AOML ANNUAL REPORT
FISCAL YEAR 1991

Climate and Global Change air sampling equipment aboard the NOAA Ship MT. MITCHELL south of Iceland.

U.S. DEPARTMENT OF COMMERCE

National Oceanic and Atmospheric Administration
Office of Oceanic and Atmospheric Research
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Atlantic Oceanographic and Meteorological Laboratory

AOML ANNUAL REPORT

Fiscal Year 1991

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Atlantic Oceanographic and Meteorological Laboratory
4301 Rickenbacker Causeway
Miami, Florida 33149

UNITED STATES
DEPARTMENT OF COMMERCE

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Atlantic Oceanographic and Meteorological Laboratory

FY 1991 Annual Report

PREFACE

This document presents the major accomplishments and plans of NOAA'S Atlantic Oceanographic and Meteorological Laboratory (AOML) for fiscal year 1991. This is the ninth annual report AOML has published in this format since the FY 1983 Annual Report was presented. No annual reports were published during the period of 1980–1982 due to federal restrictions on such documents, but the AOML accomplishments were, as always, widely published in the open literature. The AOML Collected Reprint Series which were published annually between fiscal years 1970 and 1979 provide information on the plans and accomplishments for those years. The reader is invited to contact the AOML Director's Office for additional information which may be available.

AOML is located in Miami, Florida, and is one of eleven Environmental Research Laboratories (ERL) which are housed within NOAA's Office of Oceanic and Atmospheric Research (OAR). The collected plans and accomplishments of all ten Environmental Research Laboratories are jointly published in two separate volumes: the *ERL Plans and Programs Document* and the *ERL Publication Abstracts*. This AOML document supplements the two ERL publications by providing a more detailed view of the AOML program during FY 1991.

The document is organized into four major sections: (1) the Overview section is concerned primarily with management information such as the AOML mission statement, organizational chart, program structure, and information on resources; (2) the Accomplishments/Plans section discusses major FY 1991 accomplishments and FY 1992 plans within the context of the ERL program structure; (3) the Publications section includes a complete list of AOML's FY 1991 publications, with abstracts; and (4) the AOML Staff section lists the employees assigned to the laboratory as of December 1, 1991.

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OVERVIEW

FY 1991 ANNUAL REPORT

ATLANTIC OCEANOGRAPHIC AND METEOROLOGICAL LABORATORY

Mission

The mission of NOAA's Atlantic Oceanographic and Meteorological Laboratory (AOML) is to conduct a basic and applied research program in oceanography and tropical meteorology. The program seeks to understand the physical characteristics and processes of the ocean and the atmosphere, both separately and as a coupled system. Oceanographic investigations center on the 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 principal focus of these investigations is to provide the knowledge that will ultimately lead to: improved prediction and forecasting of severe storms; better utilization and management of marine resources; better understanding of the factors affecting both climate and environmental quality; and improved ocean and weather services for the nation.

Organizational Structure

The AOML organizational structure (Figure 1) features four research divisions, organized according to scientific discipline as follows: (1) Hurricane Research Division (HRD); (2) Physical Oceanography Division (PhOD); (3) Ocean Chemistry Division (OCD); and (4) Ocean Acoustics Division (OAD). Hurricane research and physical oceanography are the major disciplines represented at AOML, with HRD comprising about a third of the total scientific effort (34%). PhOD and OCD each account for about a quarter of the research staff (27% and 24% respectively). The remaining 15% is split between OAD and the Office of the Director (OD), with OAD accounting for 9% and OD providing approximately 6% of the total research effort.

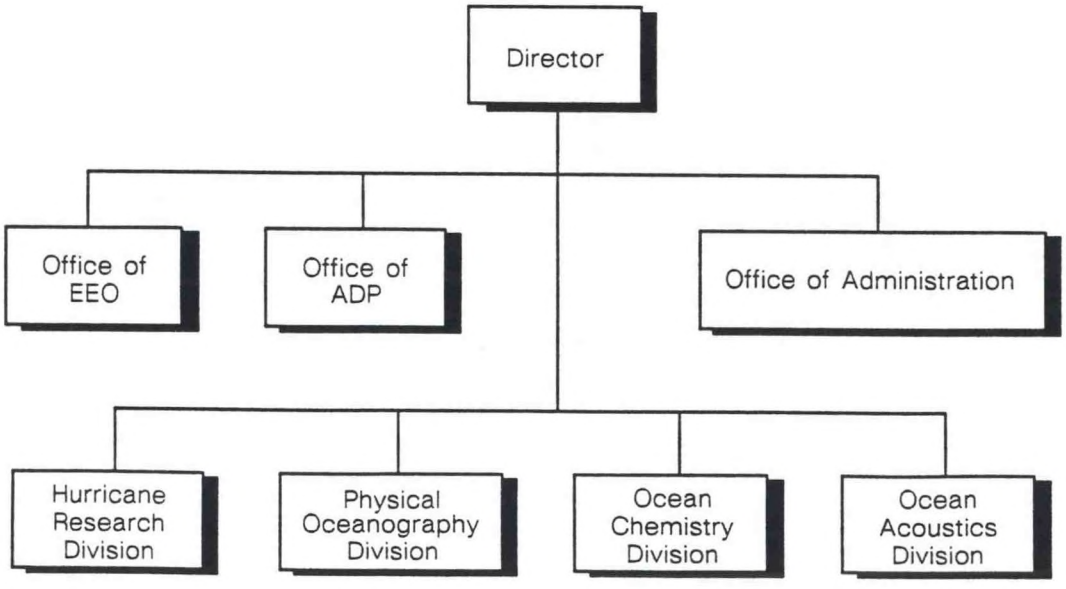

Figure 1. AOML Organizational Chart.

AOML's FY 1991 research funding level was about $8.5 million. The level of research funding has been only slightly increased during the past three years (Figure 2). A reduction in personnel has been accompanied by advances in computer technology and increases in contracted services; thus, the laboratory has been able to continue the high level of scientific productivity, in terms of quantity and quality, that it has proudly established.

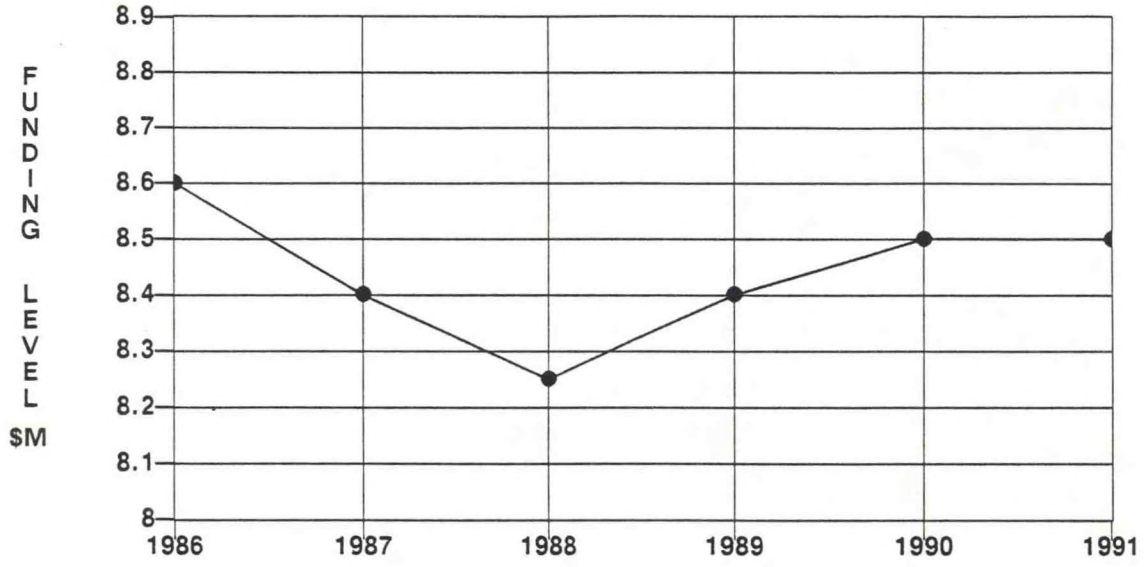

Figure 2. Research Funding Levels for FY 1986 to FY 1991.

A review of the funding sources for the laboratory's FY 1991 program (Figure 3) indicates that about 92% of the total research done at AOML is funded by NOAA, either by ERL directly (75%) or by NOAA Program Offices (18%). Only about 7% of the AOML effort is funded by reimbursable projects with agencies outside of NOAA. These percentages have been fairly stable over the past five years.

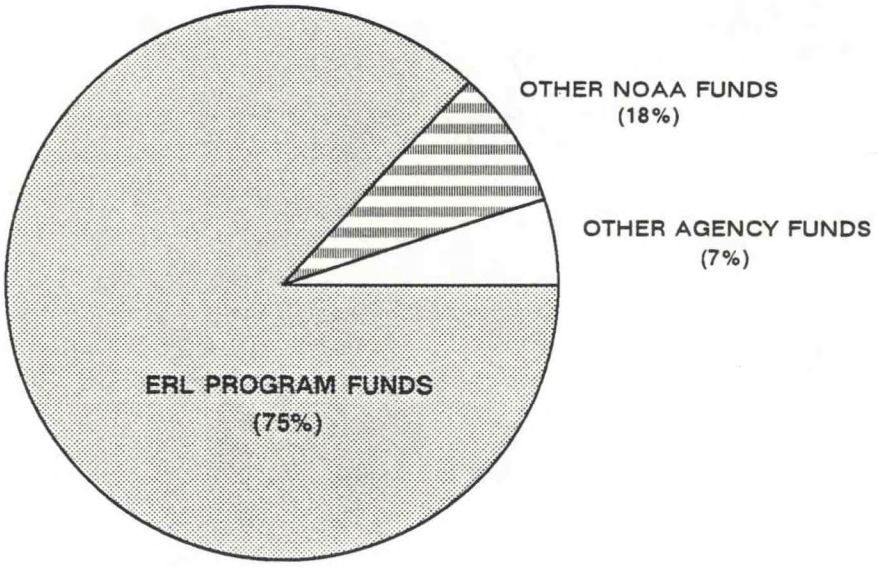

Figure 3. Funding Source Distribution (total FY 1991 funding of $8.5 million).

Figure 4 portrays how AOML's funds were disbursed during FY 1991. Climate and Air Quality programs accounted for just under $4.0 million; Weather Research was almost $2.7 million; and Marine Research work expended about $1.5 million. The distribution of funds between programs at AOML has been quite stable during the past five years.

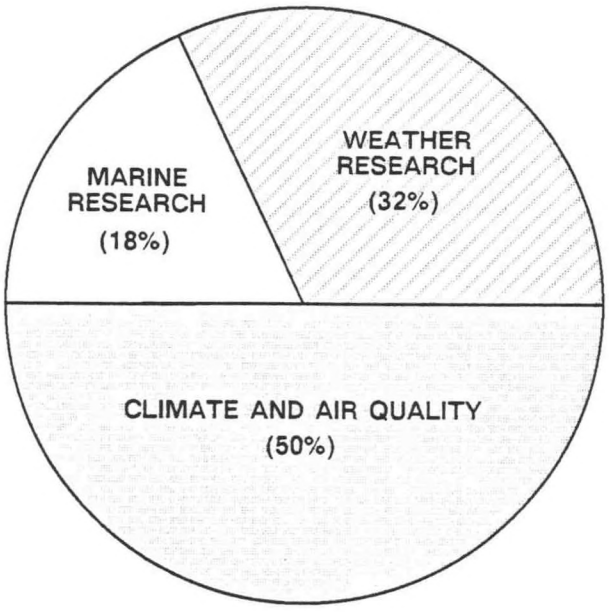

Figure 4. Expenditures by Program (total FY 1991 expenses of $8.5 million).

