will be installed by NWS and ERL. Installation will be followed by performance evaluation checks and close scrutiny of data products to be transmitted by NWS.

AEROSOLS AND RADIATION

Accomplishments FY 1985

Total radiation balance measurements were begun at Barrow Observatory. The measurements are being made a shorter distance from the Observatory buildings and are representative of only a particular surface-type local dry tundra during the summer but for about eight months of the year should be representative of nearly synoptic-scale arctic surface. Knowledge of the radiation balance at Barrow will be useful for studies of local climatic conditions and regional climatic variations.

A clear-sky solar radiation model originally developed at SERI (Solar Energy Research Institute, Golden, Colo.) was adapted to the existing conditions at the GMCC observatories. The model was then run to produce detailed clear-sky radiation climatologies for the observatories against which real-time observations could be compared. The principal purpose for the comparison is data quality control and testing of our ability to model clear-sky radiation at these sites.

The apparent atmospheric transmission procedure for monitoring aerosol loading with a pyrheliometer was examined for water vapor effects, using an atmospheric transmission model. Water vapor data used in the study were obtained from a dual-channel sunphotometer operated continuously at Mauna Loa for 6 years. It was shown that 25% of the day-to-day variance could be attributed to water vapor.

Aerosol measurements at Barrow show a repeatable annual cycle with a maximum in spring and a minimum in summer. The maximum in the spring, known as the arctic haze, was shown to be a result of long-range transport of anthropogenic pollution aerosol from the middle latitudes, primarily Eurasia and central Asia.

Aerosol measurements at Mauna Loa show a repeatable annual cycle with a maximum in late spring and a minimum in winter. The maximum in late spring was shown to be a result of long-range transport of dust from the deserts of Asia during times of vigorous dust storms and efficient transport.

Aerosol measurements at America Samoa show a scattering function that increases with increasing wavelength, unlike scattering at other GMCC sites, which decreases with increasing wavelength. Aerosol size distribution measurements and Mie scattering calculations showed that the scattering measurements

can be explained by an aerosol size distribution with a large sea-salt mode and smaller sulfate mode.

Aerosol measurements at the South Pole show that aerosol sulfur and condensation nucleus (CN) concentrations have an annual cycle with a maximum in austral summer and a minimum in winter. Aerosol scattering and sodium concentrations have a cycle with a minimum in the summer and a series of high values in the late winter. Analysis showed that sea-salt events occur when winter storms cause rapid transport of aerosol from coastal regions, and an accompanying warming and decrease in the strength of the surface temperature inversion enhances vertical transport to the surface.

Measurements of CN concentration and aerosol scattering continued at Whiteface Mountain during the summer of 1985. Haziest episodes occur during periods of high pressure when air is coming from the direction of the industrial areas of the Great Lakes regions.

Mauna Loa Observatory lidar data were reduced and analyzed in parametric form for features and variations in profile. The lidar data record extends from late 1974 to the present. The Mauna Loa lidar data were compared with Langley, Va., lidar data for nearly the same time period. The measurements were quite similar, and stratospheric aerosol error correction factors to Umkehr ozone profiles appeared reasonable, at least for data from Mauna Loa for the time period 1975-1981. Of course, lidar observations at higher latitudes will help reduce uncertainties associated with the use of Mauna Loa data only when correcting Umkehr observations.

Plans FY 1986

Total radiation balance measurements will be made 15 miles east of Boulder on top of the Boulder Atmospheric Observatory tower (900 ft above ground). The measurement program will include real-time data reduction and transmission to ERL research offices. The downward-viewing global instrumentation will integrate a signal over a diverse land surface area representative of the Colorado eastern plains comparable with the area viewed by satellites. Hightime-resolution measurements will be made during Earth Radiation Budget Satellite over-flights, and continuous measurements with lower time resolution will be collected to develop a climatology for the site.

Measurements of aerosol optical depth with more narrow spectral bands will begin at Mauna Loa. Newly designed, continuous-output, temperature-controlled, five-wavelength instruments will be used. Streamlined data processing will be developed to enhance the utility of these new sunphotometers as calibration standards. **ARL**

Radiation measurements will be made to determine radiative properties of arctic haze. Measurements will be made on the ground at Barrow and from aircraft during the Arctic Gas and Aerosol Sampling Program (AGASP) II field program, which was postponed from 1985. Radiation measurements during AGASP II will be used to obtain vertical profiles of optical properties from the aircraft and information on the impact of arctic haze on the surface radiation budget.

GMCC will participate in AGASP II planned for the spring of 1986. Important measurements will include aerosol chemistry profiles, aerosol size distribution in the Aitken size range, and aerosol optical extinction profiles.

CARBON DIOXIDE

Accomplishments FY 1985

The concentration of atmospheric CO_2 was measured continuously at Barrow, Mauna Loa, Samoa, and the South Pole. It was found that the annual increase in 1984 of the mean annual CO_2 concentration has returned to its average value since 1976, 1.5 parts per million (ppm) yr^{-1}, after the El Niño disturbance of 1982-1983.

In support of the continuous and flask analysis programs, 214 CO_2-in-air reference gas calibrations were made. All calibrations are with respect to the GMCC secondary standards, which were re-analyzed this year at the Scripps Institution of Oceanography (SIO).

Four thousand flask samples from the flask network were analyzed for CO_2. Three new sites were added: Shemya Island, Alaska; Alert in the Northwest Territories, Canada; and Midway Island. The 1983 flask data were reprocessed to take into account drifts in the concentrations of the flask analysis reference gases and analyzer nonlinearity. The flask data also show the recovery from the 1982-1983 El Niño event as the equatorial bump in the north-south concentration profile regained its "normal" amplitude. The mean annual CO_2 growth rate recorded in the flask data agreed closely with the continuous analyzers.

At Mauna Loa, measurements of CO_2 and CH_4 were performed by gas chromatography. The CO_2 data were compared with data from the nondispersive infrared analyzer. The comparison showed an offset between the instruments of about 0.1 ppm with a one sigma scatter for individual comparisons of 0.14 ppm. The offset may be due to drifts in the reference gases. The CH_4 data with a density of six values per hour were compared with flask data having a density of only one value per week. The "continuous" CH_4 data clearly exhibit structure on a time scale of days and weeks, presumably reflecting the effects of transport and the action of sources and sinks that show up only as "noise" in the flask data.

Shipboard measurements were made of atmospheric CO_2 and CH_4 concentrations and pCO_2 and pCH_4 in ocean surface waters. Data from the R/V Knorr and the R/V Discoverer generally support the representativeness of the flask network.

A manuscript was prepared describing a two-dimensional carbon cycle model that successfully describes seasonal variations in total CO_2 and its $^{13}C/^{12}C$ ratio. The model incorporates a two-layer ocean and a new treatment of carbon fluxes between the atmosphere and biosphere.

An international intercomparison of CO_2 measurements by several laboratories, initiated by GMCC under the sponsorship of WMO, was started. Three tanks filled with CO_2-in-air standards are being circulated among participating laboratories for analysis.

The record of the annual average CO_2 concentrations at Mauna Loa was examined for compatibility with large net annual emissions from sources other than fossil fuel. It was concluded that only small constant amounts of additional carbon, less than 10% of the current fossil fuel release, would be compatible with the record. If, instead, the release of additional carbon has increased annually at the same rate as fossil fuel emissions, i.e., approximately doubling over the last 25 years, such a release history could be compatible with observations. The larger the total amount of additional carbon, however, the more closely the release record has to have matched the fossil fuel record. It seems improbable that amounts of additional carbon large relative to fossil fuel emissions have been released since 1958 when the record began.

A study was initiated of the relationships between the sea surface temperature (SST) of the eastern tropical Pacific and season-to-season changes in CO_2 at the four baseline observatories. Preliminary results indicate that warmer- and colder-than-average SSTs precede above- or below-average season-to-season CO_2 changes by about one season at Mauna Loa and two seasons at the South Pole. Greater lags are indicated for Samoa (where the annual cycle is very complicated) and Barrow. Changes with time in both the magnitude of the correlation and the lag were found. Correlations are higher when El Niños are frequent. Also there appear to be preferred seasons for effects to show. The changes from fall to spring at Mauna Loa are better correlated with antecedent SST than are the changes from spring to fall.

Plans FY 1986

Continuous monitoring of the atmospheric CO_2 concentration at Barrow, Mauna Loa, Samoa, and the South Pole will continue. After receipt of the results of SIO calibrations that tie our secondary standards to the most recent manometric values, the continuous data for 1983 and 1984 will be corrected for reference gas drift and archived with WMO.

Air samples for CO_2 analysis will be collected from the 26 sites of the CO_2 flask sampling network. The 1983 and 1984 flask data, after correction for reference gas drifts, will be archived with the DOE/Carbon Dioxide Information Center and WMO. The representativeness of the flask network will be evaluated using flask sample data obtained on several cruises from 1982 to 1985. A report will describe in detail the local geography and conditions at the flask sampling sites. **ARL**

The comparison of the NOAA and SIO records at Mauna Loa for 1973-1984 will continue. A detailed comparison will be made of the flask data and the data from the four continuous-monitoring stations for 1983.

The comparative performance of the gas chromatograph and the infrared analyzer at Mauna Loa will be analyzed in more detail. A gas chromatograph will measure atmospheric CO_2, CH_4, pCO_2, and pCH_4 in ocean surface waters. In addition, flask samples will be taken on the ships.

A laser Raman scattering apparatus for measuring small variations in the atmospheric oxygen concentrations, which was recently transferred from the Lawrence Berkeley National Laboratory, will be set up and calibrated.

The relationships between SST and CO_2 changes will be explored further, particularly with attention to the lags among the stations and any changes of seasonal amplitude.

DATA ACQUISITION AND METEOROLOGICAL SUPPORT

Accomplishments FY 1985

GMCC staff completed the testing and installation of the Control and Monitoring Systems (CAMS) at the four GMCC observatories. CAMS controls the orderly conduct of calibration, scales and displays the data, and records the results. Complete data printout is provided. CAMS is a distributed system in that separate units are supplied to different measurement projects. In this way data quality is improved by avoiding long wire runs and potentially noisy ground loops. CAMS replaced the Instrumental Control and Data Acquisition System, a central computer-controlled recording system, in use at the GMCC observatories since 1974.

The anemometers and barometers at the four GMCC observatories were recalibrated. Wind and pressure measurements made over the previous 6 years were adjusted to reflect the changes in calibration. These variables, along with the temperature and dew point, were tested against physical and statistical limits to isolate questionable data. Once removed, the hourly average values for the past 8 years for each station were printed and converted to microfiche. Future distribution will be by computer-produced magnetic tape or microfiche.

During the past 5 years, the GMCC staff have developed a kinematic transport model to allow the computation of back trajectories from sampling location, to study the influence of various source regions. The most widely used model estimates the back trajectory along the standard isobaric surfaces for a period of 10 days. It has been used to identify the loess plateau and Gobi desert of Asia as a source of dust events at Mauna Loa Observatory in the spring. Back trajectories have been used to identify source region's influence on precipitation chemistry background-monitoring sites. In this reporting period GMCC produced approximately 24 station-years of trajectories. In most cases, back trajectories are produced at three standard pressure levels beginning at 0000 and 1200 GMT. More recently, kinematic methods have been used to track the modeled airflow back along isentropic surfaces. Isentropic back trajectories have been limited to case studies of specific situations, owing to the additional cost of computation. Most recently, isentropic back trajectories were used to depict the flow to Barrow during the AGASP experiment.

Plans FY 1986

In addition to the measurement of wind, pressure, temperature, and humidity, continuous monitoring of precipitation amount is to be added. Hourly average values of precipitation amount will be added to the data base at the three northernmost GMCC observatories. Furthermore, with the addition of a temperature gradient measurement at Barrow, Mauna Loa, and South Pole in 1985, it is now possible to compute the bulk Richardson number as an indication of local boundary layer stability. Such computations will begin this year.

GMCC staff plan to participate in the analysis of the flow conditions during the AGASP II study scheduled for March 1986. Isobaric and isentropic back trajectories will be used in this analysis.

A stair-access sampling tower, 128 ft high, is scheduled to be constructed at Mauna Loa Observatory. It will allow a much wider variety of sampling.

TRACE GASES

Accomplishments FY 1985

Atmospheric baseline measurements of chlorofluorocarbons (CCl_3F and CCl_2F_2) and N_2O were continued at Point Barrow, Niwot Ridge, Mauna Loa, and Tutuila Island, American Samoa. The measurement method entails collection of pair air samples at each station at weekly intervals, and subsequent analysis of the samples in Boulder with an electron capture gas chromatograph. Biweekly measurements were made at South Pole during FY 1985 with a gas chromatograph.

To upgrade measurements of the radiatively important trace gas species (RITS) at the GMCC baseline stations, automated gas chromatographs and data processing equipment were purchased for in situ measurements of CCl_3F, CCl_2F_2, CCl_4, CH_3CCl_3, and N_2O. Work also started on a gas calibration facility for the RITS program.

Monthly stratospheric balloon-borne water vapor soundings were made in Boulder using frost-point hygrometers. Soundings were obtained also in Wyoming and Alaska as part of the data validation program of the SAGE II satellite measurement system. **ARL**

Surface ozone measurements at the four GMCC baseline stations continued. Analysis of the data from the early-to-mid-1970s through 1984 indicated significant positive long-term increases in surface ozone at Barrow and at Mauna Loa Observatory. Whereas at Barrow the increase occurred primarily during summer months, the positive growth rate at Mauna Loa was strongest in winter and, to a lesser extent, in spring. In the Southern Hemisphere, at Samoa and South

Pole, the secular trends in surface ozone were negative, but not statistically significant on an annual basis. They were, however, statistically significant at these two stations during summer months.

Measurement of atmospheric methane in air samples collected from the CO_2 network continued. This is a cooperative program involving GMCC, the Commonwealth Scientific and Industrial Research Organization (CSIRO) in Australia, and the Oregon Graduate Center. Data for the first 2 years are complete. The global distribution of methane as a function of time in 1983 and 1984 was documented. The data processing equipment was upgraded and a gas chromatograph acquired for continuous use at Barrow. The data show a smooth seasonal cycle, almost a sine wave, through the Southern Hemisphere, which is superimposed on a steady increase of about 1% per year. The seasonal cycle at the Northern Hemisphere sites is more complex and differs in phase and amplitude from the Southern Hemisphere cycle, but the overall growth rate is the same for both hemispheres. There is a large North-South gradient in the concentration, about 8%.

One-liter flasks for methane were collected daily at Miami, Fla.

Plans FY 1986

Atmospheric baseline measurement of the chlorofluorocarbons and N_2O will be continued at the GMCC observatories and at Niwot Ridge, Colo. Testing of the automated gas chromatographs will continue, and several of the instruments are expected to be deployed to the field stations. A calibration facility for the RITS program will be established, and several sets of calibration gases will be prepared for use at the field station.

Monthly stratospheric water vapor soundings in Boulder will be continued. Special ozone and water vapor soundings will be made with balloon-borne instrumentation to validate the Stratospheric Aerosol and Gas Experiment (SAGE II) data. Laboratory work, previously delayed, will be performed in order to determine the reason for the measurement offset of the GMCC frost-point hygrometer sonde and the Aeronomy Laboratory's Lyman-alpha water vapor instrument.

Continuous monitoring of near-surface ozone will continue at the four GMCC baseline observatories. The feasibility of establishing an ECC ozonesonde network for long-term tropospheric ozone measurements will be investigated.

The measurement of CH_4 in flask air samples from the network by gas chromatography will continue. In situ gas chromatographs will be installed at Barrow and Mauna Loa. We will determine the feasibility of obtaining a CO determination on the same chromatogram with CH_4. Interaction will be started with the Global Atmospheric Gas Experiment (GAGE) to improve gas standards and data compatibility.

TEMPERATURE

Accomplishments FY 1985

Global tropospheric and stratospheric temperatures obtained from a 63-station radiosonde network were updated through the spring of 1985. Northern Hemisphere surface temperatures were indicated to be 0.2°C above average and 850-300 mb temperatures 0.1°C below average in 1984, compared with 0.5°C and 0.4°C above average, respectively, in 1983. Temperatures in the 300-100 mb layer bracketing the tropopause were 0.6°C below average in 1984 (compared with 0.3°C below average in 1983), and in the 100-30 mb layer of the low stratosphere 0.4°C below average (the same as in 1983). At both the surface and in the 850-300 mb layer, Northern Hemisphere temperatures were indicated to be 0.1-0.3°C below average also in the winter and spring of 1985. Binomial smoothing of these seasonal temperature deviations shows Northern Hemisphere surface and tropospheric temperatures in late 1984 and early 1985 to be the lowest since 1976. It remains to be determined whether this coolness is a longdelayed memorial to the El Chichón volcanic eruption in the spring of 1982 (delayed because of the atmospheric warming induced by the powerful El Niño of 1982-83).

Plans FY 1986

Tropospheric and stratospheric temperature data throughout the world will continue to be updated, with emphasis on the geographical extent and duration of the recent cooling.

HUMIDITY

Accomplishments FY 1985

As a preliminary step in determining if there have been detectable tropospheric humidity trends on a hemispheric and global scale, a study of humidity variations at Brownsville, Tex., and Great Falls, Mont., for a 23-year interval was completed. It is apparent that great care must be taken with regard to changes in instrumentation and measurement technique, and that for proper results the humidity should be evaluated at significant points as well as at mandatory pressure surfaces. A computer program was completed that can extract humidity data from individual soundings at the 63 stations, flag anomalous data, and determine monthly means. ARL

Plans FY 1986

After some examination of the computer output to ensure that reliable and representative humidity values are being obtained, relative humidity, mixing

ratio, and precipitable water will be monitored at the same 63 radiosonde stations used for temperature monitoring.

SUNSHINE DURATION AND CLOUDINESS

Accomplishments FY 1985

Sunshine duration and cloudiness data for the contiguous United States were analyzed through the summer of 1983, and the data are now being updated through 1984. There has been a significant tendency for United States cloudiness to be above average, and sunshine duration below average, following El Niño occurrences, but data for the summer of 1983 indicate that cloudiness and sunshine duration had already returned to average with the decline of sea-surface temperatures in eastern equatorial Pacific. Since 1950 there has also been a significant general trend of increasing cloudiness and decreasing sunshine.

Plans FY 1986

Sunshine duration and cloudiness data for the United States will continue to be updated to see if the tendency for a long-term increase in cloudiness, and decrease in sunshine duration, continues over the United States.

AERONOMY LABORATORY
Boulder, Colorado

Eldon E. Ferguson
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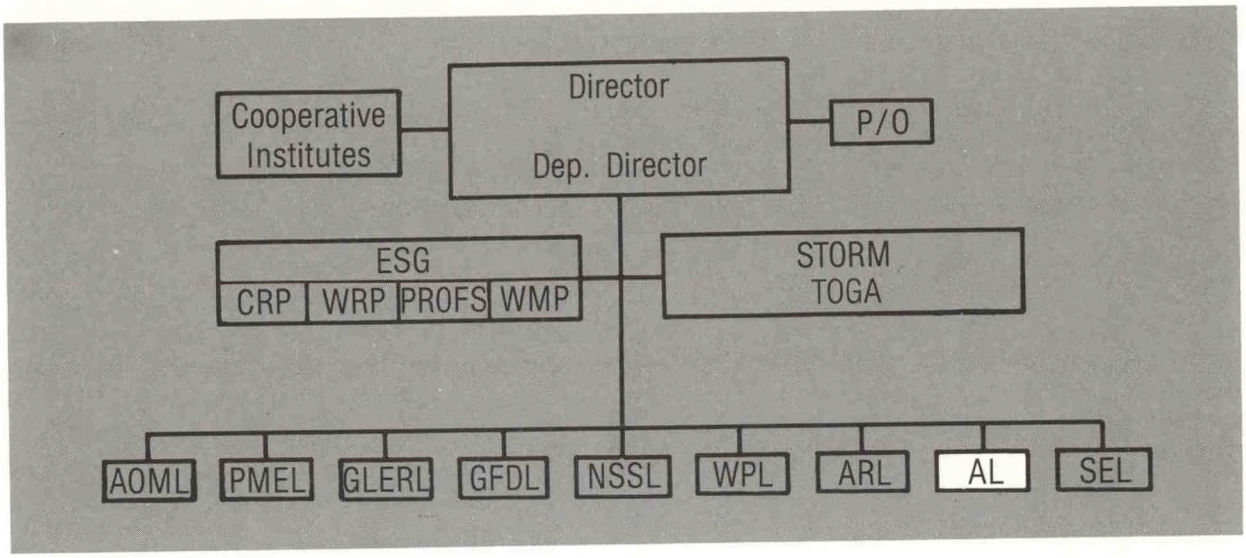

The Aeronomy Laboratory (AL) conducts research on chemical and physical processes of the Earth's atmosphere to advance the capability to monitor, predict, and control the quality of the atmosphere. The research concentrates on the stratosphere and troposphere but also involves the ionosphere.

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 seven interactive programs: Atmospheric Chemical Kinetics, Atmospheric Dynamics, Atmospheric Sampling, Atmospheric Wave and Turbulence Theory, Optical Aeronomy, Theoretical Aeronomy, and Tropical Dynamics and Climate.

The major focuses of research are Air Quality and Climate.

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. The group's research efforts 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 national or global atmospheric questions of environmental import. 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 factors 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 1985

During the summer of 1984, an intensive study of atmospheric reactive nitrogen chemistry was carried out at the Aeronomy Laboratory's Niwot Ridge research site in the Colorado mountains west of the Denver metropolitan area and near the Continental Divide. The summer period was chosen for this initial study because the elevated temperatures, solar intensity, and humidity enhance the photochemical processes under study. However, for a complete picture of the reactive nitrogen chemistry, the wintertime contrast is particularly valuable. This was studied during the following fall and winter.

Both summer and winter studies focused on the following nitrogen species: nitric oxide (NO), nitrogen dioxide (NO_2), peroxyacetyl nitrate (PAN), nitric acid (HNO_3), and particulate nitrate (NO_3^-). In addition, the sum of the reactive nitrogen species (NO_y) was addressed by a newly developed technique. The atmospheric concentrations of NO_y and the individual reactive nitrogen

species were measured with instruments developed by the Aeronomy Laboratory, except for PAN, which was examined by SRI International and the National Center for Atmospheric Research.

In the summer measurement campaign, it was found that the sum of the concentrations of the individually measured species ($NO + NO_2 + PAN + HNO_3 + NO_3^-$) was typically only 55% of the total reactive nitrogen (NO_y) measurements. In the winter, it was observed that this sum was nearly equal to the total. This implies that, in the summer, the higher level of photochemical activity promotes the formation of another unidentified reactive nitrogen species. Organic nitrate species other than PAN are candidates. These studies point out that previous inventories of reactive nitrogen species have been incomplete by typically one-half.

In addition, these contrasting summer-winter studies have revealed new important seasonal variations among the well-known reactive nitrogen species. The summertime measurements had demonstrated that PAN concentrations were often as high as those of NO and NO_2. These results illuminated the significant role that PAN plays in the nitrogen photochemistry of non-urban areas. During the wintertime measurement period, the PAN levels were in excess of four times those of NO and NO_2, which underscored this role of PAN and, since the air masses that were sampled were often quite clean, pointed out the significance of PAN as a reservoir of reactive nitrogen during long-range transport.

