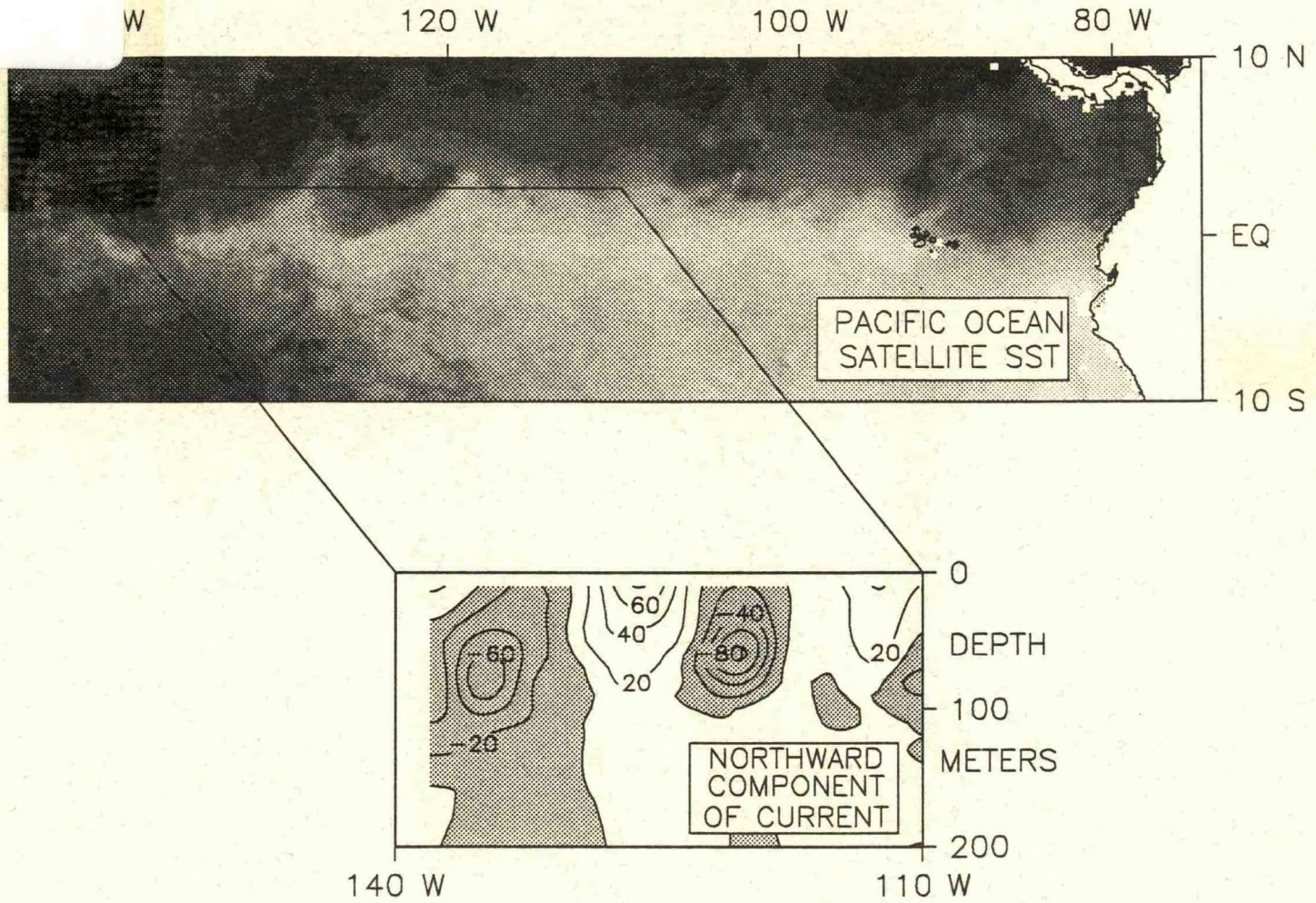
AOML ANNUAL REPORT
FISCAL YEAR 1988



U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
Office of Oceanic and Atmospheric Research
Environmental Research Laboratories
Atlantic Oceanographic and Meteorological Laboratory

AOML ANNUAL REPORT

Fiscal Year 1988

December 1988

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

UNITED STATES
DEPARTMENT OF COMMERCE

WILLIAM VERITY, SECRETARY

NATIONAL OCEANIC AND
ATMOSPHERIC ADMINISTRATION

C. WILLIAM EVANS, UNDERSECRETARY
AND ADMINISTRATOR

Environmental Research
Laboratories

Vernon E. Derr, Director

COVER:

NOAA's Equatorial Pacific Ocean Climate Studies (EPOCS) program studies conditions in the eastern Pacific Ocean related to El Nino events. (Top): The waves visible in the SST field at 3°N are the result of current instabilities, and mix the warm (darker shades) water to the north with the cold (lighter) water near the equator. The NOAA Ship *Researcher* conducted a survey of the currents associated with these instability waves in November 1987. (Bottom): Warm, southward currents are strongest below the surface, while the colder northward currents are concentrated in near-surface jets. The instability waves seem to act as a thermostat in the eastern equatorial Pacific, keeping the equatorial ocean from getting too cold and the waters to the north from getting too warm.

Satellite data courtesy of RSMAS/University of Miami.

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Atlantic Oceanographic and Meteorological Laboratory

FY 1988 Annual Report

PREFACE

This document presents the major accomplishments and plans of NOAA'S Atlantic Oceanographic and Meteorological Laboratory (AOML) for fiscal years 1988 and 1989. This is the sixth 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 ten 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 1988 and 1989.

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 1988 accomplishments and FY 1989 plans within the context of the ERL program structure; (3) the Publications section includes a complete list of AOML's FY 1988 publications, with abstracts, and a list of some publications which were published in prior years but not reported in the annual reports; and (4) the AOML Staff section lists the employees assigned to the laboratory as of December 1, 1988.

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OVERVIEW

FY 1988 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 OD, with OAD accounting for 9% and the Office of the Director providing approximately 6% of the total research effort.

The total AOML program during FY–1988 was was supported by 123 staff years of effort. Of this total, 100 people were classified as scientists or technicians involved in direct support of the research program at AOML.

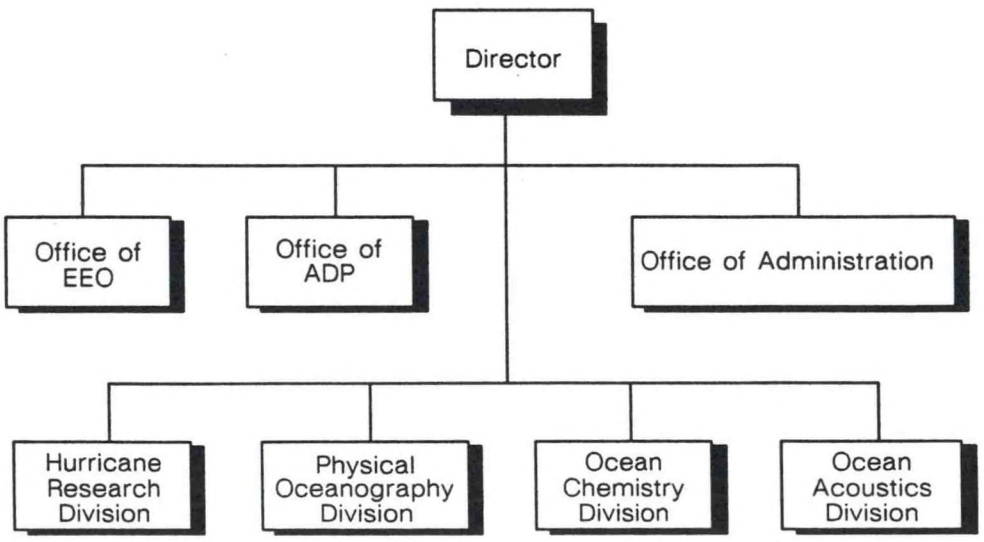

Figure 1. AOML Organizational Chart.

AOML's FY 1988 research funding level was about $8.25 million. The level of research funding has been only slightly reduced during the past few 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.

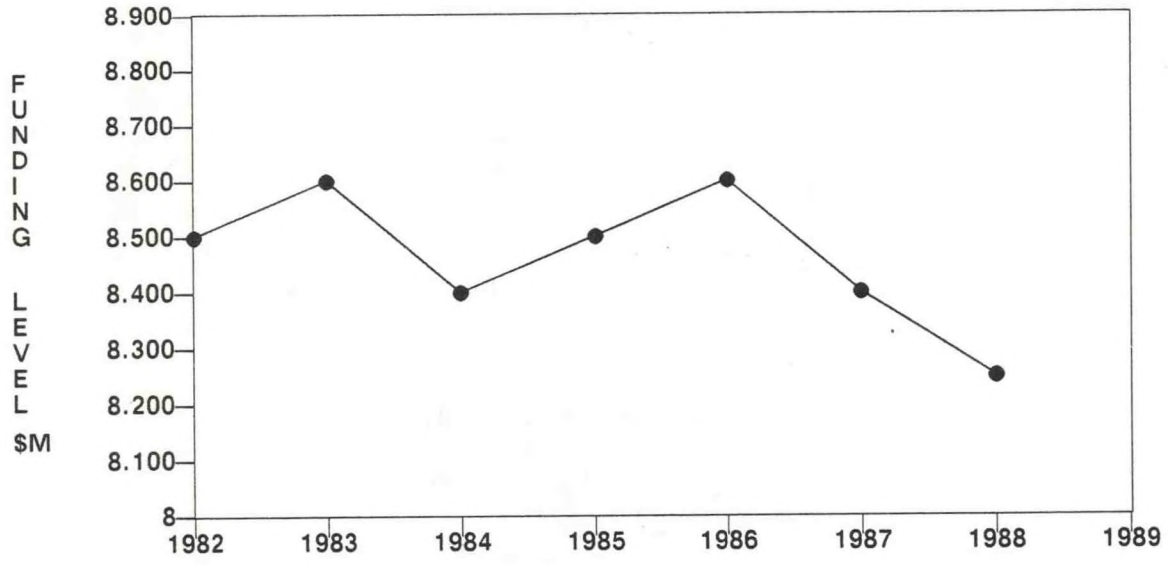

Figure 2. Research Funding Levels for FY 1983 to FY 1988.

A review of the funding sources for the laboratory's FY 1988 program (Figure 3) indicates that about 95% of the total research done at AOML is funded by NOAA, either by ERL directly (87%) or by NOAA Program Offices (8%). Only about 5% 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.

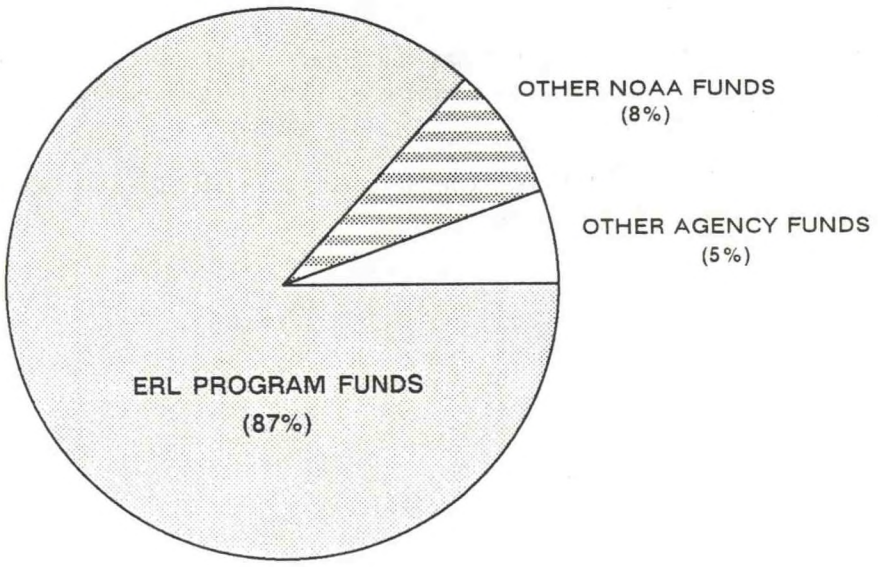

Figure 3. Funding Source Distribution (total FY 1988 funding of $8.25 million).

Figure 4 portrays how AOML's funds were disbursed during FY 1988. Climate and Air Quality programs accounted for just under $3.7 million; Weather Research was almost $2.9 million; and Marine Resources work expended about $1.9 million. The distribution of funds between programs at AOML has been quite stable during the past five years.