Fiscal year 1991 was highlighted by the completion of a major Climate and Global Change cruise to the South Atlantic by the Ocean Chemistry Division. The work, which involved radiatively trace species and CO_2, was very successful and yielded new insights into the uptake capacity of "greenhouse" gases in that ocean basin. Earlier in the year another Nutrient Enhanced Coastal Ocean Productivity (NECOP) cruise was completed.

The Hurricane Research Division flew into Hurricanes Bob, Claudette, Jimena, and Tropical Storm Fabian. The Division also participated in the TEXMEX experiment in Mexico, which studied the birth of tropical cyclones. HRD continued hurricane forecasts utilizing the VICBAR model which is proving comparable with the best presently used model.

The Ocean Acoustics Division continued analysis of acoustical data gathered on human-generated wastewater plumes and the levels of variation expected for samples gathered from such plumes. A program to collect current data in the vicinity of these outfalls was begun. The Division also began a joint effort with the Corps of Engineers and the Environmental Protection Agency regarding the fate of dredged materials in the coastal environment.

The Physical Oceanography Division continued its studies of the role of the North Atlantic Ocean in regulating global climate, and served as the Data Acquisition Center (DAC) for the WOCE Surface Velocity Program.

An overview of the major programs and accomplishments of AOML are outlined in the following section along with the major goals for next year.

FY 1991 ACCOMPLISHMENTS/FY 1992 PLANS

The Atlantic Oceanographic and Meteorological Laboratory (AOML) is organized to pursue basic and applied research programs in oceanography, ocean and atmospheric chemistry, and tropical meteorology. Oceanographic investigations center on fluxes of energy, momentum, and materials through the air–sea interface; the transport and composition (thermal and chemical) of water in the ocean; and hydrothermal processes of mineralization at seafloor–spreading centers. Meteorological research is carried out to improve the description, understanding, and prediction of hurricanes. The research program is enlarged by the Cooperative Institute for Marine and Atmospheric Studies (CIMAS), a joint enterprise with the Rosenstiel School of Marine and Atmospheric Science of the University of Miami. CIMAS enables NOAA and university scientists to collaborate on problems of mutual interest and facilitates the participation of visiting scientists. AOML's current research program concerns processes relating to global climate and air quality, weather observation and prediction, marine observation, research and prediction, and marine resources.

CLIMATE AND AIR QUALITY

Climate research at AOML focuses on aspects of ocean heat transport and storage in relation to interannual and longer term variations of weather and climate. The emphasis is on collection and analysis of oceanographic data, the ultimate goal being to improve forecasting. Improvement of skill in the use of coupled ocean–atmosphere models is essential to achieving this goal.

Activities are currently concentrated on problems associated with two different time scales of climate variations. The shorter of these, and the best recognized example, is the El Niño–Southern Oscillation (ENSO) phenomenon, which is manifested most clearly in the tropical Pacific Ocean but has global implications. Accordingly, AOML is a major participant in the Equatorial Pacific Ocean Climate Studies (EPOCS) and Tropical Ocean and Global Atmosphere (TOGA) programs in the tropical Pacific.

On longer time scales, the transfer of heat from low latitudes to high latitudes by the ocean circulation is believed to be one of the critical processes governing the climate of the Earth and its variations. Most evidence indicates that the Atlantic Ocean is particularly important in this process. The influence of Atlantic circulation on climate is a major component of the NOAA program for Climate and Global Change. AOML scientists have had a leading role in developing plans for this research program, and participate extensively in its implementation.

Participation in these programs has led to close association with the international World Ocean Circulation Experiment (WOCE).

Also, the appropriation of major new NOAA funding for climate research and applications has been associated with several new activity identifications with separate project managements. The simple TOGA/EPOCS identification is no longer appropriate for the expanded program. Beginning with FY 1992, ocean research for climate at AOML will be categorized as Climate Change: Atlantic; Climate Change: Pacific; or Climate Change: Global Ocean for those activities that are not regionally focused.

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

The Heard Island Feasibility Test, conducted this year, was designed to measure the worldwide reception of low–frequency (57 Hz) coherent underwater acoustic transmissions from Heard Island in the southern

Indian Ocean. Because acoustic time of flight is a measure of average ocean temperature over the acoustic path, such transmissions could be used to monitor ocean warming on basin and global scales.

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

Accomplishments FY 1990

TOGA/EPOCS

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

The Voluntary Observing Ship/Expendable Bathythermograph (VOS/XBT) observations program in the southeast Pacific had deteriorated significantly; that is, almost no observations were being made because of lack of funding. During the year, new funding was obtained through the Surface and Upper Ocean Observations Project of the Climate and Global Change Program (CGCP), and observations are rapidly being improved and increased in this region.

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

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

ATLANTIC CLIMATE CHANGE

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

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

Funding from the Global Sea Level component of the CGCP was used to complete the Global Sea Level Observing System (GLOSS) sea level station array in the Gulf of Mexico/Caribbean region.

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

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

RITS/TPOME PACIFIC CRUISE

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

GCE/CASE/WATOX PAPERS

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

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

RITS/CARBON DIOXIDE SOUTH ATLANTIC CRUISE

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

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

HEARD ISLAND EXPERIMENT

All objectives of the Heard Island feasibility test were met. Sound from this particular source location insonified most of the world's oceans and was received on the east and west coasts of the United States, as well as in Africa, South America, South Asia, Australia, and Pacific Islands. The Ascension receiving station was set up by a team of NOAA researchers from AOML and the Wave Propagation Laboratory (WPL). The Heard Island signal received there was judged to be of the best quality of all the receiving

stations. Many exciting features were noted of coherent acoustic signals propagating over distances never before observed. Seven nations and nine vessels participated in the experiment. Further understanding of the propagation over such long ranges, and its response to expected climate signals, is necessary for the design of a global monitoring network.

RAINFALL STUDIES

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

Plans FY 1992

CLIMATE CHANGE: ATLANTIC

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

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

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

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

CLIMATE CHANGE: PACIFIC

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

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

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

CLIMATE CHANGE: GLOBAL OCEAN

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

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

ASTEX ATLANTIC CRUISE

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

RITS/CARBON DIOXIDE EQUATORIAL PACIFIC CRUISES

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

HEARD ISLAND EXPERIMENT

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

RAINFALL STUDIES

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

WEATHER OBSERVATION AND PREDICTION

AOML's Hurricane Research Division (HRD) is NOAA's primary focus for research on hurricanes. Research teams concentrate on field programs, numerical hurricane modeling, and theoretical studies of hurricanes. The NOAA WP-3D research aircraft are used to acquire unique data sets.

Accomplishments FY 1991

HURRICANE MODELING RESEARCH

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

SYNOPTIC-SCALE ASPECTS OF HURRICANES

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

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

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

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

OBSERVATIONAL STUDIES OF HURRICANES

Analyses of electric field data collected in Hurricane Gustav (1990) and in two oceanic cumuli experiments were completed. The initial detection of vertical electric field in maritime cumuli occurred nearly

simultaneously with the initial observations of graupel and/or frozen drops. The strength of the vertical electric field increased with altitude. Large vertical fields were encountered only during cloud penetrations made at temperatures < 0 °C. Clouds that failed to reach the melting level did not exhibit detectable vertical electric fields. Hurricane Gustav contained moderate vertical electric fields at 3 km on its north and west sides. Only negative vertical electric fields were observed.

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

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

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

ATLANTIC TROPICAL CLIMATE STUDIES

An investigation of the Atlantic hurricane cycles and the tropical wind variability associated with intraseasonal oscillations is nearing completion. Wind observations for the years 1980-1989 at 200 mb and at a near-surface level were used. The winds were filtered into three bands. The "monthly" band (periods 50-85 days) includes variability on the month-to-month (60-day period) time scale. The 30-55 day band corresponds to the time scale of the well-known global tropical oscillation. The "intermediate" band (periods 18-29 days) comprises shorter-period oscillations. Maps of energy and significant spectral peaks in the three bands at the lower and upper levels were made for both the summer (May-October) and winter (November-April) seasons. This work made use of a more rigorous statistical foundation than employed by previous authors. Large regions of significant energy (over a red noise background) were found during the winter for both the 50-85 and 18-29 day bands. However, a significant peak was found only for a period of about 60 days.

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

Plans FY 1992

HURRICANE MODELING RESEARCH

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

SYNOPTIC-SCALE ASPECTS OF HURRICANES

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

OBSERVATIONAL STUDIES OF HURRICANE

Additional electric field data will be obtained in hurricanes. While only the vertical component of the electric field has been measured until now, the component parallel to the wings will also be measured in 1991.

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

The WP-3D will be equipped with a C-band scatterometer (C-SCAT) for measuring surface wind speed and direction. Comparisons between C-SCAT winds and winds from the stepped frequency microwave radiometer (SFMR) will be made. Comparisons of flight level winds adjusted to the surface and C-SCAT winds will also be made. A collaborative project with NESDIS will compare the SFMR and C-SCAT observations with ERS-1 scatterometer observations and SSM/I radiometer observations.

ATLANTIC TROPICAL CLIMATE STUDIES

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

MARINE RESEARCH

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

Ocean ridge studies are directed at determining the chemical and thermal effects on the ocean of seafloor hydrothermal venting from representative segments of the Gorda-Juan de Fuca Ridge system and the Mid-Atlantic Ridge in support of NOAA's global ocean environmental mission. The studies are a collaboration with the Pacific Marine Environmental Laboratory (PMEL), NOAA's Undersea Research Program

(NURP), and a network of leading scientists from other U.S. and foreign government agencies and universities, which multiplies NOAA funding five to ten times and augments scientific productivity. These efforts are contributing to the NOAA VENTS program, to the development of NOAA initiatives, and to NOAA's role as the lead U.S. agency with IFREMER (French Institute for Exploitation of the Oceans) in the U.S.–France Bilateral Agreement.

The Fisheries Oceanography Coordinated Investigations (FOCI) involves NOAA scientists at PMEL, AOML, and the NMFS/Alaska Fisheries Center (AFC), as well as academic contractees. The program seeks to gain understanding of the controls on recruitment variability of walleye pollock in the Shelikof Straits of the western Gulf of Alaska. The major emphasis over FY 1986–1991 has been field study of the spawning event and its physical–biological context. This ecosystem was selected because of the importance of the resource, the physically restricted study area, previously documented variability in recruitment, and the existence of ongoing NMFS fisheries catch and hydroacoustic monitoring programs. The specific goal of the AOML component has been to document the temporal change in the spatial distribution of both eggs and larvae in relation to physical processes (e.g., advection and dispersion). Field studies conducted during cruises in FY 1986–1991 enabled us to examine the fine-scale (meters to tens of meters) distribution of pollock eggs, pollock larvae, and zooplankton prey using a towed submersible camera system, specialized net sampling systems, and, most recently, high-frequency acoustics.

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

The Oceanic Plume Studies program seeks to study the interaction of water mass types and the processes that occur at their boundaries. Wastewater plumes are one category of water mass type that is released in turbulent flow into the receiving oceanic waters. Understanding the dilution that such plumes undergo is an extremely important environmental concern, and dilution is a process for which very limited data are available.

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

Accomplishments FY 1991

VENTS

Gorda-Juan de Fuca Ridge and East Pacific Rise

A prototype sonar system was developed that recorded the first whole three-dimensional images of hydrothermal plumes discharging from black smoker-type seafloor hot springs and rising into the overlying water column. These images were obtained by using the U.S. Navy Deep Submergence Vehicle TURTLE on the East Pacific Rise off Baja California. AOML and the Naval Research Laboratory (NRL) are jointly developing the sonar system with support from NURP.

A new area of seafloor hot springs was delineated on the Gorda Ridge, located off southern Oregon within the U.S. Exclusive Economic Zone. These hot springs are only the third such area identified on the 300-km-long Gorda Ridge.