Following these summer and winter measurements at Niwot Ridge in 1984, the ensemble of instruments was fitted into a van and used to explore tropospheric nitrogen chemistry at a new location on the west coast at Point Arena, Calif. This measurement series provided the opportunity to test models of the chemistry of maritime air, a system in which only a few fundamental processes are thought to be dominant.

Point Arena is located on the Pacific coast about 175 km north of San Francisco. This site receives inflow of marine air from the Pacific Ocean. Between 24 April and 4 May 1985, NO, NO_2, HNO_3, particulate nitrate, NO_3^-, NO_y, PAN, ozone (O_3) and meteorological parameters were measured. During this period, local conditions were dominated by moderately strong, northerly winds with some westerly component. Episodes of air containing quite low levels of the odd-nitrogen species were observed. During the measurement period, NO_x levels ranged from ~30 pptv to >1000 pptv, reflecting the origin and histories of the air masses that were being sampled. The systematic trends and the intercorrelations of the species' concentrations in marine air, as well as the correlation of the O_3 and odd-nitrogen concentrations with air parcel trajectory origin, are being compared with models of the expected chemistry.

AL

At Point Arena, measurements were also made of ammonia (NH_3), which is an important trace constituent in the atmosphere because of its alkalinity and its homogeneous chemistry. The measurements were made using the tungsten oxide denuder tube method. NH_3 mixing ratios ranged from 140 pptv to 1.1 ppbv, with a mean of 325 pptv. Surface wind directions were virtually always between southwest and northwest (i.e., from out over the ocean), indicating that the coastal or oceanic regions are probably a source of NH_3.

Formate and acetate, as well as other organic and inorganic anions, were measured in precipitation collected at Niwot Ridge (a remote site), Boulder (an urban site), and Mauna Loa, Hawaii (a remote oceanic 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} M occur in summer rain showers. Various dicarboxylic anions are also observed, but their concentrations are generally much lower than that of formate. Although the total ion concentration is usually less at Niwot Ridge than at Boulder, ionic balance often leads to a somewhat lower pH at Niwot Ridge. Diethylamine has also been detected in tropospheric aerosols collected at Mauna Loa and Niwot Ridge. The amine concentration was, at times, a substantial fraction of the ammonium (NH_4^+) concentration, making it potentially an important basic material in aerosols. Concentrations as large as 200 pptv were observed. A large diurnal variation was observed at both sites, the maximum occurring in late afternoon at Mauna Loa but near noon at Niwot. The present observations show that these species can be significant contributors to the acidity in urban and rural continental areas.

Sulfur compounds also have an important role in the acidification of rainfall. An assessment of the significance of natural biogenic sulfur sources compared with anthropogenic sources requires the measurement of fluxes at or below 10^{-8} g S m^{-2} min^{-1} over large geographic areas. To date, such an assessment has rested almost entirely on one study completed in 1979. In view of the importance attached to these measurements, the analytical difficulties recognized by those investigators, and recent improvements and advances in measurement techniques for trace sulfur species, a reassessment of the strengths of natural sulfur fluxes was deemed desirable. As part of this, simultaneous measurements at three previous measurement sites were undertaken jointly by NOAA, Washington State University Air Resources Laboratory, and University of Idaho Department of Chemistry in July and August 1985. The results for the magnitude, temperature dependence, and temporal variation of the flux of hydrogen sulfide (H_2S), carbonyl sulfide (COS), carbon disulfide (CS_2), dimethyl sulfide (CH_3SCH_3), and dimethyl disulfide ($CH_3S_2CH_3$) at these three diverse sites will provide crucial information for assessment of the earlier studies, as well as contribute significantly to an inventory of natural sulfur emissions.

Regarding natural nitrogen emissions, it is currently believed that the emission of NO_x from soils represents one of the major natural sources of the nitrogen oxides. Several techniques are being used to measure these fluxes, principally enclosure, gradient, and eddy correlation methods. The enclosure techniques usually measure the NO_x flux from a small, enclosed sample of soil (typically ~1 square meter); the gradient and eddy correlation methods determine the average NO fluxes from larger areas (typically thousands of square meters). The present study is aimed at intercomparing the results obtained using the enclosure and gradient methods to determine NO fluxes from the soil during the nighttime hours. These measurements were carried out on grassland at a Boulder, Colo., site during August and September 1985. The NO fluxes during this period of intercomparison ranged from 0.3 ng N m^{-2} s^{-1} to 40 ng N m^{-2} s^{-1}. There was general agreement in the results from both techniques over this range, lending a large measure of confidence to these methods.

Flights on NASA's ER-2 aircraft were conducted for the new instruments that will take part in the Stratospheric Tropospheric Exchange Program. These flights tested the Laboratory's instruments for measuring water vapor, total water (water vapor and ice), and O_3, species that are tropospheric and stratospheric tracers. Furthermore, the flights tested the inertial-separator/inlet system, which is designed to separate ice from water vapor, both of which will be measured individually.

Plans FY 1986

Field studies of nitrogen chemistry, such as those that were conducted at Niwot Ridge and Point Arena, will be continued in the summer of 1986 in conjunction with flux measurements of nitrogen species from soils. Studies will take place at a variety of sites differing in soil type and vegetation. This will constitute the first examination of nitrogen emissions from continental U.S. soils. NH_3 will also be measured.

The NO_y technique will be added to the airborne NO and NO_2 instruments for use in collaboration with the National Center for Atmospheric Research, on a series of aircraft flights in the summer of 1986. NASA's aircraft will carry a suite of instruments that will focus on the reactive nitrogen chemistry of the troposphere, including species distributions, reactions, and instrument reliability.

A diode-array spectrometer will be used to establish the temperature dependence of the absorption cross section of nitrogen trioxide (NO_3). The atmospheric concentrations of NO_3 are most often deduced using the cross section in the 662-nm region, where it has been assumed that the cross section has no temperature dependence. However, recent preliminary observations have suggested that this assumption may not be correct and hence the need for this re-investigation.

A differential absorption lidar technique will be developed as a means of measuring O_3 in the free troposphere. There is currently no fully acceptable method to do this, despite the need to assess potential human alteration of this climatically important chemical species. This instrument will be located at Fritz Peak. The goal is continuous measurements of the O_3 profile up to 15 km. The observed variance of the O_3 at each altitude will be used to test predictions that have been made by the Geophysical Fluid Dynamics Laboratory's general circulation model.

AL

The stratospheric/tropospheric exchange instrument package will be augmented by an NO_y instrument, which will provide measurements of this stratospheric tracer at ER-2 aircraft altitudes (21 km). 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.

OPTICAL AERONOMY

The Optical Aeronomy program uses optical measurements of the atmosphere as a tool for studying fundamental atmospheric processes such as energy balance, composition, and dynamics. Major attention is being given to measurements bearing on the composition and dynamics of the lower atmosphere, principally the troposphere and stratosphere. Important problems in the upper atmosphere continue to receive attention.

Accomplishments FY 1985

The total column abundance of NO_3 in the stratosphere at night has been measured by the Optical Aeronomy group for five years at 40°N; additional observations have been obtained at 19°N, 31°N, 51°N, and 64°N. At low latitude the mean abundance is about 8×10^{13} cm^{-2}; it varies little with season and appears to be in general agreement with a model based upon simple NO_x chemistry except, perhaps, in the spring. At middle latitudes the variation in abun- dance exceeds prediction and the abundance exhibits a close relation to the highest latitude experienced by stratospheric air prior to its arrival at middle latitudes; the higher the latitude the lower the NO_3 abundance. At 64°N the upper limit in April and November is 1.5×10^{13} cm^{-2}; in April this is far below what is predicted by models. From these observations we inferred that a scavenger of NO_3 is continually produced in the stratosphere at high latitude and that when there is strong equatorward flow the scavenger can at least reach middle latitudes. The identity of the scavenger remains a mystery as does the importance of its role as a sink for NO_x in the stratosphere.

The new diode array spectrograph has been in extensive use for studies of daytime stratospheric NO_2 and O_3. Data analysis is currently under way. The previous sunrise/sunset limits are now removed and full-day measurements are in progress.

Interpretation of the measurements of the effects of the El Chichón dust cloud on NO_2 continued. Large reductions in NO_2 column were observed whenever the volcanic dust cloud appeared near the latitude of Fritz Peak. Similar reductions were noted from observations of NO_2 as far south as Socorro, New Mexico. Heterogeneous surface reactions with the cloud parti- cles are certainly involved in this poorly understood phenomenon.

Work on NO_2 with the Solar Mesosphere Explorer satellite team at the University of Colorado continued. With the completion of the major stratospheric study of NO_2, work concentrated on interpretation of nadir measurements. This included work on the detection of NO_2 in the troposphere produced by both lightning and human activity. Clear signatures were found in NO_2 abundance due to lightning in the tropical ocean regions, and cities under the satellite track show up as sources of significant NO_2 due to pollution.

An automatic instrument collected data on high-altitude OH (80 km), thermospheric O^+ (300-450 km), and high-altitude O_2. Extensive data analysis and interpretation is under way.

Measurements of stratospheric OH continued at Fritz Peak. This unique series of measurements has produced a consistent seasonal and annual picture of OH. In particular, a large-amplitude oscillation in vertical column abundance was detected during a solar eclipse. This is the first observation of a ringing response of any atmospheric constituent to an eclipse. The physical mechanism for this ringing in column abundance is not understood.

Detailed analysis of the operating characteristics of Fabry-Perot spectrometers continued. Measurements of ionospheric and thermospheric winds continued, using the Fabry-Perot instrumentation at Fritz Peak.

Plans FY 1986

We shall begin development of a laser system coupled to a new high-resolution spectrograph to measure tropospheric OH by long-path absorption. Few experimental data exist on this critical species. In addition, we will develop an efficient retroreflector for use in the measurements, which will eliminate many problems with long-path intensity calibrations.

Efforts will continue in collaboration with the Naval Research Laboratory for development of a high-resolution ultraviolet shuttle spectrograph for measuring upper stratospheric and mesospheric OH and thermospheric NO on a global basis. Flight is expected by 1989.

Renewed efforts will be made to study stratospheric NO_2, NO_3, and the NO_3 scavenger with improved instrumentation and detectors. NO_3 will be studied in detail in the troposphere by long-path absorption at Fritz Peak.

The study of dynamics of NO_2 from SME satellite data will continue.

The long-term column determinations of stratospheric OH will continue.

New instrumentation will be developed for determining the tropospheric and stratospheric radiation fields. Theory has conclusively demonstrated the importance of radiative multiple scattering and ground albedo in the photochemistry of the atmosphere. Essentially no actual measurements exist. The Laboratory can make a unique contribution in measurement of this radiation field first from Fritz Peak and later from a U-2 aircraft.

Development of a high-resolution spectrograph for measuring tropospheric trace species will begin. AL

Measurements of mesospheric and thermospheric wind systems will continue.

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. In addition, the biosphere-atmosphere interaction is an important new research area. These new 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 1985

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 has 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:

- Development of a fine-resolution planetary boundary layer model to simulate the transport and photochemistry of O_3, NO_X, and hydrocarbons, especially in the surface layer.

- 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, Colorado.

- Collaboration with scientists at GFDL on modeling the tropospheric ozone and NO_x distributions with a three-dimensional general circulation 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 oxidation of NO_x and SO_2.

- Model studies of the distribution of NO and SO_2 that are produced from natural sources.

The fine-resolution planetary boundary layer model was used to evaluate the distribution and the photochemistry of naturally emitted hydrocarbons (isoprene and monoterpenes). Several important findings resulted from this study. It was found that natural hydrocarbons at typical observed values affect the ambient photochemistry significantly. The peroxyl radicals (HO_2 + RO_2) increased by more than a factor of 2. On the other hand, the OH radical is reduced by about 50% when natural hydrocarbons are included. Furthermore, the model predicts that isoprene and monoterpene mixing ratios decrease quickly with height in the surface layer. This is the result of the short chemical lifetime of these natural hydrocarbons and the highly stable condition in the surface layer.

Because of the high concentration of natural hydrocarbons in the surface layer, RO_2 and HO_2 may be high enough to account for the missing oxidant observed at Niwot Ridge. In turn, the O_3 formation rate in the surface layer will be increased proportionally. However, because of the long lifetime of O_3 its diurnal behavior is controlled by the photochemistry in the entire planetary boundary layer where the concentrations of natural hydrocarbon are much lower. It shows that measurements made near the surface need to be interpreted carefully.

The summer O_3 production efficiency per unit NO_x at Niwot Ridge was compared with production efficiency at eight other rural stations in the central and eastern United States. With only one exception, the daily O_3 production rates for these stations lie within the range of 6 to 12 ppb per ppb of NO_x, a remarkable agreement considering the wide range of geographical locations. Model-calculated efficiency agrees with observed values when NO_x is greater than 1 ppb. The consistency of the summer O_3 production efficiency suggests that the average daily O_3 production at a rural station may be predicted if NO_x is known. The dependence of O_3 production rate on NO_x also allows a crude estimate of the total O_3 production in the summer season for anthropogenically emitted NO_x and non-methane hydrocarbon. For the eastern United States, we estimate an average summer column O_3 production of 6.4×10^{11} $cm^{-2}s^{-1}$, about 13 times the average cross-tropopause O_3 flux. AL

Seasonal variation of ozone at Niwot Ridge was found to be a very sensitive function of NO_x. At NO_x level less than 0.2 ppb, the O_3 seasonal variation agrees with results from general circulation model calculation that

excludes photochemistry. When NO_x is greater than 0.3 ppb, there is a clear summer maximum due to photochemical production of ozone. The difference between the O_3 concentration for NO_x less than 0.2 ppb and the average O_3 concentration gives the lower limit estimate of the anthropogenic impact on the O_3 distribution at the site.

Peroxyacetyl nitrate (PAN) and other organic nitrates were shown to be major odd-nitrogen species in the rural atmosphere. They may be the major carrier of NO_x to the free troposphere and remote areas. In the summer, PAN correlates with O_3 and NO_x very well in the afternoon. This is consistent with the photochemistry of PAN. The peroxyacetyl radical and the equivalent acetaldehyde calculated from the observed PAN level provide valuable information on the total reactive non-methane hydrocarbon abundance at the measurement site. Organic nitrates may contribute substantially to the total odd-nitrogen observed at Niwot Ridge.

The mesoscale model development progressed as planned. A vertical diffusion based on Blackadar's scheme is added to the bulk planetary boundary layer. Some modifications to Deardorff's scheme have been made to improve the vertical mixing of momentum during calm wind conditions. At the interface between coarse-mesh and fine-mesh domains, the smoother-desmoother scheme used in the model generates noise near the interface. A new scheme similar to Newtonian relaxation was applied to the interface. It has improved the transition from the coarse-mesh domain to the fine-mesh domain. The predicted wind fields of nested grid and uniform grid were compared with observed values. It was concluded that the nested grid with two-way interaction gives the best results.

MIDDLE ATMOSPHERE

Chemical-dynamical modeling studies of the middle atmosphere continued, in collaboration with the National Center for Atmospheric Research. Research focused on possible transport effects on future ozone depletions due to chlorofluorocarbons, and on a more complete understanding of transport in the mesosphere.

Quantitative estimates of the effects of increasing chlorofluorocarbon abundances on stratospheric ozone have largely been performed with one-dimensional models. Current one-dimensional models predict a rather small steady-state ozone column reduction of about 4-6%. These small values result from a balance between large depletions in the upper stratosphere that are compensated to a substantial degree by increases in the lower stratosphere (the chemical "self-healing" effect), so that the total ozone column change is a small difference between the two.

It is, however, well established that lower stratospheric ozone is dynamically rather than chemically dominated, particularly at middle and high latitudes in the winter season, so that one-dimensional models may not be the most appropriate tool for evaluation of these effects at those latitudes and seasons. In particular, the lower stratospheric self-healing effect is likely to be significantly less important at high latitudes than one-dimensional model projections indicate. Our two-dimensional residual Eulerian model calculation of the ozone response to projected chlorofluorocarbon increases showed that

the predicted ozone reductions during winter and spring in high latitudes are likely to be substantially greater than one-dimensional model predictions, in agreement with some other multi-dimensional model studies. This occurs because ozone is largely dynamically controlled at these latitudes and seasons, and because the net transport is downward directed from higher altitudes where large ozone depletions due to chlorine increases are predicted to occur. The observed spring maximum in the annual cycle of total ozone is a direct result of the same downward transport phenomenon, strongly suggesting that a maximum in ozone depletion must be expected to occur during that season as well.

The behavior of mesospheric ozone also exhibits important variations that are likely to be due to transport processes, and can be used to test our understanding of mesospheric dynamics. In particular, ozone observations from the Solar Mesosphere Explorer (SME) satellite exhibit a pronounced equinox maximum at about 80 km which is not explained by photochemical theory. Recent work suggested that breaking small-scale gravity waves play an important role in the dynamics of the mesosphere. We incorporated a parameterization of the propagation and dissipation of gravity waves into our dynamical chemical model. The parameterization enables us to compute both the momentum forcing and turbulent diffusion induced by the waves at mesospheric altitudes, providing a physically based description of the variations in transport of photochemical constituents as a function of latitude and season. The seasonal variations in the computed eddy diffusion coefficient are consistent with the large seasonal changes in MST radar echoes at Poker Flat, Alaska, observed by the Aeronomy Laboratory's Atmospheric Dynamics group. The computed variations in eddy diffusion have important effects on the transport of chemical species in the mesosphere, particularly atomic oxygen and water vapor. Changes in water vapor densities near 80 km were shown to induce a seasonal variation in ozone closely resembling that observed by SME. The consistency between the model simulation of both chemical and dynamical observables strongly supports the suggestion that gravity waves play a very important role in determining the structure of the mesosphere and lower thermosphere.

Anther chemical tracer of interest at mesospheric altitudes is carbon monoxide. Carbon monoxide is produced very rapidly in the lower thermosphere through photodissociation of carbon dioxide. In the mesosphere, carbon monoxide is destroyed through reaction with OH. Therefore, the vertical profile of carbon monoxide generally decreases from the source region at about 100 km to the sink region near 50-70 km. The vertical structure depends strongly on the rate of transport between the thermosphere and the mesosphere, and on the abundance of mesospheric OH. OH is produced predominantly by water vapor photolysis at altitudes above about 65 km, and it is therefore present in larger quantities in summer, when the solar zenith angle is smaller, than it is in winter. In the polar night region, OH is not produced at all, and the large CO abundances obtained in the thermosphere may be transported down into the mesosphere without encountering the loss process with OH that exists in the sunlit atmosphere. Therefore, CO represents an excellent tracer for mesospheric transport, particularly inside the polar night region. We presented a two-dimensional chemical-dynamical model study of CO to examine this behavior quantitatively. Comparison with several ground-based microwave observations of CO were used to show the utility of CO for tracer studies.

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Plans FY 1986

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. The role of natural hydrocarbons, in particular, will be examined in view of their large emission rate and their high reactivity toward both O_3 and OH radicals. 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 continue in both stratospheric and tropospheric modeling.

Expanded studies of the acid deposition problem will continue with emphasis 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 and could be readily applied to study regional oxidant problems such as that of rural O_3. This model is being developed in collaboration with scientists at NCAR.

The interaction of the atmosphere and the biosphere is an important and fascinating research subject. Biogenic emissions of hydrocarbons, reactive nitrogen species, NH_3, and reduced sulfur species may have significant impact on the tropospheric O_3 and acid deposition. We plan to evaluate the effect of biogenic emissions of nitrogen oxides and hydrocarbons on the tropospheric chemistry.

MIDDLE ATMOSPHERE

The interaction of dynamics and chemistry in the middle atmosphere represents an important element in our understanding of aeronomy. Our studies of the natural and perturbed stratosphere and mesosphere will continue. We will couple a detailed treatment of infrared radiation, as well as a linear planetary wave model, into our chemical/dynamical model. With these tools, the zonally averaged radiative/chemical/dynamical behavior of the stratosphere can be investigated, and the role of chemical transport by planetary waves can be examined.

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 rate coefficients and

mechanisms of chemical reactions, thermochemical and spectroscopic data, and values of photochemical parameters.

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 that are deposited in remote rural locations. The acids may cause direct damage or they may dissolve compounds releasing toxic metals that can damage plants and wildlife.

Most chemical reactions that take place in the troposphere and stratosphere involve free radicals. These are atoms or molecules and are characterized by 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 the formation of acid rain. The Atmospheric Chemical Kinetics program emphasizes quantitative studies of the rates and mechanisms of the important gas phase reactions of atoms and radicals. Studies are made over a wide range of temperatures and pressures to simulate conditions in the atmosphere.

Accomplishments FY 1985

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Two experiments, a laser magnetic resonance (LMR) spectrometer and a chemical-ionization flowing afterglow (CI-FA), are being 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. A 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. Experiments in other laboratories have provided indirect

evidence that the gas phase SO_2 oxidation process may not consume radicals. In FY 1983 our direct LMR study confirmed these experiments and showed that the OH radical that reacted with SO_2 in the primary process was regenerated as an HO_2 radical, when oxygen was present. We have now exploited this observation to conduct further studies of the intermediate, $HOSO_2$, radical. Using LMR spectroscopy to observe the HO_2 product of the $HOSO_2 + O_2$ reaction, we have measured the rate coefficient at room temperature. The yield of HO_2 has also been measured by LMR. The CI-FA experiment has been used to directly detect both the $HOSO_2$ reactant and SO_3 product. The rate coefficient for the critical $HOSO_2 + O_2$ reaction has been measured directly by following the $HOSO_2$ concentration.

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. In FY 1984 the rate coefficient had been measured as a function of temperature for the first time. Studies in FY 1985 showed that below room temperature the rate coefficient increased with decreasing temperature, but above room temperature it did not change with temperature. Such nonlinear behavior has been observed in other radical reactions.

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. The reaction of Na with N_2O was found to be an excellent kinetic source of NaO. Using this source, we studied the reactions of NaO with H_2, H_2O, CH_4, and NO. All react quite rapidly except CH_4 whose reaction is slow. One surprising result is that the $NaO + H_2$ reaction regenerates Na on about 30% of the collisions. This mechanism indicates an unusual amount of rearrangement for an elementary reaction. The diffusion coefficients of Na in Ne, Ar, N_2 and CO_2 were measured at room temperature. Some of the results were compared with other experimental data, using Chapman-Enskog theory.

The mechanism for the atmospheric oxidation of hydrogen sulfide, H_2S, is being investigated. The objective is to determine the extent to which this compound of natural origin can contribute to the production of sul- furic acid. The first study focused on the chemistry of the HS radical. First, two kinetic sources for generating HS in a discharge flow reactor were developed. Then by use of laser magnetic resonance (LMR) detection, the rate coefficient for the reaction of HS with NO_2 was measured. The value at room temperature is different by about a factor of 2 from the result published by another laboratory. It was proposed that previous data contained an error due to secondary chemistry. The HSO product of the $HS + NO_2$ reaction was also detected by LMR.