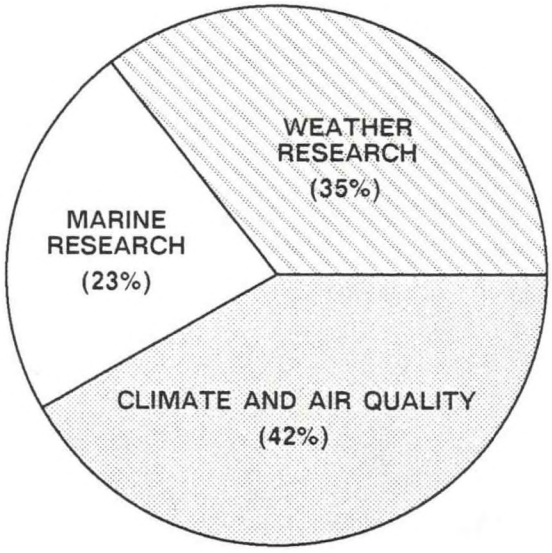

Figure 4. Expenditures by Program (total FY 1988 expenses of $8.25 million).

Fiscal Year 1988 proved to be a very challenging year for AOML's field research effort. The sudden loss of NOAA's primary east coast oceanographic research vessel, due to delays in shipyard contracts, was a difficulty that was eventually overcome through the use of two smaller ships in the NOAA Fleet. Although the vessels were not designed to support deep sea oceanography, the "can do" attitude of everyone involved in planning, preparation, and operations contributed to the successful accomplishment of all research objectives.

The hurricane research program was challenged with a flurry of late season storms that offered numerous opportunities to conduct field experiments but which taxed the flight hours and other resources available to accomplish them.

A review of AOML's FY 1988 accomplishments are outlined in the following section along with an outline of the major plans for the next year.

FY 1988 ACCOMPLISHMENTS/FY 1989 PLANS

The Atlantic Oceanographic and Meteorological Laboratory (AOML) is organized to pursue basic and applied research programs in oceanography and tropical meteorology. Oceanographic investigations center on fluxes of energy, momentum, and materials through the air–sea interface; the transport and composition (thermal and chemical) of water in the ocean; 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 interdisciplinary participation of visiting scientists. AOML's current research program concerns processes relating to global climate and air quality, weather observation and prediction, marine observation 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 scope of the problems addressed requires extensive cooperation and coordination between groups. Tradition and convenient access to sea–going research facilities result in a research program with an emphasis on collection and analysis of oceanographic data. The ultimate goal of the work is to improve forecasting of oceanic and atmospheric variations. Improvement of skill in use of coupled ocean–atmosphere models is critical to achieving this goal. The primary mission of AOML's climate program is to obtain data and descriptions of the oceanic environment and processes by means of which modeling skill can be evaluated and improved, and to develop methods for assimilation of data into models as a means of providing the best possible description of the environment with whatever observations are available.

Activities are currently concentrated on problems associated with two different time scales of climate variations. The shorter of these is the interannual time scale; the El Nino/Southern Oscillation phenomenon which is most clearly manifested in the tropical Pacific Ocean, but has global implication, is the best recognized pattern. Accordingly, AOML is a major participant in the EPOCS and TOGA programs in the tropical Pacific. AOML activities in these programs are closely integrated with those of PMEL and GFDL within ERL, and extensive cooperation exists with NWS, NMFS, NOS, and scientists in universities and in several foreign countries.

On longer time scales, the effects of ocean circulation in carrying heat from low latitudes, where it is received in excess quantity from the Sun, to high latitudes, where it is received in deficiency, 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. Therefore, AOML is leading a program named Subtropical Atlantic Climate Studies (STACS) to learn more about the process. Although STACS is a much smaller program than TOGA, or even EPOCS, it also involves close interaction with other organizations, most notably PMEL, NOS, and the University of Miami through CIMAS.

Air quality research at AOML is a multidisciplinary research program addressing the four major categories of processes that dominate geochemical cycles in the marine troposphere as well as in the global atmosphere. These categories are related to sources, transport and distribution, transformation, and removal. The program involves inorganic and organic chemistry, lower 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 the evolution of a quantitative understanding of geosphere/biosphere interactions.

AOML uses both ship and aircraft expeditions to delineate the global distributions, temporal variabilities, and air/sea fluxes of radiatively important trace species (RITS) and other substances that

directly affect their cycles. The RITS species being studied are ozone (O_3) and aerosols; among the related substances being studied are methane (CH_4), carbon monoxide (CO) and the low-molecular-weight non-methane hydrocarbons (NMHCs). A quantitative understanding of geosphere/biosphere interactions is being achieved through laboratory and field studies of the production of volatile, tropospherically important species by oceanic phytoplankton, microzooplankton, and bacteria, and the environmental factors that control this production. The laboratory program involves growing pure cultures of organisms under controlled conditions to identify volatile species being produced and to quantify their production rates as functions of parameters controlling growth. The field program involves characterization of biological activity in specific marine environments and its relationship(s) to the chemical composition of the marine boundary layer.

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 this 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 NESDIS using a system known as WOTAN (Weather Observation Through Ambient Noise).

Accomplishments FY 1988

TOGA/EPOCS PROGRAM

As part of TOGA's Equatorial Pacific Ocean Climate Studies, AOML conducted a cruise designed to study 30-day tropical instability waves and their role in oceanic transport of heat out of the tropics. The NOAA ship *Researcher* completed a set of transects supplying conductivity, temperature, and depth (CTD) data, and measurements by expendable bathythermographs (XBTs) and acoustic Doppler current profilers (ADCPs) for the eastern equatorial Pacific Ocean. The NOAA ship *Oceanographer* completed a complementary section on the equator. After the data are processed they are used in efforts to quantify the heat and momentum transport due to the instability waves, compare that transport with transport due to other processes, and identify the dynamical mechanisms responsible for the generation and decay of the waves. A major application of the wave characteristics data is comparison with waves generated by the Climate Analysis Center (CAC) equatorial Pacific Ocean General Circulation Model (OGCM) in an effort to understand the waves better and improve model performance. The model must accurately account for heat transport in the equatorial regions in order to model the ENSO cycle accurately and ultimately aid in predicting El Nino events.

A network of sea level and meteorological observing stations has been established at coastal and island points from Quepos (Costa Rica) to Valparaiso (Chile) to provide measurements over the 1985-1994 decade in support of the TOGA program. Enhanced data collection from the tropical Pacific is a centerpiece of the EPOCS program and of U.S. contributions to the International TOGA program. The AOML Eastern Pacific Sea Level Project is receiving data that will be used for estimation of heat transport by ocean currents, for verification of ocean circulation models, and for diagnostic studies of the ENSO phenomenon. The data are made available for monitoring of conditions by operational centers by means of data telemetry via satellite. The data are collected most cost effectively by establishing cooperative working relationships with agencies in Latin America.

Unclassified data from the U.S. Navy geodetic altimeter satellite (GEOSAT) were used to develop and evaluate methods for application of satellite altimeter data to oceanographic research and operations. Satellite altimetry holds a potential for global observations of sea level at sea, but contains errors that are large compared to variations of importance in connection with ocean currents. The established method of coping with these errors is to work with "crossover differences," whereby the average changes of sea level over large regions can be extracted. At AOML a method for obtaining absolute sea level at fine resolution

on each satellite pass using coincident *in-situ* sea level observations was developed and evaluated. Results to date indicate that in mid-ocean regions where the geoid is relatively smooth an accuracy on the order of 3 cm is attainable, but tectonically complex regions are likely to be less tractable due to small-scale, large-amplitude variations of the geoid.

A major expansion of the use of satellite-tracked drifting buoys for collection of sea-surface temperature and current data in the tropical Pacific Ocean was effected by entry into a joint venture with investigators at SIO and WHOI, and in France and Australia. By the end of 1988, approximately 150 drifting buoys will be working in the tropical Pacific to provide accurate sea-surface temperature data, and for the first time, an extensive set of current measurements. A centralized data processing function was established at AOML in support of the cooperative project.

A new concept for assimilation of observed data into models of the oceanic circulation (or other processes) was developed at AOML. Analysis and prediction of climate variations is limited by the availability of observations of the atmosphere, and especially the ocean. Furthermore, the cost of increasing the observations is very large. It is imperative, therefore, to make the very best use possible of the observations made. The new procedure finds that solution to the numerical model equation that best fits all available observations in the generalized least square sense, and provides in the process (1) a statistically precise test of model validity, (2) a complete analysis of the state of the modeled system during the observation interval, (3) a statistically optimal set of initial conditions for a subsequent model forecast, (4) a method of extracting statistically optimal estimates of unknown parameters of the numerical model itself from the data, (5) a procedure for analyzing the adequacy of observation strategies, and (6) a method for calculating the statistical uncertainty of the model state determined by the assimilation.

SUBTROPICAL ATLANTIC CLIMATE STUDIES (STACS)

A continuing field program was conducted to document the oceanographic currents and other conditions and their variation in the Straits of Florida and along the western boundary of the North Atlantic Ocean between about 27°N and 5°N. Three research cruises were made for shipboard data collection and to set recording current meters and other instruments in the ocean. Data from coastal and island sea level stations and induced electrical potential measurements using a telegraph cable also were used in the work. Large variability in currents east of Florida on short time scales indicates the need for new *in-situ* or remote observing systems to collect the long-term data required for climate research. The observations of circulation patterns off South America will provide the basis for planning further research in that region. Intensive observations with international participation is being planned for this region as part of the World Ocean Circulation Experiment.

Inverted echo sounder data has been gathered in a series of deployments east of Abaco Island in the Bahamas and in a series of deployments in the Pacific. Data from these deployments are being processed and analyzed. An in-depth study of the calibration of IES systems in the area of Abaco is underway.

GLOBAL CLIMATE CHANGE/RITS

A two-month field program encompassing the entire North Atlantic basin was conducted in FY 1988. Different portions of the cruise track had different scientific objectives based, primarily, on geographical location. The first portion of the cruise extended from the east coast of the United States to the oligotrophic central gyre of the North Atlantic and was conducted with coordinated aircraft operations. This portion of the cruise examined the potential transport of biologically-fixed carbon from nearshore shelf water offshore to the Gulf Stream. A second objective was to evaluate procedures for investigating dispersion of point source inputs within the water column. These two objectives were addressed using

drifting and sediment trap arrays. This portion of the cruise was also coordinated with aircraft and designed to investigate the transport of terrestrially-produced atmospheric species from the east coast to the North Atlantic. A second objective of the atmospheric program involving aircraft was to investigate deposition (*i.e.*, removal) of terrestrially-derived material over the North Atlantic at a time when the trade-wind regime has been established.

Throughout the field program, atmospheric sampling was being conducted from a bow tower on the ship as part of our investigations of the atmospheric chemistry of various sulfur, nitrogen and carbon compounds and their biogeochemical cycles. The second leg of the cruise extended across the Arctic Circle to quantify atmospheric trace species in polar air. This portion of the cruise basically crossed all of the hydrographic regimes of the temperate and subarctic Atlantic as well as all of the atmospheric transport routes from North America to this region. The third and fourth portions of the cruise were designed to transit the entire North Atlantic from Arctic to equatorial latitudes along its eastern edge. This portion of the cruise crosses all of the oceanic circulation and atmospheric transport routes of the North Atlantic. The third portion of the cruise included an investigation of the biological provinces of the North Atlantic in preparation for expanding CO_2 research. The northern portion of the cruise continued investigations of the removal of terrestrially-derived material begun during the northward transect along the east coast of North America. The last portion of the cruise investigated the atmospheric transport of material from Europe and North Africa to the North Atlantic.

Preliminary results from the cruise indicate that, during this time of the year, material transported off the east coast of the United States is either rapidly removed and does not reach the central gyre of the North Atlantic or is transported to the north away from the central gyre. Species such as SO_2, O_3 and radon (Rn), a tracer of terrestrial material, rapidly reached background levels in the subtropical and temperate North Atlantic off of the east coast of the United States. The oceanic dispersion experiments were highly successful indicating that we can track point source dispersion in oligotrophic central gyres.

In FY 1988 AOML began controlled ecosystem experiments on the production of atmospheric volatiles by marine microorganisms. These experiments are being conducted to quantify the kinetics of production, as well as the production of specific volatiles by specific organisms. The results of our FY 1987 field programs were presented at several meetings and submitted for publication in FY 1988. Additionally, a broader view of processes controlling the distribution of relatively non-reactive trace species such as O_3 was developed based on laboratory experiments conducted this year and the 1987 field programs. This has been formulated into a set of hypotheses regarding the role of fundamental atmospheric thermodynamic processes, as opposed to photochemical processes, in determining atmospheric distributions. These hypotheses are being tested and one manuscript addressing these ideas was accepted for publication in FY 1988.