- Defined fundamental differences in the characteristics and distribution of seafloor hot springs on the northern Gorda Ridge and the southern Juan de Fuca Ridge.
- Convened a symposium on global seafloor hydrothermal activity. The papers presented at this symposium are being prepared for publication.
- Updated an interactive, computerized bibliography of scientific publications on oceanic ridge processes prepared for use by VENTS program investigators.

Mid-Atlantic Ridge

- Discovered a new type of seafloor hot springs high in greenhouse gases (methane and carbon dioxide) and prepared four papers describing various aspects of the discovery with French collaborators in the French American Ridge Atlantic (FARA) program in support of NOAA's lead role in the U.S.-France Bilateral Agreement.
- Discovered what may possibly be the largest mound of polymetallic sulfides found in the oceans on a collaborative dive series with the Soviet MIR submersibles on the Mid-Atlantic Ridge in support of NOAA's role in the U.S./USSR Bilateral Agreement.
- Combined NOAA-NSF-IFREMER support by preparing a research proposal for a joint U.S.-France effort to conduct collaborative dives with the deep submergence vehicle (DSV) *Alvin*, planned for FY 1993.
- Convened a symposium on Atlantic hydrothermal activity at the American Geophysical Union 1990 Annual Meeting. The symposium provided a forum for the U.S. and French work at the Mid-Atlantic Ridge, and related work by British, Canadian, Icelandic, and Soviet scientists. The symposium papers are being prepared for publication.

FOCI

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

NECOP

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

OCEAN PLUME STUDIES

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

Plans FY 1992

VENTS

Gorda-Juan de Fuca Ridge

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

Mid-Atlantic Ridge

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

FOCI

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

NECOP

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

OCEANIC PLUME STUDIES

The year–long study of plume behavior and potential exposure sites begun in FY 1991 will continue. Extensive data sets of currents, density, dilution, nutrients, chemical constituents, and biological constituents will be gathered in the study. Data reduction will continue in parallel with the field efforts.

FY 1991 PUBLICATIONS

ABERSON, S.D., and M. DEMARIA. A nested barotropic hurricane track forecast model (VICBAR). Preprints, 19th Conference on Hurricanes and Tropical Meteorology, Miami, FL, May 6–10, 1991. American Meteorological Society, Boston, 81–86 (1991).

No abstract.

Baik, J.-J., M. DEMARIA, and S. Raman. Observational evidence for upper tropospheric asymmetric eddy momentum forcing and subsequent hurricane intensity change. Preprints, 19th Conference on Hurricanes and Tropical Meteorology, Miami, FL, May 6–10, 1991. American Meteorological Society, Boston, 478–481 (1991).

No abstract.

Barnes, G.M., J.F. GAMACHE, M.A. LeMone, and G.J. Stossmeister. A convective cell in a hurricane rainband. *Monthly Weather Review* 119(3):776–794 (1991).

On 10 October 1983 the two NOAA WP-3D aircraft completed a mission designed to provide airborne Doppler radar data for a convective cell embedded in a weak rainband on the trailing side of Hurricane Raymond. Comparisons of the wind field produced from the pseudo-dual-Doppler radar technique with in-situ wind measurements suggest that the larger convective-scale features may be resolved if the sampling time is kept to a minimum. The convective cell was found to move downband faster than any environmental winds, but slightly slower than the winds found in the reflectivity core that delineates the cell. In the core of the cell the tangential wind is increased and the radial inflow turns to outflow with respect to the circulation center. The flow field demonstrates that the downband stratiform portion of a rainband is not from cells currently active, since the updraft detrains upwind relative to the cell, but rather it is due to the fallout from ice particles placed into the upper troposphere by clouds that have since dissipated. The mass flux of this cell is estimated to be 5%–10% of the mass flux accomplished by an eyewall of a moderate tropical cyclone. This finding supports the concept that large, convectively active rainbands have a major effect on the sub-cloud layer air flowing toward the eyewall.

Barnes, G.M., and M.D. POWELL. The inflow thermodynamics of Hurricane Gilbert. Preprints, 19th Conference on Hurricanes and Tropical Meteorology, Miami, FL, May 6–10, 1991. American Meteorological Society, Boston, 486–489 (1991).

No abstract.

Beryulev, G.P., P.G. BLACK, and A.V. Litinetsky. Intercomparison of wind and temperature data from the research aircraft WP-3D and AN-12BC in Hurricane Gilbert, 1988. Preprints, 19th Conference on Hurricanes and Tropical Meteorology, Miami, FL, May 6–10, 1991. American Meteorological Society, Boston, 587–588 (1991).

No abstract.

BLACK, M.L., R.W. BURPEE, and F.D. MARKS, JR. Vertical motions in tropical cyclones determined with airborne Doppler radial velocities. Preprints, 19th Conference on Hurricanes and Tropical Meteorology, Miami, FL, May 6–10, 1991. American Meteorological Society, Boston, 409–411 (1991).

No abstract.

BLACK, P.G., and F.D. MARKS, JR. The structure of an eyewall meso-vortex in Hurricane Hugo (1989). Preprints, 19th Conference on Hurricanes and Tropical Meteorology, Miami, FL, May 6-10, 1991. American Meteorological Society, Boston, 579-582 (1991).

No abstract.

Bosart, L.F., and J.A. Bartlo. Tropical storm formation in a baroclinic environment. (Research supported by NOAA Grant NA-85-WCC-06191.) *Monthly Weather Review* 119(8):1979-2013 (1991).

An analysis is presented of the large-scale conditions associated with the initial development of Tropical Storm Diana (September 1984) in a baroclinic environment. Ordinary extratropical wave cyclogenesis began along an old frontal boundary east of Florida after 0000 UTC 7 September and culminated in tropical cyclogenesis 48 h later. Water-vapor satellite imagery showed that the initial cyclogenesis and incipient tropical storm formation was nearly indistinguishable from a classical midlatitude development. Cyclogenesis occurred in three stages. A large-scale cold trough and associated frontal system crossed the Atlantic coast, while a small potential vorticity maximum aloft fractured off the main trough and stalled over central Florida in the first stage. As the main trough sheared off eastward, cyclogenesis began along the southwestern end of the stalled frontal zone east of Florida. Anticyclogenesis to the north in the wake of the shearing trough allowed a surge of cooler and drier air to flow southeastward behind the front toward the developing cyclone. Combined surface sensible and latent heat fluxes in excess of 1000 W m^{-2} acted on this inflowing air, producing a warming and moistening of the boundary layer. Cyclogenesis intensified during the second stage in response to positive potential vorticity advection aloft ahead of the slow moving cutoff cyclone over Florida. The maximum ascent was centered near 300 mb, indicative of deep tropospheric ascent and cyclonic vorticity production by convergence in midlevels. The ascent occurred along uplifted isentropic surfaces that defined the cold dome associated with the potential vorticity anomaly aloft. Low-level potential vorticity was generated in the vicinity of the developing storm below the presumed level of maximum diabatic heating. The third stage of cyclogenesis was marked by the collapse of the mid- and upper tropospheric cold dome and associated potential vorticity maximum and the simultaneous initiation of a warm thickness ridge. This occurred in response to the widespread outbreak of convection at the southwestern end of the baroclinic zone, where the greatest destabilization occurred for air parcels subject to prolonged surface sensible and latent heat fluxes in the persistent northeasterly flow. Upright ascent associated with the convection short-circuited the slantwise ascent ahead of the advancing potential vorticity anomaly, triggering warming aloft and the eventual disappearance of the potential vorticity anomaly and associated cold dome. Tropical storm development and intensification occurred as the low-level vorticity center (potential vorticity maximum) moved northwestward to become situated beneath the midlevel vortex embedded within a local 500-200 mb warm thickness anomaly. The interaction of the upper and lower level potential vorticity anomalies appeared to be important in the initial strengthening of the tropical cyclone. The interpretation is equivalent to earlier energetic arguments by Riehl and others that tropical cyclogenesis is often preceded by the collapse of a nearby cold dome.

BURPEE, R.W. Radar characteristics of hurricanes. In *Federal Meteorological Handbook No. 11, Doppler Weather Radar Observations*. Part B: Radar meteorology and theory. Federal Coordinator for Meteorological Services and Supporting Research, Washington, D.C., 9-1 to 9-14 (1990).

No abstract.

BURPEE, R.W., and P.G. BLACK. Strong surface winds and mesoscale convective systems in the unnamed tropical storm of 1987. Preprints, 19th Conference on Hurricanes and Tropical Meteorology, Miami, FL, May 6-10, 1991. American Meteorological Society, Boston, 412-415 (1991).

No abstract.

BURPEE, R.W., J.S. GRIFFIN, J.L. FRANKLIN, and F.D. MARKS, JR. Airborne analysis of observations from a NOAA P-3 in support of operational hurricane forecasting. Preprints, 7th International Conference on Interactive Information and Processing Systems for Meteorology, Oceanography and Hydrology, New Orleans, LA, January 13-18, 1991. American Meteorological Society, Boston, 195-197 (1991).

No abstract.

BURPEE, R.W., J.S. GRIFFIN, J.L. FRANKLIN, and F.D. MARKS, JR. Airborne analysis of observations from a P-3 aircraft in support of operational hurricane forecasting. Proceedings, 4th Interagency Airborne Geoscience Workshop, La Jolla, CA, January 29-February 1, 1991. NASA, Washington, D.C., 123-124 (1991).

No abstract.

Carey, A.G., Jr., D.L. Stein, and P.A. RONA. Benthos of the Gorda Ridge axial valley (northeast Pacific Ocean): Taxonomic composition and trends in distribution. *Progress in Oceanography* 24:47-57 (1990).

Distribution and relative abundance of invertebrate mega-epifauna and benthos fishes were studied in the Gorda Ridge central rift valley off southern Oregon and northern California, USA. Faunal distribution and relative abundance were correlated with location, geological setting, substrate type, and depth. Bottom photographs and videotapes were from 1985-1986 cruises by the U.S. Geological Survey and the U.S. National Oceanic and Atmospheric Administration. Voucher specimens were collected by rock dredge, fish trap and the Deep Submergence Vehicle (DSV) *Sea Cliff*. Location, rather than substrate, appears to have more effect on the overall taxonomic composition of the mega-epifauna in the northern and southern parts of the rift valley. Within each location, substrate type, i.e., soft sediments and rock outcrops, and percentage cover of these substrates appear to influence the existing faunal composition. Characteristic fauna are associated with each substrate type, e.g., crinoids, gorgonians and sponges (Demospongiae) on rocky surfaces. In the southern sediment-filled Escanaba Trough, deposit-feeding organisms, particularly ophiuroids, asteroids and holothuroids, are interspersed with stalked suspension feeders, such as hexactinellid sponges and pennatulids. Epifaunal community structure in the northern and southern sectors differ, even on similar substrate combinations. Except for the ubiquitous macrourids, fish species distributions may be correlated with substrate type. Abundant particulate material in the bottom water layer probably accounts for large concentrations of suspension and detritus feeding epibenthos.

DAMMANN, W.P., J.R. PRONI, J.F. CRAYNOCK, and R. Fergen. Oceanic wastewater outfall plume characteristics measured acoustically. *Chemistry and Ecology* 5:75-84 (1991).

A study, called SEFLOE, of the dispersion characteristics of several wastewater outfalls was conducted off of the coast of southeast Florida (USA). In this study, the feasibility of utilizing high frequency (20 kHz and 200 kHz) acoustic echoes to characterize the dilution characteristics of the effluent wastewater was examined. It is hypothesized that the background corrected acoustic backscattered intensity may be used to guide chemical/biological sampling, and that one or more plume subfields may be revealed by the scattering strength field. Data from SEFLOE have indicated that the wastewater plume field is divided into regions of higher concentration spatially separated by regions of lower concentration; we call these regions of higher concentration "boluses." When the water column is density stratified, subsurface plumes may peel off of the main rising plume and remain at equilibrium on a density gradient.