A new experiment employing a high-resolution Fourier transform spectrometer (FTS) was developed to evaluate the products and intermediates of atmospheric radical reactions. The experiment consists of radical sources, a

reactor, a 1.6-m-long multipass absorption cell with a high-speed pump, and the Fourier transform interferometer. Initial tests with this system demonstrated that product molecules are detectable at concentrations down to 10^{10} or 10^{11} molecules cm^{-3}. The first kinetics study with this experiment was on the reaction of OH with NO_2. This reaction is the major source of nitric acid (HNO_3) in the atmosphere and is an important removal process for both OH and NO_2 radicals. Our objective was to find if HNO_3 is the exclusive product of this important reaction or if the isomer peroxynitrous acid, HOONO, is also formed. Searches at several different wavelengths in the infrared region were unsuccessful, and no evidence of the HOONO species was produced. From infrared measurements of the amount of HNO_3 formed, it was concluded that the yield of HNO_3 is 80% or greater. The FTS was used also to record the absorption spectrum of all three of the fundamental infrared bands of the HO_2 molecule. These data demonstrate the potential of this experiment to take spectra of polyatomic transient species and they are useful in analyzing for HO_2 lines in atmospheric absorption spectra.

The reaction of HO_2 radicals with ozone is very important in stratospheric and tropospheric chemistry as a mechanism that destroys ozone.

$$HO_2 + O_3 \rightarrow OH + 2O_2$$

In the atmosphere it is coupled with the reaction of OH with ozone,

$$OH + O_3 \rightarrow HO_2 + O_2 \quad ,$$

and these taken together demonstrate how the odd hydrogen radicals OH and HO_2 can catalytically destroy ozone. There has been only one direct study of the $HO_2 + O_3$ reaction and that was done in the Aeronomy Laboratory about 5 years ago. The difficulty in studying this reaction is that the $OH + O_3$ reaction is much faster and regenerates the HO_2 reactant. The new approach to this problem was to use isotopically labeled HO_2 molecules that cannot be regenerated. Preliminary results at room temperatures using isotopically labeled oxygen in the HO_2 were in good agreement with the previous study.

A new experiment using pulsed laser photolysis and pulsed-laser-induced fluorescence was assembled. This apparatus was designed to study reactions at pressures up to 1 atmosphere. As a test of this system, the photophysics of NO were investigated. The radiative lifetime and some quenching rate coefficients for the first electronically excited state ($A^2\Sigma$) of NO were measured.

Several studies of ion-molecule kinetics were completed in collaborations with scientists at several institutions. The reaction of O_2^+ with CH_4 was studied under a wide variety of experimental conditions. Although this reaction is very complex, a great deal was learned about the details of its mechanism. The deactivation of excited diatomic species in ion-molecule reactions was also studied. Rate coefficients for deactivation of vibrationally excited N_2 by NO^+ and of electronically excited O_2 ($a^1\Delta$) by NO^+ (v=1) were measured.

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Plans FY 1986

The SO_2 oxidation study will be completed. The chemical ionization apparatus will be used to evaluate the temperature dependence of the $HOSO_2$ + O_2 reaction and to measure the yield of SO_3 from this reaction. An attempt will be made to determine the thermochemistry of the $HOSO_2$ radical by examining the reverse reaction, HO_2 + SO_3.

A new experiment utilizing vacuum UV photoionization mass spectrometric detection of free radicals will be developed. A prototype hydrogen Lyman alpha light source has been tested and has demonstrated a detection limit of about 10^8 molecule cm^{-3} for nitric oxide. As a first test of this experiment, the products of the NO^2 + O_3 reaction will be examined. The long-term objective of this experiment is to study the mechanisms for atmospheric hydrocarbon oxidation. These reactions are a central part of tropospheric chemistry since they play a role in oxidant production and they involve all major free radical families.

The studies of NO_3 radical kinetics will be continued. The next reactions to be examined are those of NO_3 with reduced sulfur compounds such as hydrogen sulfide and dimethylsulfide. Since NO_3 is a nighttime radical reactant, these studies will examine the possibility that there is nighttime radical chemistry involving sulfur species. If there are significant reactions among these chemicals, other reactive radicals may be produced, and perhaps other aspects of nighttime chemistry should be examined.

The kinetics of Na and its compounds will be extended to include studies of the temperature dependence of some selected processes. First, the temperature dependence of some Na diffusion coefficients will be measured. These results will be compared with the predictions of the Chapman-Enskog model, using published data on Na-inert gas potentials. The temperature dependence of some Na and NaO reactions will also be examined. Some reactions of NaO with organic compounds will be studied to determine how NaO reaction mechanisms parallel other reactants.

The analysis of the H_2S oxidation mechanism will be continued. First the temperature dependence and product analysis of the HS + NO_2 reaction will be completed. Then the kinetics of the HS + O_3 reaction will be examined. A study of HSO kinetics has been initiated. Some details of the kinetic sources of HSO still need to be established. The first studies of the chemistry of this radical will include the reactions of HSO with O_2, NO_2, and O_3.

The Fourier transform spectrometer will be used to examine the high-resolution spectrum of gaseous molecules. First, searches will be made for the transient species $HOSO_2$ and HSO. Both of these radicals are important intermediates in acid precipitation chemistry. Next, the reaction of HO_2 radicals with NO_2 will be studied to determine the relative yields of HONO and $HOONO_2$ products. The formation of significant amounts of HONO in this reaction would be an important finding because this molecule is rapidly photolyzed to produce highly reactive OH and NO radicals. The $HOONO_2$ molecule, on the other hand, has very different atmospheric effects. The high-resolution spectrum of $HOONO_2$ will be examined for the purpose of providing data that can be used to make quantitative measurements of $HOONO_2$ in the atmosphere, using infrared spectroscopy.

The kinetics study of the $HO_2 + O_3$ reaction, using isotope-labeled HO_2 radicals, will be completed. The mechanism of the reaction will be examined by measuring the yield of isotope-labeled OH product. A few other atmospheric reaction mechanisms will be studied using similar isotope-labeling techniques.

At night, N_2O_5 is a major odd-nitrogen reservoir in both the stratosphere and the troposphere. During sunlit hours, N_2O_5 is photolyzed to release the active NO_x species (NO_3, NO_2, and NO). The products of N_2O_5 photolysis are uncertain. NO_3 and $O(^3P)$ have been identified as products and their quantum yields measured in the wavelength range 248-305 mm. To completely understand the photolysis process, the quantum yields for NO as a function of wavelength are needed. The NO quantum yields will be measured by laser-induced fluorescence following N_2O_5 photolysis by an excimer laser or a Nd:YAG pumped-dye laser system. The wavelength range of 248 to 305 mm will be covered.

In the methane oxidation cycle a major subject of uncertainty is the chemistry of CH_3OOH. The rate coefficient for the reaction of OH with CH_3OOH, one of the CH_3OOH removal mechanisms, will be measured as a function of temperature. A pulsed Xe lamp will be used for photolytic production of OH. Pulsed-laser-induced fluorescence will be used to follow the OH concentration during the reaction. Information regarding the products of the reaction will be obtained by isotope-labeling the reactants. The quantum yield for the production of OH in the photolysis of CH_3OOH will also be measured using the same experimental technique.

Carbonyl sulfide (COS) is believed to be quite inert in the troposphere. But it is possible that its reaction with OH is enhanced by the presence of O_2, just as the analogous reaction of CS_2 with OH is much faster when O_2 is present at high pressures. This possibility will be investigated using the same apparatus and methodology as those used in the study of $OH + CH_3OOH$ reaction.

NO_3 is known to be an important intermediate in the troposphere as well as in the stratosphere. Its atmospheric concentration is usually measured using long-path absorption at 662-nm wavelength. To calculate concentrations from measured absorbances, the value of the absorption cross section at the atmospheric temperature is needed. Preliminary investigations have shown that the absorption cross section of NO_3 in the 662-nm band is temperature dependent, contrary to previous belief. Therefore, the temperature dependence of the entire NO_3 spectrum will be investigated. Two flowtubes will be used in tandem, in conjunction with two diode array spectrometers. By this method the relative changes in cross sections with temperature will be measured. N_2O_5 thermolysis will be used to produce NO_3, and titration with NO will provide the absolute NO_3 concentration. AL

The major source of odd-nitrogen in the stratosphere is the reaction of $O(^1D)$ with N_2O. The major loss process for N_2O in the stratosphere is photolysis in the 190-210 nm wavelength region. Experimental investigations will be carried out to assess the possibility of NO production directly from N_2O photolysis, and to measure the NO production rate from the $O(^1D)$ reaction with N_2O under stratospheric conditions. Laser-induced fluorescence detection of NO will be used to measure NO.

ATMOSPHERIC DYNAMICS

The objective of the Atmospheric Dynamics Program is to further our understanding of the dynamics of the atmosphere, particularly mesoscale and small-scale dynamics of the free atmosphere. Thus, we devote most of our research to the study of internal gravity waves (also called buoyancy waves), turbulence, etc. These mesoscale and small-scale processes are important for several reasons: (1) They are important problems in atmospheric and, more generally, geophysical fluid dynamics. (2) They are the meteorological background noise against which synoptic-scale measurements are made. (3) Gravity waves transport energy and momentum upward from sources in the lower atmosphere to sinks in the upper atmosphere. (4) Gravity waves are thought to be the source of all of the turbulence in the free atmosphere, which is the cause of most of the energy dissipation in the free atmosphere and part of the vertical mixing and transport of trace species. The study of mesoscale and small-scale processes takes advantage of the unique experimental and analytical capabilities of the group.

The observational base for the research of the Program consists largely of measurements of wind profiles obtained using the MST (Mesosphere-Stratosphere-Troposphere) radar technique. This technique measures the wind in the clear air, using very sensitive Doppler radars. Since such radars can measure wind profiles as often as every minute, about 1000 times faster than routine balloons or rockets, they are uniquely suited for studying phenomena that vary rapidly in time, such as gravity waves and turbulence.

Accomplishments FY 1985

AIR QUALITY

The MST radar technique measures the radial velocity versus time and radial range, leading to power spectra of radial velocity versus radial wavenumber. On the other hand, model gravity wave spectra are expressed in terms of vertical and horizontal velocities as a function of vertical and horizontal wavenumbers. In order to interpret MST radar spectra, we derived model radial spectra from the normal spectra. These model radial spectra agree well with radial spectra in the summer mesosphere observed by the Poker Flat MST radar near Fairbanks, Alaska, showing that the observed spectra were dominated by gravity waves.

The usual models of gravity wave spectra, and the fluid dynamical theories that support them, apply to intrinsic spectra, that is, spectra in a reference frame moving with the background wind. Radars, on the other hand, observe in a fixed reference frame, so that they observe a Doppler-shifted intrinsic spectrum. In order to gain insight into the meaning of the observed spectra, we started to develop a model for the calculation of Doppler-shifted spectra from intrinsic spectra.

We showed that, although the energy in gravity wave frequency spectra increases by a factor of several hundred from the troposphere to the meso-

sphere, the energy in vertical wavenumber spectra does not increase significantly. This anomaly has been explained in terms of a model for the saturation of gravity wave spectra as they propagate upward through the atmosphere.

In July and August 1983 we studied the generation of gravity waves by thunderstorms, or, more generally, the relation between gravity waves and thunderstorms, using an array of existing ST (stratosphere-troposphere) radars together with a network of 22 microbarographs in northeastern Colorado. We found that on some occasions the gravity waves and the thunderstorms move together, suggesting that the gravity waves initiate the convection and that perhaps the convection reinforces the gravity waves.

As the antenna-pointing direction of a radar operating at lower VHF frequencies is moved from an oblique angle to the zenith, the reflectivity is often greatly enhanced by partial specular or Fresnel reflection from horizontal stratification of the radio refractive index. However, there has been controversy over the dependence of the Fresnel reflectivity on the radar range resolution. Careful measurements of this dependence made with the Sunset radar showed that, in most cases, the reflectivity from stable layers was linearly proportional to the effective length as predicted by simple theory; in a small fraction of cases the reflectivity varied as a larger power (up to 2) of the effective length.

From 23 January to 10 February 1984 and from 23 January to 1 March 1985, the Sunset radar was used to measure the wind, particularly the vertical component, over the Front Range of Colorado in an FAA-sponsored experiment to assess the reliability of aircraft altimeters over mountains. As part of this experiment, many other meteorological sensors were operated by the FAA, NCAR, WPL, and NWS.

The rapid, ground-based measurement of wind velocity is an important meteorological capability of ST radars. The Sunset radar was used to test the consistency of ST radar wind measurements by comparing horizontal vectors calculated in several ways from the radial velocities measured with five antenna beam positions. It was found that the inclusion of the measured vertical velocity in the calculation of the horizontal wind vector velocity results in a significant improvement in the estimation of the horizontal wind velocities.

Plans FY 1986

AL

AIR QUALITY

We will continue to study the gravity wave field and its effects. In particular, the model for radial velocity spectra will be generalized to include wave fields that are azimuthally anisotropic. The parameters of the anisotropic spectra will then be determined by comparing the model with observations from ST radars. These anisotropic spectra will be used later to examine gravity wave propagation (and subsequent transfer of horizontal momentum) from the troposphere through the stratosphere into the mesosphere. The model study of Doppler-shifting of intrinsic spectra will be completed.

Studies of the vertical flux of horizontal momentum will be extended, using data from the Sunset radar and other radars.

We will also continue to study methods of deriving the total wind vector from radial velocity measurements. This study is particularly timely because of the development of ST radars or wind profilers for operational wind sounding and their use in major experiments such as the STORM-Central phase of the National STORM Program, which will deploy up to 70 ST radars.

Most existing middle- and high-latitude ST radars are in or near regions of strong topographic relief. The lee waves generated by the terrain often vitiate the interpretation of the data. For the nation to have radar capability in a location free from this effect, we have proposed to the National Science Foundation to construct and operate a state-of-the-art ST radar in very flat terrain near Urbana, Ill. University atmospheric science groups will collaborate, both in experiments and in the analysis of data. Extensive design studies have been conducted using existing radar data to determine the optimum system configuration for the proposed experiments. Innovations resulting from these studies are being tested with the Sunset radar. If the Flatland radar is funded, studies with it will constitute a major new direction for the Air Quality program.

TROPICAL DYNAMICS AND CLIMATE

A growing awareness of the profound role of the tropics in influencing our global weather and climate patterns has resulted in the formation within the Aeronomy Laboratory of the Tropical Dynamics and Climate/Program.

In general terms, the purpose of this newly formed program area is to study, by radar techniques and ancillary data bases, the effects of small- and meso-scale dynamic processes (e.g., gravity waves, turbulence, and convection) in the tropical atmosphere on worldwide climate. Associated tasks include studies of relatively short-term climatic variations, exemplified by the recent El Niño event, which had disastrous effects over a significant portion of the globe.

The Tropical Dynamics and Climate program can contribute uniquely to such studies by making use of its extensive expertise in developing and using wind-profiling radar systems. Wind profilers were originally developed by AL scientists as an outgrowth of initial studies at Peru's Jicamarca Radar Observatory, itself a former AL project. The Laboratory designed the large MST (mesosphere-stratosphere-troposphere) radar at Poker Flat, Alaska, and has operated it for the past 6 years. AL recently established a pair of more conventional profilers in the tropical Pacific at Ponape (E. Caroline Islands) and Christmas Island (Republic of Kiribati). Similar systems have been used in temporary experimental programs in Colorado, Oklahoma, and Southern France. The Laboratory also designed and operates, with WPL, a profiler in Platteville, Colo., that served as a prototype system for WPL's current program to establish a mesoscale network of similar systems throughout the Midwest, to provide high-resolution wind profiles for the National Weather Service.

Wind profilers are capable of providing height profiles of the total wind vector, atmospheric waves and turbulence, spectral kinetic energy density, and gravity wave momentum flux. They can also provide a continuous measurement of the tropopause height. In addition to their ability to obtain continuous data, another major advantage of profilers over more conventional balloon-borne systems is that profilers measure the vertical wind. Although this parameter is considered to be a major factor in a variety of atmospheric processes, it is virtually unmeasurable on a continuous basis by any other technique. Profiler operation is continuous, relatively inexpensive, and essentially unattended.

Accomplishments FY 1985

CLIMATE

The Aeronomy Laboratory's Poker Flat MST radar in Alaska ceased normal operation in April 1985, following more than 6 years of almost continuous data taking. During this period, the radar produced data on atmospheric winds and related parameters in the troposphere, lower stratosphere, and mesosphere. Technological spin-offs from Poker Flat resulted in the formation of at least one small business in Boulder's private sector. This radar, which was funded primarily by the National Science Foundation, is being reconfigured and the existing data set is being archived for use by the scientific community (see Plans, FY 1986).

The Ponape wind profiler, which was established in the Central Pacific in May 1984, produced some 16 months of continuous data on vertical winds in the troposphere and lower stratosphere. A preliminary analysis of the mean vertical motion showed upward motion in the troposphere during convective episodes and weak downward motion at times of little or no convective activity. Spectral analysis of the quiet periods between convective episodes revealed a power spectrum very similar to the observed spectrum of internal waves in the ocean.

A second profiler in the tropical Pacific is being established on Christmas Island (Republic of Kiribati) with funding from Project TOGA (Tropical Oceans and Global Atmosphere). In addition to the high-time-resolution data obtained for analysis within the program area, 6-hourly data from the Christmas Island radar will be telemetered via GOES satellite and transferred automatically onto the Global Telecommunication System (GTS) for worldwide distribution. Establishment of a remote wind profiler on Christmas Island represents a major milestone in remotely monitoring winds from remote locations.

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Using theories developed in-house, we established that profiler echoes can be used to continuously monitor the height of the tropopause with an rms error of a few hundred meters. Radar determination of the tropopause to this accuracy is more than adequate to aid the retrieval of temperature profiles, using satellite and ground-based radiometry.

We have compiled a climatology of the quantity of C_n^2, using long-term observations of radar reflectivities from Poker Flat and Platteville. This

quantity is very important in electromagnetic wave propagation in the atmosphere, as well as a useful proxy indicator of eddy dissipation rate, an important parameter of atmospheric turbulence. The climatological studies revealed that C_n^2 is log-normally distributed and has significant seasonal and diurnal variations.

Frequency spectra of vertical velocity fluctuations in the troposphere and lower stratosphere were obtained by profilers from a variety of geographical locations. Comparisons of these spectra, which were obtained at sites from the Arctic to the Equator and from the central plains to the middle of the ocean, show remarkable similarities but some significant differences, and attest to the general universality of the spectrum of vertical atmospheric motions.

In addition to measuring frequency spectra by radar, we recently completed a climatological study of wavenumber spectra of winds and temperatures measured by commercial aircraft during routine flights. Briefly, the analysis reveals the remarkable result of a nearly universal and comparable spectrum for wind and temperature. Scale sizes ranging from a few kilometers to 5,000 km are resolved in the analysis.

A direct measurement of the mean large-scale vertical motion of the atmosphere was achieved by averaging vertical velocities measured by a wind profiler at a single station. Under ideal conditions, it can be demonstrated that these directly measured vertical velocities are comparable with vertical velocities inferred from NMC analyses. In a related case study, vertical motions observed by the Platteville radar were shown to be well correlated with rainfall rates observed nearby during an upslope storm.

Height profiles of the average kinetic energy density of the atmosphere were extracted from the Poker Flat MST radar data base. The results are consistent with the idea that atmospheric gravity waves, which are generated in the troposphere, grow in amplitude as they propagate upward into the more rarified atmosphere. This growth is limited by wave saturation; the excess wave energy is eventually deposited into in situ turbulence or modifies the local mean flow. The emerging picture is one in which large height regions of the atmosphere, between 1 and 100 km, contain a fully saturated spectrum of waves. In other height ranges, specifically in the lower stratosphere, wave saturation is not complete because the upward-propagating waves are being modified by other processes.

A study of interannual variability of tropopause heights over a wide range of tropical longitudes from the western Pacific to the eastern Atlantic was completed. The height of the tropopause was found to vary coherently over this spatial range on interannual time scales, and to be related to both the quasi-biennial oscillation in tropical stratospheric winds and to the phase of the southern oscillation.

A relationship between tropical tropopause heights and the global angular momentum of the atmosphere found earlier, using monthly mean data, was extended using atmospheric angular momentum data at 3-day intervals. Preliminary results showed that the correlation takes place mainly within the tropics themselves; i.e., there is a highly significant correlation between tropopause height variations in the western tropical Pacific and variations in the

height-integrated, zone-integrated winds in the ±15° latitude belt. The interpretation of these results is not yet complete, but the key role of tropical convective activity in the global-scale dynamics of the atmosphere is already clear.

The effect on tropopause heights of the stratospheric aerosol cloud generated by the eruption of the El Chichón volcano in April 1982 was investigated using data from the western tropical Pacific. The behavior of tropopause heights and potential temperatures leads to the conclusion that the influence of El Chichón was largely canceled out by the opposing influence of the great ENSO (El Niño/Southern Oscillation) event during the latter half of 1982.

Also, using the long-term data base of tropospheric, stratospheric, and mesospheric wind available from Poker Flat, we investigated possible changes in velocity fluctuation statistics following El Chichón. In the lower atmosphere, the variance of horizontal winds was found to be significantly lower in early 1983 compared with 1982 and 1984. At mesosphere altitudes, an increase in tidal energy was found. This increase would be expected to follow enhanced heating in the lower stratosphere.

Plans FY 1986

CLIMATE

As mentioned before, the Poker Flat MST radar is being modified for a beam-steering capability in order to measure gravity wave momentum flux (GWMF) and associated phenomena. The determination of a climatology of GWMF is considered to be a crucial factor in our eventual understanding of global atmospheric circulation.

An additional effort will be to prepare an archive of the Poker Flat 6-year data set. This archive, when complete, will be transferred to the National Center for Atmospheric Research (NCAR) for use by the scientific community. The data set will also continue to be studied within the program area to establish long-term trends in gravity wave and turbulence activity, and the seasonal characteristics of the height distribution of these parameters.

The vertically directed radar profile at Ponape, which produced continuous vertical wind data, will also be reconfigured into a beam-steerable system for GWMF measurements. These measurements will provide an exciting first look at the vertical distribution and character of GWMF in the tropics.

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Operation of the Christmas Island profiler will begin, following the installation of a diesel generator to provide continuous power to the station. Inclusion of the Christmas Island data set in our existing Ponape data set will stimulate a number of preliminary studies of the short-term dynamics of the tropical atmosphere.

In addition to our activities at Ponape and Christmas Island, we will continue to examine other sites to complete our Tropical Pacific chain. In

general, the most crucial tropical regions that should be included lie in the western edge of the Pacific Basin (i.e., near Indonesia and Malaysia) and in the region containing the Galápagos Islands and the Ecuadorian-Peruvian coast. Preliminary site surveys have been made in both regions.

We will begin an intensive study of the climatology of convective dynamics by combining the existing 16-month data set from the Ponape radar with additional data sets from satellites and rawinsondes. In addition, if we can identify the small, long-term mean vertical motions in the radar data associated with the large-scale Hadley and Walker circulation cells, we will begin to explore the variability of these circulations within the context of the broad-scale features of tropical dynamics being explored by TOGA.

Study of the tropical tropopause region, using radiosonde data, will continue. Emphasis will be on (1) completing the study of the relationship between tropopause heights and atmospheric angular momentum, (2) studying the effects of the ENSO event of 1982-83 on the tropical tropopause region, (3) investigating the relationship between anomalies in Pacific sea surface temperatures and in atmospheric temperatures in the tropical upper troposphere and lower stratosphere, and (4) developing a conceptual picture of the mechanism of troposphere-stratosphere exchange in the tropics.