WOTAN

AOML took delivery of an advanced design WOTAN (Weather Observation Through Ambient Noise) system and carried out an initial engineering deployment test in September 1988. The data from that test is now being processed.

Plans FY 1989

TOGA/EPOCS PROGRAM

A data-assimilating version of the GFDL general circulation model will be completed. The GFDL-GCM is considered to be the premier general circulation model in use today and is being applied to

research problems at some 20 locations in the U.S. and abroad. A data-assimilating version of it will be of enormous value to those research efforts and could well become the centerpiece of such large programs as TOGA and WOCE. The model is extremely complex and developing the code for a data-assimilating version is a painfully tedious, though mathematically straightforward, task.

The surface currents of the western tropical Pacific Ocean are complicated by the presence of many islands and variations of surface winds on monsoonal and shorter time scales. In their extreme variation these currents are thought to be instrumental in initiation of El Nino events that envelope the entire tropical band of the Pacific, and impact climate globally. These surface currents are one of the air-sea interaction phenomena being investigated within the U.S./PRC cooperative program for TOGA. Satellite-tracked drifting buoys are being released during each cruise to document the evolution of surface currents between the periods of cruise activity.

The spatial and temporal variations of the North Equatorial Countercurrent (NECC), the role of the NECC in the advection of heat into the eastern Pacific and the possible relationship between variations in the NECC and El Nino events will be investigated. This relates to the goal of investigating the mechanisms that produce variations of the sea surface temperature which, in turn, affects global climate on seasonal and interannual time-scales. The MALCOLM BALDRIGE will conduct meridional CTD/XBT/acoustic Doppler current profiler (ADCP) sections at 110°W and meridional and zonal sections which encompass an EPOCS NECC mooring array centered at 7°30'N, 130°W.

Sea surface temperature is the most critical oceanic variable for climate variation, and ocean surface currents are one of the major processes that determine it. Satellite IR data are the principal tool for monitoring sea surface temperature. Satellites give unrivaled spatial and temporal coverage, but provide data of lower accuracy than is required for the TOGA research program unless they are supplemented with accurate *in-situ* measurements for adjustment. There are no operational products that routinely provide ocean current observations. Satellite-tracked drifting buoys will be operated in substantial numbers in cooperation with investigators funded by other agencies and other countries during a two-year period to collect sea surface temperature and current data across the entire tropical band of the Pacific Ocean. These data will be provided to operational product offices and to developers of numerical models as well as used for descriptive studies of various aspects of the surface currents of the tropical Pacific.

The eastern Pacific coastal station array will be completed and the information stream will be established. Satellite-transmitting, Handar tide stations will be installed on Cocos Island (Costa Rica) and Malpelo Island (Colombia) by fall 1989, to complete the sea level network. A sea level data set consisting of 1977-88 time series at stations in Peru, Ecuador and Chile (including Galapagos and Easter Island) will be completed. Statistical and graphical data summaries for several key stations and variables will be prepared on a monthly basis and made available to climate investigators by electronic mail.

SUBTROPICAL ATLANTIC CLIMATE STUDIES (STACS)

A STACS field experiment will be conducted in January 1989 in conjunction with researchers at the University of Kiel. A trans-Atlantic section will be occupied at 14.5°N, with AOML collecting data in the west and Kiel in the east. CTD and tracer (freons) data will be collected to determine watermass distributions, meridional heat flux and changes in watermass properties since earlier cruises. The STACS sections at Abaco and north of South America will also be occupied to continue monitoring of these transects.

Repeated velocity/tracer sections have been collected by the STACS program from 1984 through 1988 in the Florida Current, across the Caribbean Sea, east of the Antilles from 29°N to 13°N, and north of South America. The data were collected to relate western boundary variability to interior variability; to understand the role of these structures in modulating global climate; and to develop long-term monitoring

strategies for climatically important features. Data analyses include computing average transport of mass, heat and tracers for each section and determining variability of these properties about their respective means and with respect to each other. The effect of these quantities on such climate processes as heat transport, watermass formation and spreading, ventilation of the ocean interior from the western boundary and cross equatorial fluxes of heat and mass are to be examined.

A satellite altimetry verification study will be performed. Measurement of sea surface height from collinear orbit satellite altimeters requires *in-situ* verification data for error minimization. Tide gauges from islands are frequently considered essential in providing this verification data, yet the transfer functions relating island tide gauges to open ocean sea level and then relating open ocean sea level to altimeter footprint measurements are unknown. Existing GEOSAT altimeter data and coincident island tide gauge and nearby offshore inverted echo sounder/pressure gauge data will be used to assess the magnitude of the problem, and to initiate physical modeling of the transfer functions.

Additional deployments or the continuance of present deployments of inverted echo sounders are planned. As data are gathered they will be processed and analyzed.

GLOBAL CLIMATE CHANGE/RITS

In FY 1989 AOML will be conducting a field program in the subtropical and tropical mid-north and mid-south Pacific Ocean. The program will include meridional transects across the equator approximately 3,000 km apart to investigate processes responsible for the previously documented O_3 minimum at the time when it appears to be developing and at its maximum intensity. This transect is designed to interface with a PMEL transect along the eastern edge of the Pacific basin. The subtropical north Pacific portion of the cruise will conduct an investigation on the role of marine microbiological processes in the atmospheric sulfur cycle as this region of the globe has been documented as having high levels of atmospheric DMS, presumably due to marine microbiological processes. The southern Pacific portion of the cruise will concentrate on the sources of NO and NO_2 and the production and removal rates of tropospheric O_3 in remote marine regions.

WOTAN

A deployment of the WOTAN system is planned in November 1988. This deployment will be for about 30 days. If the data from this deployment is encouraging a second deployment in the spring or summer off Cape Canaveral is planned.

WEATHER OBSERVATION AND PREDICTION

AOML's Hurricane Research Division (HRD) is NOAA's primary focus for research in tropical meteorology and hurricanes. Research teams concentrate on field programs, numerical hurricane modeling, and theoretical studies of hurricanes. The Laboratory's hurricane field program makes use of NOAA research aircraft to acquire unique data sets. AOML interacts with the National Hurricane Center (NHC) and the National Meteorological Center (NMC) in problems of hurricane prediction, with the National Center for Atmospheric Research (NCAR) on scientific investigations of the inner cores of hurricanes, with NMC and the Geophysical Fluid Dynamics Laboratory (GFDL) on hurricane modeling, and with several university groups on a variety of hurricane related problems.

Accomplishments FY 1988

HURRICANE FORECASTING WITH AIRCRAFT DATA

Data available to the airborne scientist on the NOAA P-3 aircraft contain information that would be of help to hurricane forecasters if they could be made available in real time. AOML has developed a scheme to transmit and analyze the required data almost as fast as it becomes available on the aircraft. A MicroVAX II computer, dedicated to this project, was installed permanently at NHC on a protected power supply and provided with good communications to computers and terminals at AOML. Real-time programs to determine track, structure, intensity change, and to monitor the progress of the aircraft mission have been developed. Successful tests of the system were carried out during Hurricanes Emily and Floyd of 1987, Hurricane Gilbert of 1988, and tropical storms Chris and Florence of 1988. Short-term hurricane track forecasts made with these data have proven to be quite accurate.

OBJECTIVE ANALYSIS OF THE TROPICAL ATMOSPHERE

Inadequate initial analysis of tropical winds is a major stumbling block to improved hurricane track prediction with both dynamical and statistical models. This research seeks to develop an objective analysis scheme that can be used both for the large-scale tropics and for the environments of hurricanes. The analysis scheme ingests Omega dropwindsonde (ODW) data gathered by AOML in the environments surrounding hurricanes as well as rawinsondes, NOAA P-3 aircraft data, USAF reconnaissance data, and satellite-derived products.

The analysis code was installed on the NMC NAS 9000 computer. A real-time version of the analysis package is being used by AOML to compare the AOML and NWS tropical analysis products during the 1988 hurricane season. These studies have shown that the AOML analysis is a substantial improvement over the operational tropical analyses in use at NHC. The real-time version of the code was also tested in Tropical Storm Florence with excellent results.

ESTIMATION OF SURFACE WIND SPEEDS IN HURRICANES

The primary source of information for estimating hurricane winds over the ocean is reconnaissance aircraft. Presently, the surface wind is estimated from the aircraft data by simply assuming it to be the same as the flight level value. The Stepped Frequency Microwave Radiometer (SFMR), an instrument designed and built at the University of Massachusetts, provides a new airborne remote sensing method for estimating the surface wind in hurricanes. Comparison of the surface wind derived from the SFMR with flight level winds show the surface wind is about 75 percent of the flight level wind. The average error of the surface wind estimated from the SFMR is about 3 kts.

Verification of the relationship between flight level wind and the surface wind determined from the SFMR has been made by comparing surface buoy observations with concurrent aircraft observations. The buoy mean surface wind is also 75 percent of the flight level wind for unstable conditions defined by negative air-sea temperature differences. The buoy mean surface wind is only 53 percent of the flight level wind for stable conditions defined by positive air-sea temperature differences.

THE WIND STRUCTURE OF HURRICANE NORBERT'S EYEWALL

Hurricane Norbert (1984) is the first hurricane with a complete set of winds obtained from airborne Doppler radar. The kinematic structure of this storm has been described in detail. Norbert's horizontal

wind components were partitioned into a horizontal mean wind (as a function of altitude), a mean circular vortex (a function of radius and height) and a perturbation from the mean vortex. The wind partitioning showed that the mean vortex was characterized by a tangential wind maximum of 52 m/sec at 26 km radius and 1.5 km altitude. This wind maximum sloped outward with increasing altitude. Two channels of upward vertical velocity (about 1 m/sec) were found. One channel is along the inside of the tangential wind maximum, sloping outward with height. The second vertical velocity maximum was nearly vertical and was centered at 16 km radius. This appears to be the remains of an old inner eyewall.

CONVECTIVE AND MESOSCALE STRUCTURE OF LANDFALLING HURRICANES

A study of rainfall distributions derived from digitally-recorded NWS radar data in the inner core regions of Hurricanes Alicia (1983) and Elena (1985) prior to landfall was completed. There was considerable variability in the eyewall rain rate over periods of 1-3 hr. Most of the variability was accounted for by convective areas with rain rates greater than 10 mm/hr. The percentage of the eyewall region covered by rain rates greater than 10 mm/hr varied from 4-20%. The contribution of rain rates greater than 10 mm/hr to the total eyewall rain rate averaged about 50%. On the average, the maxima of the eyewall and inner rainband rain rates were in the left front quadrant for Alicia and the right front quadrant for Elena. The difference in the spatial orientation of the rain maxima is related to differences in the forward motion of the hurricanes and is consistent with theoretical calculations of the distribution of boundary-layer convergence in translating hurricanes.

DIAGNOSTIC ANALYSIS OF TROPICAL WEATHER SYSTEMS

Observations from land stations, ships, coastal marine stations, and offshore rigs were analyzed for the purpose of understanding some features of tropical depression (TD) #2 (1987), and Hurricane Floyd (1987).

In TD #2, observations from automatic weather stations on rigs showed that a large area of gale-force wind developed upstream from an area of heavy convection. At some locations, sustained winds in excess of gale force blew for more than 12 hours. Only a few of these rig observations were received in real time at the NHC and no reports were received from the reconnaissance flight in the high wind quadrant of the system.

Analysis of data from a morning aircraft flight showed that cold air north of a front was entrained into Floyd's circulation and formed a cold front extending south-southeast. By the time Floyd passed offshore from Miami in the early evening, the colder air had passed offshore. This created a stable boundary layer over the south Florida peninsula which prevented near hurricane force winds, measured by aircraft at 1500 ft from penetrating to the surface. In some locations, surface winds were less than 50% of the winds at 1500 ft.

HURRICANE STEERING FLOWS

This work is concerned with steering currents and their effects on mature hurricanes. Data are obtained from Omega dropwindsondes (ODWs) deployed from the NOAA P-3 aircraft. Cooperative research with NMC seeks to determine the impact of these data on NMC's dynamical hurricane track prediction models. ODW data sets were obtained in Hurricanes Emily and Floyd during the 1987 hurricane season and in Tropical Storm Florence in 1988.