DEMARIA, M. Normal mode initialization in a tropical cyclone model. *Journal of the Atmospheric Sciences* 118(10):2199–2214 (1990).

The effect of nonlinear normal mode initialization (NMI) on tropical cyclone simulations is investigated using a three-layer axisymmetric model. It is shown that the balance condition proposed by Machenhauer, which neglects the time tendencies of the gravity-mode amplitudes, is valid in a tropical cyclone simulation. The boundary layer friction, adiabatic nonlinear and diabatic heating terms are important in the balance. A highly truncated version of the model with linearized physical parameterizations is used to analyze the convergence properties of several iterative schemes developed to solve the initialization equations. When diabatic heating is neglected, the schemes will always converge if the linear friction coefficient α is smaller than the Coriolis parameter f. For small horizontal-scale modes, the iterative schemes will also converge for values of α much larger than f. When diabatic heating is included, the rate of convergence of the small horizontal-scale modes becomes extremely slow. The schemes are also tested in the nonlinear version of the model by first running a 7-day tropical cyclone simulation. The initialization schemes are applied at day 5 after the model has produced an intense tropical cyclone. Results show that the tropical cyclone rapidly weakens relative to the uninitialized run during the 6–12 h after the NMI is applied. This weakening occurs because the small horizontal-scale modes do not converge, making the secondary radial circulation much too weak. A scheme is proposed where the NMI is followed by a short integration with the geostrophic modes held fixed. This procedure compensates for the lack of convergence of the small horizontal-scale gravity modes.

DEMARIA, M., and J. KAPLAN. A statistical model for predicting tropical cyclone intensity change. Preprints, 19th Conference on Hurricanes and Tropical Meteorology, Miami, FL, May 6–10, 1991. American Meteorological Society, Boston, 521–525 (1991).

No abstract.

DODGE, P.P., R.W. BURPEE, and F.D. MARKS, JR. Airborne Doppler radar analyses of the core of Hurricane Gilbert. Preprints, 19th Conference on Hurricanes and Tropical Meteorology, Miami, FL, May 6–10, 1991. American Meteorological Society, Boston, 551–552 (1991).

No abstract.

ENFIELD, D.B. Book review, "Study in Geophysics: Sea Level Change." *Bulletin of the American Meteorological Society* 72:1282–1283 (1991).

No abstract.

ENFIELD, D.B. Statistical analysis of El Niño/Southern Oscillation over the last 500 years. *TOGA Notes* 1:1–4 (1990).

No abstract.

FEUER, S.E., and J.L. FRANKLIN. Nested analyses of Hurricane Gloria from dropwindsonde and Doppler radar data. Preprints, 19th Conference on Hurricanes and Tropical Meteorology, Miami, FL, May 6–10, 1991. American Meteorological Society, Boston, 130–133 (1991).

No abstract.

FRANKLIN, J.L. Dropwindsonde observations of the environmental flow of Hurricane Josephine (1984): Relationships to vortex motion. *Monthly Weather Review* 118(12):2732–2744 (1990).

Omega dropwindsonde (ODW) observations from three synoptic-flow experiments in the environment of Hurricane Josephine have been analyzed in a research mode using an objective analysis procedure. The nominal times of the analyses are 0000 UTC, 10, 11, and 12 October 1984. The filtered, three-dimensional analyses have been used as a basis for several diagnostic and prognostic calculations relating to the motion of the hurricane. Examination of Josephine's environment revealed a strong variability of the flow with distance from the storm center and with pressure. Josephine moved at right angles to the azimuthally averaged wind at 500 mb; the vortex motion was more consistent with the flow near 700 mb. Forecasts made with a barotropic forecast model showed a high sensitivity of the forecast track to the vertical layer used in the initial analysis. These results demonstrate the potential value of vertical sounding information from the ODWs and show that single-level midtropospheric information is not always representative of a hurricanes's environment flow. On each of the three days, the motion of Josephine deviated significantly from its environmental "steering" as measured by an azimuthal average of the 300–850 mb mean flow over the 5°–7° radial band. This deviation from steering (the so-called "propagation" vector) was oriented with components parallel and to the left of the gradient of absolute vorticity in the asymmetric wind field. The magnitude of the propagation was proportional to the strength of the absolute vorticity gradient. These results are consistent with many barotropic modeling studies.

FRANKLIN, J.L., M. DEMARIA, and C.S. Velden. The impact of Omega dropwindsonde and satellite data on hurricane track forecasts using the VICBAR model. Preprints, 19th Conference on Hurricanes and Tropical Meteorology, Miami, FL, May 6–10, 1991. American Meteorological Society, Boston, 87–92 (1991).

No abstract.

Frazel, D.W., and G.A. BERBERIAN. Distributions of chlorophyll and primary productivity in relation to water column structure in the eastern North Atlantic Ocean. *Global Biogeochemical Cycles* 4(3): 241–251 (1990).

Latitudinal variations in the megascale (10^3 km) distribution of biological properties are described in relation to water column structure between 60° and 7°N in the eastern North Atlantic Ocean. Stations were occupied along a meridional transect of stations at 20°W in August–September, 1988, during the third leg of the National Oceanic and Atmospheric Administration Global Change Expedition. An additional transect to the south (38°N to 7°N) was occupied to extend the total range of latitudinal observations. Chlorophyll *a* concentrations were highest in the northern latitudes (<2.51 mg m^{-3}), decreasing to >0.2 mg m^{-3} in the vicinity of the subtropical gyre, south of 40°N. The nitracline was associated with a shoaling of the pycnocline in the northern latitudes. At 7°N, high chlorophyll concentrations (approximately 0.5 mg m^{-3}), and enhanced primary productivity (375.5 mg C m^{-2} d^{-1}) were associated with a lens of fresh Amazon River Water.

GALLAGHER, M.S., T.P. CARSEY, and M.L. FARMER. Peroxyacetyl nitrate in the North Atlantic marine boundary layer. *Global Biogeochemical Cycles* 4(3):297–308 (1990).

An automated system utilizing packed column gas chromatography and electron capture detection for the determination of peroxyacetyl nitrate (PAN) is described. The system was calibrated with a cryogenic PAN sublimation device, a molybdenum catalyst, and a chemiluminescent nitric oxide detector. Computer control of the analysis resulted in an analytical precision level of ~1%. A total of 1,178 PAN measurements were made from August 6 to September 5, 1988, in the marine boundary layer during the GCE/CASE/WATOX cruise (66°N to 7°N). Overall, PAN concentrations were highest at high latitudes (up to 40 ppt); PAN levels in the lower latitudes of the cruise track were usually <10 ppt. A number of episodes of elevated

PAN are described which were characterized by elevated radon concentrations and a discernible diurnal cycle in the PAN concentration. These higher PAN levels are attributed to air masses with some continental influence, and to the enhanced stability of PAN at the cooler temperatures characteristic of the sub-Arctic region. In aged air masses of marine origin, PAN concentrations were significantly less and did not display diel changes; this is interpreted as a measure of the "background" PAN signal.

Galloway, J.N., W.C. Keene, A.A.P. PSZENNY, D.M. Whelpdale, H. Sievering, J.T. Merrill, and J.F. Boatman. Sulfur in the western North Atlantic Ocean atmosphere: Results from a summer 1988 ship/aircraft experiment. *Global Biogeochemical Cycles* 4(4):349-365 (1990).

To investigate the relative importance of anthropogenic versus marine sources of sulfur in the North Atlantic Ocean troposphere, sulfur species were measured from aircraft, ship, and island-based platforms as part of the Global Change Expedition/Coordinated Air-Sea Experiment/Western Atlantic Ocean Experiment conducted during the summer of 1988. Four synoptic meteorological cases were examined: flow from highly populated North America; lightly populated North America; tropical oceanic regions; and polar oceanic regions. Literature values suggest that 2-10 μmol m^{-2} day^{-1} of $(CH_3)_2S$ are emitted from the ocean to the atmosphere in marine regions associated with the first three synoptic cases. Data from this experiment indicate that 36, 16, and 14 μmol m^{-2} day^{-1}, for the highly populated North America, lightly populated North America, and tropical oceanic region synoptic cases, respectively, were deposited to the ocean's surface. Differences between previously estimated natural emissions and calculated deposition suggest that anthropogenic sources of sulfur contribute significantly to sulfur deposition for these cases. The sulfur deposition rate for the polar oceanic region's synoptic case was 20 μmol m^{-2} day^{-1}. Given the larger range of literature values for the corresponding $(CH_3)_2S$ emission rate (1-14 μmol m^{-2} day^{-1}), however, the relative importance of the non-marine S source is less certain in this case.

GAMACHE, J.F. Inner core budget studies of Hurricane Norbert (1984). Preprints, 19th Conference on Hurricanes and Tropical Meteorology, Miami, FL, May 6-10, 1991. American Meteorological Society, Boston, 545-550 (1991).

No abstract.

GAMACHE, J.F., F. Roux, and F.D. MARKS, JR. Comparison of three methods to deduce three-dimensional wind fields in a hurricane with airborne Doppler radar. Preprints, 25th International Conference on Radar Meteorology, Paris, France, June 24-28, 1991. American Meteorological Society, Boston, 462-465 (1991).

No abstract.

GRIFFIN, J.S., R.W. BURPEE, J.L. FRANKLIN, and F.D. MARKS, JR. Preliminary results of airborne analysis of observations in support of operational hurricane forecasting. Preprints, 19th Conference on Hurricanes and Tropical Meteorology, Miami, FL, May 6-10, 1991. American Meteorological Society, Boston, 144-147 (1991).

No abstract.

Hansen, A.D.A., R.S. Artz, A.A.P. PSZENNY, and R.E. Larson. Aerosol black carbon and radon as tracers for air mass origin over the North Atlantic Ocean. *Global Biogeochemical Cycles* 4(2):189-199 (1990).

We present results from the Global Change Expedition/Coordinated Air-Sea Experiment/Western Atlantic Ocean Experiment (GCE/CASE/WATOX) research cruise conducted from July to September

1988 in the North Atlantic Ocean aboard the NOAA ship *Mt. Mitchell*. We examine the correlations between measurements of aerosol black carbon (BC, a tracer for combustion emissions), radon 222 (Rn, a tracer for natural emissions from land masses), and calculated isentropic back trajectories from the ship's position during two portions of the cruise that circled the North Atlantic Ocean. The results suggest four distinct categories of origin of the sampled air mass, with trajectories connecting back to different geographical areas: case A, trajectories from inhabited land, with the air mass containing strongly correlated BC and Rn; case B, trajectories from uninhabited (far northern) land, with Rn but little BC; case C, contaminated marine air, with little Rn but moderate BC, correlated with observations of combustion sources (other ships, etc.) in the vicinity; and case D, air masses of remote marine origin, with low BC and low Rn content. The requirements of the trajectory analyses lead to an improved understanding of the transport pathways across the ocean. We conclude that real-time measurements of aerosol black carbon and radon, coupled with timely meteorological analyses, can be a powerful indicator of air mass origin both retrospectively and during the course of an experiment to assist in the scheduling of other measurements.

HANSEN, D.V. Subsurface current and temperature patterns in the western tropical Pacific. Proceedings, U.S.-PRC International TOGA Symposium, Beijing, China, November 15-17, 1988. China Ocean Press, Beijing, 121-127 (1990).

No abstract.

HANSEN, D.V., and G.A. MAUL. Anticyclonic current rings in the eastern tropical Pacific Ocean. *Journal of Geophysical Research* 96(C4):6965-6979 (1990).