In order to improve this lower limit of current profile technology and to provide higher resolution in the first 2 to 3 km of the atmosphere, we are designing an inexpensive "Boundary Layer" radar that will operate at much higher frequencies and be capable of observing the region between about 300 m and 2 to 3 km altitude. This system will supplement our existing VHF system on Christmas Island.

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 1985

The Atmospheric Waves and Turbulence program (1) calculated the manner in which a gravity wave "breaks" in the atmosphere, and presented arguments to

establish this "breaking" to be the principal process by which waves cause mass transport in the atmosphere; (2) determined the influence of stable stratification on the pressure-strain term, a crucial term of boundary layer models; (3) explained observed (MST) mesosphere-stratosphere-troposphere radar spectra as being caused by strongly interacting gravity waves with an important consequence for atmospheric transport; (4) determined the spectrum of temperature fluctuations in atmosphere and oceans, and corrected a commonly quoted 20-year-old error in the literature concerning such spectra; (5) proved that "return to isotropy"--the principal hypothesis of turbulence models--is invalid, and developed a theory to determine realistic deviations from isotropy; (6) theoretically determined how observed height variations of gravity wave amplitudes can be used to infer eddy diffusivities in the middle atmosphere; (7) discovered a nonlinear instability by which gravity waves cause local fluid overturns and turbulence in the middle atmosphere.

Plans FY 1986

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 methods of turbulence theory. This year's goal is to calculate the influence of stress and dissipation anistropy upon the planetary boundary layer.

- Develop theory to explain the turbulence "collapse" phenomena recently observed in laboratories, and almost certainly occurring in the atmosphere.

- Continue efforts to explain theoretically, and calculate, the apparently universal spectrum observed for vertical scales of fluctuations in oceans and the atmosphere.

- Determine if there exists a theoretical relationship between observed temperature and velocity fluctuations in the atmosphere.

- Continue work applying theory to the boundary layer model currently used by the Naval Environmental Prediction Research Facility (NEPRF). Eventually, the NEPRF facilities will be used to test and expand the theory.

Planned studies of gravity waves include continuation of theoretical investigations of the spectral distribution, and harmonics, of atmospheric gravity waves; theoretical search for unidentified instabilities by which gravity waves cause turbulence and transport; continuation of 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 circulation, the role of tidal waves in atmospheric diffusion, and the interaction of gravity waves with airglow and minor atmospheric constituents; determination whether there is a connection between gravity wave heat flux and temperature spectra in oceans and atmospheres. Major effort will be given to determine the nonlinear properties of gravity waves from a rigorous, yet simple, analytical approach.

AL

SPACE ENVIRONMENT LABORATORY
Boulder, Colorado

Harold Leinbach
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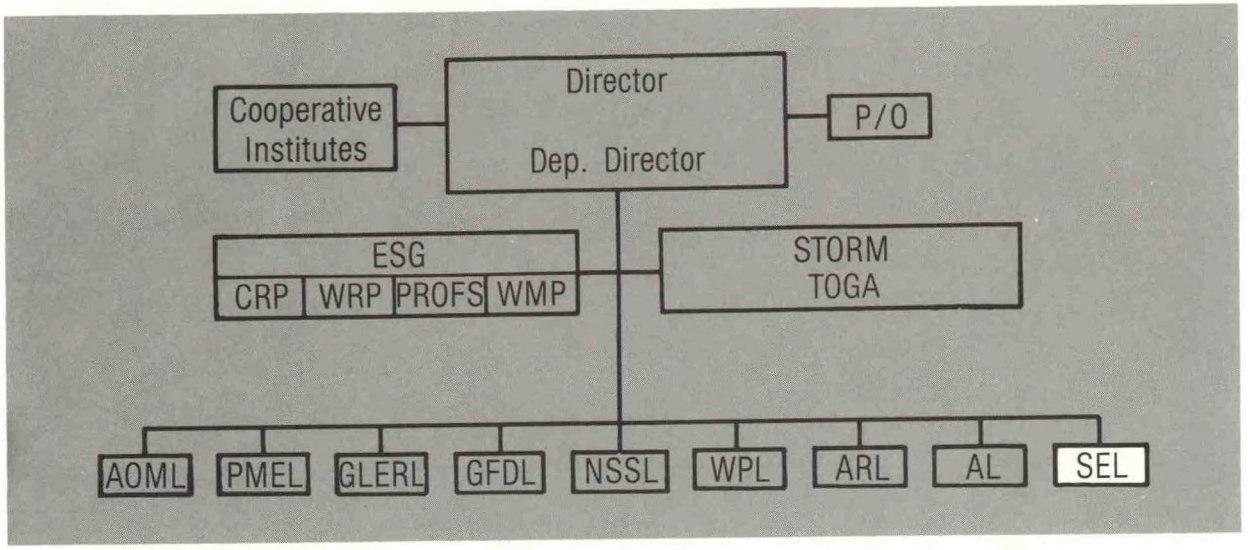

The Space Environment Laboratory (SEL) is unique in ERL in providing around-the-clock, real-time forecasts and warnings of solar and space disturbances, and at the same time, conducting research to support and improve the service activities.

The center of the nation's present solar-terrestrial services is the Space Environment Laboratory at Boulder, Colo., where, with the cooperation of the U.S. Air Force Air Weather Service (AWS), monitoring and forecasting services are carried out to meet a wide variety of civilian, military, commercial, and Federal agency requirements. Laboratory activities include real-time collection of solar-terrestrial data, issuance of forecasts, alerts and warnings of adverse solar-terrestrial conditions, archiving and processing of global data from satellites and observatories, and development of a better understanding of the behavior of the solar-terrestrial environment to yield significant service improvements.

SEL is composed of three Divisions: 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.

The accomplishments of 1985 include these highlights:

- The new Space Environment Laboratory Data Acquisition and Display System (SELDADS II) was dedicated. It will be steadily improved and tested before it completely replaces the old system.

- The SEL Solar Image System (SELSIS) began operation, acquiring solar images from Kitt Peak National Observatory and Holloman AFB in digital form. The system will be expanded and improved to take advantage of

higher resolution of images and capabilities for data manipulation inherent in the digital data.

- An initiative for the installation of Solar X-Ray Imagers on GOES satellites I-M was submitted.

- As a pilot project, SEL collaborated with the Computer Science and Psychology Departments of Colorado University to construct a small expert system emulating sunspot classification and solar flare forecasting methodology.

- A new scientific workstation system was begun to provide interaction with the DOC and SELDADS II computer systems for the display and manipulation of scientific data.

- The Space Environment Services Center (SESC) provided solar-terrestrial support to the Shuttle program, particularly Shuttle orbiter Challenger/Spacelab 2 having a complement of solar telescopes that made new discoveries about the Sun.

At the end of FY 1985, the President's budget for FY 1986 did not include full funds for SEL research.

SPACE ENVIRONMENTAL SERVICES

The Space Environment Services Division contains the Space Environment Services Center (SESC) and Real-Time Data Services (RTDS). SESC is operated jointly by the National Oceanic and Atmospheric Administration (NOAA) and AWS. SESC provides 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. The Real-Time Data Services group collects and processes data from NOAA satellites and ground sensors operated by cooperating agencies 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 disturbed 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 geomagnetic storms. The U.S. Navy issues corrected satellite ephemerides based on the forecast or observed level of geomagnetic 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 1985

The Space Environment Products and Services listed below were provided throughout the year in accordance with an interdepartmental agreement on standard products and services required to meet the multiple needs of various Federal agencies and public users (see National Plan for Space Environment Services and Supporting Research, 1983-1987, NOAA, FCM-P10-1983).

Space Environment Products and Services
Monitoring Reports
Solar-geophysical indices (broadcast)
Daily High-Frequency Radio Propagation Report
Solar-Geophysical Activity Summary (daily)
Solar Region Summary (daily)
7- and 27-day outlook (weekly)
Solar and geophysical alerts and warnings (as required)
Preliminary Report and Forecast of Solar-Geophysical Data (weekly)
Primary Report on Solar and Geophysical Activity (daily)
General purpose data base (SELDADS)
Alerts
Solar X-ray index (2 thresholds)
Geomagnetic K index (4 thresholds)
Geomagnetic A index (3 thresholds)
Magnetic storm sudden commencements
Solar protons (2 thresholds)
High-altitude radiation hazard (1 threshold)
10-cm solar radio flux (1 threshold)
245-MHz solar radio flux (2 thresholds)
Type II, Type IV solar radio bursts
Forecasts
Proton events
Geomagnetic variation
X-ray flares
10-cm flux
General level of solar activity
Smoothed sunspot number

SEL

In addition to the standard services provided to Federal agencies, universities and research groups, commercial users, the general public, and cooperating foreign countries, reimbursable special support was provided to the NASA Solar Maximum Mission at NASA/Goddard Space Flight Center and to the Spacelab 2 and 3 missions at the NASA/Johnson Space Center.

Data sources used in operation of SESC the previous year were continued (see Programs and Plans 1984-1985). Coverage of solar wind disturbances from the NASA Satellite ICE (Interplanetary Cometary Explorer) degraded as the satellite moved away from Earth toward its encounter with the Comet Giacobini Zinner.

During 1985, solar flare activity was low; thus most geomagnetic activity was associated with coronal holes and disappearing filaments. Such activity is more difficult to forecast than geomagnetic activity following large, highly visible solar flares. Geosynchronous-satellite operators were increasingly concerned about spacecraft charging, which can result in loss of data, upsets of satellite orientation, or damaged electronic components. While the cause-and-effect relationships are still being established, satellite users are attempting to use currently available space environment data in formats not well suited to the problem. Talks were initiated with user agencies regarding the development of indices and other standardized ways to provide information to the user agencies.

Only 20% to 30% of all solar events including solar flares and energetic particle events are "geo-effective", i.e., produce geomagnetic storms. Research indicates that solar mass ejections may be the key to understanding whether solar activity of various kinds will affect the Earth. Following this lead, the SESC staff began studies aimed at identifying the characteristics of solar mass ejections that cause magnetic storms; they are using real-time data from solar mass ejection monitors flown by the U.S. Naval Research Laboratory on Defense Department satellites.

The SESC staff also participated in working groups to help the U.S. Air Force define requirements for the next generation of satellite-borne solar monitors, and to define the requirements for and the benefits to be gained from an X-ray imaging telescope on the GOES satellite.

Phase I in the implementation of the Space Environment Laboratory Data Acquisition and Display System (SELDADS II) was completed; the system was installed and attained much of the capability of the older system early in the year. Capabilities will increase as software is implemented in Phases II and III. The system comprises eight micro-based computers networked with a super minicomputer to provide parallel, redundant processing for the collection, storage, editing, analysis, and transmission of data, forecasts, indices, and alerts into and out of SESC.

Networking of the system was completed, and a project to design and install the software began. Software design is being driven by a set of service requirements developed by the operational forecast center staff. Design and implementation are being done by a group of analysts, engineers, and programmers from the Services Division and Support Division.

A preliminary stage of the Space Environment Laboratory Solar Imaging System (SELSIS) was used to support the Spacelab 2 mission. Digitized solar images were collected from Holloman AFB and Kitt Peak National Observatory and displayed at SESC and at the Science Area of NASA/Johnson Space Center, Houston, Tex.

Changes in communications included conversion from the obsolescent Astro-geophysical Teletype Network to the modern Continental U.S. Meteorological Data System (COMEDS) network, and a growth in numbers of users of the SESC satellite broadcast network. This broadcast system permits users to receive SESC services directly on their own commercially available receivers, as broadcast from a commercial satellite.

Plans FY 1986

The standard complement of services, including forecasts, alerts, indices, and advisories, will continue to be provided by SESC.

Studies into the nature of solar mass ejections will continue. A system of numerical guidance will be developed and put on line for the forecast staff. A climatological data base, for use in geomagnetic forecasts and solar flare forecasts (based on models using parameters provided by the USAF Solar Observing Optical Network [SOON]), will be established.

A "core" system of SELDADS II will be put into operational service later in the year. The functions provided will be sufficient to allow the shutdown of the old SELDADS system after a period of parallel operation. The follow-on phases of SELDADS II will include the provision of numerical guidance programs, full real-time handling of all satellite and magnetometer data (exceeding the capacity of the old system), and a verification system for continuous evaluation of SESC forecasts and other forecast models.

A set of forecast user and operational requirements will be developed for SELSIS software to analyze solar images, which is now done manually. Follow-on phases will develop new solar forecast analysis procedures, using digital image processing such as image subtraction techniques.

A study will be completed in cooperation with the USAF, and recommendations will be made regarding the future of the High-Latitude Monitoring Station at Anchorage, Alaska, which is now jointly operated by the USAF and NOAA.

DEVELOPMENT

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. **SEL**

Accomplishments FY 1985

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 Space Environment Services Center (SESC). The provision of instruments to

replacement spacecraft and the development of new or improvement of existing instruments for spacecraft is, therefore, a very important supporting activity.

Instruments are normally produced by contractors (or subcontractors) to NASA, which acts in turn to supply NOAA with the entire operational satellite. SEL sets the requirements for the SEM systems and assists with the technical supervision of the instrument contractor. SEL has been asked by NASA to perform recalibration and repair on off-the-shelf instruments awaiting flight and also recently was asked to assemble for the GOES-H program one new instrument, a High Energy Proton and Alpha Detector (HEPAD), from existing spare parts. This detector provides operational information on radiation hazards caused by very-high-energy solar particles during some solar flare events. The new detector was substantially completed in FY 1984. After acceptance testing and calibration, the instrument was delivered to the contractor for systems integration in January.

The existing TIROS instruments awaiting flight were supported as necessary. Two Medium Energy Proton and Electron Detector (MEPED) units were checked and requalified for flight. Actual repairs were necessary because of component failures in one of the MEPEDs and also in the GOES HEPAD.

The GOES NEXT program was supported by providing evaluations of the bidders' proposals for the SEM system. Unlike previous spinning GOES spacecraft, the new satellite will be a three-axis stabilized vehicle. This will require changes in the design of the SEM instruments, and it will be necessary to work closely with NASA and the contractor in the coming year to ensure satisfactory SEM performance.

The effort to provide an operational Solar X-Ray Imager instrument was supported with analysis of the GOES-NEXT contractor's proposal. Off-line processing of data from the TIROS and GOES spacecraft continued routinely during FY 1985. The major programming effort was to realize the real-time processing of TIROS and GOES data in the new SELDADS II system.

SELSIS—SEL SOLAR-IMAGING SYSTEM

SELSIS will replace the present SESC system that handles solar image data in photographic form and transmits by analog wire photo systems. Data will be handled in digital form from the earliest possible stage. The benefits expected are greatly improved image quality and, most important, the ability to combine image data from more than one source and carry out quantitative image processing.

The overall system will comprise (1) the observatory processors that collect the image data at the various cooperating observatories and make it available for transmissions to Boulder, and (2) the central SELSIS in the SESC, which collects and processes the image data, and makes them available to the SESC forecaster. During FY 1985 the design of the observatory processor system was completed. It is based on standard personal computer hardware and advanced adaptive modem technology for dial-up lines. Observatory processors were installed at the AWS Holloman AFB solar observatory in New Mexico, and at Kitt Peak National Observatory in Arizona. An observatory processor was also

installed in SESC as a temporary substitute for the more powerful SELSIS system. It permits the forecasters to obtain and view high-resolution digital images from the two observatories, although there is no processing or hard copy capability. During the recent shuttle-launched Spacelab 2 mission, a compatible system was installed at Johnson Space Center in Houston. This enabled Spacelab scientists to receive the SELSIS imagery as an aid to planning the pointing of their high-resolution solar-viewing experiments.

Development of the full SELSIS system, which is based on an advanced high- resolution color workstation, is proceeding. Software for the communications and for basic image display has been completed.

DEVELOPMENT OF EXPERT SYSTEMS

Knowledge-based "expert systems" attempt to capture on computer the knowledge of a human expert in a limited domain and make this knowledge available to a user with less experience. Such systems could be valuable as an assistant to a forecaster or for training purposes. In a pilot project during FY 1985, SEL collaborated with the Computer Science and Psychology Departments of Colorado University in Boulder to construct a small expert system emulating a methodology for sunspot classification and solar flare forecasting developed in SEL. The project convincingly demonstrated the possibilities of this type of computer assistance, which also proved to be a useful tool for formally expressing a methodology and verifying its performance. The system, which has been named THEO, performed as well as a skilled human forecaster using the same methods, and scored well compared with actual SESC performance in the period covered by the test data.

SEL SCIENTIFIC WORKSTATION SYSTEM

With the development of high-performance 32-bit microprocessors and high-resolution graphics systems, it is now feasible to consider a single workstation for a scientist's desk, to interact with computer systems and display scientific data. The local computational capability provides rapid source code editing and debugging, and networking to other workstations and to the DOC mainframe scientific computer system which provides the power for major computations and the capability to return the results for graphical display and manipulation.

During FY 1985, three workstations, one with multicolor display and two with monochrome, were delivered and installed for individual users. A fourth, multicolor-display, workstation will be used for developing image-processing techniques for SELSIS. The workstations are networked with a 12 Mbit/second token ring system, which permits transparent sharing of the network resources. A number of scientific applications requiring graphical output were successfully transferred to the workstation system and a number of graphic display tools were developed.

Plans FY 1986

OPERATIONAL SATELLITE INSTRUMENTATION

We will continue to support the SEM instrument systems on TIROS and the existing GOES series as well as working to ensure that the GOES-NEXT system will meet our needs. A new instrument procurement for TIROS will be initiated. The off-line data processing and data quality control system will be integrated into SELDADS II as this new system is brought into operational use.

SELSIS—SEL SOLAR-IMAGING SYSTEM

The first stage of the development of the SELSIS system will be completed and the system installed in SESC. This will permit incoming images to be scaled, rotated, and gridded so that the forecaster will have a uniform presentation and the capability of accurate position location. SELSIS will also include a high-quality laser printer system for producing hard copy.

DEVELOPMENT OF EXPERT SYSTEMS

We plan to extend the pilot system to include additional solar data and to continue work on verification. We will study other possible applications of knowledge-based expert systems to the SESC operation.

SEL SCIENTIFIC WORKSTATION SYSTEM

Five more monochrome-display workstations will be added and network gateways to the SELDADS II MV10000 computer and to the DOC scientific computer system will be installed. Software will be made available for preparing technical documents, and communications from the existing administrative and word processing 8-bit microprocessor network will be added.

RESEARCH

The Research Division carries out research in solar-terrestrial relations, with the objective of improving our understanding of the effects of solar activity on human activities.

Accomplishments FY 1985

SOLAR PHYSICS

The objective of the Solar Physics project is to improve medium and long-term solar predictions and to understand the structure and evolution of the solar corona to improve prediction of solar disturbances. During the past year, the activities of the project concentrated on the following:

Expert Systems

The group provided the input to the rule base and supported extensive testing and verification of the prototype expert system for solar flare forecasts. This system is based on the white light sunspot group classification developed by this group and on the group's research relating solar flares to sunspot structure and evolution.

Solar X-Ray Imager

The installation of operational solar X-ray imagers (SXI) on board the GOES-NEXT geosynchronous satellites was a major objective of the Laboratory. A single-instrument concept had been selected that incorporated soft X-ray and extreme ultraviolet (EUV) imaging. The SXI, as a part of the Space Environment Monitor (SEM), will contribute important improvements to predictions of proton flares, geomagnetic storms, and real-time EUV heating of the thermosphere. In a major effort, the Laboratory continued to explore the operational value of the X-ray imager as a forecasting tool and encouraged its implementation on the new GOES series of spacecraft. As a result, the National Environmental Satellite, Data, and Information Service (NESDIS) proposed an FY-1987 initiative for installation of five SXIs on GOES-I through -M and NOAA's Office of Oceanic and Atmospheric Research (OAR) proposed an FY-1987 initiative for supporting research and technique development. SEL also sought interagency funding for the program. The NOAA-proposed initiative has been deferred to FY-1988 for budgetary reasons, but provision will be made on the spacecraft for the SXI to be added as a plug-in option when funding becomes available.

Solar Maps

The ability to prepare solar synoptic maps by computer, facilitated by acquisition of the scientific workstation system, has enabled high-resolution color graphics to be employed in the generation of maps and, more important, for the study of time series of maps. Solar maps for approximately 2 years were entered into the data base for use in the development and testing of computer programs for display and analysis of solar atmospheric dynamics. Both color and black-and-white versions of solar maps, with all labels and legends, can be displayed on the workstation screens. Solar maps have led to the introduction of a new model for the formation and evolution of sunspots, based on the fact that sunspots form in preferred locations with respect to the large-scale patterns of magnetic fields that precede sunspot formation. A threat to solar mapping is the possible closure of two major observatories that provide solar data--Mount Wilson and Sacramento Peak. **SEL**

Solar X-Ray Studies

By use of data from the full-disk, X-ray monitor on the GOES satellites, a new method was developed for determining flare temperatures and densities as a function of time. With densities, it is possible to calculate other phys-

ical properties of the flare plasma, such as volume, mass, total thermal energy, gas pressure, radiative loss, and conductive loss.

Solar Magnetic Structures

A model of a solar prominence, based on eigenvalue solutions, was constructed. The model described topologically different magnetic configurations with continuous magnetic field and finite magnetic energy. The thermodynamic parameters, including the total mass of a prominence, calculated by the model agreed well with observations. The eigenvalue approach has been extended to a three-dimensional model of the solar atmosphere. Force-free electromagnetic oscillations were proposed as an important physical process in magnetized-ionized atmospheres. It was proposed also that, during solar flares, force-free electromagnetic solitons are formed.

Solar Activity

To study the evolution and persistence of solar active and inactive longitudes, a 14,000-item data base was created covering nearly three sunspot cycles (1956 to 1982). A specific objective is to establish whether the change from domination of the solar disk by active longitudes to domination by inactive longitudes occurs in a discontinuous manner. A by-product of this study is information on the asymmetry between the northern and southern solar hemispheres, needed for planning the Solar Polar Mission.

INTERPLANETARY PHYSICS

The objective of the Interplanetary Physics Project is to improve forecasts of the occurrence, duration, and severity of geomagnetic storms through the development of magnetohydrodynamic (MHD) models of the propagation of solar disturbances through the solar wind.

Arrival Times of Flare-Generated Shock Waves

An operational "shock wave" algorithm was developed in which real-time observations of solar radio bursts, from flares detected by the USAF Radio Solar Telescope Network, are input to calculate the time-of-arrival at Earth of the shock wave. Impact of the shock wave on the Earth's magnetosphere can initiate a geomagnetic storm when the dynamic pressure of the solar wind and (or) the polarity of the interplanetary magnetic field (IMF) are appropriate.

Propagation of Solar Wind Disturbances

Two interplanetary models have been developed: a $2\frac{1}{2}$-dimensional ($2\frac{1}{2}$-D) model confined to the ecliptic plane, and a fully three-dimensional (3-D) model. The $2\frac{1}{2}$-D model was transferred to SEL's scientific workstation system and provides a cost-effective tool for two purposes: (1) sensitivity tests for solar input parameters and (2) a test-bed for operational usage. The 3-D

model, designed for eventual input of solar X-ray images, was tested on a CRAY-1 computer. The models provide geoeffective parameters such as solar wind dynamic pressure, solar wind power, and the IMF polarity, all of which are crucial diagnostics for predictive capability.