QUASI-SPECTRAL HURRICANE MODEL

The long-term goal of this research is to predict the motion, intensity, and structure of hurricanes. A general-purpose base model (code name QVADIS) has been developed. This model uses an accurate and flexible numerical method called the spectral application of finite element representation method. A two-dimensional version of the QVADIS model, on nested multiple domains, has been completed and is being used in AOML research projects.

The nested resolution model will handle many of the geometrical aspects of the multi-scale hurricane problems. The moist physics for future hurricane models must be improved. Towards this end, a uniform definition for entrophy, that is valid both for saturated and unsaturated air, has been successfully derived.

The spectral nesting technique described above is being tested in the context of the simplest system of equations which can be used for hurricane track prediction, the barotropic vorticity equation, and the shallow water equations. Tests of these models, with idealized simulations of an isolated vortex, provided insight to the grid systems and the outer boundary conditions. Deep layer mean winds, to initialize these models, were obtained from data archives at NHC.

A set of idealized numerical experiments has been designed to investigate the influence of divergence and advective nonlinearities on hurricane motion and to study asymmetries due to the variation of the Coriolis parameter with latitude (the beta effect). The multi-nested numerical model, QVADIS, was used in a one-layer, shallow water (primitive equation) form. In the first set of experiments, the environment was taken to be at rest. Theory indicates that divergence should have a very small effect on hurricane motion. These numerical experiments confirm that the vortex track is essentially unaffected by divergence, with only a 4% difference in total displacement after 72 h between divergent and non-divergent simulations.

INITIALIZATION OF TROPICAL CYCLONE MODELS

The applicability of normal mode techniques to the initialization of tropical cyclone models is being studied. A highly truncated version of a three-layer spectral tropical cyclone model in isentropic coordinates was developed and its initialization was studied analytically in a linearized version of the model. The linear results showed that normal mode initialization is valid in the hurricane model, but the iterative technique used to solve the initialization equations converges too slowly to be practical. When some nonlinearity was included, the iterative scheme was found to diverge if the vortex amplitude was large. An alternative initialization scheme, which allows the gravity mode amplitudes to come to a quasi-steady state, was found to produce much better results than the usual iterative techniques.

STUDIES OF TROPICAL CLIMATE

A study of the relationship of the Quasi-biennial oscillation (QBO) to Atlantic tropical storm activity was completed. The largest correlation was found between storm activity and the QBO in June, which is about three months before the central part of the hurricane season. Correlations with storm incidence for individual calendar months confirmed an approximate two to three month lead of the QBO relative to tropical storm formation.

Possible relationships between sunspot numbers and tropical storm activity was investigated. For years during the eastern phase of the QBO, the correlation is large, positive, and significant at about the 90% level. The estimated true skill is about 10% of the variance. Consistent with these results, the in-phase association between sunspot numbers and 700 mb heights for August-October of 1952-1981 indicate a

large area of significant correlation over western Africa (the genesis region for many Atlantic tropical systems) only during the eastern phase of the QBO. It is not possible to determine whether there are cause and effect relationships between these variables.

Plans FY 1989

HURRICANE FORECASTING WITH AIRCRAFT DATA

The user interface to the real-time data analysis system will be improved and the system will be integrated into NHC's operations and communications. Work will start on the adaptation of the system to the VAS Data Utilization Center (VDUC).

OBJECTIVE ANALYSIS OF THE TROPICAL ATMOSPHERE

A study of the thermodynamic data from Debby (1982) will be completed. Analysis of the Hurricane Josephine and Gloria data will continue. Real-time analyses of the tropical atmosphere at the 850 and 200 mb levels will continue to be compared and evaluated with respect to current NMC and NHC products. Work on the incorporation of airborne Doppler wind data from Hurricane Gloria (1985) into the analysis scheme will continue. Similar work with data for Hurricane Emily (1987) will be started.

ESTIMATION OF SURFACE WIND SPEEDS IN HURRICANES

The study of the relationships between winds measured on NOAA aircraft and buoy platforms will be completed. A detailed evaluation of the SSM/I microwave instrument on board a DMSP satellite will be carried out to determine its usefulness in measuring surface winds in and around hurricanes.

THE WIND STRUCTURE OF HURRICANE NORBERT'S EYEWALL

A paper describing the kinematic structure of Norbert's eyewall will be completed. Work will continue on an analysis of the eyewall water budget in Hurricane Norbert. Analysis of data from an eyewall water budget experiment flown in Hurricane Emily (1987) will be started. A climatology of vertical incidence reflectivity and vertical velocity data collected in mature hurricanes since 1983 will be started.

CONVECTIVE AND MESOSCALE STRUCTURE OF LANDFALLING HURRICANES

Land-based radar reflectivity data from five days as Elena (1985) evolved from a tropical storm to a major hurricane will be used to study the evolution of Elena's precipitation structure. Results will be compared with previous studies of Hurricanes Allen (1980) and Alicia (1983). Airborne Doppler radar data, collected on six flights into Elena, will be used to study the evolution of the wind field within 50 km of the storm center as Elena intensified from a tropical storm to a major hurricane.

DIAGNOSTIC ANALYSIS OF TROPICAL WEATHER SYSTEMS

Timely diagnostic analysis will be carried out for particularly interesting tropical weather systems that occur during the 1988 hurricane season. Provided that adequate data are available, emphasis will be given to systems that have presented especially difficult problems for NHC forecasters.

HURRICANE STEERING FLOWS

Cooperative studies with NHC and NMC that examine the impact of the ODW data on the operational analyses and hurricane track models will continue. Data collected during the 1988 hurricane field program will be used in diagnostic and prognostic studies of hurricanes. Additional ODW data will be obtained on one or two days during the 1989 hurricane season.

QUASI-SPECTRAL HURRICANE MODEL

A vertical plane two-dimensional model will be developed to investigate computational problems associated with vertical discretization of the stratified atmosphere. In view of the proposed new formulation of moist thermodynamics, this step appears necessary before going to a fully three-dimensional model.

The nested model will be initialized with deep-layer mean winds and will be used to produce hurricane track forecasts. Tests will be made with data from Josephine (1984), Debby (1982), Gloria (1985) and Emily (1987).

Environments with nonuniform mean flow will be included. The model will be generalized to a two-layer version to investigate baroclinic interactions. The implications of the results for the initialization of operational hurricane track forecast models will be studied.

INITIALIZATION OF TROPICAL CYCLONE MODELS

This study will be extended to the fully nonlinear case. The question of uniqueness of the initialization equations will be addressed.

STUDIES OF TROPICAL CLIMATE

A paper describing the results of research on the relationship between the QBO and Atlantic tropical storm activity will be prepared. An investigation of the Atlantic hurricane cycles and tropical wind variability associated with the 30-60 day oscillation will be started.

MARINE RESEARCH

AOML studies in Marine Research include understanding the processes involved with seafloor ridges, the dispersion of wastewater in the ocean environment, and the effects of the environment on fisheries populations.

AOML's VENTS program is 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. The studies are collaborative with NOAA PMEL, and with leading scientists from other U.S. and foreign government agencies and universities. These efforts are contributing to the NOAA VENTS Program, to the development of the NOAA RIDGEFLUX Initiative, and to NOAA's role as lead agency in the U.S.-France Bilateral Agreement For Cooperation in Oceanography.

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

The Fisheries Oceanography Coordinated Investigation (FOCI) is an interdisciplinary study of the physical and biological factors which influence the spawning success of individual year classes (recruitment) of walleye pollock within the Gulf of Alaska. In order to meet this objective the AOML component of the FOCI project has conducted a series of annual cruises quantifying egg and larval distributions in the Gulf of Alaska in conjunction with scientists from PMEL and the NMFS Northwest and Alaska Fisheries Center. The specific goal of the AOML studies is to document the temporal change in the spatial distribution of both egg and larvae in relation to physical processes (advection, dispersion). These studies have concentrated on examining the fine-scale distribution of pollock eggs and larvae by means of a towed submersible camera system and specialized net systems. A knowledge of such distributions is essential to better our understanding of how environmental factors regulate the year-to-year variability in recruitment within this commercially-important fishery.

Accomplishments FY 1988

VENTS

Gorda Ridge

The northern 50 km long segment of the Gorda Ridge has a well-defined rift valley and a diversity of igneous rock types like the slow-spreading Mid-Atlantic Ridge and thus is unlike the Juan de Fuca Ridge, or any of the other intermediate- to fast-spreading ridge in the Pacific Ocean. Significant advances were made in locating and characterizing two hydrothermal venting zones in this northern segment previously known only from regional water column surveys, as follows:

- Interpretation of a high-resolution, side-scan sonar (SeaMARC IA) survey of the northern segment performed in August 1987 revealed that the locations of the two venting zones (GR-14 and GR-15) are controlled by the intersection of a regional fracture trend parallel to the ridge axis with an anomalous transverse trend related to the local stress regime. This finding both elucidates the seafloor controls of the hydrothermal activity and targets the two venting zones for near-field characterization.

- A bathymetric comparison in progress of the Gorda Ridge with the Mid-Atlantic Ridge confirms that the intermediate-spreading northern Gorda Ridge has slow-spreading morphology unlike the intermediate-spreading Juan de Fuca Ridge to the north, although differences from the Mid-Atlantic Ridge are also becoming apparent.

- Analyses of the mineralogy and composition of suspended particulate matter recovered in the water column reveals minerals near sites GR-14 (atacamite) and GR-15 (anhydrite) indicative of high-temperature black smoker-type venting.

- A dive series with the U.S. Navy DSV *Sea Cliff* was organized and conducted (September 1988) to close range on and initiate characterization of the high-temperature venting zone at the GR-14 site involving a cooperative scientific team from NOAA, USGS and academia sponsored by the Gorda Ridge Technical Task Force of the Minerals Management Service.

Juan de Fuca Ridge

- A near-bottom water temperature survey using temperature sensors mounted on the submersible *Alvin* of the ASHES Vent Field in the caldera of Axial Seamount was carried out to determine the relation between hydrothermal heat flux and flow regimes.

- A comparative study of how hydrothermal effluents transfer heat and chemicals into the surrounding ocean by the formation of plumes based on prior VENTS work for the Juan de Fuca Ridge and an

original data set for the Atlantic revealed fundamental differences related to different deep salinity gradients in the Pacific and Atlantic Oceans; at their equilibrium level, Pacific plumes are hot and salty relative to surrounding seawater, while Atlantic plumes are cold and fresh.

- A collaborative AOML–PMEL program of collection and analysis of sediment cores to determine the flux of hydrothermal particulate components through time at definitive sites on the Juan de Fuca Ridge was continued on 1988 cruises. At least two of nine cores (16 m of sediment) collected on the western flank of the ridge contain a distinct hydrothermal signal which is being calibrated with C–14 geochronology and correlated with microfossil and oxygen isotope trends.

- Analyses and interpretation of rare earth elements (REE) in the hydrothermal component of sediments collected from the Juan de Fuca Ridge, the northern Gorda Ridge, and the Mid–Atlantic Ridge as indices of hydrothermal interactions indicate REE patterns for the Pacific samples similar to the East Pacific Rise and distinct from Atlantic patterns.

Mid–Atlantic Ridge

- A detailed analysis of hydrothermal venting at the TAG Hydrothermal Field, the discovery site of the first Atlantic black smokers by the VENTS Program, distinguishes types of sources (diffuse and individual), flow regimes (laminar and turbulent), and related heat transport; the analysis provides the first reliable estimate of components of convective heat transfer from an Atlantic hydrothermal site and establishes procedures for application to an analogous data set collected at the ASHES Vent Field in Axial Seamount caldera of the Juan de Fuca Ridge.

- The first description of the physical properties and behavior of a hydrothermal plume in the Atlantic Ocean based on VENTS Program observations at the TAG Hydrothermal Field was completed and compared with VENTS Program observations of hydrothermal plumes at the Juan de Fuca Ridge; in collaboration with a physical oceanographer from Woods Hole Oceanographic Institution, these observations were incorporated into a model which accurately predicts differences in behavior between hydrothermal plumes in the Atlantic and Pacific Oceans which influence how chemical and thermal properties of the plume are transferred into the surrounding ocean.

- Computer–based modeling of nephelometer data of the distribution of suspended particulate matter in the TAG plume indicates that a current shear exists in the water column causing a bi–directional dispersal of the hydrothermal plume within the rift valley.

- Chemical analyses of the suspended particulate matter in the TAG hydrothermal plume indicate that adsorption by hydrothermal particles probably plays a major role in oceanic budgets of certain elements; for example, an estimated 4×10^7 grams/y of vanadium are adsorbed onto hydrothermal suspended particulate matter in the TAG plume, when prior estimates by other workers discounted this process for the oceanic mass balance of vanadium.