Observations from satellite-tracked drifting buoys, XBT and CTD data, and GEOSAT altimeter data are used to describe anticyclonic eddies that occur in small numbers off the Pacific coast of Central America. These eddies are similar in many respects to the well-known, warm-core rings that are observed north of the Gulf Stream off the Atlantic coast of North America, except that they occur in an environment that also is warm, and they contain considerably greater kinetic energy. It is hypothesized that they are formed as a result of conservation of potential vorticity when the North Equatorial Countercurrent (NECC) turns northward upon approaching the eastern boundary during its autumnal maximum. The rings so formed have a strongly nonlinear character which causes them to propagate westward between 9°N and 14°N with a speed in excess of that of long Rossby waves. Due to a relatively small available potential energy content, these rings have a dissipation time scale of about six months and perhaps end by collision with and reabsorbtion into the NECC. The rings account for the observed enhancement of surface kinetic energy, and probably for the seaward transport of waters enriched in copper.

HARVEY, G.R., and M. SPRINGER-YOUNG. Correction to "Ozone in seawater and lake water: A reversible reservoir." *Geophysical Research Letters* 18(2):353 (1991).

No abstract.

Hastie, D.R., S. Malle, D.L. Toom, D.M. Whelpdale, W.C. Keene, J.N. Galloway, J. Maben, and A.A.P. PSZENNY. Inorganic nitrogen over the western North Atlantic Ocean. *Global Biogeochemical Cycles* 4(3):267-278 (1990).

The concentrations of the reactive nitrogen species NO_2, NO_x (=NO + NO_2), NO_y (the sum of all compounds of nitrogen and oxygen with the exception of N_2O), particulate NO_3^-, and volatile NO_3^-, were measured from ship and aircraft platforms over the western North Atlantic Ocean as part of the GCE/CASE/WATOX experiment. Air masses sampled were divided into continentally influenced and typical marine on the basis of trajectories, and radon and black carbon measurements. From the NO_3^- measurements on size separated aerosol and the altitude variations of volatile NO_3^- and particulate NO_3^-, a significant interaction between volatile NO_3^- and sea salt aerosol was indicated. The average marine concentrations measured

were: 18 nmol m^{-3} for NO_2, 29 nmol m^{-3} for NO_x, 46 nmol m^{-3} for NO_y, and 10 nmol m^{-3} for total inorganic NO_3^-. The reactive nitrogen species were present at concentrations some 40 times those encountered in the remote Pacific Ocean, where the inorganic NO_3^- was only three times higher.

HITCHCOCK, G.L., D.B. Olson, G.A. Knauer, A.A.P. PSZENNY, and J.N. Galloway. Horizontal diffusion and new production in the Sargasso Sea. *Global Biogeochemical Cycles* 4(4):253–265 (1990).

Estimates of vertical particulate carbon flux and inorganic nitrogen input from rain events were evaluated in relation to horizontal diffusion during a short-term (4 days) study in the Sargasso Sea. Productivity (~300 mg C m^{-2} d^{-1}) and particulate organic C flux (f-ratio of 0.17) from sediment trap arrays were similar to those recently documented in this region. The drifters traversed the periphery of a small anticyclonic eddy, and an estimate of horizontal diffusivity (~3 to 10 x 10^4 cm^2 s^{-1}) was derived from relative drifter separation. The corresponding length scale (a few kilometers) and time scale (a day) is related to the effective collection area from which drifting sediment traps can sample the surrounding environment. Measurements of inorganic nitrogen from two rain events were similar to those in a more extensive series of observations from Bermuda. The summer Bermuda data are used to evaluate the inorganic nitrogen input to the oligotrophic surface waters with respect to phytoplankton uptake rates and horizontal diffusion. For small, convective rain events, diffusion may be as important as phytoplankton uptake in reducing nitrogen concentrations to ambient nanomolar levels.

HOUSTON, S.H., and M.D. POWELL. Effects of Tropical Storm Marco (1990) on Florida's west coast. Preprints, 5th Conference on Meteorology and Oceanography of the Coastal Zone, Miami, FL, May 6–9, 1991. American Meteorological Society, Boston, 131–133 (1991).

No abstract.

JONES, R.W., and M. DEMARIA. A variational method for including persistence in a hurricane track forecast model. Preprints, 19th Conference on Hurricanes and Tropical Meteorology, Miami, FL, May 6–10, 1991. American Meteorological Society, Boston, 331–334 (1991).

No abstract.

KAPLAN, J., and J.L. FRANKLIN. The relationship between the motion of Tropical Storm Florence (1988) and its environmental flow. Preprints, 19th Conference on Hurricanes and Tropical Meteorology, Miami, FL, May 6–10, 1991. American Meteorological Society, Boston, 93–97 (1991).

No abstract.

Karson, J.A., and P.A. RONA. Block-tilting, transfer faults, and structural control of magmatic and hydrothermal processes in the TAG area, Mid-Atlantic Ridge, 26°N. *Geological Society of America Bulletin* 102:1635–1645 (1990).

Seven Alvin dives (14 km total) and numerous deep-towed camera traverses using ANGUS and NOAA camera systems provide dense coverage of a 12 km^2 portion of the eastern wall of the Mid-Atlantic Ridge in the TAG area (26°N latitude). These data, in conjunction with recent Soviet MIR submersible data, provide important constraints on the tectonic, magmatic, and hydrothermal history of this spreading center segment. Active hydrothermal venting occurs near the junction of the median valley floor and eastern median valley wall and appears to be tectonically controlled by the intersection of major fault zones. An east-west fault-line scrap interpreted as an accommodation zone intersects escarpments associated with 020°-trending (ridge-parallel) normal faults that bound the median valley floor. The accommodation zone permits differential extension and rotation between major crustal blocks to the north and south. On the

basis of the distribution of tilted chalk beds and geochemical anomalies in sediments, this fault zone has been intermittently active for at least 5×10^4 yr. The accommodation zone has apparently provided a conduit of high permeability oriented at a high angle to the ridge axis. Observations and samples from areas surrounding active and inactive vent sites provide evidence for three distinct episodes for hydrothermal outflow driven by separate magmatic events. The geometry of this active system may have implications for the location of hydrothermal systems in active spreading regimes and for massive sulfide exploration in ophiolite terranes.

Keene, W.C., A.A.P. PSZENNY, D.J. Jacob, R.A. Duce, J.N. Galloway, J.J. Schultz-Tokos, H. Sievering, and J.F. Boatman. The geochemical cycling of reactive chlorine through the marine troposphere. *Global Biogeochemical Cycles* 4(4):407-430 (1990).

Heterogeneous reactions involving sea-salt aerosol in the marine troposphere are the major global source for volatile inorganic chlorine. We measured reactant and product species hypothesized to be associated with these chemical transformations as a function of phase, particle size, and altitude over the North Atlantic Ocean during the summer of 1988. Concentrations of HCl were typically less than 1.0 ppbv near the sea surface and decreased with altitude and with distance from the U.S. east coast. Concentrations of Cl volatilized from aerosols were generally equivalent to the corresponding concentrations of HCl and ranged from less than detection limits to 125 nmol m^{-3} STP. Highest absolute and percentage losses of particulate Cl were typically associated with elevated concentrations of anthropogenic combustion products. Concentrations of product nss SO_4^{2-} and NO_3^- in coarse aerosol fractions indicate that, on average, only 38% of measured Cl- deficits could be accounted for by the combined effects of acid-base desorption and reactions involving nonacidic N gases. We hypothesize a mechanism for the Cl loss initiated by reaction of O_3 at sea-salt aerosol surfaces, generating Cl_2, followed by rapid photochemical conversion of Cl_2 to HCl via Cl atoms ($Cl\cdot$) and eventual recapture of HCl by the aerosol. Simulations with a zero-dimension (0-D) photochemical model suggest that oxidation by $Cl\cdot$ may be an important tropospheric sink for dimethyl sulfide and hydrocarbons. Under low NO_x conditions, the rapid cycling of reactive Cl would provide a catalytic loss mechanism for O_3, which would possibly explain the low O_3 concentrations often observed above the world's oceans.

Kumar, M., and G.A. MAUL (editors). *Marine Positioning into the 1990's*. PIP Publishing, Rockville, MD, 593 pp. (1991).

The International Symposium on Marine Positioning (INSMAP '90) was the first quadrennial effort after its predecessor held in 1986. It attracted a broad spectrum of national and international scientists, focused stimulating discussions on a wide arena of subjects, and drew attention to many challenging tasks and research topics ahead. INSMAP '90's technical success was hailed unanimously, and its next link in 1994 is eagerly awaited. Our special thanks are expressed to the U.S. Geological Survey; Charting and Geodetic Services, NOAA/NOS; Institute of Naval Oceanography; and the Naval Oceanic and Atmospheric Research Laboratory for their support through financial grants as partial funding to INSMAP '90. We are also grateful to the Rosenstiel School of Marine and Atmospheric Science, University of Miami, for their support and providing the auditorium in making the symposium a success. Over one hundred persons attended INSMAP '90, of which about half were from outside the United States. Twelve technical sessions and five workshops were held within a five-day format. These proceedings contain the written version of the talks, presentations, and reports as submitted by the authors or workshop chairpersons. A few papers have also been included (with appropriate remarks) which were submitted but could not be presented at the INSMAP '90 due to last minute exigencies. We acknowledge with gratitude the support and help of all of the committee members, authors, chairpersons, and participants of INSMAP '90, and are very grateful to Dr. Devi Kumar for her effort in editing and organizing these proceedings.

Lagos, P., D.V. HANSEN, and A. Herman. Climatological atlas of the subsurface thermal structure of the eastern tropical South Pacific Ocean. NOAA TR ERL 444–AOML 34 (NTIS number not yet available), 303 pp. (1991).

Monthly climatological maps of objectively analyzed fields of temperature are presented at standard oceanographic observation levels from the surface to 300 m depth on a 1° latitude–longitude grid in the region between the equator and 20°S and between the South American coast and 90°W. The temperature data used in this study were from bathythermograph measurements obtained from 1952 to 1987 from Peruvian and other research vessels; they were made available by research institutions in Peru and the United States and by the National Oceanographic Data Center and the Fleet Numerical Oceanographic Center. The data set was blended with recent data to form a data base containing 14,000 observations. The method of analysis consists of optimally interpolating the value at each mapping grid point, using observations taken at known nearby locations. This method, known as Kriging, is a best linear unbiased estimator that also yields an estimate of the uncertainty of each interpolated value. A brief discussion of the major characteristic features of the temperature fields is given, including a comparison of the SST results with results from other SST climatologies.

Lee, W.–C., and F.D. MARKS, JR. Real–time display of mean 3–D hurricane structure using the VTD technique. Preprints, 25th International Conference on Radar Meteorology, Paris, France, June 24–28, 1991. American Meteorological Society, Boston, 470–473 (1991).

No abstract.

Lee, W.–C., F.D. MARKS, JR., and R. Carbone. Real–time display of mean 3–D hurricane structure using the VTD technique. Preprints, 19th Conference on Hurricanes and Tropical Meteorology, Miami, FL, May 6–10, 1991. American Meteorological Society, Boston, 445–450 (1991).

No abstract.

Lhermitte, R., and P.T. WILLIS. Small Doppler radar as a precipitation gauge. Preprints, 25th International Conference on Radar Meteorology, Paris, France, June 24–28, 1991. American Meteorological Society, Boston, 790–792 (1991).

No abstract.

MARKS, F.D., JR., D. Atlas, and P.T. WILLIS. Probability matched Z–R relations for hurricanes from aircraft observations. Preprints, 25th International Conference on Radar Meteorology, Paris, France, June 24–28, 1991. American Meteorological Society, Boston, 778–781 (1991).

No abstract.

MARKS, F.D., JR., and R.A. Houze, Jr. Kinematic structure of the eyewall of Hurricane Emily (1987) as determined from an airborne Doppler radar. Preprints, 19th Conference on Hurricanes and Tropical Meteorology, Miami, FL, May 6–10, 1991. American Meteorological Society, Boston, 437–440 (1991).

No abstract.

MAUL, G.A. INSMAP '90: The Second International Symposium on Marine Positioning. *Bulletin Geodesique* 65(1):3–4 (1991).