Solar-Terrestrial Environment Model

With the collaboration of external scientists and the Department of Defense, a strategy was developed that holds promise for tracking disturbances from the Sun to the auroral ionosphere and thermosphere. A composite model was devised that inputs photospheric data into a 2-D chromospheric and coronal model and whose output serves as input to a 1-D interplanetary model. The output of the latter model provides the starting point at the Earth's magnetosphere for the propagation of a disturbance through the magnetosphere to the 300-km level of the auroral atmosphere. This permits calculation of the temporal profile of energy input to the thermosphere, which indicates possible atmospheric density increases by a factor of 10. The energy deposited into the auroral ionosphere agrees with that required to account for the short-time (minutes) increases in the ultraviolet intensities observed by the Dynamics Explorer satellites. The neutral density increase at 300 km, over several hours, is sufficient to explain observed satellite drag.

Multi-Fluid Solar Wind Studies

To improve the existing models of the solar wind, two changes were introduced: (1) The spatial scales over which the magnetic field in the solar wind can change polarity were reduced to 10^5 km. (2) The importance given to multi-fluid structure (e.g., protons and electrons) was increased. The change allows short-time-scale processes caused by non-neutrality and results in coupling by means of electric fields. The results will be combined with earlier work that incorporates realistic dissipative effects such as thermal conductivity, temperature anistropies, and non-Maxwellian energy distributions. The use of small spatial scales in the interplanetary models will result in more accurate prediction of IMF polarity changes and, therefore, more accurate predictions of the coupling of energy between the solar wind and the magnetosphere.

MAGNETOSPHERIC PHYSICS

The objective of the Magnetospheric Physics Project is an improved understanding of the dynamical processes by which material and energy are transported from the solar wind into the magnetosphere, stored, and eventually dissipated in the Earth's ionosphere. Both applications and research are pursued to improve the quality and utility of the Laboratory's products and services. **SEL**

Polar Cap Studies

The Earth's magnetic field restricts the direct entry of charged energetic particles. Low-energy protons can reach the Earth's atmosphere only in the polar regions, whereas higher energy protons can reach the Earth at lower

latitudes. Energetic protons from solar cosmic ray events represent a radiation hazard to space activities and high-altitude aircraft. A preliminary computer procedure was developed that identifies the (polar cap) entry region for solar cosmic rays. The size of the entry region is a function of particle energy, geomagnetic disturbance conditions, and local time.

Data Support

Procedures for the analysis of GOES particle data were entirely re-evaluated, and the resulting recommended procedures were incorporated into algorithms that are being included in the SELDADS II real-time data system. With the new procedures, data interpretation is simpler and more consistent.

The computer codes for the off-line processing of the NOAA/TIROS particle data were rewritten. The original codes had evolved in an ad-hoc fashion, and had become unwieldy. The new codes are well designed and efficient. Trial implementation and debugging are near completion.

GOES magnetometer data were analyzed with respect to the nightside topology of the geomagnetic field at geostationary orbit. Some short-lead-time predictive capability is possible in that the field becomes more tail-like in the $\leq$ 20-min interval prior to a geomagnetic substorm. However, this capability is of limited use because it represents a necessary but not sufficient condition for ensuing activity.

External Cooperation

Both data and consultation support continue to be provided to the Defense Nuclear Agency (DNA) for the conduct of its Long Wave Program to study ionospheric propagation of low-frequency signals. A data distribution system, for use with a personal computer, was initiated for easy exchange of satellite particle data in as near a universal and friendly format as possible.

Cooperative studies concern the Theta Aurora, first observed by imaging instruments aboard the Dynamics Explorer satellites; data correlation, in conjunction with the Middle Atmosphere Program (MAP); and plasma theory.

Numerical Studies

Earlier theoretical studies of plasma phenomena in the magnetosphere relied on MHD approximation to ensure tractable equations. It has become clear that important physics have, thereby, been neglected. Therefore, new emphasis was placed upon computer plasma simulations in magnetospheric studies.

Simulation studies of particle behavior in an x-type magnetic neutral point configuration, like that expected to occur in the geomagnetic tail, were undertaken to establish the role of this magnetic configuration in the acceleration of particles. As a point of departure, initial calculations had confirmed the successful tail acceleration mechanism previously proposed by SEL scientists. Experimental study has identified this region of the

magnetosphere as being important for the transfer of electromagnetic energy to the particle populations, which subsequently modify the properties of the ionosphere.

Study continued on magnetic reconnection, through which energy is coupled from the interplanetary medium to the magnetospheric system, and also on the wave-particle interactions that the magnetospheric plasma populations undergo in energy transfer processes.

ATMOSPHERE–IONOSPHERE–MAGNETOSPHERE INTERACTIONS

The objectives of this project are an improved understanding of the transfer of electrical and mechanical energy from the Earth's magnetosphere into the upper atmosphere, and a characterization of the possible consequences of this input in the Earth's ionosphere and upper atmosphere.

Data Acquisition

Observations from instruments on board the TIROS/NOAA-6 and -7 spacecraft continued to be obtained, processed, and used in both research and as a quantitative measure of geophysical activity. Because of the aging of the detectors, the quality and amount of these observations degraded during the year. Early in CY 1985, spacecraft operational difficulties often reduced the flow of data from a normal 95% to less than 40%. Tracking of NOAA-7 ended as NOAA-9 (without a space environment monitor) came into operation. The net result is that the amount of data now acquired is about 40% of that a year ago, and the quality has deteriorated somewhat.

Data Studies

Several studies were carried out using the NOAA/TIROS total energy data. For example, a study was made of the symmetry, or conjugacy, of the energy input to the atmosphere occurring simultaneously in the Northern and Southern Hemispheres. Data from NOAA/TIROS and the Defense Meteorological Satellite Program show that considerable symmetry exists in the energy input over the equatorward and center portions of the auroral precipitation regions. This symmetry breaks down in high (polar cap) latitudes where the energy input into one hemisphere may bear little resemblance to that in the other hemisphere. A second example is a study of energetic particle precipitation in latitudes equatorward of the auroral zone, using data from NOAA/TIROS and the Stimulated Emissions of Energetic Particles experiment. This study showed that precipitation may be short lived but can extend over large distances. There is a possibility that the precipitation is triggered by lightning strokes and that a single stroke affects the energetic particle population over a wide region so that tropospheric phenomena may exert a significant control over the inner magnetosphere. A third example is participation in the Global Thermospheric Modeling Study, a project directed toward the detailed analysis of the behavior of the Earth's upper atmosphere during three selected periods in 1984. Data from the NOAA/TIROS detectors were used to characterize the degree of geophysical disturbance (power input) and also provide information on the energy input (on an hour-by-hour basis) as a driving input to the models. The

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use of the power input as a measure of geophysical disturbance is gaining acceptance in the scientific community.

Ionospheric Conductivity Maps

The total energy deposition data base was used to construct maps of the electrical conductivities of the ionosphere in the polar regions. Constructed for different levels of auroral activity, the maps use the same activity parameters as those used to construct the patterns of particle energy influx, viz., hemispheric power input. The maps are important because the major source of heat to the auroral upper atmosphere is the heat generated by currents flowing in a resistive ionosphere. A combination of conductivity maps with patterns of electric fields, together with energy input by the particles themselves, allows the total heat input to be determined. This leads to a better assessment of the magnitudes of the perturbations resulting from the heating.

Correlation Studies

A correlation study was performed between the estimated hemispherical power input activity, the conventional magnetic activity indices, and parameters of the interplanetary medium that are thought to control geophysical activity. Correlation was good (coefficient approximately 0.75) between the power input and magnetic indices, but it had a large variance. This suggests that the two parameters may be measuring different aspects of geophysical activity and/or that neither is a good measure of activity. Furthermore, an association between power input and the interplanetary magnetic field showed reasonable agreement as, for example, with the north-south component of the IMF, but again the variance was large, suggesting the absence of cause-and-effect relationship.

Operational Aspects

In addition to their use in the above studies, TIROS data were made available for operational purposes. For example, an extensive data set, concerning the very largest energy fluxes, was made available to the Jet Propulsion Laboratory for the purpose of specifying the particle environment that will be encountered by polar-orbiting shuttles.

Plans FY 1986

SOLAR PHYSICS

- Develop expert systems for application of research results to solar-terrestrial prediction services; conduct further testing of THEO against observed activity, persistence, and forecasters, and test performance with different users.

- Establish a solar data base management system to assure a supply of high-quality solar observations through contracts with established observatories and contracts for enhancement of a solar data base through scaling and statistical studies.

- Enter archives of solar synoptic charts into a digital data base accessed by a state-of-the-art graphics computer. Develop graphics displays that facilitate analysis of relationships between large-scale aspects of solar activity and the occurrence of solar sources of geophysical disturbances.

Solar X-Ray Imager

- Participate in preparation of two FY-1988 initiatives for hardware (with NESDIS) and for supporting research (OAR).

- Further develop operational uses of X-ray images using prototype images from Skylab. Establish a limited SEL data base for image analysis and manipulation.

- Prepare a plan for realizing SXI operational utility in conjunction with duty forecasters and researchers. This will involve technical and scientific assistance in SXI design, fabrication, and performance testing and the outlining of suitable calibrations, operating modes, and algorithms necessary to bring the SXI to operational use immediately after launch.

- Prepare a priority plan for future SXI research tasks such as verification procedures, new X-ray flare classification schemes, application of recent Solar Maximum Mission flare results, and other science goals.

INTERPLANETARY PHYSICS

- Evaluate the sensitivity of MHD model predictions of travel time of solar disturbances and predictions of the bulk solar wind parameters at Earth, with respect to uncertainties in input parameters.

- Make quantitative assessment of the value of measurements of solar wind parameters, using the scintillation of radio stars, for use in empirical and quantitative forecasting models of the transmission of solar disturbance energy to Earth.

- Extend the three-dimensional model to include a simple heliospheric current sheet and coronal hole configurations. The model will be transferred to the CYBER 855/205 computer in Gaithersburg. **SEL**

- Reduce grid size by half in the $2\frac{1}{2}$-D model, to study finer spatial and temporal structure in the solar wind.

- Further develop the strategy for a solar-terrestrial environment model.

- Study multi-fluid, electrified plasmas to assess the importance of strong electric fields and small-scale structures in the solar wind.

MAGNETOSPHERIC PHYSICS

- Determine an empirical relationship between geomagnetic activity and the cutoff latitudes of solar cosmic rays. This operational relationship will be used to estimate the geographical extent of radiation hazards and radio communication disruptions.

- Provide support to assure the quality of real-time and non-real-time data and data processing.

- Begin use of WAVE plasma simulation routines to study phenomenology of the magnetosphere boundary.

- Complete a data processing system (energetic particles) for use with a personal computer.

- Study effects of magnetic field merging in the magnetosphere.

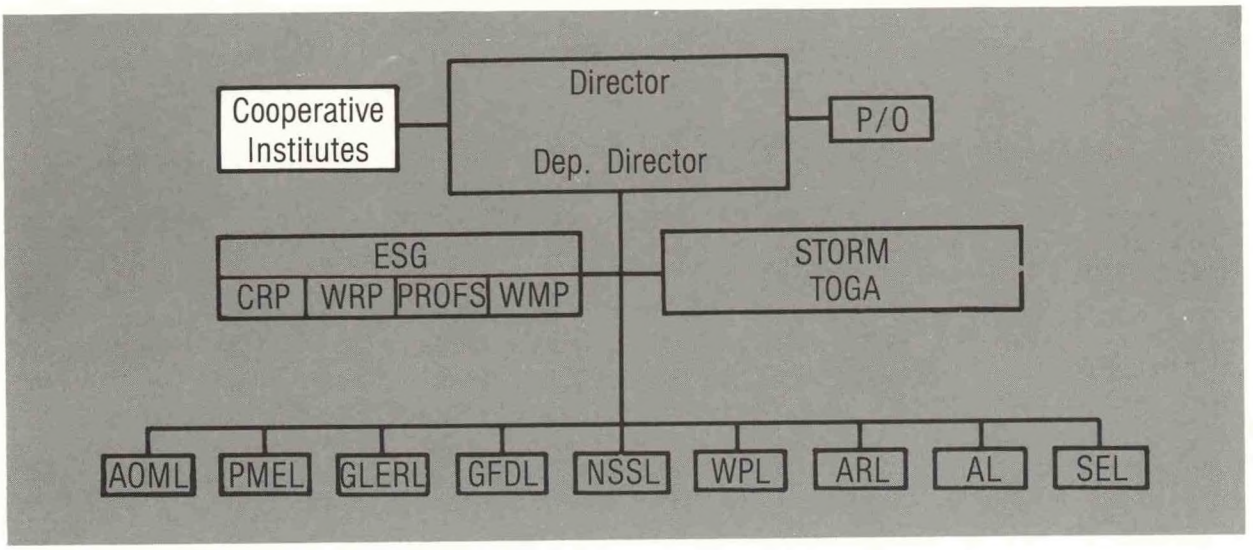
ATMOSPHERE–IONOSPHERE–MAGNETOSPHERE INTERACTIONS

- Establish disturbed ionospheric conductivity patterns as a function of the geophysical activity parameter, using the particle energy patterns from the NOAA/TIROS total energy detector data.

- Process data from the NOAA/TIROS total energy detector and distribute.

- Use the NOAA/TIROS particle data as input to a thermospheric dynamical model to calculate changes in temperature, density, and composition as a function of energy input.

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 an association between NOAA and the University of Miami's Rosenstiel School of Marine and Atmospheric Science (RSMAS) to stimulate cooperative research between the institutions. The three research themes of CIMAS are Climate Variability, Ecosystem Dynamics, and Ocean-Sea Floor Hydrothermal Interactions.

The primary CIMAS staff consists of nine Fellows who are appointed from RSMAS faculty and NOAA's laboratories in Miami and who conduct collaborative research. Also included in the staff during FY 1985 were six Members, three Associate Scientists, six Research Associates, four Postdoctoral Associates, and four graduate students. Members of the staff conduct research at the CIMAS building, the RSMAS campus, and NOAA laboratories. CIMAS also conducts research through partial support of visiting collaborating scientists who augment the expertise at RSMAS and NOAA. During FY 1985 the visiting scientists provided more than 8 man-months of collaborative research and 33 lectures.

Accomplishments FY 1985

CLIMATE VARIABILITY

Research on climate variability concerned Subtropical Atlantic Climate Studies (STACS), Equatorial Pacific Ocean Climate Studies (EPOCS), and atmospheric carbon dioxide (CO_2) loading.

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. A CIMAS research effort in support of STACS is 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. Investigations were prompted by the strong correlation (0.95) between the transport at the straits and the cycle of the wind stress curl over the Caribbean--particularly over the Cayman basin (the straits lagging the basin by 6 days).

A linear barotropic flat bottom model reproduced the spin-up time scale and suggested that there should be inflow through the Windward Passage in phase with the forcing. Examination of the tide gauge data at Guantanamo Bay, Cuba, and Port Au Prince, Haiti, confirmed this hypothesis. What has been particularly rewarding, however, is the introduction of bottom topography in the form of geostrophic contours (i.e., f/h contours, where f is the Coriolis force and h is the fluid depth). There is a nexus in these contours at the Florida Straits. Contours on the eastern side of the straits encircle the Bahamas Bank and are closed. On the western side of the straits the contours are blocked to the south. Since the barotropic signal propagates along f/h contours, the response on the western side of the straits is sensitized to the forcing along the boundary--including the coast of the Gulf of Mexico, the coast of the Caribbean Sea, and the coast of South America as far south as 6°N. Furthermore, because of the nexus in the f/h contours at the Florida Straits, the forcing to the south will influence the pressure distribution around the Bahamas Bank. The seasonal response of the transport at the Florida Straits is forced by the curl of the wind stress over the Cayman basin. The geostrophic contours extend uninterrupted from the Gulf of Mexico through the Cayman basin. The curl of the wind stress forces a barotropic boundary layer response into the Gulf of Mexico. Because of the character of the geostrophic contours at the western end of Cuba, any return flow is blocked and the signal propagates to the Florida Straits.

Heat is transported from the tropical Atlantic into the Caribbean principally along the northern coast of South America. One of the principal mechanisms driving the flow is an along-shore pressure gradient built up in response to the upwelling along the coast. Along the coast, the Ekman transport is offshore causing the upwelling. Though the interior transport is onshore, it is not strong enough to compensate for the offshore Ekman transport. Since the bottom slope effectively shuts off the contribution by the bottom Ekman layer, continuity requires the interior transport to be supplemented by an onshore geostrophic flow. On the average, then, there is an increase in the pressure along f/h contours northward, toward the Florida Straits. This pressure gradient on the average turns the Sverdrup transport to the north toward

the Florida Straits, and its modulation contributes to the mass flux through the eastern Caribbean and hence contributes to the heat transport.

The other major Atlantic research effort consists of (1) analysis of field data from current meters, Pegasus ocean velocity profiler, tide gauges, telephone cables, and other instrumentation used in the Florida Current components of the STACS experiment, and (2) field experiments, including several cruises, to study surface and deep currents in the southern part of the Gulf Stream recirculation region, including the Deep Western Boundary Current (DWBC).

Analysis of the Florida Current data progressed to the point where an integrated picture can be formed of the mean and perturbation flow parameters (mean velocity, temperature and density fields, heat perturbation and momentum fluxes, etc.) across the Florida Current at 27°N, the location of the major field experiment. Enough statistics on flow fluctuations were obtained to determine how a reduced set of measurements (in particular, cable measurements, but also subsets of Pegasus profilers or current meters) could be used for long-term monitoring of Florida Current transport. In addition, some interesting local effects in the Florida Current due to its interaction with local topography are under analysis.

The area of research on the transport of mass and heat in the Florida Current/Gulf Stream system was extended northward, using a 3-year series of Pegasus absolute velocity and temperature sections taken in the Gulf Stream northeast of Cape Hatteras and similar measurements taken in the Florida Current. The time-averaged data sets from the three cross-stream locations (27°, 29° and 36°N) were used to examine the transport of the current by depth and temperature layers. After the sections were aligned, a "velocity anomaly" over the cross sections was computed by least-squares minimization of the temperature fields, to further examine transport fluctuations.

Field work was extended to the region of the North Atlantic Ocean northeast of the Bahamas, to study both the recirculation of the Gulf Stream surface flow and to make, for the first time, a more detailed study of the DWBC. This joint effort included two NOAA vessel cruises as well as one cruise by a RSMAS vessel. During the latter cruise, deep (to 4 km) absolute velocity profiles of the DWBC were obtained for the first time, using Pegasus. Preliminary results suggest that the DWBC is much wider and extends much higher up into the water column than had previously been thought.

Pacific Ocean research in support of EPOCS consisted of analysis of drifting buoy and tritium data.

CIMAS

Several analyses were completed on some aspects of the satellite-tracked drifting buoy data collected by the EPOCS program. Intensive analysis of the structure and energetics of mesoscale eddies associated with the cusp-shaped long waves commonly observed in sea surface temperature patterns of the eastern equatorial Pacific was completed. All the data collected prior to the El Niño event of 1982-83 were used to generate a monthly climatology of surface currents in the eastern tropical Pacific. This climatology was used to compute the rate of equatorial upwelling from the divergence of near-surface current, which is the first estimate of equatorial upwelling with the associated error base.

Local and Lagrangian heating in the Eastern Tropical Pacific Ocean was the subject of intensified research. The evolution of sea surface temperature and current fields before, during, and after the El Niño event of 1982-83 was investigated using the data from satellite-tracked drifting buoys. Local and net heating and the zonal and meridional advective import/export were computed separately from the buoy data, and vertical advection of heat was estimated as a residue. Assuming that heat exchanges are confined to a 50-m thick mixed layer, clear annual cycles of both local and net heating, with amplitudes of about 70 Wm^{-2} and 80 Wm^{-2}, respectively, were found in the region 0°-10°S, 90°-130°W. Seasonal heating anomalies of up to about 40 Wm^{-2} were found during both normal and El Niño periods. The major event in the net heating anomaly series is a long period of strong net anomalous cooling from early 1982 through 1983. A strong zonal advective heating is clearly seen during the El Niño period from the winter of 1981 through the fall of 1983; a brief anomalous cooling occurred in the winter of 1982. An intense downwelling, which also seems to have an important role in the 1982-83 event, is found from mid-1982 through early 1983.

Tidal currents in the eastern equatorial Pacific were investigated by applying modal decomposition to the current meter records obtained from 10 levels near the Equator at 110°W to separate the barotropic (surface) and baroclinic (internal) tides. The barotropic tide shows a reasonable agreement with the existing numerical global modals of the M_2 tide. It was found that most baroclinic energy is confined to the upper ocean, for both east and north velocity components. The baroclinic energy could be accounted for by the strong density stratification and related to the slope of the thermocline in the equatorial Pacific. Seasonal variability shows that baroclinic tide is stronger in the winter than in the summer.

Isopycnal advection in the mean wind-driven circulation was found to be the dominant process for the penetration of tritium from high northern latitudes into the tropical Pacific. The tritium data show that there is a closed decadal-time-scale meridional circulation extending from high northern latitudes to the Equator above 26.8 sigma-theta. Thus the North Pacific thermocline is ventilated to the Equator on decadal time scales. The tritium data were shown to be in large part consonant with the recently developed ventilated-thermocline theory.

There is a prominent signature of equatorial upwelling in the tritium field. This signature provides unique insights and conclusions about equatorial upwelling. Tritium data provide a means of separating the role of advection of cool Southern Hemisphere water from that of upwelling in the maintenance of the equatorial "cool tongue". Tritium data showed that the upwelling occurs above the 26.2 sigma-theta surface. The tritium data also showed that there is substantial zonal variability in the upwelling, a maximum occurring between 120°W and 150°W.

Research on the relation between atmospheric CO_2 loading and climate consisted of modeling deep ocean chemical cycling and making ocean measurements by cyclosonde and radar imagery in the Marginal Ice Zone Experiment (MIZEX).

In the geologic record, one of the most striking indicators of different oceanic climate states is the existence of layers of black organic-rich deep-

sea sediments indicative of widespread anoxia. A simple coupled model of the ocean's carbon, oxygen, and phosphate (COP) system was developed to study the occurrence of anoxia. Recent isotopic measurements in ice cores indicate that atmospheric CO_2 changes may have occurred on several-hundred-year time scales, which suggests that CO_2 variations may have played a role in the forcing of the glacial-Holocene climate transition. A time-dependent version of the COP model shows that these CO_2 variations could be forced by perturbations in the marine carbon cycle.

During MIZEX in the summer of 1985 more than 1,100 cyclesonde vertical profiles of temperature, electrical conductivity, and velocity were recorded in the Fram Straits from drifting ice floes tracked by Argos transmitters. Instruments were deployed from the R/V Polar Queen and its helicopters. In addition one cyclesonde recorded downwelling, light intensity, and light transmission.

The MIZEX work in FY 1985 concentrated on the analysis of the 1983 and 1984 field data. Preliminary results show strong vertical gradients in temperature, salinity, and velocity in the upper 200 m of the ocean under the ice. These gradients are modulated by tidal/inertial period motions together with strong wind event responses. The light transmission data show a highly repeatable vertical; maximum light absorption occurs near the surface and in a thin layer located between 35 and 55 m depth. The deeper maximum in light absorption coincides with a maximum in phytoplankton concentration, and there is some indication of coincident oxygen maximum. These data indicate that primary productivity in the marginal ice zone may be greater than previously supposed.