- Textural, mineralogical and chemical data indicate that resedimentation by downslope movement of sulfides from sources in the TAG Hydrothermal Field may account for >50% of the sediment accumulation in those areas.

- A cooperative NOAA–IFREMER cruise to the Mid–Atlantic Ridge with the NOAA ship *Oceanographer* including university scientists was organized and conducted (August 1988) to continue comparative Atlantic–Pacific plume studies and investigate a new, previously unstudied, type of hydrothermal venting site as groundwork for submersible investigations during the U.S.–France Bilateral Agreement for Cooperation in Oceanography in 1990–1992.

Seafloor Spreading Center System

- A global synthesis of hydrothermal venting sites at oceanic ridges and the physical and chemical characteristics of the venting at these sites was prepared for publication.

OCEANIC PLUME STUDIES

A series of wastewater plume study cruises were undertaken in FY 1988; these cruises were designed to obtain acoustical, chemical, dye and biological data for six different southeast Florida outfalls. The acoustical systems were shown to be able to detect and map the intricate turbulent patterns characteristic of the outfall plumes. These data are currently being processed and analyzed.

ECHO FORMATION MODELS

Analysis of the Chesapeake Bay data has led to the evolution of an improved model for bottom echo formation. Final reports have been completed on this study.

FISHERIES OCEANOGRAPHY

The primary focus of the FY 1988 effort was to complete development and integration of an acoustic sensor into the towed camera system for quantifying the distribution of copepods (larval food), and a spring 1988 cruise in the Gulf of Alaska. The acoustic sensor was developed in concert with investigators at Tracor, Inc., and provided the first acoustic realization of larval food distributions within the spawning grounds. The additional data on distributions from both the camera and MOCNESS surveys will be utilized to assess the usefulness of this potentially important tool for rapidly examining plankton distributions. The FY 1988 cruise examined the spatial distribution of eggs and early larvae within the spawning "patch" in the Shelikof Straits. Although egg densities were not as high as in previous years, the preliminary observations indicate that the study was able to quantify the period when the major egg–larvae transition occurs. A camera transect was also completed through a mesoscale eddy within the spawning grounds; information from this survey should assist physical oceanographers and fishery biologists in assessing the importance of advection as an environmental factor influencing recruitment variability.

Plans FY 1989

VENTS

- Continue work on location and characterization of high–temperature hydrothermal venting sites at the northern Gorda Ridge based on analysis and interpretation of data sets from September 1988 DSV *Sea Cliff* dive series and SeaMARC IA high–resolution, side–scan sonar records.

- Complete analysis, interpretation and preparation for publication of a quantitative bathymetric comparison of the Gorda Ridge with the Mid–Atlantic Ridge.

- Cooperatively organize and conduct a cruise with PMEL colleagues to perform detailed deepsea camera–temperature work in conjunction with water column studies to continue location and characterization of high–temperature venting sites at the northern Gorda Ridge contingent on availability of shiptime and schedule considerations.

- Complete interpretation and preparation for publication of existing data on rare earth elements in hydrothermal components of sediment samples from the Juan de Fuca Ridge, the northern Gorda

Ridge and the Mid-Atlantic Ridge, and test these interpretations with analyses of a more definitive set of samples to be collected at these locations on 1988 cruises.

- Continue workup of mineralogy, geochronlogy, chemistry and sedimentological history of cores collected from the Gorda-Juan de Fuca Ridge System in FY 1988; these include two sets of cores collected in collaboration with PMEL colleagues in the Juan de Fuca Ridge study area comprising a ridge parallel set on the western flank to define far-field transport of hydrothermal components, and a set at the spreading axis (with DSRV *Alvin)* to define the present near-field input of these components; analyze and interpret another set of cores recovered from a high-temperature hydrothermal area at the northern Gorda Ridge (GR-14; with DSV *Sea Cliff)* to define the presence, nature and extent of the hydrothermal record.

- Prepare a comparison of hydrothermal, volcanic and tectonic characteristics of the Mid-Atlantic Ridge with those of the Juan de Fuca Ridge based on the deepsea camera imagery from the 1988 Mid-Atlantic Ridge cruise in collaboration with participating colleagues from Lamont-Doherty Geological Observatory contingent on obtaining a good camera data set.

- Continue work on comparison of the physical characteristics and behavior of hydrothermal plumes in the Pacific (Juan de Fuca Ridge; East Pacific Rise) and the Atlantic (Mid-Atlantic Ridge) in collaboration with colleagues at IFREMER.

- Carry out a preliminary evaluation of the role of hydrothermal venting by interaction of seawater with subcrustal rocks of the upper mantle at fracture zones and its impact on ocean chemistry in collaboration with colleagues at IFREMER.

- Continue work on developing and testing an active sonar to image and measure flow velocity of black smoker-type venting designed to operate from a submersible or an ocean bottom observatory contingent on support.

- Organize and conduct a collaborative NOAA-WHOI-MIT dive series with DSRV *Alvin* contingent on availability of dive time to continue characterization of hydrothermal venting sites at the Mid-Atlantic Ridge as a basis for extrapolating work on chemical and thermal effects of venting on the ocean from a regional to a more global perspective in support of the RIDGEFLUX Initiative and the U.S.-France Bilateral Agreement.

OCEANIC PLUME STUDIES

Processing and analysis of the wastewater plume data gathered in FY 1988 will continue. Comparison with model predictions will be made where feasible. Comparison of acoustical data with dye, chemical and biological data will be carried out.

COASTAL ZONE OCEANOGRAPHY/OCEAN DUMPING

A new cooperative coastal oceanography program is planned; the NOS, AOML and the Institute of Marine Environmental Protection in Dalian, China will cooperate in the study of the dispersion of materials dumped in the coastal ocean. A field experiment is planned in the summer of 1989.

ECHO FORMATION MODELS

Consideration of the implementation of the findings of this study into future NOS echo sounding systems will be carried out; determination of the need for additional experiments will be made.

CODAR

The CODAR Project in the Straits of Florida was initiated to give an operational demonstration using HF surface radar scatterometry to routinely measure Gulf Stream surface currents. An evaluation of Miami CODAR accuracy by comparison with direct and indirect measurements, of the operational problems, and of certain interference effects on local CODAR operations will be quantified. Extension to analysis of the data for determining sea surface winds from the Miami CODAR will be initiated.

FOCI

The current plans for FY 1989 are to continue the sample analysis of the camera and MOCNESS tow material from the spring 1988 cruise, and then analyze the spatial distributions with respect to the physical forcings (mechanisms) within the spawning grounds. Additionally, it will be necessary to evaluate the efficacy of the acoustic sensor with data derived from the camera and MOCNESS tows. A cruise is planned within the spring 1989 period to the Shelikof Straits to examine the distribution of pollock eggs and larvae in relation to the mesoscale mixing processes; this effort was re-scheduled from the original 1988 work plan.

FY 1988 PUBLICATIONS

AO-001

ATWOOD, D.K., F.J. Burton, J.E. Corredor, G.R. HARVEY, A.J. Mata-Jimenez, A. Vasquez-Botello, and B.A. Wade. Petroleum pollution in the Caribbean. *Oceanus* 30(4):25-32 (1987).

No abstract.

AO-002

ATWOOD, D.K., F.J. Burton, J.E. Corredor, G.R. HARVEY, A.J. Mata-Jimenez, A. Vasquez-Botello, and B.A. Wade. Results of the CARIPOL Petroleum Monitoring Project in the wider Caribbean. *Marine Pollution Bulletin* 18(10):540-548 (1987).

Since 1979, about 9,000 data points for tar on beaches, floating tar, and dissolved/dispersed petroleum hydrocarbons have been collected by fourteen governments in the Caribbean/Gulf of Mexico region. Analysis of these data has allowed an assessment as to the status of petroleum pollution in the region. Tar levels on windward-exposed beaches are very high and impact tourist usage of them. Data also indicate that dissolved/dispersed hydrocarbons in the Gulf of Mexico are much higher than that measured by the 1979-1980 MAPMOPP study in "clean" areas of the World's oceans. Indications are that about half of the tar in the region enters by way of the prevailing current and wind regime from the North Atlantic gyre system. The remaining half comes mostly from tanker cleaning and ballast discharge in the region.

AO-003

BITTERMAN, D.S. The NOAA-AOML drifting buoy program. Proceedings, International Service ARGOS Users Conference and Exhibit, Greenbelt, MD, September 15-17, 1987, 107-116 (1988).

No abstract.

AO-004

BLACK, P.G. Hurricane-ocean interaction near the subtropical front. Preprints, 7th Conference on Ocean-Atmosphere Interaction, Anaheim, CA, January 31-February 5, 1988. American Meteorological Society, Boston, J60 (1988).

No abstract.

AO-005

BLACK, P.G., R.L. Elsberry, and L.K. Shay. Airborne surveys of ocean current and temperature perturbations induced by hurricanes. In *Advances in Underwater Technology, Ocean Science and Offshore Engineering*. Vol. 16, Oceanology '88. Graham and Trotman, London, 51-58 (1988).

No abstract.

AO-006

BLACK, P.G., R.L. Elsberry, L.K. Shay, R.M. Partridge, and J. Hawkins. Atmospheric boundary-layer and oceanic mixed-layer observations in Hurricane Josephine obtained from air-deployed drifting buoys. *Journal of Atmospheric and Oceanic Technology* 5(6) (1988).

Three drifting buoys were successfully air-dropped ahead of Hurricane Josephine. This deployment resulted in detailed, simultaneous measurements of surface wind speed, surface pressure and subsurface ocean temperature during, and subsequent to, storm passage. This represents the first time that such a self-consistent data set of surface conditions within a tropical cyclone has been collected. Subsequent NOAA research aircraft overflights of the buoys, as part of a hurricane planetary boundary-layer

experiment, showed that aircraft wind speeds, extrapolated to the 20 m level, agreed to within ± 2 m s^{-1}, pressures agreed to within ± 1 mb, and sea-surface temperatures agreed to within ± 0.8 °C of the buoy values. Ratios of buoy peak 1 min wind (sustained wind) to 1/2 h mean wind > 1.3 were found to coincide with eyewall and principal rainband features. Buoy trajectories and subsurface temperature measurements revealed the existence of a series of mesoscale eddies in the subtropical front. Buoy data revealed storm-generated, inertia-gravity-wave motions superposed upon mean current fields, which reached a maximum surface speed > 1.2 m s^{-1} immediately following storm passage. A maximum mixed-layer temperature decrease of 1.8 °C was observed to the right of the storm path. A temperature increase of 3.5 °C at 100 m and subsequent decrease of 4.8 °C following storm passage indicated a combination of turbulent mixing, upwelling and horizontal advection processes.

AO-007

Bluestein, H.B., and F.D. MARKS, JR. A note on the structure of the eyewall of Hurricane Diana (1984): Comparison of radar and visual characteristics. *Monthly Weather Review* 115(10):2542-2552 (1987).

Features seen in aerial and satellite photographs of the inside edge of the eyewall of Hurricane Diana (1984) are compared with features seen in digitized three-dimensional airborne radar reflectivity data. The photographs show regularly spaced, upwind (downshear) tilted striations in the northeast, east, and southeast sectors of the eyewall that are nearly collocated with upwind (downshear) tilted axes of relative reflectivity maxima of approximately 15 dBZ.

AO-008

Brown, M.G., F.D. Tappert, D.R. PALMER, and H.F. BEZDEK. Chaos in nonseparable wave propagation problems. Proceedings, Seventeenth Conference on Mathematical Geophysics, Blanes, Catalumo, Spain, June 21-25, 1988.

No abstract.

AO-009

BURPEE, R.W. Forecaster biography. Grady Norton - hurricane forecaster and communicator extraordinaire. *Weather and Forecasting* 3(3):247-254 (1988).

No abstract.

AO-010

Campbell, A.C., M.R. Palmer, G.P. Klinkhammer, T.S. Bowers, J.M. Edmond, J.R. Lawrence, J.F. Casey, G. Thompson, S. Humphris, P.A. RONA, and J.A. Karson. Chemistry of hot springs on the Mid-Atlantic Ridge. *Nature* 335:514-519 (1988).

The first hydrothermal fluid samples collected along the slow-spreading Mid-Atlantic Ridge (MAR) are remarkably similar in composition and temperature to fluids collected along the shallower, faster-spreading East Pacific Rise (EPR). The MAR fluids, like those from the EPR, appear to be in equilibrium with a greenschist-facies mineral assemblage. In contrast to the EPR, the more fractured nature of the MAR apparently allows fluids at one of the MAR sites to interact with weathered basalt.