No abstract.

MAUL, G.A., S.R. Baig, and M. BUSHNELL. Nowcasting cross-stream profiles of ocean surface current in the Straits of Florida. *Journal of Atmospheric and Oceanic Technology* 8(1):179–185 (1991).

Cross-stream profiles of ocean surface currents between Florida and the Bahamas are highly correlated with the cross-stream averaged current. When the cross-stream averaged speed is high, the speed axis of the Florida Current is to the west, and when the cross-stream averaged speed is low, the speed axis is near the center of the Straits. Since sea level and weather along the Florida coast are routinely used to nowcast cross-stream averaged speed, nowcasts of cross-stream surface current profiles and location of the speed axis can also be routinely reported. An improved algorithm using cross-stream sea level difference and local weather, and a description of the revised NOAA Gulf Stream product from the National Hurricane Center, are presented.

MAUL, G.A., and K. Hanson. Interannual coherence between North Atlantic atmospheric surface pressure and composite southern United States sea level. *Geophysical Research Letters* 18(4):653–656 (1991).

Annual mean sea levels along the southern United States have been examined for interannual variability. Fifteen sea level stations from Cape Hatteras to the Rio Grande that best covered the three lunar nodal cycles from 1931–1987 were selected for analysis. Linear trends, ranging from +0.2 cm/yr to +1.4 cm/yr, were subtracted from their respective series, leaving remarkably similar residuals. The composite time series of the 15 residuals was compared with time series of surface air pressure over the North Atlantic Ocean during the period 1947–1987. The best correlation is a negative relationship between composite sea level and wintertime air pressure north of 45°N, and a positive relationship from 20°N– 45°N. The most significant correlations (–0.73 and +0.51) were found for 60°N, 20°W and for 30°N, 25°W, respectively. Wintertime meridional air pressure gradients between these two latitudes represents about 50% of the variance in composite annual mean sea level. Both the sea level and air pressure time series had significant spectral peaks at 13.3 and 4.4 years, with about 52% of the covariance coming from these two periods.

MAUL, G.A., K. Hanson, and H.F. BEZDEK. A note on determining potential anthropogenic signals in sea level: An example from Florida and juxtaposed areas. In *Towards an Integrated System for Measuring Long Term Changes in Global Sea Level*, H.F. Eden (ed.). Joint Oceanographic Institutions, Inc., Washington, D.C., 17–25 (1990).

No abstract.

MAYER, D.A., and G.A. MAUL. Refinement of the statistical relationship between Straits of Florida sea level difference and Florida–Bahamas cable voltages. *Journal of Geophysical Research* 96(C3): 4971–4972 (1991).

Analyses of a composite 6.5-year record of Bahamas minus Miami sea level difference (SLD) and Florida–Bahamas volume transport determined from submarine cable voltages (CABLE) support the hypothesis advanced by Maul *et al.* (1990) that SLD is the better variable for monitoring volume transport than western side sea level alone. In the subseasonal frequency band BW1 (393^{-1}–182^{-1} cycles per day), modeled CABLE, when using SLD, accounts for 79% of the variance of observed CABLE. Further, the phase relationships of modeled CABLE with respect to SLD in BW1 represent approximately a simple time shift in that SLD leads CABLE by a little more than two weeks.

MCLEISH, W., and G.A. MAUL. An ocean eddy off Miami. Proceedings, 5th Conference on Meteorology and Oceanography of the Coastal Zone, Miami, FL, May 6–9, 1991. American Meteorological Society, Boston, 94–97 (1991).

HF radar maps of ocean surface currents near Miami often show an intermittent counterclockwise eddy between the northward flowing Florida Current and the coast. The maximum average southward speed in

the eddy is 20 cm/s at a location near shore, and a typical diameter is 15 km. The eddy develops at times when the offshore current speed decreases and a low speed zone develops near shore. The eddy persists a few days with no propagation detected and dissipates as higher northward speeds near shore return. The development of the eddy, when it occurs, might be caused by flow of the Florida Current past an underwater topographic rise in the continental slope south of Miami. This induces a cyclonic circulation feature extending well into the water and not just a surface phenomenon. A number of earlier studies of the Florida Current consisted of measurements at one or a few locations distributed mostly across the Florida Current but were insufficient to reveal the complete circulation. Although these studies did not hypothesize it, they are consistent with the existence of this intermittent, non-propagating eddy. Similar stationary eddies on a larger scale have been reported in other locations.

MCLEISH, W., and G.A. MAUL. CODAR in the Straits of Florida: Final Report. NOAA TR ERL 447-AOML-35 (NTIS number not yet available), 50 pp. (1991).

The Atlantic Oceanographic and Meteorological Laboratory (AOML) operated a Coastal Ocean Dynamics Applications Radar (CODAR) from 1986 through 1988 in a project to measure ocean surface currents near Miami and produce a series of maps of ocean surface current vectors. The project, CODAR in the Straits of Florida, also evaluated the feasibility and value of routine operational use of this HF radar system. The CODAR system produced many excellent maps that showed the west and central portions of the Florida Current. The core speed of this rapid flow, its distance offshore, and the often sharp decrease in speed nearshore were apparent. In addition, the maps showed at times a band of water nearshore that was moving slowly southward along the coast, and sometimes a cyclonic eddy about 15 km in diameter that was centered in a nearly fixed location 20 km northeast of Miami. However, on the whole this CODAR system could not be used as the project planned. The system required excessively frequent maintenance to remain on line. More significantly, the maps produced were inadequate for the intended uses, and too many maps were missing. The maps frequently contained too few current vectors, and without further computer editing, many of the vectors that did appear were grossly incorrect. With added direction editing, major features of the circulation were omitted, and even fewer vectors remained on the maps. Examination of several CODAR maps and the calculated data from which they were produced showed certain limitations of the contractor-supplied data analysis procedure. Various interferences in the antenna voltage readings led to erratic radial velocity readings. In addition, the type of radial velocity combining procedure used was inaccurate with the sometimes erratic data. The concept of a fully automatic system to produce valid CODAR results was not realized in the version of the CODAR system that the project evaluated. In a suggested alternative calculation technique, the assimilation of CODAR data into a numerical model should result in many more maps with few missing data points in the coverage area. This CODAR system might then furnish results equivalent to those from several previous studies that gave valuable information on ocean circulations.

McPhaden, M.J., D.V. HANSEN, and P.L. Richardson. A comparison of ship drift, drifting buoy, and current meter mooring velocities in the Pacific South Equatorial Current. *Journal of Geophysical Research* 96(C1):775-781 (1991).

In this note we compare mean seasonal cycles of zonal and meridional velocity in the Pacific South Equatorial Current based on current meter mooring data, drifting buoy data, and ship drift data. Monthly averages of ship drift and drifting buoy data were computed over 2° latitude by 10° longitude rectangles centered at the positions of multiyear current meter moorings near 0°, 110°W, and 0°, 140°W. All three representations of the flow field show the basic character of the annual mean and its variations, provided that the sampling characteristics associated with each measurement technique are taken into account. In particular, we find that more than 15 days of drifter data (regardless of year) are required on a 2° latitude by 10° longitude basis to produce monthly mean estimates that agree with moored estimates to within about 5-10 cm s^{-1} rms. We also infer that windage affects climatological monthly mean ship drift velocities, although uncertainties in the data limit a precise determination of the windage magnitude. An upper bound

appears to be about 3% of the surface wind speed, though the actual effect of windage may be considerably smaller.

MOLINARI, R.L., E. JOHNS, and J.F. FESTA. The annual cycle of meridional heat flux in the Atlantic Ocean at 26.5°N. *Journal of Physical Oceanography* 20(3):476–482 (1990).

Total meridional heat flux through a zonal oceanic section at 26.5°N in the Atlantic Ocean is computed from hydrographic, direct current, and surface wind observations. The oceanic current and temperature fields are decomposed into depth-averaged and depth-dependent (including Ekman and geostrophic) components to perform the calculation. The mean annual heat flux is estimated to be 1.21 ± 0.34 PW. Mean monthly values of net heat flux are also computed from the data. The annual cycle of net heat flux determined from these values ranges from a minimum of 0.69 PW in February to a maximum of 1.86 PW in July. Thus, in contrast to an earlier estimate of the annual cycle of oceanic heat flux derived indirectly from surface energy fluxes and upper-layer heat content changes, there is no net southward heat flux during the fall. Results from a simulation of the circulation of the North Atlantic give an annual cycle of heat flux similar to our calculations with a summer maximum and winter minimum. However, the simulated mean value and range of the annual cycle are less than observed.

MOLINARI, R.L., D. Olson, and G. Reverdin. Surface current distributions in the tropical Indian Ocean derived from compilations of surface buoy trajectories. *Journal of Geophysical Research* 95(C5): 7217–7238 (1990).

Three different satellite-tracked drifting buoy data sets are compiled and used to generate a monthly climatology of surface currents in the tropical Indian Ocean. Buoys were deployed between 1975 and 1987. The data density is maximum on and near the equator and decreases poleward. Drift characteristics of the different buoy configurations are compared using a structure function analysis. The differences in windage effects are consistent with the buoy designs and small compared with the signals studied. The currents in the tropical Indian Ocean during boreal winter and spring can be characterized as two counterrotating gyres. A southern clockwise rotating gyre is bounded on the south by the South Equatorial Current (SEC) and on the north during winter by the Equatorial Countercurrent (ECC) and during spring by the Equatorial Jet (EJ). A northern counterclockwise rotating gyre is bounded on the south by the ECC and EJ, depending on season, and on the north by the North Equatorial Current (NEC). The two gyre systems break down during boreal summer. During this season, the SEC is located closer to the equator, and the NEC is replaced by the eastward flowing Indian Monsoon Current (IMC). The western boundary circulation becomes more complicated from late spring through early autumn with the observation of two intense smaller scale gyres. The large-scale southern gyre reappears during boreal autumn with the reappearance of the EJ. The northern gyre begins to reappear in December, with the reversal of the IMC and the reappearance of the NEC. The monthly buoy speeds are compared with a monthly climatology generated from ship drift reports. Differences between the two climatologies are, in general, small except in regions of few trajectories. The annual cycles in amplitudes and phases of the major currents in the region are thus comparable.

OOYAMA, K.V. A dynamic test of the diagnostic pressure calculation. Preprints, 19th Conference on Hurricanes and Tropical Meteorology, Miami, FL, May 6–10, 1991. American Meteorological Society, Boston, 171 (1991).

No abstract.

OOYAMA, K.V. A thermodynamic foundation for modeling the moist atmosphere. *Journal of the Atmospheric Sciences* 47(21):2580–2593 (1990).

With advances in numerical modeling of the atmosphere, we have experienced that the return to the first principles of physics often enables a model to cope more easily with the complexities of the real atmosphere.

The return to the primitive equations of motion from historical balance approximations is an example. This paper proposes a way to return to the "primitive" form of moist thermodynamics, in which prediction is made strictly in terms of conservative properties, such as mass and entropy. There is no conservation law that would apply directly to temperature or pressure. These intensive properties, therefore, should be diagnostically determined by thermodynamics, from the predicted conservative properties. The scope of the paper is limited to the thermodynamics of reversible processes. Irreversible processes, which would make a model alive with real weather, are not discussed here, since each of them requires a separate empirical treatment. It is shown, however, that the proposed formulation of thermodynamics facilitates modularization of various approximations within a model, and among models. For example, both the hydrostatic and nonhydrostatic models can be built under an identical design, differing only in the manner of calculating vertical motion. The proposed formulation is extended to include the ice phase within reversible thermodynamics. Also discussed are numerical problems in the spatial representation of thermodynamic discontinuities, which are caused by the phase transition of water substance.

PALMER, D.R., T.M. Georges, and R.M. Jones. Classical chaos and the sensitivity of the acoustic field to small-scale ocean structure. *Computer Physics Communications* 65:219-233 (1991).