Analysis of radar imagery of the Arctic pack ice and marginal ice zone was initiated. This consisted of organizing the imagery and construction of overlays of the flight tracks. The initial emphasis was placed on the 6 July period when surface windstress measurements were obtained by the Bedford Institute of Oceanography. A preliminary comparison of observed and model drag coefficients indicated that the surface measurements are somewhat high. This may be due to the local nature of the measurement in comparison with the integrated result obtained by a moving aircraft. Further examination of these results requires computer processing of the imagery on a small scale.

Another aspect of the imagery is the strong enhancement of ridges and rough structure as a result of the high incidence angles of the low-altitude imagery. Although the radar look-angles were low enough to limit shadowing, the shallow grazing angles resulted in very high returns from ridges within a floe and from the fractured regions between floes. It thus appears that a roughness index based upon these returns can be established and compared with roughness indices obtained from the laser altimeter. As heat and momentum transfer are a function of the roughness and thickness of the ice, these data may result in refinements of the classification of ice types.

ECOSYSTEM DYNAMICS

Understanding the causal mechanisms of fish stock variability is the primary objective of CIMAS ecosystem dynamics research. Efforts are focused in two areas: (1) the early life history stages, and survival and dispersion

caused by physical, chemical, and biological oceanic processes, and (2) the effects of fishery exploitation on tropical and subtropical ecosystems.

The abundance of bluefin tuna larvae spawned in the Gulf of Mexico in 1982 and 1983 was estimated after the South East Area Monitoring and Assessment Program (SEAMAP) ichthyoplankton data base for those two years had been edited. From these estimates and previous ones for 1977, 1978, and 1981, fishery-independent estimates were made of spawning stock biomass and population size for western North Atlantic bluefin tuna. These estimates indicate that spawning stock has declined since 1978. An indication that spawning increased slightly in 1983 is tentative, since the Gulf of Mexico sampling grid was not completed because of bad weather. The larval data frequency followed a delta distribution. The non-zero larval catches were log-normally distributed, so unbiased minimum variance estimates of mean catch and its variance could be made. The derived confidence intervals were proportionally narrower with this method than with other methods in general use.

Additional larval fish research consisted of completing the SEAMAP data base for serranids (groupers), beginning analysis of the serranid data, and completing a larval drift model study. The last was applied to anchovy larvae to determine the advection by the ocean processes of geostrophic and wind-driven currents to 50 m depth and turbulent diffusion. It was found that the peak time of spawning (March) coincided with the minimum period of advection.

An initial study of a multispecies reef fish assemblage was completed. Data from the Puerto Rican reef fish fishery were used to parameterize a multispecies simulation model. The model was employed to determine the effects of exploitation, and management strategies and state-of-the-art assessment techniques. Preliminary results for the tropical reef fish assemblage, i.e., without consideration of interspecies interactions, indicated that management strategies must take into account the relative species mix in the catch and that the consequences of not doing so could have long-term effects. Under very restrictive assumptions, state-of-the-art assessment techniques can be used. However, the restrictive nature of the assumptions indicates a strong need for the development of new assessment methods.

Understanding the biological processes associated with larval fish survival requires the development and application of innovative sampling technologies for the zooplankton communities of which the larval fishes are a part. In a new research project, the major task of the first few months was completed--a 2-week Gulf Stream cruise on the R/V Cape Florida. Equipment was also designed and built; testing included three separate days of sea trials of the plankton camera system on R/V Calanus.

The objectives of the first cruise were (1) the proving of new equipment designs, (2) intercomparison of plankton sampling/mapping techniques, (3) determining fine-scale distribution of the zooplankton of the upper 100 m of the water column, (4) documenting the evolution of populations in the Gulf Stream, and (5) observing the changes across the western Gulf Stream front. The Doppler acoustical instrument and computer hardware successfully operated throughout the cruise. Data were obtained from 22 deployments of plankton cameras and 10 deployments of multiple opening/closing net environmental sensing systems (MOCNESS). Deployments were done back to back with 26 multifrequency acoustic plankton surveys (MFPS). They took place both night and

day, and included two 24-h cycles in the Gulf Stream, and two transects across the front off Cape Canaveral. Two cross-stream XBT surveys (30-nm tracks) for stream flow computations were completed, and several submarine photometer profiles were made. Live MOCNESS samples were silhouette-photographed on board, and live copepods were collected and processed for gut fluorescence studies.

Work on chemical oceanic properties continued with research and development of methods for the identification and determination of oxidized organosulfur species in the marine environment. The gas chromatographic techniques for doing so have been refined. Previously unreported dimethylsulfoxide and dimethylsulfone had been identified in rain samples collected over the equatorial Pacific. The concentrations of these compounds are typically 1-10 µg/l. These oxidized sulfur compounds are formed by the oxidation of biogenic dimethylsulfide in the boundary layer.

OCEAN SEA-FLOOR HYDROTHERMAL INTERACTIONS

This research theme was approved for CIMAS during FY 1984. Planning efforts for the modeling and measurement of the physical dynamics of sea floor vent plumes continued through FY 1985.

Plans FY 1986

CLIMATE VARIABILITY

Research on ocean-related aspects of climate will continue in FY 1986 in support of STACS, EPOCS, and the CO_2 loading problem. Atmospheric research supporting EPOCS will be undertaken as a new effort.

The local forcing project will examine in more detail the effect of the nexus in the f/h contours at the Florida Straits since this nexus implies that the pressure distribution around the Bahamas Bank is influenced by the forcing along the boundary to the south. As the northward geostrophic flow through the straits increases, the mean pressure around the bank should increase in phase. Consequently, on the North Atlantic side one might expect to observe an offshore pressure gradient set up to oppose the formation of an Antilles current. There are two points here: (1) Because of the topography, the response should be trapped near the boundary, and (2) because the response is barotropic, its effect should be felt throughout the water column. It need not be strong enough to reverse any shallow Antilles current; it need merely make it more diffuse. And since it is barotropic, it may serve to accelerate the deep western boundary current. This latter point is especially interesting for it may mean that the northward seasonal transport at the Florida Straits is compensated primarily by a southward seasonal transport in the deep western boundary current. If this is true (and current meter measurements do suggest that the deep western boundary current has a seasonal component), the seasonal component of the heat transport could be considerably larger than has been estimated in the past.

Further analysis and modeling of the Florida Current, based on STACS data set, will be undertaken. An important part of this work will include efforts

to predict the time-variable temperature field (and thus the "heat flux") from cable (or other) transport data and a limited number of temperature measurements. Analysis of cruise data obtained last year in the Gulf Stream recirculation region and the DWBC will proceed. Several additional research cruises to the DWBC/recirculation region will be conducted.

In the continuation of the moored-current-meter data analysis, a transport series will be derived from the STACS VI array (June 1984-June 1985), which had a much-reduced set of instruments compared with the previous arrays. Therefore, besides direct transport calculations, regressions with Pegasus and cable data will be used. The larger scale variability and its relation to wind forcing will be studied by merging the STACS data with those from FACTS moorings. Jointly, the data cover a stretch of about 500 km of the Florida Current and a period close to 2 years.

A new field program with three moorings east of the Bahamas was initiated with AOML. Moorings will be deployed in April by the R/V Researcher for 1 year. Possible extensions of the field program include moored acoustic Doppler profilers and reciprocal acoustic transmissions.

The northern segment of the Florida Current/Gulf Stream transport study will be completed. The associated analysis of the Antilles Current data will begin. Efforts will be made to include additional hydrographic measurements in future cruises. Such measurements will allow examination of the Pegasus absolute velocity data in the context of the larger-scale dynamic height field.

Work on the EPOCS drifting buoy data will continue with research on techniques of process analyses. Emphasis will be placed on the largest space scales and annual and interannual time scales.

In support of EPOCS, analysis of the existing Global Climate Monitoring (GCM) data archived at the National Center for Atmospheric Research (NCAR) will begin in order to investigate possible mechanisms for the maintenance of tropical Pacific sea surface temperature (SST) anomalies. History tapes from several model runs already completed will be used to compute, for the equatorial Pacific, the patterns of sensible heat flux, radiative heat flux, evaporation, and wind stress. These patterns will be compared with the prescribed SST anomaly that was used for each experiment. The objective is to see whether these atmospheric forcing patterns are such as to promote a tendency for the SST anomaly to increase, to decay, or to move. In addition, a search for the 30-60 day oscillation in the tropical Pacific will be conducted for our GCM runs. If such an oscillation is present, its structural characteristics will be documented, and an attempt will be made to determine the origin of this oscillation in the GCM.

Research associated with the CO_2 loading problem will continue with hierarchical modeling, cyclosonde measurements, and radar imagery. The latter two efforts will continue in association with MIZEX.

ECOSYSTEM DYNAMICS

Planned research on larval fish includes (1) a continuation of analysis of bluefin larval abundance with respect to oceanographic conditions, to develop a better understanding of the ecological correlates of spawning and larval survival, and subsequent fluctuations in adult stocks; (2) a critical review of the literature to assess the relative importance of environment, predation, and competition on the survival of larval fishes; and (3) the development of sampling strategies for coral reef fish larvae.

Zooplankton sampling technology application research will begin the analysis phase, including an integration with material provided by colleagues. Experimentation will begin with a digitizing system for inputting data directly to a microcomputer, which may eventually help to automate at least the proximal examination of MOCNESS silhouette data, and perhaps eventually the plankton camera data. Two cruises will be conducted during 1986.

Fisheries dynamics research will be expanded to examine the responses of a broader set of communities. New research to develop assessment techniques for tropical and subtropical ecosystems will be undertaken.

The main feature of the chemical process research planned for FY 1986 is a research cruise in the tropical Atlantic. Detailed boundary layer vertical profiles of volatile organic compounds, ozone, and ancillary data will be obtained. Volatile organics will be analyzed using a new gas chromatograph/ mass spectrometer system.

OCEAN SEA-FLOOR 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), ERL, and NOAA through the National Severe Storms Laboratory (NSSL). 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, University staff, and student appointees. The present council of Fellows, which helps formulate policy, includes two members from NSSL, both of whom hold adjunct professional appointments at OU, and three members from OU. The Advisory Council, which includes representative from OU, NOAA, and outside organizations, meets annually.

CIMMS is addressing several research issues important to NOAA/ERL. Programs will lead to improved observation and forecasting of meteorological

systems at the mesoscale down to the microscale. These systems produce most of our local weather but currently are not well understood. The potential economic and social benefits of accurate observation and prediction of severe storms, winds, and precipitation are immense.

CIMMS can most effectively address its scientific goals with a small, core scientific staff augmented by a temporary scientific staff of Postdoctoral Fellows. The Postdoctoral Fellows (both new graduates and experienced scientists) are appointed for up to two years. These individuals are selected on the basis of demonstrated research ability in the needed theme project areas. A small permanent scientific staff is required to assure continuity of research programs. This staff is drawn from the University of Oklahoma, NOAA, and full-time research scientists. Both OU and NOAA provide important basic support for CIMMS, but neither directly funds the research done by the permanent CIMMS staff. Such additional support is derived from grants and contracts.

Accomplishments FY 1985

During 1985, CIMMS was host to researchers from China, Taiwan, Japan, and France, who undertook studies in mesoscale meteorological modeling and development of optimization analysis in Doppler radar meteorology. A CIMMS research scientist has continued his work on the Alpine Experiment (ALPEX) and satellite-based analysis techniques. In October 1985 he will travel to Venice, Italy, to attend the First Conference on the Results of ALPEX. A research scientist received a grant from NSF to study extended theories of conditional symmetric instability and their application to problems associated with frontal rainbands. Another research scientist, also supported by an NSF grant, is working on turbulence statistics in laboratory-simulated tornado vortices. His group is obtaining a high-caliber flow visualization device capable of resolving fine structures in the flow trajectories, thus providing turbulent velocity correlation statistics useful in obtaining the frictional force in theoretical studies. A high-resolution 3-D numerical model is being developed in an attempt to simulate the turbulent flow. Laboratory flow measurements will serve as a check for verification of the model. Two Postdoctoral Fellows on multiyear appointments work in mesoscale modeling and convective instability. Fourteen graduate students employed by CIMMS are engaged in research studies that may lead to advanced degrees.

CIMMS research results were reported in nine reports and five publications during FY 1985.

In October 1985, CIMMS will be host to the International Symposium on Variational Methods in Geosciences.

Plans FY 1986

The main objective of CIMMS cooperative research efforts is to develop advanced and automated weather nowcasting and forecasting technology, or more specifically to provide techniques leading to reliable diagnosis and predic-

tion of paralyzing severe weather at the mesoscale--flash floods, heavy snowfall, gusty winds, poor visibility, and icing; and tornadoes, hail, and lightning.

Through these research efforts CIMMS will continue to address the following research themes:

- Mesoscale modeling. Develop models that include mesoscale initialization and assimilation of new input data, parameterization of diabatic processes, and terrain-influenced boundary layers. The goals are to develop mesoscale models that are physically sound and practically useful for analysis and prediction of mesoscale weather phenomena in a 0-36 h time frame.

- Mesodynamics. Investigate symmetric and shearing convective instabilities to reveal mechanisms of initiation, development, and decay of severe weather. The ultimate goal is to improve physics in mesoscale diagnostic and prognostic models.

- Orography and lee cyclogenesis. Discover mechanisms of boundary layer formation, separation, and diurnal variation; develop a more realistic and predictable terrain-influenced boundary layer parameterization for mesoscale models; develop an understanding of how these phenomena lead to cyclogenesis.

- Variational optimization analysis. Develop efficient and accurate techniques for analysis of remotely sensed data including Doppler radar and Profiler observations, which promise to be important for diagnosing hazardous mesoscale severe weather and which may provide initialization and assimilation data for diagnostic and prognostic mesoscale models.

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 World Climate Research Program).

Five NOAA/NESDIS scientists in residence at CSU constitute the Regional and Mesoscale Meteorology Branch of the NESDIS Satellite Applications Laboratory. They lead the CIRA collaboration with ERL in short-range weather forecasting research.

The CSU departments engaged in CIRA research are Atmospheric Science, Statistics, Psychology, Civil Engineering, Electrical Engineering, and Recreation Resources. Currently 24 separate research projects have been funded through CIRA, including an IPA (Intergovernmental Personnel Act) Fellow with the National Weather Service. CIRA personnel consist of 14 Fellows, 4 Visiting Fellows, 11 Research Associates, 2 Visiting Scientists, a Deputy Director, and a Director. During FY 1985, six Graduate Research Assistants received degrees--three M.S. and three Ph.D. Each year the Visiting Fellows Program provides the opportunity for independent research at CSU in collaboration with selected NOAA scientists. A "co-op" program allows CSU graduate students to work in residence at NOAA Laboratories.

CIRA was host to a WMO-sponsored workshop entitled "Cloud Top Boundary Layer", on 22-26 April 1985. Twenty-seven scientists from throughout the world participated. In coordination with NASA-Goddard Space Flight Center, CIRA was host to NASA personnel for a week during July 1985. Their visit involved interaction with many of the faculty and research personnel at the Department of Atmospheric Science and CIRA.

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 "Acid Deposition in Colorado--A Potential or Current Problem; Local Versus Long-Distance Transport Into the State" is planned for 1986. This workshop will facilitate interaction among participants from several departments of CSU.

CIRES

The Cooperative Institute for Research in Environmental Sciences (CIRES) is jointly sponsored by the University of Colorado and NOAA and receives a roughly equivalent amount of support from other public and private sources. CIRES Fellows have academic affiliations with eight departments at the University of Colorado: Chemistry, Chemical Engineering, Physics, Geography, Geological Sciences, Electrical Engineering, Mechanical Engineering, and Astrophysical, Planetary and Atmospheric Sciences. Current research in CIRES is in four broad areas: Environmental Chemistry, Atmospheric Dynamics, Climate Dynamics, 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 1985

CIRES research in environmental chemistry contributes to important NOAA programs in acid rain, radiatively important trace species, and global atmospheric chemistry, as highlighted below.

It is known that both natural and anthropogenic chemical species can modify deposition. Even if emission of the latter were reduced, natural sources would continue to contribute to deposition. Thus, the anticipation of benefits from controlled reduction of a compound could be erroneously optimistic if natural sources made a significant contribution to the total budget of the compound. In particular, natural emissions of sulfur-containing compounds from biogenic sources provide the irreducible minimum background for sulfuric acid, which is the principal acid deposited in the eastern United States. An understanding of the natural component of this sulfate deposition requires an understanding of the biological processes responsible for the natural sulfur emissions. Work in progress is aimed at elucidating the biogeochemical cycling of sulfur in relation to the biogenic emission of sulfur gases. This research focuses on the origin of methylated sulfur species such as methanethiol, dimethylsulfide, and dimethyldisulfide. Little is known concerning the mechanism(s) and physiological regulation involved in the production of these species. The release of dimethylsulfide as a major sulfur compound in the atmosphere has been attributed to its formation and release from vegetation and aquatic algae. Our recent results indicate that another important source of this sulfur gas is microbial methylation of hydrogen sulfide. Various bacteria isolated from soil, water, and plant surfaces were found to exhibit high cellular activity for the methylation of exogenous hydrogen sulfide, emitting a mixture of methanethiol and dimethylsulfide. All these isolates were shown to contain relatively high levels of an enzyme, thiol methyltransferase, that carries out the methylation of sulfide. The same enzyme was shown to catalyze the methylation of methanethiol, yielding dimethylsulfide. In addition, the same enzyme catalyzes the methylation of hydrogen selenide. Thus these bacteria also have the capability of emission of methylated selenium gases. These results have important implications for interpreting field measurement data on the flux of biogenic sulfur gases from soil and vegetation.

New analytical techniques to measure trace gases in the atmosphere are needed to support continued progress toward unraveling the complexities of the chemistry of the troposphere and stratosphere. Work under way at CIRES and the Aeronomy Laboratory is aimed at the development of surface conversion techniques to be used as detectors for important atmospheric trace gases. One such effort involves the use of a gold catalyst to cause the reduction of reactive nitrogen oxide compounds, NO_y, to NO, a compound that can be sensi-

tively detected. During the past year, Laboratory capabilities were developed for detailed studies of the chemisorption and reaction of gases on solid surfaces. It is now possible to obtain vibrational spectra of adsorbed molecules on well-defined, single-crystal surfaces in order to determine molecular structure and chemical bonding. Most work is focused on studies to elucidate the catalytic reaction mechanism of NO_y reduction in atmospheric detection instruments that use a gold catalyst.

In addition, new detectors for high-performance chromatography based on chemiluminescent reactions were developed. Of particular relevance to environmental chemistry is the development of a sulfur-selective detector for High Performance Liquid Chromatography having low picogram detection limits. This detector had earlier been developed and applied to gas chromatography. With this new capability the sulfur selection detector can now be used to analyze liquid and liquid-extracted samples.

Work is also progressing on research aimed at understanding the chemistry and spectroscopy of atmospheric trace compounds and radicals. Flow tube kinetics methods were used to study reactions important in regulating the quantity and distribution of ozone in the stratosphere. The rate constants for the reactions

$$O + NO_2 \rightarrow NO + O_2$$

$$O + ClO \rightarrow Cl + O$$

were measured over the temperature range 220-387 K. These reactions are the rate-determining steps for the NO_x and ClO_x catalytic cycles, which largely control the concentration of ozone in the stratosphere.

The ultraviolet absorption spectrum and the stratospheric reactions of the HOCl molecule were also investigated. These studies were made possible by the development of a new dynamic source for the generation of HOCI having very low impurities of the interfering species Cl_2O. Absolute absorption cross sections were obtained in the wavelength range 240-390 nm, and rate constants for reactions of HOCl with OH and H were determined. The product branching ratio in the reaction with HOCl with Cl was also measured.

In addition to the research efforts that are being carried out in CIRES laboratories, CIRES research associates and assistants are collaborating with scientists from the ERL on a variety of programs in Boulder and elsewhere, including measurement of the global budget of CO_2, methane, and ozone; study of the arctic haze; measurement of natural emissions that contribute to atmospheric acidity and alkalinity; investigation of processes involved in acid deposition, the tropospheric/stratospheric exchange processes, and kinetics of tropospheric and stratospheric reactions.

Plans FY 1986

The programs described above are ongoing and will continue. Other program areas will contribute important new capabilities to CIRES basic research.

Gas chromatography (GC) and liquid chromatography (LC) utilizing mass spectrometric (MS) detection are used for trace compound identification and

analysis in a wide variety of applications. The sensitivity and/or specificity of these instruments is often determined by the method used to ionize the analyte compound in the mass spectrometer. In CIRES, GC-MS and LC-MS instruments are now operational, employing laser multiphoton ionization as the ionization/fragmentation method. Techniques have been developed to use these instruments for trace metal speciation and organic molecular analysis. The detection method is selective toward compounds that absorb radiation at wavelengths 260 nm or greater. These instruments will be used to obtain laser-induced fluorescence and/or multiphoton ionization spectra of molecules. Other potential applications include the analysis of environmental samples (liquid or gaseous) and the study of unimolecular photochemical reactions.

The rate constant and product distribution of the reaction between ClO and BrO radicals will be measured as a function of temperature. This reaction could participate in a significant cycle for ozone depletion in the stratosphere:

$$ClO + BrO \rightarrow Cl + Br + O_2$$

$$Cl + O_3 \rightarrow ClO + O_2$$

$$Br + O_3 \rightarrow BrO + O_2$$

$$\text{Net: } 2\,O_3 \rightarrow 3\,O_2$$

Other atmospheric reactions to be studied include those of S_2 with O_2, O_3, and NO_2. S_2 is occasionally injected into the stratosphere by volcanic eruptions.

ATMOSPHERIC AND CLIMATE DYNAMICS

Atmospheric and Climate Dynamics (ACD) research at CIRES encompasses a broad spectrum of theoretical, experimental, and observational investigations. This is reflected in the fact that ACD personnel actively collaborate with ERL scientists in five different Laboratories. In addition, research is conducted with funding by various other Federal, state, and private agencies. Interactions among investigators from the various projects have fostered a fertile working environment that often leads to unexpected and gratifying results.

Much of the CIRES/ACD research takes place as part of ERL programs described by the Laboratories:

- Research on the dynamics of the solar corona and the interactions of the solar wind with the Earth's magnetosphere, at SEL.
- Research on the remote sensing of the middle atmosphere and the interactions of upper atmospheric chemistry and dynamics, at AL.
- Research on the changing amounts of atmospheric trace chemical species and volcanic dust, at ARL.
- Research on atmospheric remote sounding, influences of topography on weather, and techniques for prediction of aircraft icing, at WPL.

- Research on the climatology, morphology, and predictability of the large-scale climatological phenomenon known as the Southern Oscillation/El Niño, at ESG/Climate Research Program.

Other funding for CIRES/ACD research is derived from NSF, NASA, DOE, DOD, and other, smaller, sources. For convenience, this work can be subdivided into three categories: atmosphere-ocean interaction, cryosphere-climate interaction, and interactions of waves and turbulence with mean flows. As the titles suggest, ACD research is mainly concerned with the interactions among the various media and component processes of the Earth's climate system on virtually all scales of time and space. The following Accomplishments and Plans pertain to this interdisciplinary research.