AO-011

CHEW, F. Comments on "Gulf stream kinematics along an isopycnal trajectory." *Journal of Physical Oceanography* 18:932-933 (1988).

No abstract.

AO-012

CLARKE, T.L., J.R. PRONI, and L. Huff. High temporal resolution observation of high-frequency acoustic bottom echoes. *Journal of the Acoustical Society of America* 82:S-122 (1987).

Acoustic bottom echoes at frequencies from 10 to 380 kHz were recorded for a variety of bottom types in southern Chesapeake Bay. Short pulse lengths and direct digital recording allowed temporal resolution of 100 μs to be achieved. Supporting measurements of sediment characteristics and bottom roughness allowed comparison of the measurements with theory. The field observations were in good agreement with the theory after corrections for the interaction of transducer beam patterns with bottom roughness were made.

AO-013

CLARKE, T.L., J.R. PRONI, D.A. Seem, and J.J. TSAI. Joint CGS-AOML acoustical bottom echo-formation research I: Literature search and initial modeling results. NOAA Technical Memorandum ERL-AOML-66 (PB88-202007/XAB), 73 pp. (1988).

A literature survey has found work dealing with the problem of echo-formation for rough sedimentary bottoms. The main attempts at practical application have been at frequencies lower than those used for echo-sounding work. A model has been formulated that includes the effect of surface scattering and volume scattering in a unified manner. This model has been implemented on the AOML computer and exercised for a variety of bottom types and echo-sounding frequencies.

AO-014

Cornejo-Rodriguez, M.P., and D.B. ENFIELD. Propagation and forcing of high-frequency sea level variability along the west coast of South America. *Journal of Geophysical Research* 92(C13):14,323-14,334 (1987).

Tide and wind data from coastal and island stations from Buenaventura, Colombia (4°N), to Callao, Peru (12°S), have been analyzed for the 1979-1984 time period to determine the propagation and forcing characteristics of coastal sea level variability at periods of days to weeks, as well as how they vary either with season or between the 1982-1983 El Nino-Southern Oscillation (ENSO) period and non-ENSO years. During four non-ENSO years, the ensemble averaged cross spectra between coastal sea level height (SLH) and local winds show weak evidence of local forcing during the whole year without significant differences between the austral summer and winter seasons, other than a greater energy in the wind fluctuations at Talara during summer. Cross spectra between SLH series from neighboring stations show evidence of poleward phase propagation during winter seasons at speeds of about 20 m s^{-1} between La Libertad and Talara at periods of a week or more, and about 2.7 m s^{-1} between Talara and Callao at periods of 5-11 days, but no propagation is found during summers. During the 1982-1983 ENSO there is a large increase in SLH energy at most frequencies at all coastal stations, but especially in the 8-11 day band, where energies are enhanced by as much as an order of magnitude above non-ENSO levels. The cross spectra between adjacent SLH stations indicate a nondispersive poleward propagation of events during the 1982-1983 ENSO with phase speeds of 2.2-3.5 m s^{-1} from La Libertad to Talara (periods of a week or more) and 3.4-3.6 m s^{-1} from Talara to Callao (3.5 days or more). As with the SLH energy, the coherence and phase propagation were much stronger along the Peru coast in 1982-1983 than during non-ENSO periods, especially in the 8-11 day band. The one-third increase in phase speeds during the ENSO over the non-ENSO speeds is found to be consistent with the anomalous depression of the density structure during El Nino. Comparisons between coastal SLH and the local alongshore wind suggest that locally forced SLH variability was obscured during the 1982-1983 ENSO by noncoastally forced, but energetic propagating fluctuations, which probably originated in the equatorial waveguide.

AO-015

DAMMANN, W.P., and C.A. LAUTER. High-resolution acoustic bottom roughness measurement in support of bottom echo interaction modeling. *Journal of the Acoustical Society of America* 82:S-123 (1987).

A high-resolution acoustic bottom profiler using an extremely narrow-beam, three-megahertz echo sounder was developed at the Ocean Acoustic Division of NOAA/AOML. The device was used to measure bottom roughness over a range of scales from less than 1 cm to several meters. Roughness measurements were made in the lower Chesapeake Bay area over mud, fine to medium grain sand, and course grain sand. The data produced were used to appraise the performance of an acoustic echo formation model that predicts the effects of marine bottom characteristics on a reflected acoustic pulse envelope. Major aspects of the design and use of the system, procedures for processing generated data, and examples of processed output are presented.

AO-016

DeMARIA, M. The effect of physical processes on the convergence of Machenhauer's normal mode initialization scheme. Preprints, 8th Conference on Numerical Weather Prediction, Baltimore, MD, February 22-25, 1988. American Meteorological Society, Boston, 751-757 (1988).

No abstract.

AO-017

DeMARIA, M., and J.D. Pickle. A simplified system of equations for simulation of tropical cyclones. *Journal of the Atmospheric Sciences* 45(10):1542-1554 (1988).

A simplified system of equations that can simulate the development and mature stages of tropical cyclones is presented. The model is similar to that presented by Ooyama (1969), except that the assumption of incompressible fluid layers is relaxed. Instead, the governing equations for a compressible fluid in isentropic coordinates are discretized vertically by considering three fluid layers with constant potential temperatures. This makes the inclusion of thermodynamic processes more straightforward. The governing equations in the adiabatic case are mathematically equivalent to the equations used by Ooyama, except with an extra term in the pressure gradient force. The model equations are solved using a spectral method where the basis functions are the normal modes of the linearized equations. Numerical simulations show that the model sensitivity to vertical stability, sea-surface temperature and midlevel moisture are similar to results from more general models. The sensitivity to these factors can be explained qualitatively by consideration of the vertical stability factor used in the cumulus parameterization. The sensitivity to latitude is investigated in more detail than in previous work. Low-latitude storms are smaller than high-latitude storms, but intensify more rapidly initially. This difference is related to the radial positioning of the diabatic heating, which is much closer to the storm center for low-latitude storms. This occurs since the air in the boundary layer can penetrate closer to the storm center when the Coriolis force is smaller. The model is also initialized with climatological values of sea-surface temperature as a function of latitude appropriate for the western Pacific. Despite its simplicity, the model can reproduce the observed variations of storm size and intensity with latitude.

AO-018

DODGE, P.P. A climatology of rainbands observed by coastal radars in GALE. Reports of GALE/CASP Preliminary Analysis Workshop, Virginia Beach, VA, November 2-6, 1987. GALE Project Office, NCAR, Boulder, 19-22 (1988).

No abstract.

AO-019

ENFIELD, D.B. Introduction, El Nino: An AGU Chapman Conference. *Journal of Geophysical Research* 92(C13):14,187–14,188 (7C0772) (1987).

No abstract.

AO-020

ENFIELD, D.B. Progress in understanding El Nino. *Endeavor* 11(4):197–204 (1987).

Prior to the work of Jacob Bjerknes, the El Nino phenomenon was regarded as an aperiodic climatic event confined to the Pacific coast of South America. Spurred by a growing consciousness of the oceans' role in global climate, there has been an explosion of El Nino research in the last two decades. El Nino is now recognized to be an integral part of a Pacific-wide ocean relaxation, with global climatic impacts and economically important ecological consequences. However, we are still groping for the final prize: the ultimate cause of this climate anomaly and the ability to reliably predict its onset and intensity.

AO-021

ENFIELD, D.B. The intraseasonal oscillation in eastern Pacific sea levels: How is it forced? *Journal of Physical Oceanography* 17(11):1860–1976 (1987).

No abstract.

AO-022

ENFIELD, D.B., M. Cornejo-Rodriquez, R.L. Smith, and P.M. Newberger. The equatorial source of propagating variability along the Peru coast during the 1982–1983 El Nino. *Journal of Geophysical Research* 92(C13):14,335–14,346 (1987).

Using data obtained from tide gauges in South America, current meters along the equator and the Peru coast, and an array of pressure gauges and inverted echo sounders within and around the Galapagos archipelago, we have analyzed the equatorial origin of coastal trapped waves observed by Cornejo-Rodriquez and Enfield (this issue) along the Peru coast during the intense 1982–1983 El Nino. The propagating fluctuations along the coast were much stronger at that time either before or after the El Nino, and the variability was not locally forced by coastal winds. We find that the coastal variability was also more energetic during previous El Nino occurrences. At periods of one to two weeks the meridional component of currents on the equator was up to an order of magnitude more energetic than the zonal fluctuations and was consistently associated with sea level that fluctuates antisymmetrically between hemispheres. At periods longer than two weeks the zonal velocity component was more energetic and the cross-equatorial sea level variability was symmetric. The meridional and zonal phase structures of cross spectra involving the currents and sea level established the one- to two-week equatorial fluctuations as mixed Rossby-gravity (Yanai) waves of low wave number with infinite phase speed (standing oscillations) in the middle of the band (10 days); the corresponding structures for longer periods were consistent with nondispersive Kelvin waves. Frequency domain EOF modes of the sea level and current data established the mixed Rossby-gravity waves as the principal source of the strong trapped wave variability in the one- to two-week band along the Ecuador-Peru coast during the 1982–1983 El Nino episode.

AO-023

FRANKLIN, J.L., and S.J. LORD. Comparisons of VAS and Omega dropwindsonde thermodynamic data in the environment of Hurricane Debby (1982). *Monthly Weather Review* 116(8):1690–1701 (1988).

Synoptic-scale thermodynamic fields in the environment of Hurricane Debby (1982) determined from two sets of VAS soundings (VAS1, VAS2) are compared with those obtained from *in-situ* data (INS).

VAS1 soundings were derived from an iterative solution of the radiative transfer equation with manual quality control. VAS2 soundings, which represent the present state-of-the-art, were derived from a simultaneous solution of the transfer equation with objective quality control. INS data were obtained primarily from Omega dropwindsondes. Comparisons are made for 0000 UTC 16 September 1982 at the mandatory pressure levels up to 400 mb. The integrated effect of VAS/INS difference is estimated by comparing 400 mb geopotential height fields and their associated gradient winds. The comparisons show that the VAS1 temperature biases are not spatially uniform at most levels. The quality of the VAS2 data is much improved over VAS1; however, the VAS2 analyses also show spatially nonuniform biases at some levels. Thus, VAS data may be of irregular quality on the synoptic scale. Geopotential height fields at 400 mb imply gradient wind differences from INS of up to 12 m s^{-1} for VAS1 and 6 m s^{-1} for VAS2 data. The VAS2 sounding set could be improved further by the use of manual data editing and a more accurate first-guess of the surface temperature analysis.

AO-024

FRANKLIN, J.L., S.J. LORD, and F.D. MARKS, JR. Dropwindsonde and radar observations of the eye of Hurricane Gloria (1985). *Monthly Weather Review* 116(5):1237-1244 (1988).

Two soundings from the eye of Hurricane Gloria (1985) during a period of rapid deepening are described. The soundings were made by Omega dropwindsondes (ODW's) during research flights of the NOAA Hurricane Research Division on 24-25 September 1985. During the 4.7 h between the two ODW drops, Gloria's minimum sea-level pressure fell from 932 to 922 mb. The ODW's indicate substantial warming due to dry adiabatic descent from 580-660 mb. Descent rates are estimated to be about 11 cm s^{-1}. Near 500 mb, ascent is indicated. Approximately 60% of the 10 mb pressure fall is associated with thermodynamic changes below 500 mb.

AO-025

GAMACHE, J.F., F.D. MARKS, JR., and R.A. BLACK. The bulk water budget of Hurricane Norbert (1984) as determined from thermodynamic and microphysical analyses retrieved from airborne Doppler radar. Preprints, 10th International Cloud Physics Conference, Bad Homburg, Federal Republic of Germany, August 15-20, 1988. American Meteorological Society, Boston, 711-713 (1988).

No abstract.

AO-026

Georges, T.M., D.R. PALMER, R.M. Jones, and J.P. Riley. A survey of acoustic techniques for monitoring El Nino. NOAA Technical Memorandum ERL-WPL-149 (PB88-157615/XAB), 58 pp. (1988).