Ray theory is usually the basis of data inversion schemes for acoustic remote sensing of the ocean. Chaotic ray paths are expected to be present whenever the ocean environment possesses small-scale, range-dependent structure. We are studying the implications of their presence for data inversion schemes. Using numerical simulations we consider ray-path characteristics for acoustic remote sensing of the Florida Current. We find small-scale bathymetric structure results in chaotic ray paths and an exponential proliferation of eigenrays. As a result, for each feature in the time-of-arrival pattern, there is associated not a single eigenray but a group, thereby limiting the spatial resolution of a remote sensing system.

PIOTROWICZ, S.R., C.J. FISCHER, and R.S. Artz. Ozone and carbon monoxide over the North Atlantic during a boreal summer. *Global Biogeochemical Cycles* 4(2):215-224 (1990).

Ozone mixing ratios observed on a cruise from the east coast of North America to Bermuda, to Iceland, to the Azores and terminating in Barbados in a boreal summer exhibit wide variability. Increases above a North Atlantic background of 10-20 ppbv appear to be associated with transport from terrestrial systems. In the central gyre of the North Atlantic and in the tropical North Atlantic, ozone mixing ratios below 10 ppbv are commonly observed when the air being sampled does not have a recent (10 days) history of terrestrial input. Carbon monoxide mixing ratios within the boundary layer vary latitudinally from an average of 124 ppbv in the westerlies to 88 ppbv in the tropical North Atlantic. Variability in the distribution of CO appears to be dominated by transport from terrestrial source regions.

POWELL, M.D. Surface wind distribution of Hurricane Hugo in the Carolinas. Preprints, 19th Conference on Hurricanes and Tropical Meteorology, Miami, FL, May 6-10, 1991. American Meteorological Society, Boston, 441-444 (1991).

No abstract.

POWELL, M.D., and P.G. BLACK. Meteorological aspects of Hurricane Hugo's landfall in the Carolinas. *Shore and Beach* 58(4):3-10 (1990).

No abstract.

POWELL, M.D., and P.G. BLACK. The relationship of hurricane reconnaissance flight-level wind measurements to winds measured by NOAA's oceanic platforms. *Journal of Wind Engineering and Industrial Aerodynamics* 36:381-392 (1990).

A well-known problem in hurricane forecasting and in the administration of hazardous weather warnings and advisories concerns what adjustment to make to flight-level reconnaissance wind observations in order to make them representative of sustained surface winds. To solve this problem, a study was initiated comparing NOAA reconnaissance flight-level winds to 10 m level observations from NOAA's oceanic buoys and platforms. A data base was created that consisted of comparisons made whenever the aircraft observation was: (1) within 10 km radial separation from the surface platform (in a storm-relative coordinate system); (2) within ±4 h of the surface observation time; and (3) within ±2 h of the surface observation time. The data base contains all storms flown by NOAA aircraft in the vicinity of the Atlantic and Gulf of Mexico buoy network over the 11-year period from 1975-1986. Comparisons from these criteria are discussed in terms of the ratio of the buoy-measured wind speed (V_B) to the aircraft-measured wind speed V_A. Results indicate that the 10 m level surface winds over water were within 55%-85% of the winds measured by the reconnaissance aircraft. The ratio V_B/V_A depended strongly on the low-level atmospheric stability as indicated by the buoy air-sea temperature.

POWELL, M.D., P.P. DODGE, and M.L. BLACK. The landfall of Hurricane Hugo in the Carolinas: Surface wind distribution. *Weather and Forecasting* 6(3):379-399 (1991).

Hurricane Hugo struck Charleston, South Carolina, on 22 September 1989 as the most intense hurricane to affect the United States since Camille in 1969. The northeastern eyewall, which contained the maximum winds measured by reconnaissance aircraft shortly before landfall, moved inland over a relatively unpopulated area and there were few fatalities. However, no observations were available to document the surface wind distribution in this part of the storm as it continued inland. To improve specification of surface winds in Hugo, empirically adjusted aircraft winds were combined with coastal, offshore, and inland surface observations and were input to the Ooyama objective analysis algorithm. The wind analysis at landfall was then compared with subsequent analyses at 3 and 6 h after landfall. Reconstruction of the surface wind field after landfall suggests that the maximum (~13 min mean) surface wind at the coast was 50 m s^{-1} in the Bulls Bay region, ~40 km northeast of Charleston. Surface roughness over land caused wind speeds to drop off rapidly just inland of the coast to only 50% of values measured by reconnaissance aircraft at the same location relative to the storm over water. Despite relatively rapid increases in the central sea-level pressure and decreases in the mean circulation as Hugo progressed inland, hurricane-force wind gusts extended Hugo's damage pattern well past Charlotte, North Carolina, 330 km inland. Accurate determination of surface wind distribution in landfalling hurricanes is dependent upon the spatial density and quality of surface wind measurements and techniques to adjust reconnaissance flight-level winds to the surface. Improvements should allow forecasters to prepare more accurate warnings and advisories and allow more thorough documentation of poststorm effects. Empirical adjustments to reconnaissance aircraft measurements may replace surface data voids if the vertical profile of the horizontal wind is known. Expanded use of the airborne stepped-frequency microwave radiometer for remote sensing of ocean surface winds could fill data voids without relying upon empirical methods or models. A larger network of offshore, coastal, and inland surface platforms at standard (10 m) elevations with improved sampling strategies is envisioned for better resolution of hurricane wind fields. A rapid-response automatic station network, deployed at prearranged coastal locations by local universities with meteorology and/or wind engineering programs, could further supplement the fixed platform network and avoid the logistical problems posed by sending outside teams into threatened areas.

PSZENNY, A.A.P., J.N. Galloway, R.S. Artz, and J.F. Boatman. Overview of the 1988 GCE/CASE/WATOX studies of biogeochemical cycles in the North Atlantic region. *Global Biogeochemical Cycles* 4(2):121-131 (1990).

The 1988 Global Change Expedition/Coordinated Air-Sea Experiment/Western Atlantic Ocean Experiment (GCE/CASE/WATOX) was a multifaceted research program designed to study atmospheric

and oceanic processes affecting the biogeochemical cycles of carbon, nitrogen, sulfur, and trace metals in the North Atlantic Ocean region. Field work included: (1) a 49-day research cruise aboard NOAA ship *Mt. Mitchell* (Global Change Expedition) from Norfolk, Virginia, to Bermuda, Iceland, the Azores, and Barbados; (2) eight flights of the NOAA King Air research aircraft, four off the Virginia Capes and four near Bermuda (CASE/WATOX); and (3) a research cruise aboard the yacht *Fleurtie* near Bermuda (WATOX). Objectives of GCE/CASE/WATOX were: (1) to examine processes controlling the mesoscale distributions of productivity, chlorophyll, and phytoplankton growth rates in Atlantic surface waters; (2) to identify factors controlling the distribution of ozone in the North Atlantic marine boundary layer; and (3) to estimate the contributions of sources on surrounding continents to the biogeochemical cycles of sulfur, nitrogen, and trace metals over the North Atlantic region during the boreal summer season.

PSZENNY, A.A.P., G.R. HARVEY, C.J. Brown, R.F. Lang, W.C. Keene, J.N. Galloway, and J.T. Merrill. Measurements of dimethyl sulfide oxidation products in the summertime North Atlantic marine boundary layer. *Global Biogeochemical Cycles* 4(4):367-379 (1990).

Chemical data derived from air and precipitation samples collected during the Global Change Expedition/Coordinated Air-Sea Experiment/Western Atlantic Ocean Experiment (GCE/CASE/WATOX) over the North Atlantic Ocean (NAO) are interpreted using simple box models. Estimated total sulfur (S) deposition fluxes from air masses with tropical oceanic, African, clean North American, and polluted North American origins are 4.4, 16, 33, and 70 μmol m^{-2} day^{-1}, respectively, with associated uncertainties of at least factors of 2 to 3. Crude estimates of the fractions of deposition attributable to marine biogenic versus anthropogenic S sources suggest that the latter may be enhancing the natural NAO atmospheric S cycle by a factor of 0.5 to 0.8. Combination with similar estimates for the North Pacific region (Savoie and Prospero, 1989) yields an overall, area-weighted enhancement factor of approximately 0.3 for northern hemisphere ocean areas, consistent with estimates by Wigley (1989) based on climate modeling studies.

ROSENTHAL, S.L. A note on relationships between Western Sahel rainfall and U.S. hurricane activity. NOAA TM ERL AOML-68 (PB91-176511), 22 pp. (1991).

A recent research paper concluded that the probabilities of major hurricane strikes on the east coast of the United States, particularly the east coast of Florida, are greatly enhanced when rainfall over the Western Sahel is abundant and that these probabilities are substantially smaller when drought conditions prevail over the Western Sahel. This conclusion was based upon a 43-year sample of 1947-1989. In the work presented here, a search is made for simple, statistically significant (at the 5% or better level) relationships between Western Sahel rainfall for 1947-1990 and eight types of hurricanes that are defined in the text. When hurricane frequencies for the 11 wettest and 11 driest Western Sahel years are compared, statistically significant differences are found for all hurricane types studied, *except for Florida landfalling hurricanes*. Significant relationships are found for major hurricanes striking the east coast of the United States north of Florida, and for hurricanes of all intensities striking the east coast of the United States north of Florida. *However, no significant relationships are found for hurricanes striking Florida*. When the wetter 22 years are compared with the drier 22 years, a statistically significant relationship is found for the total of hurricanes of all intensities that strike the Florida Peninsula. For this type of hurricane, the largest frequency is found in the second quartile of Western Sahel rainfall years and not in the wettest quartile. This makes the interpretation of the results difficult.

Roux, F., and F.D. MARKS, JR. Eyewall evolution in Hurricane Hugo deduced from successive airborne Doppler observations. Preprints, 19th Conference on Hurricanes and Tropical Meteorology, Miami, FL, May 6-10, 1991. American Meteorological Society, Boston, 558-563 (1991).

No abstract.

Roux, F., F.D. MARKS, JR., and J.F. GAMACHE. Three-dimensional circulation in a hurricane from airborne Doppler radar data: Extended velocity track display. Preprints, 25th International Conference on Radar Meteorology, Paris, France, June 24-28, 1991. American Meteorological Society, Boston, 466-469 (1991).

No abstract.

SHAPIRO, L.J. The effect of vertical wind shear on hurricane motion in a three-layer model. Preprints, 19th Conference on Hurricanes and Tropical Meteorology, Miami, FL, May 6-10, 1991. American Meteorological Society, Boston, 356-357 (1991).

No abstract.

Shay, L.K., P.G. BLACK, J.D. Hawkins, R.L. Elsberry, and A.J. Mariano. Sea surface temperature response to Hurricane Gilbert. Preprints, 19th Conference on Hurricanes and Tropical Meteorology, Miami, FL, May 6-10, 1991. American Meteorological Society, Boston, 574-578 (1991).

No abstract.

THACKER, W.C. Large least-square problems and the need for automating the generation of adjoint codes: Computational solution of nonlinear systems of equations. *Lectures in Applied Mathematics* 26:645-677 (1990).

Some important least-squares problems that arise in oceanography and meteorology are large because they are based on systems of partial-differential equations. The function to be minimized is defined with the aid of a computer code, so the equations stating that the gradient should vanish are not available explicitly. It is possible to construct a second code that evaluates the gradient for a computational effort approximately equal to that of evaluating the function. Since the gradient code can be derived from the function code by following a well-defined set of rules, it should be possible to construct a compiler-like utility to do this task automatically. Such a compiler should find wide applicability, not only within oceanography and meteorology, but for optimization problems in general, as well as for solving systems of nonlinear equations and for checking the sensitivity of outputs of complicated codes to their inputs.