Accomplishments FY 1985

ATMOSPHERE-OCEAN INTERACTION

Because of its small thermal and mechanical inertia, the atmospheric component of the Earth's climate system, the weather, responds relatively quickly to changes in boundary conditions. The atmosphere's lower boundary condition, however, is largely determined by the temperature of the sea surface, which, owing to the much larger inertia of the oceans, behaves with very different time and space scales. The interaction of atmosphere and ocean at the sea surface is therefore a multiple-scale problem of considerable importance to understanding climate. CIRES/ACD research into air-sea interaction includes theoretical and observational work on the boundary layers on each side of the interface and their interactive physics.

In FY 1985, a series of field experiments, in collaboration with ERL and NASA scientists using a NOAA/OAO P-3 research aircraft, was performed to investigate the radiative and dynamical interactions within the marine stratocumulus cloud deck that is a dramatic climatological feature of the Pacific off the coast of California. This is a particularly interesting climatic regime because the clouds' existence significantly reduces the solar energy absorbed by the underlying ocean, and there is reason to believe that the presence of the clouds is determined in part by low surface temperatures. The research missions in FY 1985 were performed as a contribution to the First Regional Experiment of the International Satellite Cloud Climatology Project in support of a multi-platform, multi-agency field program to occur during FY 1987.

The mechanisms that connect the atmospheric boundary layer to the underlying ocean, i.e., the processes that move heat, moisture, and momentum between the media, have been and continue to be studied in detail using sampling techniques developed by CIRES researchers. Experimental data from very-fast-response turbulence measurement systems (the NOAA/ERL gust probe system and the NCAR system) were analyzed with conditional sampling, which uses thresholds to determine significant events, and with bivariate analysis, which uses joint frequency distributions, to examine the mechanics of various categories of plumes that carry sea-surface properties to the atmosphere and redistribute heat, moisture, and momentum within the atmospheric boundary layer. Evidence

is beginning to accumulate that these discrete events are not only dominant over continuous, isotropic turbulence but may also be used as tracers. This will increase understanding of atmospheric turbulence for a wide variety of conditions.

On the other side of the air-sea interface, CIRES/ACD research has investigated the feasibility of including in an adiabatic flow model of the large-scale ocean dynamics the nonadiabatic processes associated with atmosphere-ocean interaction. In collaboration with University of Miami (Fla.) scientists, an isopycnal model of the ocean dynamics (that is, a model in which potential density is an independent--pseudo-vertical--coordinate) was generalized to include a mixed-layer model of the oceanic boundary layer that takes account of the solar heating and turbulent fluxes of latent and sensible heat at the ocean surface. This new development in ocean circulation modeling will allow the numerical advantages of the adiabatic flow properties of the interior ocean, particularly those associated with the ability to resolve regions of large density gradients without special numerical methods, to be exploited in the study of climatic aspects of atmosphere-ocean interaction. It will also allow the development of truly interactive modeling of the processes at the sea surface and the way these processes affect the deep ocean.

CRYOSPHERE-CLIMATE INTERACTION

On longer time scales the climate is affected by and controls the changes in the Earth's ice sheets, sea ice, and glaciers. The amount of water locked in the Antarctic ice sheets alone is equivalent to some 54 m of global sea level, and the presence or absence of ice caps is an important factor in the Earth's energy balance. The possibility that instabilities in glacial dynamics can exist has prompted a strong interest in glacial ice-stream flow studies in recent years. Research at CIRES has centered on modeling the dynamics of the West Antarctic ice sheet, one of the continent's largest. Dynamical models of the ice streams have been extended to include processes associated with basal friction and hydraulics, features that had been previously neglected. Included in these studies are climatic-forcing scenarios such as the probable changes in the atmosphere due to the carbon-dioxide-induced "greenhouse" and the ice sheets' response.

CIRES also houses the World Data Center A for Glaciology [Snow and Ice] and the associated National Snow and Ice Data Center. During FY 1985 these centers' responsibilities were extended to include the newly developed Cryospheric Data Management System (CDMS). A dedicated computer system and relevant software were acquired for the purpose of archiving and servicing data from the special sensor microwave imagery system on the Defense Meteorological Satellite Program (DMSP) satellites. Of particular interest to climate researchers will be the capability of snow/cloud discrimination with the satellite data. Since snow cover, particularly snow that does not melt during the summer, is very important in climate dynamics, this capability will provide a new tool for monitoring climate change. Analysis of these data is facilitated by the newly acquired image analysis system that is mated to the CDMS computers. Work began on several projects using the DMSP imagery: Frequency of Arctic cloudiness was determined for April-June 1979 and 1980 and is being compared with existing climatologies and statistics generated by a numerical

general circulation model; surface melt of Arctic ice was mapped; and lake freeze-up/break-up data for Finland and Canada were shown to agree with fall and spring temperature records.

INTERACTION OF WAVES AND TURBULENCE WITH MEAN FLOWS

The processes by which small-scale turbulent motion interacts with larger scale dynamics are relevant to studies of both atmosphere and ocean. In addition, interactions of waves with flows that can be considered to be a larger-scale mean environment are also important features in scale interaction in fluids. The best-known example of the latter process is the absorption of wave energy in mean flow "critical layers" wherein the wave group speed matches the flow rate. Turbulence/mean-flow interaction is less well studied, but research at CIRES/ACD is beginning to indicate that analogous processes may occur.

Experimental studies using the WPL Boulder Atmospheric Observatory, a 300-m instrumented tower, were conducted to examine the fine structure of statically stable atmospheric layers. These studies showed a small-scale sheet-and-layer structure in both temperature and humidity to exist that had not been observed in the atmosphere but had been reported to occur in the ocean's thermoclines and in density gradients in lakes and estuaries. This structure has strong implications for electromagnetic wave propagation and will need to be taken into account in future modeling studies of the stable boundary layer.

Modeling studies of wave/mean-flow interaction in the middle atmosphere were aimed at understanding dissipation processes and the transport of nitric oxide. This transport is important in trying to determine the processes involved in the winter anomaly, an event in which an increase in radio wave absorption is observed. Preliminary results of the model indicate that planetary waves and auroral activity are necessary to provide the required transport of nitric oxide out of the polar regions and into the middle latitudes. Experimental work was done using Doppler radars in the equatorial middle atmosphere. An experiment, at the Jicamarca, Peru, observatory was designed to measure the neutral winds in order to examine the diurnal tide. This tide is believed to be important in providing frictional drag in the equatorial middle atmosphere.

Plans FY 1986

ATMOSPHERE-OCEAN INTERACTION

Experimental work on the atmospheric boundary layer will continue with CIRES scientists' participation in the forthcoming Frontal Air-Sea Interaction Experiment (FASINEX) in February and in the subsequent data analysis. FASINEX is a multi-agency field program to investigate the atmospheric and oceanic processes on each side of the subtropical Atlantic (ocean) front; in addition to the NOAA/OAO P-3 used by the CIRES researchers, the field plan includes five other research aircraft and two research ships; extensive satellite data analysis will take place during and after the field phase. In support of

FASINEX, the hybrid ocean model discussed above will be used to simulate the frontal dynamics and changes in air-sea interaction across the front.

The extensive marine stratocumulus cloud data set obtained during the FY-1985 missions will be analyzed in detail with several objectives. These include the examination of the influences of the diurnal cycle on the dynamics of the cloud deck, for which purpose early-morning and late-afternoon missions were flown; one of the least-known aspects of cloud dynamics is the effect of variable radiative forcing on the cloud, and these data will lend insight into those processes. The field program was coordinated with dedicated retrievals of LANDSAT Thematic Mapper images of the cloud deck (with nominal resolution of 30 m), and an important aspect of the data analysis will be comparison of the radiative properties of the clouds as observed by the aircraft and the satellite. These high-resolution platforms will be compared with the GOES operational data that were recorded routinely. Although interactions of cloud dynamics and radiative transfer are relatively obscure, it is known that the stratocumulus-topped boundary layer represents a case of strong interaction. The conditional sampling of gust probe data will be extended to this case, and results compared with the more canonical cases analyzed previously. This should provide fundamental insight into very basic aspects of boundary-layer theory, including a new perspective on the scaling quantities.

CRYOSPHERE-CLIMATE INTERACTION

Two aspects of the glacial surge studies will be pursued. The modeling studies will be cross-validated with data from glacial monitoring for a variety of locations, and the models improved on that basis. In addition, other modeling assumptions will be tested using the data set to be assembled. The major new initiative will involve a combined field/modeling study of the Jakobshavens ice stream in Greenland. Airborne (helicopter) sampling of the saline properties of the outflow fjord will establish the rate of basal melting, and this will be compared with model predictions. During the sampling missions, photographic surveys will record changes in the thickness and the flow rate of the ice.

It is expected that the suite of analytic instruments associated with the CDMS project will be expanded with the acquisition of an automated digitizing system. This device will be used to re-digitize selected parts of the extensive DMSP film archive housed at CIRES at nearly the original resolution, and hence allow construction of climatological data bases on Arctic sea ice and clouds. When combined with the power of the image analysis system, it will also provide a means of integrating previously incompatible data formats. The ability to perform data services for the Data Centers' customers will be increased markedly. In-house analyses to occur during FY 1986 include comparisons of DMSP-inferred Arctic melt progression with that observed by the Nimbus-7 passive microwave system, and comparisons of Antarctic sea ice extent and sea surface temperatures with atmospheric trends in carbon dioxide at Southern Hemisphere stations.

INTERACTION OF WAVES AND TURBULENCE WITH MEAN FLOWS

The analysis of the fine-structure observations will be completed with emphasis on explaining the occurrence of layering and the spacing between the sheets and layers. This will include multiple-regression/partial-correlation analyses of the mean gradient and the turbulence quantities to examine the implications for atmospheric diffusion. The roles of Kelvin-Helmholtz instability and gravity waves in creating the fine structure will be studied, and further implications for wave propagation will be explored.

An outgrowth of the ESG/Climate Research Program investigations concerning the development of extratropical waves in relation to convective episodes in the tropics will be explored. The case study will use GOES sounder data that, serendipitously, captured a wave development episode that seems to be related to deep convective forcing in the central equatorial Pacific. The wave subsequently propagated eastward and brought significant weather to the U.S. Gulf Coast. The study to be initiated will begin the investigation of the predictability of such weather events, based on wave development in the Pacific.

The investigation of the winter anomaly will continue. In addition, another modeling effort will begin on the interaction of stationary and transient planetary waves and their coupling between the troposphere and stratosphere. The data obtained from the Jicamarca experiment will be analyzed for the winds. Other experiments are being planned for studying large-scale atmospheric waves. One such experiment involves the hardware and software design of a portable system that can be attached to existing radar systems.

The interactions between large-scale (quasi-geostrophic) waves in the stratosphere and the mean zonal flow will be studied with a numerical model. In particular, the effects of transient versus stationary forcing of the wave on the wave's structure will be examined to determine the role of frequency of the forcing and the resultant wave amplitudes. This will lead to insight into the role of transient forcing in the structure of resonant traveling waves and the stratospheric mean flow.

SOLID-EARTH GEOPHYSICS

Accomplishments FY 1985

Solid-earth geophysics continues to be a major theme of CIRES research, although support for the program is obtained predominantly from outside NOAA/ERL (e.g., USGS, NSF, NASA, DOD). 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 whole-earth geodesy, geodynamics, laboratory studies of rock failure and rock properties under high stresses, earthquake prediction and other observational seismology, theoretical studies of wave generation and propagation, and engineering seismology.

The geodynamics program has used a variety of modern techniques to investigate local and regional deformation of the crust. Current research, funded by and of importance to the National Geodetic Survey includes two- and three-color laser electronic distance measurement instruments (which are being used to measure crustal movement in southern California); theoretical and observational studies of variations in the rotation of the Earth, Earth and ocean tides, and other large-scale motions within the Earth.

Research directed to understanding local and regional crustal deformation is based on (1) high-precision measurements of changes in the length of lines several kilometers long that monitor tilts of the crust, and (2) the development and use of NASA-sponsored extraterrestrial geodetic techniques using laser ranging to satellites and radio interferometric observations of natural or artificial radio sources in space.

Recently the University Navstar Consortium was awarded $1.5 million to begin the assembly and testing of satellite geodetic terminals. The terminals will make use of the Navstar Global Positioning System (GPS) satellites. The principal investigator of the project is in CIRES. One of the important aspects of GPS geodesy is correction for path delay resulting from tropospheric water vapor. The use of microwave water vapor radiometers (WVRs) is being investigated with recent funding from USGS. A follow-up GPS test was conducted in the spring of 1985 by the consortium and a number of other agencies. The resulting data set is now under analysis, including corrections for ionospheric, tropospheric, orbit, and phase ambiguity resolution errors.

Observational seismology is directed to the investigation of dynamic Earth processes and Earth structure on the basis of the data from seismograms of earthquakes or other seismic sources. Earthquake prediction research provided a focus for much of the work in observational seismology in the past year; seismotectonic studies offered a closely related second focus. In the search for approaches to earthquake prediction we are currently studying seismicity patterns, focal mechanisms, seismic wave velocities, crustal deformations, average magnitudes of earthquake sets, stress drops, wave attenuation, and the chemistry of soil gas. We have shown that some of these observables have changed before past major earthquakes.

The theoretical seismology program, which is largely supported by DOD as part of its nuclear test-monitoring research program, has resulted in the development of powerful computer codes for calculating synthetic seismograms and new approaches to source interpretation based on the analysis of very-high-frequency seismic waves.

A major theme of experimental and theoretical studies is seismic velocity anisotropy. A recently completed study, supported by NSF, yielded a pattern of anisotropy in the upper mantle beneath Tonga and Fiji that can be related to flow patterns associated with major plate movements. The laboratory rock physics group has developed new models of upper mantle mineralogy that accounts well for many observed properties, including anisotropy.

The engineering seismology program, funded by NSF, has included studies of surface motion amplification due to topographic features and alluvial valleys, and investigation of dynamic response of extended underground struc-

tures like pipelines and tunnels. Work has continued also in wave dispersion and attenuation in media with microstructures, e.g., cracks, voids, inclusions.

The present efforts of the rock physics group are directed to gaining better understanding of the dependence of rock deformation and fracture on time and ambient conditions. This work is motivated by the desire to elucidate such diverse phenomena as the evolution of planetary crusts, earthquake mechanisms and precursors, and problems associated with the disposal of hazardous waste materials.

The group recently embarked on a challenging experimental approach to gaining an understanding of the stresses within the mantle that drive tectonic plates. The attenuation of seismic waves in the mantle seems to be due to dislocations within mantle crystals. The equilibrium dislocation density is a function of the stress within the mantle. The experimental approach will be to measure the attenuation of elastic waves in the seismic frequency band as a function of dislocation density. The experiments will have to be performed with the sample at temperatures in excess of 1000°C. Parallel with the experimental effort there will be theoretical studies of the seismic anisotropy of Earth's crust and mantle. As results from seismology are combined with those of solid state physics, an understanding of the physics of flow of the mantle is emerging.

Plans FY 1986

We are extending current models of the Earth's rotational motion (nutations, variations in rotation rate, etc.) to compare with the rapidly improving observations in an attempt to learn about the Earth's deep interior. We are modeling deformation of the Earth's surface caused by nontectonic processes, such as atmosphere and oceanic forcing, so that its effects can be removed from high-quality geodetic data.

For FY 1986, the form of support for the Central Aleutian seismic network provided by the U.S. Geological Survey (USGS) will change to a cooperative agreement, rather than a contract. Network operations and earthquake catalog preparation will continue. The prediction research effort, with USGS support, will concentrate on the analysis of physical parameters along the main fault zone under the Central Aleutian Islands and the application of fracture mechanics theory to the interpretation of time-varying stress patterns.

Work on precursors to Hawaiian earthquakes will continue.

Some work has been initiated in the area of ultrasonic nondestructive evaluation of composite plates. This is a combined and theoretical study of wave propagation and scattering in layered anisotropic plates. Funding for this work is being actively sought from NSF, ONR and ARO. Recent developments of a high-frequency, absolute displacement transducer will allow precise ultrasonic signed measurements. Work is also in progress in phase transformations in ceramic materials under stress and in the nondestructive evaluation of failure progression in concrete.

Work in the engineering seismology area is now directed toward wave propagation and amplification in layered media. Also under investigation is the dynamic response of structures embedded in layered media.

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 1985

CLIMATE RESEARCH

JIMAR's climate research in FY 1985 included studies of interactions between middle-latitude and tropical circulation, Pacific island rawinsonde profiles, and surface wind fields derived from surface and satellite data.

Composites of middle-latitude dropwindsonde data collected near tropical east Pacific cirrus surges during the Global Weather Experiment (Special Observing Period-1) were analyzed. The analyses indicated that surges were caused by equatorward-penetrating middle-latitude systems. Cross sections of individual events agreed with the composites. We confirmed a published composite model that linked Asian winter monsoon activity with synoptic developments in the Hawaiian region.

Empirical orthogonal function analysis showed an inverse relationship between large-scale convective activity over the Australian monsoon region and the Society Islands. Spectral analysis indicates that systems with 20-40 day periods account for the inverse relationship.

Pacific island station rawinsondes for 1971-1976 were also examined. Power spectrum analysis of zonal winds showed 15-30 day oscillations in the midtroposphere for the 1972-1973 El Niño. In the upper troposphere 30-60 day modes were insignificant during El Niño but appeared significant during pre- and post-El Niño periods.

The meshed data from ships, buoys, small islands, and atolls, and derived surface winds from low-level satellite winds were analyzed and grid point data extracted through March 1983 for the Pacific Ocean. Owing to the extreme wind anomalies during the 1982-83 ENSO, our normal method of using climatological shear to derive surface winds from satellite data was modified for the period November 1982 through May 1983. Subjective analysis and evaluation of the Comprehensive Ocean-Atmosphere Data Set (COADS) revealed many instances of suspect and/or misplaced data. The COADS data have proved sufficient for a very reasonable wind analysis over most areas of all three oceans. The COADS pressure data permit a subjective analysis of the atmospheric pressure at sea level, which is in good agreement with the winds.

EQUATORIAL OCEANOGRAPHY

JIMAR's equatorial oceanography activities in FY 1985 included new observational efforts with the Line Islands Array and Western Equatorial Pacific Ocean Circulation Study (WEPOCS), data analysis of NORPAX and PEQUOD data sets, and theoretical studies. Several sea level networks, data centers, and projects also continued.

In February and March 1985 inverted echo sounders and shallow subsurface pressure gauges were installed in the equatorial central Pacific using the R/V Machias. The Line Islands Array consists of these instruments in combination with island tide gauges. This array will be maintained for 5 years to study synoptic oscillations in sea level and their relation to wind and current fluctuations. Sixty-two hydrographic stations were occupied on two meridional sections throughout the array.

WEPOCS field work started in June 1985. Large-scale hydrographic surveys were conducted, and five shallow subsurface pressure gauges were deployed from the R/V Thompson in the Solomon and Bismarck seas. Pegasus current profiles at six sites along 150°E were carried out aboard the Australian R/V Franklin. An Acoustic Doppler Current Profiling program began on the R/V Moana Wave and R/V Franklin. Near-surface relative current profiles were made on both WEPOCS cruises and on an equatorial transit aboard the R/V Moana Wave.

Analysis of NORPAX and PEQUOD data continued, using more than 500 Pegasus profiles taken during the Line Islands Profiling Project. Studies of the structure of the deep equatorial jets indicated that the jets did not propagate vertically during the 16-month period of these observations.

Event detection methods were used to study near-equatorial sea level events. Many events appear to be Kelvin wave pulses generated by westerly wind bursts, best described statistically by a Poisson process model. A seasonal cycle of event frequency, and interannual variability of both event frequency and event sign were observed in the data.

Theoretical studies continued, and development began on a model of the influence of Indian Ocean coastal geometry on equatorial wave generation. This model will be used extensively to look at 40-50 day oscillations in the Indian Ocean as part of an India/U.S. bilateral effort on monsoon variability. Work on a second model began cooperatively with investigators from JISAO on a model to study interaction of equatorial waves and mean flows. Studies on vertically propagating Kelvin waves have led to a more general study of equatorial waves.

Research on sea level studies continued in several areas. Operation of the Pacific Sea Level Network continued through 1985, and data were routinely processed and evaluated. Four additional stations were converted to satellite data transmission, bringing the total to ten. Sea level observations were used to estimate the amounts of warm water exchanged during the 1982-83 El Niño event; an eastward flux of about 40×10^6 m^3 s^{-1} is indicated.

The TOGA Sea Level Data Center, established in 1984, acquired necessary equipment and moved into new accommodations. A data-handling system was developed, and the bulk of past monthly mean sea level data for the tropical oceans was acquired. Acquisition of past daily sea level data from a variety of sources started.

The Integrated Global Ocean Station System (IGOSS) Sea Level Pilot Project, established in early 1984, continued to issue monthly maps of sea level for the Pacific Ocean. Data from 67 stations located in 25 IGOSS member states are included in the analysis for each Pacific map.

TSUNAMI RESEARCH

The construction of five solid-state tsunami gauges was funded by the University of Hawaii. The electronic and package work was completed as well as design and fabrication of a prototype model. The tsunami observer list was updated with the addition of five new observers.

Plans FY 1986

CLIMATE RESEARCH

- Examine the role of tropical storms in ENSO and delineate large-scale climate system fluctuations necessary for their occurrence.
- Participate in the United States/Peoples' Republic of China western Pacific research project cruises starting in December 1985.
- Continue production of the Pacific Ocean surface wind data set and evaluate non-U.S. satellite products and meteorological reports from fishing fleets.

EQUATORIAL OCEANOGRAPHY

- Continue PEQUOD analysis and comparison with NORPAX shuttle observations.
- Continue to operate the Pacific Sea Level Network and convert three more stations to satellite data transmission.
- Establish a data base of the Indian Ocean at the TOGA Sea Level Data Center.

TSUNAMI RESEARCH

JIMAR

- Deploy five gauges to test calibration and gain field experience.

JISAO

The Joint Institute for Study of the Atmosphere and the 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 1985

CLIMATE

JISAO contributed to the EPOCS and TOGA programs through the support of four postdoctoral appointees and one visiting scientist whose research involved both observational and theoretical studies, and through active participation in planning for TOGA at the national and international levels.

A continuing study of nonlinear Rossby waves showed that critical layers provide a theoretical framework on which to base many ideas concerning the breaking of Rossby waves. More and more evidence is becoming available that in the atmosphere this process is extremely important in the transport of potential vorticity and chemical tracers.

This study of nonlinear Rossby waves concentrated on four topics:

(1) Evolution of a nonlinear critical layer. Novel physical effects include the possibility of long-term absorption, the formation of a wake in which material contours are highly contorted, and the tendency for closed-streamline regions to be inhibited as the enduring vorticity field in turn alters the streamfunction.

(2) Barotropic instability of a nonlinear critical layer. A great deal of time was spent on simulating the evolution of the entire nonlinear critical layer including the instability in a numerical model. This effort provided very strong evidence that the instability is highly effective in changing the evolution of the nonlinear critical layer. A number of problems remain to be solved before this study is complete.

(3) Simple analytical and numerical solutions of critical layer behavior. A precise picture was revealed of the way in which reflecting/absorbing properties of critical layers are affected by numerical resolution and flow curvature.

(4) Research related to the effect of potential vorticity mixing in the stratosphere on atmospheric free modes.