The challenge of understanding the El Nino-Southern Oscillation (ENSO) cycle in the equatorial Pacific Ocean is a test of our abilities to observe, model and forecast the processes of global climate change. The only viable technology for monitoring the structure, dynamics and energetics of the ocean interior on the space-time scales of the ENSO signal appears to be acoustic remote sensing. We, therefore, examine how the following acoustic techniques might be used to monitor ENSO-induced changes in the upper ocean: (1) ocean acoustic tomography; (2) a long-range acoustic thermometer; (3) passive monitoring of ambient acoustic noise level; (4) an occulation technique that depends on the bottom absorption; and (5) space-time scintillation analysis. We computed the acoustic properties of ocean models based on the 1982-1983 ENSO event and found out how sensitive different acoustic measurables are to the temperature changes that accompany a strong El Nino. In the eastern Pacific, for example, the largest (and earliest) temperature increases occur between 40 and 100 m depth. For long-range (ducted) sound rays to pass through this region without being absorbed by the bottom, the ocean must be at least

4 km deep. Pulse tomography, applied to vertical ocean slices, could adequately sample the temperature and currents in the upper ocean if appropriate receiving arrays were used. The passive listening scheme could monitor changes in the ambient noise level with the onset of El Nino, but it raised many questions about the natural variability of the noise environment. An occulation scheme that uses a vertical receiving array could economically monitor changes in average thermocline depth. The long-range acoustic thermometer could monitor the heat content of the equatorial ocean, a likely ENSO precursor. The horizontal covariance of acoustic scintillations might be used to measure the structure of transverse currents crossing a long acoustic path. If problems in extending the theoretical model to longer ranges can be solved, scintillation analysis could be used to monitor subsurface equatorial currents that transport heat eastward along the equator. Each technique examined offers some remote-sensing potential, but each also poses problems to be solved before its relative advantages in cost, coverage or convenience over *in situ* methods are clear.

AO-027

Hanes, D.M., C.E. Vincent, D.A. Huntley, and T.L. CLARKE. Acoustic measurements of suspended sand concentration in the C2S2 experiment at Stan Hope Lane, Prince Edward Island, Canada. *Marine Geology* 81:185-196 (1988).

A three megahertz acoustic concentration meter (ACM) was deployed, along with electromagnetic flowmeters, in the nearshore region in October 1984 at Stan Hope Lane, Prince Edward Island, Canada, as a component of the Canadian Coastal Sediment Study. The ACM measured the backscatter of acoustic energy in the region within approximately one meter of the seabed. Laboratory calibration experiments were conducted to verify a methodology for converting acoustic backscatter into suspended sand concentration profiles. The ACM worked well when there were no air bubbles in the water. Both suspended sand concentration profiles and the bottom location were measured with approximately one second time resolution and one centimeter spatial resolution. The suspension of sand is related to the wave and current forcing, with suspension dominated by large events.

AO-028

Hannington, M.D., G. Thompson, P.A. RONA, and S.D. Scott. Gold and native copper in supergene sulfides from the Mid-Atlantic Ridge. *Nature* 333:64-66 (1988).

In 1985 black smokers and massive sulfide deposits were discovered in the TAG hydrothermal field in the rift valley of the Mid-Atlantic Ridge near latitude 26°08'N (ref. 1). Sulfide samples from chimneys and mounds were recovered by dredging at depths between 3,620 and 3,670 m. Mineralogical and chemical analyses of the samples reveal: (1) primary, unaltered Zn-Fe-Cu sulfides containing 0.8-4.0 ppm Au (0.02-0.12 oz. per ton); and (2) secondary Cu-rich sulfides with native copper, formed by supergene alteration of primary Cu-Fe-sulfides, containing up to 16.4 ppm Au (0.48 oz. per ton) as free native gold. This is the first reported occurrence of secondary enrichment of gold and copper in recent submarine sulfides. The high gold grades and native copper associated with secondary Cu-sulfides resemble occurrences in some supergene gossans overlying ancient massive sulfide deposits in land.

AO-029

HANSEN, D.V., and A. HERMAN. A seasonal isotherm depth climatology for the eastern tropical Pacific. NOAA Technical Report ERL 434-AOML-33 (NTIS number not yet available), 35 pp. (1988).

A seasonal climatology of the depths of the 10°C, 15°C, and 20°C isotherms in the eastern tropical Pacific is presented. The analyses used Kriging, which is a method for optimal interpolation of data fields. The data set consisted of 10,505 expendable bathythermograph (XBT) and conductivity-temperature-

depth (CTD) stations collected during non-El Nino years. Results are presented on shaded contour maps with values overprinted at 2° intervals. The method of analysis also yields an estimate of the uncertainty of each interpolated point.

AO-030

HANSEN, D.V., and C.A. Paul. Vertical motion in the eastern equatorial Pacific inferred from drifting buoys. *Oceanologica Acta* 6:27-32 (1988).

Surface current measurements have been obtained from the eastern tropical Pacific Ocean by means of drifting buoys tracked by the NIMBUS and ARGOS satellite systems since 1977. Near-equatorial divergence of Ekman transport is indicated qualitatively by persistent avoidance of the equator by drifters. Upwelling velocity and transport were estimated from the horizontal divergence of surface current fields obtained by optimum interpolation of overall and monthly composite data. The estimated divergence is predominantly meridional. Average upwelling velocity and transport in the region 1.5°N-1.5°S, 80°W-130°W are estimated to be 1.5 m da^{-1} and 32 x 10^6 m^3 s^{-1}. Seasonal variation of the estimated upwelling agrees closely in phase but is larger in magnitude than that implied by the annual and semi-annual constituents of 14°C isotherm depth variations in the eastern equatorial Pacific.

AO-031

HARVEY, G.R. Comments on azide and mercuric salts as seawater preservatives, and alkenes in the Gulf of Mexico. *Marine Chemistry* 24:199-202 (1988).

A homologous series of volatile low molecular weight 1-alkenes was found in the surface waters of the Gulf of Mexico. Previous workers in the Gulf and other tropical waters did not report these compounds but they had poisoned their samples at sea for analysis later. We tested the efficiency of azide and mercuric salts to preserve a representative alkene, 1-heptene, and heptane was tested. Neither salt significantly prevented loss of the hydrocarbons from spiked seawater. The 1-alkenes are most likely the abiotic products of photochemical oxidation and fragmentation of n-alkenes.

AO-032

Houze, R.A., Jr., F.D. MARKS, JR., and R.A. BLACK. Mesoscale patterns of ice particle characteristics in Hurricane Norbert. Preprints, 10th International Cloud Physics Conference, Bad Homburg, Federal Republic of Germany, August 15-20, 1988. American Meteorological Society, Boston, 708-710 (1988).

No abstract.

AO-033

Johns, W.E., and F. Schott. Meandering and transport variations of the Florida Current. *Journal of Physical Oceanography* 17:1128-1147 (1988).

Current meter observations were collected from a three-dimensional array moored in the Florida Straits between December 1983 and June 1984 as part of the Subtropical Atlantic Climate Studies (STACS) program. Approximately one-fourth of the total subinertial velocity and temperature variance contained in these records is associated with meandering of the Florida Current on time scales ranging from several days to a few weeks. There appears to be no strong correlation between the occurrence of meanders and variations in Florida Current volume transport or local wind forcing. Utilizing frequency-domain empirical mode analysis we find the most coherent, energetic meandering signals within two limited frequency bands centered near periods of 12 days and 5 days. These meanders propagate downstream (northward) with phase speeds and wavelengths of approximately 28 km d^{-1} (340 km) and

36 km d^{-1} (170 km) respectively. Periodic wave forms composed from these modes indicate an asymmetric meander pattern with wave crests and troughs leading on the eastern side of the Florida Straits. These meanders appear to be giving up significant energy to the mean flow through up-gradient eddy momentum and buoyancy fluxes in the cyclonic shear zone of the Florida Current, with the net energy transfer being generally dominated by barotropic (eddy momentum flux) processes.

AO-034

JONES, R.W. A simulation of hurricane landfall with a numerical model featuring latent heating by the resolvable scales. *Monthly Weather Review* 115(10):2279-2297 (1987).

A nested grid hurricane model is used to transport a strong vortex over a straight coastline at about 4 m s^{-1}. The track, at landfall, of the vortex is about 20 km to the left of a control simulation without land. Just before landfall, a 15 km amplitude trochoidal oscillation of the vortex track occurs. This amplitude is nearly double that of similar oscillations of the control simulation. About 10 h before landfall, a spiral rainband nearly surrounds the vortex at radii of about 135 km. This rainband has a weak secondary maximum in the tangential wind and is the model analog of the secondary eyewalls observed by Willoughby *et al.* in several hurricanes. The rainfall in spiral rainbands diminishes during the 7 h before landfall. However, rainfall in the inner core of the vortex is greater during landfall than in the control simulation. The greatest rainfall accumulation is to the right of the vortex. However, compared with the control simulation, rainfall is greater to the left and less to the right of the vortex. This may be the result of an increase of the relative radial inflow in the boundary layer in the left-front quadrant near landfall. To the extent which is possible, these characteristics of landfall are related to observations.

AO-035

Komar, P.D., and D.B. ENFIELD. Short-term sea-level changes and coastal erosion. In *Sea-Level Change and Coastal Evolution*, D. Nummedal (ed.). *Society of Economic Paleontologists and Mineralogists* 41:17-27 (1988).

Investigations of the role of sea level in producing coastal erosion have focused mainly on the long-term rise due to melting of glaciers and thermal expansion of seawater. There are additional shorter term changes in the local sea level produced by a variety of ocean processes. Variations in the coastal currents, for example, can alter the water level at the shoreline due to the geostrophic balance between the current and the offshore sea-surface slope. Other factors which may alter local sea level include changes in atmospheric pressure, winds blowing either in the longshore or cross-shore directions, and the occurrence of upwelling. Because the inclined continental shelf and slope act as a wave guide, the fluctuations often become trapped and propagate over longshore distances beyond where they are actually generated. In that many of these processes are typically seasonal, the responding sea level also has a pronounced seasonal cycle, but frequently there can be significant fluctuations at periodicities of several days to a few weeks. The magnitudes of such changes vary considerably with coastal location but are typically on the order of 10 to 30 cm, achieving a maximum of about 100 cm in the Bay of Bengal. The occurrence of an El Nino in the equatorial Pacific is known to have considerable impact on the erosion of the coasts of California and Oregon. This occurs because associated with an El Nino are shifts in the storm paths and a temporary rise in sea level. An El Nino is a breakdown of the normal equatorial wind and current patterns. This breakdown releases water which is normally set up in the western Pacific by the trade winds. The release creates a "wave" of sea-level rise, which first propagates eastward along the equator and then poleward along the eastern ocean margin. Such "waves" have been measured in the tide records of the western United States, amounting to some 20 to 60 cm and lasting for several months. Such transient sea-level changes have likely played an important role in coastal erosion.

AO-036

Lautenschlager, M., D.P. Eppel, and W.C. THACKER. Subgrid-parameterization in helical flows. *Beitrage zur Physik der Atmosphare* 61(2):87-97 (1988).

A new parameterization for the turbulent momentum fluxes of an incompressible flow is suggested. Assuming the turbulent field to carry internal structure, the expansion of the subgrid fluxes in terms of average vorticity leads, in addition to subgrid kinetic energy, to subgrid helicity as an extra parameter to characterize this internal structure. In a simple model the expansion coefficients are connected to the resolution scale of the numerical grid model used. It is shown that the new subgrid-helicity dependent terms act against diffusion as they can transport additional rotation into the mean motion. In the limit of vanishing turbulent helicity the new parameterization reproduces the well-known diffusion parameterization of the turbulent fluxes.

AO-037

Leaman, K.D., and R.L. MOLINARI. Topographic modification of the Florida Current by Little Bahama and Great Bahama Banks. *Journal of Physical Oceanography* 17(10):1724-1736 (1987).

The effect of local topography in modifying the structure and variability of the Florida Current is examined using shipboard acoustic Doppler and Pegasus acoustic current profiler data. Pegasus absolute velocity data were obtained during 16 cruises in the Florida Current at 27°N as part of the Subtropical Atlantic Climate Studies (STACS) program. The ensemble average of all Pegasus velocity data shows that the effect of the constriction imposed on the mean Florida Current by Little Bahama Bank can be detected up to 30 km into the Straits of Florida. A simple model is proposed to explain how this effect can produce the subsurface maximum of northward flow commonly observed in the eastern Straits. Pegasus and acoustic Doppler data obtained during the March 1984 STACS cruise are used to describe the temporal and spatial variability of the flow. It is shown that intermittent southward flow can exist in a band 10-15 km wide off Little Bahama Bank; one such event was detected during this cruise. The Pegasus data suggest that these events are associated with meandering of the Florida Current. These results may explain earlier observations in satellite synthetic aperture radar images of small-scale vortices moving southward across the mouth of Northwest Providence Channel.