TSAI, J.J., and J.R. PRONI. Dredged material disposal at the edge of the Florida Current. First International Ocean Pollution Symposium, Mayaguez, Puerto Rico, April 28-May 3, 1991. University of Puerto Rico, Mayaguez, 80 (1991).

A field data collection project was undertaken to evaluate the potential environmental impact of dumping in the designated Miami Ocean Dredged Material Disposal Site before the actual dredging of Miami River and Miami Harbor Turning Basin. Strong Gulf Stream current and relatively deep water depth at the disposal site make the study unique and important. Acoustic remote sensing techniques with current measurements from acoustic Doppler current profiler and in-situ oceanographic measurements were used to monitor the physical processes and the dispersive characteristics. Results indicate that during the period of observations of the study, materials were transported north-northeast away from sensitive reef areas and penetrated the strong pycnoclines to reach the bottom in the first few minutes. For the first time, intercomparison among all field data and numerical prediction provides dispersive characteristics of dredged material disposal at the western edge of the Florida Current.

WILLIS, P.T., and J. Hallett. Microphysical measurements from an aircraft ascending with a growing isolated maritime cumulus tower. *Journal of the Atmospheric Sciences* 48(2):283-300 (1991).

The development of precipitation in the top of an isolated marine cumulus is traced by four rapid penetrations with an instrumented aircraft between 400 and 1000 m below the visible top of the growing tower.

The hydrometeor distribution evolves from the first appearance of a few large supercooled drops [0.45 l^{-1}, $D > 0.5$ mm] to well-developed precipitation (largely ice) in 500 s. This development results from accretion and coalescent growth in the cloud top volume, not from advection by the updraft of large drops from below. Large supercooled drops precede the appearance of ice at −9 °C near the cloud top. The cloud and precipitation water budgets are computed and compared with observed values, which indicate that, once precipitation is well-developed, the convective tower cannot maintain itself as a steady-state entity. The budget computations demonstrate a sensitivity of cloud evolution to the ice particle density.

WILLIS, P.T., and A.J. Heymsfield. Trajectories of hydrometeors in Hurricane Emily. Preprints, 19th Conference on Hurricanes and Tropical Meteorology, Miami, FL, May 6–10, 1991. American Meteorological Society, Boston, 192–197 (1991).

No abstract.

WILLIS, P.T., F.D. MARKS, JR., and J. Hallett. Tracing the interactions of precipitation evolution and cloud dynamics using airborne Doppler radar and in-situ data. Preprints, 25th International Conference on Radar Meteorology, Paris, France, June 24–28, 1991. American Meteorological Society, Boston, 916–919 (1991).

No abstract.

WILLOUGHBY, H.E. Reply. *Journal of the Atmospheric Sciences* 48(9):1209–1212 (1991).

No abstract.

WILLOUGHBY, H.E. Semispectral models of moving hurricane-like vortices. Preprints, 19th Conference on Hurricanes and Tropical Meteorology, Miami, FL, May 6–10, 1991. American Meteorological Society, Boston, 383–384 (1991).

No abstract.

Winter, A., C. Goenaga, and G.A. MAUL. Carbon and oxygen isotope time series from an 18-year Caribbean reef coral. *Journal of Geophysical Research* 96(C9):16,673–16,678 (1991).

Colonies of *Montastrea annularis* live near La Parguera, Puerto Rico, which may be 700 years old. Time series from 1964 to 1982 of $\delta^{13}C$ and $\delta^{18}O$ from a continuous core of these corals are compared to an adjacent environmental record. At the intra-annual level, $\delta^{18}O$ correlates well with water temperature. Changes in the amplitude of the $\delta^{18}O$ signal between 1967–1976 are attributed to sampling frequency but may be also due to environmental changes such as salinity. Average annual $\delta^{18}O$, $\delta^{13}C$ and sea surface temperature show similar trends for the period from 1964–1982 but especially from 1969 onwards. Changes in average annual values during this time interval are most likely due to water mass changes brought about by interannual variability of the North Atlantic circulation. Since water temperatures at La Parguera are representative of changes occurring in the Wider Caribbean, the isotope record from La Parguera corals could be used as a proxy for large scale environmental changes beyond the historical record through the Little Ice Age.

ADDENDUM

Giese, G.S., D.C. Chapman, P.G. BLACK, and J.A. Fornshell. Causation of large-amplitude coastal seiches on the Caribbean coast of Puerto Rico. *Journal of Physical Oceanography* 20(9):1449–1458 (1990).

Sea-level oscillations at supertidal frequency with amplitudes of the order of the mean tidal range have been reported from the Caribbean coast of Puerto Rico. Analysis of a 10-year time series of digital tide data from Magueyes Island, Puerto Rico, demonstrates that sea-level variance at the fundamental normal mode (seiche) frequency of the shelf has a pronounced fortnightly distribution with a maximum occurring 6–7 days after new and full moon. The sieche variance also shows a bimodal seasonal distribution with an inverse relationship to easterly wind stress. It is argued that the seiches are excited by internal waves generated by strong tides in the southeastern Caribbean. Support is provided by airborne radar imagery showing sea-surface patterns suggesting the presence of internal waves near the southern Aves Ridge, and by the results of two field experiments, carried out during times when large-amplitude seiches were expected, to research for evidence of internal wave forcing near the shelf break. During the first experiment, large negative-amplitude, pulse-like internal waves were recorded 6 km seaward of the shelf break during a period of strong seiche activity. Such pulses were not observed during the second experiment. However, high-frequency temperature variance 2.3 km seaward of the shelf break, possibly resulting from internal surf, increased with depth and reached a maximum 6–7 days following new moon, again suggesting the presence of internal waves. The 10-year time series analysis shows that large tides are necessary, but not sufficient, to generate high seiche activity. This is supported by the two field experiments; during the first, large-amplitude seiches occurred as expected, while during the second experiment they did not. We suggest that this behavior is related to variations in stratification, which in turn alter the energy transfer from tides to seiches.

LONG, R.B., and W.C. THACKER. Data assimilation into a numerical equatorial ocean model, Part 1: The model and the assimilation algorithm. *Dynamics of Atmospheres and Oceans* 13:379–412 (1989).

Numerical modeling provides a powerful tool for the study of the dynamics of oceans and atmospheres. However, the relevance of modeling results can only be established by reference to observations of the system being modeled. Typical oceanic observation sets are sparse, asynoptic, of mixed type and limited reliability, generally inadequate in some respects, and redundant and inconsistent in others. An optimal procedure for interfacing such data sets with a numerical model is the so-called adjoint method. This procedure effectively assimilates the observations into a run of the numerical model by finding that solution to the model equations that best fits all observations made within some specified space-time interval. The method requires the construction of the adjoint of the numerical model, a process made practical for models of realistic complexity by the work of Thacker and Long (1988). In the present paper, the first of two parts, we illustrate the application of Thacker and Long's approach by constructing a data-assimilating version of an equatorial ocean model incorporating the adjoint method. The model is subsequently run for five years to near-steady state, and exhibits many of the features known to be characteristic of equatorial oceanic flows. Using the last 54 days of the run as a control, a set of simulated sea level and subsurface density observations are collected, then successfully assimilated to demonstrate that the procedure can recover the control run, given a generous amount of data. In Part 2, we conduct a sequence of numerical experiments to explore the ability of more limited sets of observations to fix the state of the modeled ocean; in the process, we examine the potential value of sea level data obtained via satellite altimetry.

LONG, R.B., and W.C. THACKER. Data assimilation into a numerical equatorial ocean model, Part 2: Assimilation experiments. *Dynamics of Atmospheres and Oceans* 13:413–439 (1989).

A sequence of numerical experiments is conducted using a linear, semi-spectral equatorial ocean model and an advanced data assimilation scheme. The numerical model is based on decomposition of the oceanic

fields into Kelvin and Rossby waves belonging to the baroclinic modes of a stratified equatorial ocean. The assimilation procedure finds that solution to the model equations that best fits, in the generalized least-squares sense, all observations made within some specified space-time interval. All experiments are of the "identical twin" type; synthetic data are generated by sampling the observable fields produced by a control run of the model, then the data are assimilated using the same model. The sequence of numerical experiments serves two purposes: to demonstrate the performance of the assimilation procedure in the context of a fully three-dimensional, time-varying equatorial ocean model, and to examine the utility of specified data sets, and in particular, observations of sea level, in estimating the state of the equatorial ocean. The results indicate that the assimilation procedure works very well when sufficient data are provided. However, sea level data alone are not sufficient and must be supplemented with subsurface observations if more than a few baroclinic modes are allowed in the model ocean. The required amount of supplementary subsurface data (in the form of density profiles in these experiments) can be reduced by imposing smoothness contraints on the recovered model solution.

Molinari, J., and D. Vollaro. External influences on hurricane intensity. Part II: Vertical structure and response of the hurricane vortex. (Research partially supported by NOAA Grants 50-WCNR-8-06055 and 50-WCNR-9-06080.) *Journal of the Atmospheric Sciences* 47(15):1902-1918 (1990).

The vertical structure of the interactions of Hurricane Elena (1985) with a baroclinic wave was evaluated using analyses from the European Centre for Medium Range Weather Forecasting. During the period of interaction, azimuthal eddies produced a localized flux convergence of cyclonic angular momentum in the upper troposphere which shifted to progressively small radii prior to major secondary deepening of the storm. These momentum fluxes decayed above and below the outflow layer. Eddy heat fluxes showed maximum cooling in the middle and upper troposphere and warming in the lower stratosphere, reflecting the temperature structure of the baroclinic wave as it moved into the hurricane volume. The response of the hurricane vortex to the fluxes of heat and angular momentum was determined by solution of Eliassen's balanced vortex equation. The balanced solutions showed a band of upward motion, with deep inflow and narrow outflow, which shifted inward from the 500 km radius to the hurricane core in the 24 hours prior to the secondary deepening. The position and timing of this feature corresponded to the contracting outflow maximum found in Part I. Eddy heat fluxes contributed to the induced circulation in the same manner as momentum fluxes near the core, but with smaller magnitude and areal coverage. The contracting outflow maximum thus appeared to represent the upper branch of a secondary circulation excited primarily by the eddy momentum fluxes. The reintensification of hurricanes is often directly associated with formation of a wind maximum at inner radii which replaces or reinforces the original eye wall as it contracts. Such a feature was seen in reconnaissance data in Elena at the time the secondary circulation reached inner radii. It is speculated that the relatively weak secondary circulation evolved into a local wind maximum through the actions of diabatic heat sources. The approaching trough is thus viewed not as a direct cause of deepening, but as a catalyst which organized the diabatic sources in such a way as to excite internal instabilities of the system.

ROSENTHAL, S.L. A history of NOAA's Hurricane Research Division, including interactions with F.S.U.'s Department of Meteorology. Proceedings, 40th Anniversary Celebration, Department of Meteorology, Florida State University, November 30-December 1, 1989. Florida State University, Tallahassee, 42-47 (1990).

No abstract.

THACKER, W.C. The role of the Hessian matrix in fitting models to measurements. *Journal of Geophysical Research* 94:6177-6196 (1989).

A numerical model can be fit to data by minimizing a positive quadratic function of the differences between the data and their model counterparts. The rate at which algorithms for computing the best fit to

data converge depends on the size of the condition number and the distribution of eigenvalues of the Hessian matrix, which contains second derivatives of this quadratic function. The inverse of the Hessian can be identified as the covariance matrix that establishes the accuracy to which the model state is determined by the data; the reciprocals of the Hessian's eigenvalues representing the variances of linear combinations of variables determined by its eigenvectors. The aspects of the model state that are most difficult to compute are those about which the data provide the least information. A unified formalism is presented in which the model may be treated as either strong or weak constraints, and methods for computing and inverting the Hessian matrix are discussed. Examples of the uncertainties in the best-fit analyses using an oceanographic model are given for several different sets of hypothetical data.

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