Another climate study area focused on low-frequency variability of the sea level and near surface temperature at the Galápagos Islands during 1979-84. The analysis concentrates on the 2-30 day frequency band where peaks are observed at 5 and 12 days.

Previous theoretical work was extended on the ocean response to spectral wind forcing on a continental margin, removal of the long-wave approximation, handling the "corner" region and merged Ekman layers, and cross shelf variation in bottom friction.

Scientific activity at the Experimental Climate Forecast Center focused on the preparation of a reformatted version of the National Meteorological Center (NMC) data. The new form is intended to be one that can be updated with NMC grids in real time. Real-time diagnostics in the context of the long-term climatic record will then be done.

ENVIRONMENTAL CHEMISTRY

Research continued on the absorption and removal of dissolved constituents in sea water by settling particles, which is termed scavenging. Scavenging is considered to be one of the main removal mechanisms of trace elements from seawater and a sink for pollutants in the coastal zone. The rates of scavenging under natural conditions were estimated by measurements of the distribution of dissolved and particulate Th-234. Laboratory experiments were used to extend the field measurements on Th-234 to a wide range of other elements. Experiments on the kinetics and equilibrium uptake of Th-234 and other elements by natural marine particulate matter were designed and conducted. Field and laboratory measurements were brought together to develop a model for scavenging in the open ocean and in Puget Sound. A box model to predict the rate of uptake of reactive elements in Puget Sound was constructed.

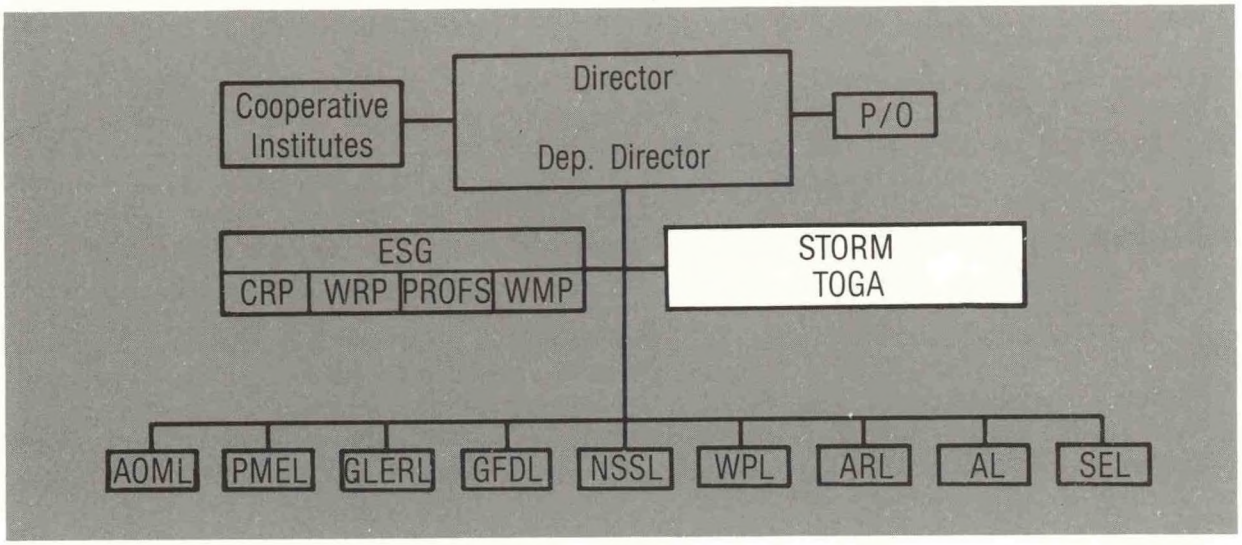
JISAO continued its role of facilitating collaboration and interaction among environmental chemists working in several departments on the University campus. The annual Environmental Chemistry Day was held on 24 January.

Plans FY 1986

- Continue an active program in climate with four postdoctoral appointees, a senior visiting scientist in residence, and a large number of short-term visitors who will be giving seminars.
- Secure funding for continuation of the core program in Environmental Chemistry.
- Sponsor a 3-day workshop on oceanic general circulation in January 1986; 25 from outside the Laboratory are expected to attend.
- Begin a Distinguished Scientist Program.

STORM PROGRAM OFFICE
Boulder, Colorado

Rex J. Fleming
Director



The National Stormscale Operational and Research Meteorology (STORM) Program Office was established in NOAA in November 1984. The office is funded by and serves the Federal agencies expected to participate in the National STORM Program, receives its general guidance from the Federal Coordinating Committee for Science, Engineering, and Technology Subcommittee on Atmospheric Research (SAR), and obtains its administrative support from the Environmental Research Laboratories of NOAA. The main function of the office is to prepare the documentation needed to obtain fiscal support for the program, and ultimately, to prepare the detailed implementation plans for each of the field phase efforts throughout the 14-year life of the program.

WEATHER OBSERVATIONS AND PREDICTION

STORM is a major interagency operational and research program that will enable the United States to deal with the mesoscale weather elements that actually affect day-to-day activities. The purpose of the program is to make dramatic improvements in observation, prediction, and warning systems for those weather phenomena that take tolls in life and property.

Progress in meteorology has been significant on the synoptic scale and on the microscale. The mesoscale has eluded us, in a relative sense, for technological reasons; the barely perceptible progress over the last 25 years in numerical prediction of precipitation is but one example of this. However, we now have the technology to advance. Soundings from geostationary satellites, atmospheric wind profiling systems, NEXRAD and other new research radars on the ground and in the air, automated surface stations, rapid communications, and new software for display, analysis, and prediction are now here or on the immediate horizon.

The Program Design for STORM-Central had been written in 1984 and endorsed by the National Academy of Sciences. The plan contains a novel use of technology and highly skilled people to accelerate technology transfer, through the use of Experimental Forecast Centers. The plan calls for new basic and applied research, and offers a framework for significant contributions to other disciplines such as hydrology and atmospheric chemistry.

Stating that a National STORM Program is long overdue, the National Academy of Sciences recommended that the government take action. In the 98th Congress, the Senate passed Senate Concurrent Resolution 109, calling for a National STORM Program with NOAA as the lead agency. The same Congress appropriated FY 1985 funds for NOAA to initiate PRE-STORM activities. A successful Oklahoma-Kansas PRE-STORM field phase was conducted in the summer of 1985. Results will be incorporated into the detailed design of STORM.

STORM-Central should begin in the spring of 1990 and will cover the center third of the country. It will focus on severe weather, flash floods, and severe winter storms. It will also concentrate on improving the predictions of those mesoscale convective systems that bring beneficial rain to the corn and wheat belts. STORM-East is scheduled for the early 1990s, and STORM-West is scheduled for the mid-1990s. Both will have a notable oceanographic component.

The Federal agencies will work together to implement this program and supply the budgetary and personnel resources required. The budget is large relative to conventional meteorological funding but not large relative to the budgets of other national activities of comparable importance to society.

Accomplishments FY 1985

The STORM Program Office initiated studies and discussions with scientists, engineers, and potential contractors to define a workable and affordable communications system for the real-time requirements of STORM-Central. It is expected that the Geostationary Operational Environmental Satellite (GOES) data collection system of NOAA will be used to deliver data from several of the automated data systems to be used in STORM-Central. A separate real-time communications network, linking the data sources with the Experimental Forecast Centers and the Operational Control Center, will be established; its hub will be colocated with the ERL/PROFS facility.

The STORM Office established academic working groups to revise the STORM-Central Implementation Plan. More than 80 of the best mesoscale scientists in government laboratories and universities have agreed to serve and work toward creating a revised STORM-Central Program Design that will provide a consistent scientific direction to mesoscale research.

Plans FY 1986

- Further studies and discussions will be conducted to define staffing and logistical requirements for each of the major STORM-Central observing systems, and for the forecasting facilities.

- A new budget will be prepared, consistent with the revised timing of STORM:

    - Eliminating or reducing the budget for those elements required in STORM-Central, but now wholly or partially planned for implementation elsewhere.

    - Tightening the budget in specific areas by further use of base funds or other actions.

    - Soliciting further support from other agencies whose planned role in STORM was slight or nonexistent.

- The research radar network strategy will be revised on the basis of the new implementation schedule of the Next-generation Radar (NEXRAD) systems in the STORM-Central region.

- The STORM-Central Program Design document will be revised to be more specific about the role of the program in winter storm forecast improvement, STORM-related hydrology, and STORM-related chemistry.

INTERNATIONAL TOGA PROJECT OFFICE

The Director of the National STORM Program Office is also responsible for implementation of the International Tropical Ocean and Global Atmosphere (TOGA) Project Office. This office, with its own staff, serves those international organizations supporting the 10-year TOGA program, receives its general guidance from the Director of the World Climate Research Programme (located in Geneva, Switzerland, within the World Meteorological Organization), and obtains its administrative support from the Environmental Research Laboratories of NOAA. Its main function is to prepare Implementation Plans for the TOGA program.

The scientific aspects of TOGA have been defined and planned by the TOGA Scientific Steering Group (SSG). The SSG was established by the Joint Scientific Committee of WMO and ICSU and by the Committee on Climate Change and the Ocean (CCCO) formed by the IOC and SCOR. The SSG also formulates scientific priorities for the implementation of TOGA.

Research on large-scale oscillations of the tropical atmosphere has been conducted for more than 80 years. Through the years, scientists correlated these low-frequency atmospheric oscillations with changes occurring in the tropical oceans. Later, it was realized that these interactions between the tropical oceans and atmosphere were linked to changes of weather and climate in the higher latitudes of both hemispheres. However, it is only recently that the latest analyses of data and results from field experiments and theo-

retical work have come together to create a sense of priority in the scientific community concerning this subject.

In the last few years, recognition of the importance of predicting variations in the Earth's climate has led to a large increase in individual research investigations. However, it is clear that progress in understanding and predicting these climate events will require information about the relevant atmospheric and oceanic variables. An international activity that will provide this information has been organized and is called the TOGA program. TOGA is part of the World Climate Resarch Programme (WCRP) established by the World Meteorological Organization (WMO) and the International Council of Scientific Unions (ICSU) to determine to what extent climate can be predicted and the extent of human influence on climate. The TOGA program was organized with the joint support of SCOR (ICSU's Scientific Committee for Oceanic Research), WMO, and the UNESCO Intergovernmental Oceanographic Commission (IOC).

The scientific community has been aware of the existence of anomalous oceanic and atmospheric circulation patterns that develop on time scales of several months to several years, and has recognized that a significant part of these variations can be explained by the dynamics of the coupled system consisting of the tropical oceans and the global atmosphere. The study of this system is the objective of the TOGA program.

New insights have been gained on the planetary-scale monsoon system under the Monsoon Experiment (MONEX) Sub-programme of the First GARP Global Experiment (FGGE), as well as under national, bilateral, and international monsoon research programs prior to MONEX. The sub-seasonal and interannual variability of monsoons is now regarded as having close links with ocean surface conditions on regional and planetary scales. Monsoon variability is also a function of interactions with other major atmospheric systems. Recognizing the important role of the planetary-scale monsoons, as an energy source for the global atmosphere and as a potential link to Southern Oscillation and El Niño events, the TOGA program has included the study of monsoon variability as an important element in achieving its overall objectives.

Accomplishments FY 1985

A conference on the TOGA Scientific Programme was convened in Paris 17-21 September 1984. Representatives from 38 countries attended. It was a successful conference and there was considerable enthusiasm for participating in the TOGA program. Several representatives from various countries expressed concern that there needed to be accessible information about TOGA. That information is now being made available.

The International TOGA Project Office (ITPO) contributed to two chapters of the TOGA Scientific Plan. The plan has been completed and will be distributed in October 1985 by the World Meteorological Organization. The ITPO prepared several drafts of the International TOGA Implementation Plan for appropriate review, and the final version was completed in October 1985.

The ITPO began publishing a quarterly newsletter, "TOGA Topics." The purpose of the newsletter is to keep the international community informed of activities at the Project Office, to pass along news of interest and, most

important, to provide the meteorological and oceanographic communities with recent information on the status and operation of TOGA.

The ITPO also prepared a high quality brochure that describes the TOGA program in laymen's terms, indicates what contributions are needed, and offers suggestions to countries on how to make such contributions. The brochure is to be available in English, French, Spanish, Russian, Japanese, and Chinese.

The ITPO produced two satellite films documenting cloudiness and precipitation during the record 1982-83 El Niño event. One film was composed of a sequence of 1-h full-disk images of GOES-West (135°W) infrared radiances, for the period 1 May 1982 through 20 November 1982. The second film was composed of a similar sequence of infrared images from GOES-East (75°W) for the period 1 November 1982 through 15 June 1983. Copies of these films were distributed to countries expressing an interest in TOGA, and a library system of loan copies of these films has been established. The films offer an additional scientific tool for assessing the Southern Oscillation phenomena; the second film is especially interesting because it depicts intense mesoscale convective systems in the eastern Pacific and along the coast of South America--regions where they rarely occur.

The TOGA program had already begun by January 1985. Considerable resources are already in place (XBT lines, tide gauge stations, and enhanced meteorological observations). The program will continue to evolve as new technology becomes available.

Plans FY 1986

- Distribute 1000 copies of the International TOGA Implementation Plan to the international community.
- Prepare material and make necessary "marketing" trips to help the international organizations supporting the TOGA program achieve the remaining data management center commitments.
- Prepare material and letters to various countries and organizations to encourage further contributions of observing systems.
- Distribute the TOGA brochure to every country in the world, in English, French, Spanish, Russian, Japanese, or Chinese. Countries will be encouraged to contribute to the TOGA program on a continuous basis--no contribution is too small or too late.
- Distribute "TOGA Topics" and Implementation Plan changes to the international community.

APPENDIX: Acronyms and Initialisms

ACE	Arctic Cyclone Experiment
ACM	acoustic current meter
AFOS	Automation of Field Operations and Services (NWS)
AGASP	Arctic Gas and Aerosol Sampling Program
AID	Agency for International Development
AIMCS	Airborne Investigations of Mesoscale Convective Systems
AL	Aeronomy Laboratory (ERL)
ALPEX	Alpine Experiment
ANL	Argonne National Laboratory
ANU	Australian National University
AOML	Atlantic Oceanographic and Meteorological Laboratory (ERL)
APEX	Arctic Polynya Experiment
APM	Airshed Photochemical Model
ARL	Air Resources Laboratory (ERL)
ARTCC	Air Route Traffic Control Center
ASCOT	Atmospheric Studies in Complex Terrain (DOE)
ATD	Atmospheric Transport and Diffusion [model]
ATDD	Atmospheric Turbulence and Diffusion Division (ARL)
ATLAS	Automated Temperature Line Acquisition System
ATOLL	Analysis of the Tropical Ocean Lower Layer
AWIPS-90	Advanced Weather Interactive Processing System for the 1990's
AWS	Air Weather Service (USAF)
AXCP	airborne expendable current probe
BAO	Boulder Atmospheric Observatory (ERL)
CAC	Climate Analysis Center (NWS/NMC)
CAMS	control and monitoring system
CAPTEX	Cross-Appalachian Tracer Experiment
CCCO	Committee on Climate Change and the Ocean (IOC-SCOR)
CDM	Climatological Dispersion Model
CDMS	Cryospheric Data Management System
CESD	Computer and Engineering Support and Development (NSSL)
CG	cloud to ground
CHILL	Chicago - University of Illinois [radar system]
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
COE	Corps of Engineers (U.S. Army)
COMEDS	Continental U.S. Meteorological Data System
CONDORS	Convective Dispersion Observed by Remote Sensors
COP	carbon, oxygen, phosphate
CRP	Climate Research Project (ERL/ESG)
CSIRO	Commonwealth Scientific and Industrial Research Organization (Australia)
CSU	Colorado State University
CTD	conductivity, temperature, depth
CTDM	Complex Terrain Diffusion Model
CWP	Central Weather Processor (FAA)

DAR³E	Denver AWIPS-90 Risk Reduction and Requirements Evaluation (FAA)
DMS	dimethyl sulfide
DMSP	Defense Meteorological Satellite Program
DOD	Department of Defense
DOE	Department of Energy
DOM	dissolved organic material
DOPLIGHT	Doppler-Lightning
DOPLOON	Doppler-balloon
DRASER	Doppler Radar And Storm Electricity Research (NSSL)
DWBC	deep western boundary current
ECC	electrochemical concentration cell
EDA	energy dispersive analysis
ENAMAP	Eastern North American Model of Air Pollution [superseded; see RELMAP]
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)
EUC	Equatorial Undercurrent
EUV	extreme ultraviolet
EWH	echo weak hole
FAA	Federal Aviation Administration
FACE	Florida Area Cumulus Experiment
FACTS	Florida Atlantic Coast Transport Study
FASINEX	Frontal Air-Sea Interaction Experiment
FGGE	First GARP Global Experiment
FM-CW	frequency modulation-continuous wave
FOCI	Fisheries Oceanography Cooperative Investigations (NOAA)
FOX	Fishery Oceanography Experiment
GAGE	Global Atmospheric Gas Experiment
GALE	Genesis of Atlantic Lows Experiment
GARP	Global Atmospheric Research Program
GC	gas chromatography
GCM	general circulation model
GCM	Global Climate Monitoring
GFDL	Geophysical Fluid Dynamics Laboratory (ERL)
GLERL	Great Lakes Environmental Research Laboratory (ERL)
GMCC	Geophysical Monitoring for Climatic Change (ARL)
GOES	Geostationary Operational Environmental Satellite
GPS	Global Positioning System
GTN	Global Trends Network
GTS	Global Telecommunication System
GWMF	gravity wave momentum flux
HEPAD	High Energy Proton and Alpha Detector
HF	high frequency
HPBL	hurricane planetary boundary layer
HPLC	high performance liquid chromatography

HRC	highly reflective clouds
IAGLR	International Association for Great Lakes Research
ICE	Interplanetary Cometary Explorer
ICSU	International Council of Scientific Unions
IES/PG	inverted echo sounder/pressure gauge
IGOSS	Integrated Global Ocean Station System
IMF	interplanetary magnetic field
INS	Inertial Navigation System
IOC	Intergovernmental Oceanographic Commission (UNESCO)
IPA	Intergovernmental Personnel Act
ITPO	International TOGA Project Office
IUWDS	International Ursigram and World Days Service
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
LANL	Los Alamos National Laboratory
LC	liquid chromatography
LFM	limited-area fine mesh
LLNL	Lawrence Livermore National Laboratory
LMR	laser magnetic resonance
L-RERP	Long-Range Effects Research Program
MAG	Mesoscale Applications Group (ESG/WRP)
MAP	Middle Atmosphere Program (SEL)
MAPS	Mesoscale Analysis and Prediction System (PROFS)
MCC	mesoscale convective complex
MCS	mesoscale convective system
MEPED	Medium Energy Proton and Electron Detector
METREX	Metropolitan Tracer Experiment
MFM	movable fine-mesh [hurricane model]
MFPS	multi-frequency acoustic plankton survey
MHD	magnetohydrodynamic
MIZEX	Marginal Ice Zone Experiment
MOCNESS	multiple opening/closing net environmental sensing system
MONEX	Monsoon Experiment (FGGE)
MRG	Mesoscale Research Group (ESG/WRP)
MS	mass spectrometry
MSG	Mesoscale Studies Group (ERL/ESG)
MST	mesosphere-stratosphere-troposphere
NAPAP	National Acid Precipitation Assessment Program
NASA	National Aeronautics and Space Administration
NBS	National Bureau of Standards
NCAR	National Center for Atmospheric Research
NCDC	National Climatic Data Center (NESDIS)
NDBC	National Data Buoy Center
NECC	North Equatorial Countercurrent

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)
NMFS	National Marine Fisheries Service (NOAA)
NOAA	National Oceanic and Atmospheric Administration
NOMAD	Navy Oceanographic Meteorological Automatic Device
NORPAX	North Pacific Experiment
NRC	Nuclear Regulatory Commission
NSF	National Science Foundation
NSSL	National Severe Storms Laboratory (ERL)
NWAFC	Northwest and Alaska Fishery Center
NWP	numerical weather prediction
NWRI	National Water Research Institute (Canada)
NWS	National Weather Service (NOAA)
OAR	[Office of] Oceanic and Atmospheric Research (NOAA)
ODW	Omega dropwindsonde
O-K PRE-STORM	Oklahoma-Kansas PRE-STORM
PACE	Precipitation Augmentation for Crops Experiment
PAH	polycyclic aromatic hydrocarbon
PAM	portable automated mesonetwork
PBL	planetary boundary layer
PEQUOD	Pacific Equatorial Ocean Dynamics
PMEL	Pacific Marine Environmental Laboratory (ERL)
POWER	PROFS Operational Weather Education and Research
POWS	PROFS Operational Work Station
PPI	plan position indicator
P-PRIME	Pollutant-Particle Relationships In the Marine Environment
PRECP	Processing of Emissions by Clouds and Precipitation
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
RADM	Regional Acid Deposition Model
RELMAP	Regional Lagrangian Model of Air Pollution
RFC	River Forecast Center (NWS)
RITS	Radiatively Important Trace Species
ROM	Regional Oxidant Model
RSMAS	Rosenstiel School of Marine and Atmospheric Science (U. of Miami)
SAGE	Stratospheric Aerosol and Gas Experiment
SANBAR	Sander's Barotropic [model]
SAR	Subcommittee of Atmospheric Research (STORM)
SBUV	solar backscatter ultraviolet
SCCCMP	South Central Coast Cooperative aerometric Monitoring Program

SCOR	Scientific Committee for Oceanic Research (ICSU)
SDHS	Satellite Data Handling System
SEAMAP	Southeast Area Monitoring and Assessment Program
SEC	South Equatorial Current
SECC	South Equatorial Countercurrent
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
SIR	shuttle imaging radar
SLEUTH	System for Locating Eruptive Underwater Turbidity and Hydrography
SME	Solar Mesosphere Explorer
SOON	Solar Observing Optical Network
SPM	suspended particulate matter
SSG	Scientific Steering Group (TOGA)
SST	sea surface temperature
ST	stratosphere-troposphere
STACS	Subtropical Atlantic Climate Studies
STORM	Stormscale Operational and Research Meteorology
SXI	solar x-ray imager
TAG	Trans-Atlantic Geotraverse
THRUST	Tsunami Hazard Reduction Using System Technology
TIROS	Television and Infrared Observation Satellite
TMAP	Tropical Modeling and Analysis Program (PMEL)
TOGA	Tropical Oceans and Global Atmosphere
TOTO	Totable Tornado Observatory
TRIP	Thunderstorm Research International Program
TVS	tornado vortex signature
UGLCCS	Upper Great Lakes Connecting Channels Study
USAF	U.S. Air Force
USGS	U.S. Geological Survey
UV	ultraviolet
VACM	vector-averaged current meter
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
WCRP	World Climate Research Programme (WMO-ICSU)
WEPOCS	Western Equatorial Pacific Ocean Circulation Study
WMO	World Meteorological Organization
WMP	Weather Modification Program (ERL/ESG)

WOCE	World Ocean Circulation Experiment
WPL	Wave Propagation Laboratory (ERL)
WRIPS	Wave Rider Information Processing System
WRP	Weather Research Program (ERL/ESG)
WRR	World Radiometer Reference
WSFO	Weather Service Forecast Office
WVR	water vapor radiometer
WWA	World Warning Agency
WWCE	westerly wind/convection episode
XBT	expendable bathythermograph

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