AO-038

LEETMAA, A., D.W. BEHRINGER, A. Huyer, R.L. Smith, and J. Toole. Hydrographic conditions in the eastern Pacific before, during and after the 1982/83 El Nino. *Progress in Oceanography* 19:1-47 (1987).

Between June 1981 and June 1984 a total of thirteen CTD sections were made across the equator along 85°W. On some of these cruises additional sections were made along 5°S and 10°30'S between 85°W and the South American coast. This sampling period covers the events that took place during the 1982/83 El Nino. These sections are used to describe the variability that took place before, during and after this major event. At the surface little evidence was found for a major southward flooding of warm, low salinity water from north of the equator that has been observed during some previous El Ninos. Major changes took place in the subsurface hydrographic structures. The thermostad between 13°C and 16°C, which is a prominent feature of the hydrography in this region, disappeared early in 1983 and reappeared early in 1984. The vertical temperature gradient along the equator and along the coast, which is usually quite variable with depth, became much more uniform in early 1983; it regained its normal structure by early 1984. Changes were not confined to the upper ocean but were evident over the whole depth interval sampled (1000 m). During November 1982 evidence was found for symmetric poleward spreading of the equatorial disturbance along the eastern boundary. Many of the changes that took place are consistent with linear models based on equatorial wave theory. These observations presented a unique opportunity for observing the ocean response to a major interannual change in the wind forcing.

AO-039

LORD, S.J. The 17th Conference on Hurricanes and Tropical Meteorology, 7-10 April, 1987, Miami, Florida. *Bulletin of the American Meteorological Society* 68(11):1431-1437 (1987).

No abstract.

AO-040

LORD, S.J., and J.L. FRANKLIN. Diagnostics of thermodynamic and wind fields in the environment of Hurricane Debby (1982). Preprints, 8th Conference on Numerical Weather Prediction, Baltimore, MD, February 22-25, 1988. American Meteorological Society, Boston, 605-610 (1988).

No abstract.

AO-041

LORD, S.J., and J.L. FRANKLIN. The environment of Hurricane Debby (1982). Part I: Winds. *Monthly Weather Review* 115(11):2760-2780 (1987).

A three-dimensional, nested analysis of wind fields in the environment of Hurricane Debby (1982) has been completed. The basic analysis tool combines a two-dimensional, least-squares fitting algorithm with a derivative constraint that acts as a spatial low-pass filter on the analyzed field. Gridded results of horizontally analyzed fields are combined into vertical cross sections and then analyzed to produce vertical continuity. Consequently, a three-dimensional analysis is obtained. The nested analysis method has also been applied to the surface pressure field for Debby. The data base for our analysis comes primarily from Omega dropwindsondes (ODW's), rawinsondes and satellite-derived winds in the environment of Hurricane Debby near 0000 GMT 16 September 1982. Since these data come from many different sources, and thus are not evenly distributed in the horizontal or vertical, techniques have been developed to alleviate difficulties associated with inhomogeneous data. Our analyzed wind fields provide an independent evaluation of satellite-derived winds at and below 400 mb at this analysis time. General features of the environmental wind and pressure fields surrounding Debby are described. The wind analyses are then used to diagnose terms in the vorticity equation: the spatial orientation of a calculated dipole in the horizontal vorticity flux convergence term indicates that it is not an accurate indicator of Debby's observed short-term motion. Finally, experimental track forecasts with a barotropic model are performed with our wind analyses and operationally available data outside our analysis domain. Initial errors in the forecast tracks are directly related to the improper orientation of the vorticity flux convergence dipole. Results show that this research wind analysis gives a substantial reduction in track error for short-term (12 h) forecasts. This improvement is due to a more realistic representation of the synoptic-scale trough in which Debby was embedded.

AO-042

LORD, S.J., and J.M. LORD. Vertical velocity structures in an axisymmetric, nonhydrostatic tropical cyclone model. *Journal of the Atmospheric Sciences* 45(9):1453-1461 (1988).

A statistical analysis of several experiments with different microphysical parameterizations in an axisymmetric, nonhydrostatic tropical cyclone model illustrates the impact of ice-phase microphysics on model vertical velocity structure. The parameterizations are designed to illustrate the effects of (1) thermodynamic input through latent heating, (2) vertical sorting of microphysical species by fallspeed, and (3) different time scales for the parameterized microphysical processes. The results confirm previous studies on the thermodynamic effect of melting, but they also show that the other factors are important in determining model vertical velocity structure and evolution. Model storms with a greater percentage of convective activity grow at a slower rate, but ultimately become more intense than those that have larger scale vertical velocity structures.

AO-043

MAUL, G.A. Report on INSMAP'86: The International Symposium on Marine Positioning. *Marine Geodesy* 11(4):269-276 (1987).

The International Symposium on Marine Positioning, INSMAP'86, organized by the Marine Geodesy Committee of the Marine Technology Society, was held 14 to 17 October 1986, under the sponsorship of seventeen organizations, at the U.S. Geological Survey National Center Auditorium in Reston, Virginia. INSMAP'86 was convened to focus attention on the special problems associated with positioning in the marine environment, to provide a timely forum for in-depth discussions and exchange of ideas, to identify immediate and future applications and requirements, and to promote inter-disciplinary and interagency collaboration between numerous investigators and users. The nine sessions and five workshops were attended by over 150 registered attendees representing North, Central, and South America, Europe, Asia, and Australia. In addition, 13 exhibitors set up demonstrations in the corridors leading to the auditorium. Forty-five papers, including invited addresses, were presented, and are available in a single volume of symposium proceedings.

AO-044

MAUL, G.A., J.R. PRONI, and J.L. Mitchell. On the integration of satellite altimeter data with *in situ* oceanographic data to provide precise profiles of absolute dynamic height anomaly. Proceedings, PACON '88, Pacific Congress on Marine Science and Technology, OST2, 9-10 (1988).

In 1984, the U.S. National Academy of Science, and in 1985 the U.S. National Science Foundation, issued reports on global observations and understanding of the general circulation of the oceans, and on the emergence of a unified ocean science. Both reports note that there are certain critical areas in the ocean where horizontal fluxes must be monitored: the Gulf Stream; the Kuroshio; East Australian, Brazil, and Somali Currents; Norwegian and Mediterranean Seas outflows; through the Drake Passage and across the equator at several Pacific and Atlantic sites. These fluxes are required as boundary conditions in numerical models, as verification data for forecasts and remote sensing, and as time series signals to measure changes at climatically sensitive sites. Results from the NOAA Subtropical Atlantic Climate Study (STACS) have shown that volume flux is closely related to changes in sea surface topography across one of the most important of these critical areas: the Florida Current portion of the Gulf Stream system. This paper investigates the role of satellite altimetry in precise determinations of the variations of absolute dynamic topography anomaly across critical areas of the Gulf Stream system in the STACS region, and the tropical Pacific in the Equatorial Pacific Ocean Climate Study (EPOCS) region near 110°W. From error budgets for GEOSAT, ERS-1, and TOPEX/POSEIDON, it is clear that satellite altimeters alone cannot provide both the precision and accuracy required to determine absolute dynamic topography anomaly across a critical ocean area. Conversely, for both logistic and financial reasons, no *in situ* measuring scheme alone is reasonably able to observe horizontal fluxes, such as volume transport on interannual time scales. Some combination of remote sensing and *in situ* observations will provide the proper mix of technologies; satellite altimetry coupled with independent measures of sea level and/or dynamic height, supplemented by buoy, mooring, and ship-of-opportunity data, is such a mixture. Based on experience with GEOSAT, we are developing sampling strategies that use mixed data inputs to create time series of absolute dynamic topography anomaly along short (1000 km) exact repeat mission (ERM) tracks. RSS accuracies due to media effects are estimated to be less than $\pm$ 5 dynamic centimeters (dyn-cm) for the GEOSAT ERM when coupled with *in situ* observations. ERS-1 and TOPEX/POSEIDON promise to provide significant improvements over this figure, and should allow monitoring volume transport at the $\pm$ 1 gigaliter per second (10^6 m^3 sec^{-1}) level in the subtropics, as well as documenting oceanic equatorial waves and other tropical circulation features such as those associated with ENSO events. In the open ocean, inverted echo sounder/pressure gauge (IES/PG) assemblies have been found to provide *in situ* verification data that is accurate within $\pm$ 3 dyn-cm. However, on more careful examination of the record, a seasonal dependence in the correlation between acoustic travel time and dynamic height anomaly has been discovered. In the equatorial Pacific Ocean, thermistor strings that measure the upper

500 m at 50 m intervals have been found to be as accurate as IES/PGs, with the added benefit of realtime data transmission for nowcasting purposes. In coastal regions, open ocean tide gauges and/or shallow water pressure gauges are shown to provide calibration data at the ± 1 dyn-cm precision level, but may have distorted amplitudes of the tidal wave component of instantaneous sea level. This work is conducted as part of the overall NOAA EPOCS and STACS efforts in climate, and as such benefits from other aspects of these programs such as numerical modeling at GFDL, *in situ* observations from NOAA ships and moorings, other satellite studies, sea-level/weather stations, and cooperative efforts with several institutes and universities. Using a space-time objective analysis, we show variability in dynamic height derived from GEOSAT, to provide information that is in agreement with *in situ* observations, and that is precise at ± 5 dyn-cm.

AO-045

MOLINARI, R.L., and K.D. Leaman. Variability of Gulf Stream surface currents in the Straits of Florida. *Marine Weather Log* 31(3):10-13 (1988).

No abstract.

AO-046

OOYAMA, K.V. Scale-controlled objective analysis. *Monthly Weather Review* 115(10):2479-2506 (1987).

The major topic of this paper is the resolvable spatial scales that can be analyzed by statistical interpolation of an undersampled dataset. The inquiry was motivated by the need to design the most appropriate procedures for spatial analysis of the upper air sounding data from the GARP Atlantic Tropical Experiment. A reliable representation of horizontal scales in the analyzed wind fields was a matter of utmost concern, since the derived fields of vorticity, divergence and vertical motion were also of vital interest. To achieve our goal, it was found that the traditional premise of statistical interpolation had to be reexamined. The main conclusions of this theoretical inquiry are: (1) resolvable scales are determined by the geometrical distribution of observing stations; (2) precise knowledge of the second-moment statistics improves the analysis by de-aliasing the amplitude of resolvable scales, but has no effect on the definition of resolvable scales; (3) residual effects of unresolvable signals in the data are removable by a spatial filter and must be so removed; and (4) spatial phases of de-aliased resolvable scales may still be in error. On the basis of these findings, the objective analysis procedures we have developed are targeted on the best achievable analysis of resolvable scales. The procedures include the following: an adequate estimate of "true" statistical fields from the given ensemble of data, a search for the optimum spatial filter by monitoring the targeted error variance, and a rational method of desensitizing the analysis to statistically errant data. In order to reduce the spatial phase error of propagating disturbances, the procedures are extended to the analysis of the timewise Fourier-transformed dataset (actually in the frequency-band analog). Since the wind is a physical vector, the entire procedure for the wind analysis is given in the tensor-invariant form, which is decidedly advantageous for very practical reasons. For example, the tensor approach eliminates the notorious ambiguity in normalization that is encountered in the multivariate approach. The paper also describes, in the Appendix, a method of filtered mechanical interpolation, which is specifically designed, with a variety of optional boundary conditions, for application to analysis in a finite domain.

AO-047

PALMER, D.R., M.G. Brown, F.D. Tappert, and H.F. BEZDEK. Chaotic behavior of ray trajectories in a range-dependent ocean environment. *Journal of the Acoustical Society of America* 83:S37 (1988).

It has been demonstrated that ray trajectories propagating in a range-dependent ocean environment can exhibit chaotic behavior. A particularly simple sound-speed model was considered consisting of the

Munk reference sound-speed profile to which is added a small range-dependent, deterministic perturbation having a harmonic dependence on range and decreasing exponentially with depth. Chaotic ray trajectories were identified from an examination of Poincare sections and power spectra. The sensitivity of chaotic trajectories to initial conditions and the consequent implications for predictability were investigated by considering the evolution with range of a bundle of rays that initially occupy a very small region in phase space. The largest Lyapunov exponent was determined by considering the spreading of the bundle. Since the ray equations define a nonautonomous Hamiltonian system with one degree of freedom, our results can be understood in terms of recent contributions to the study of classical chaos.

AO-048

PALMER, D.R., L.M. Lawson, Y.-H. DANESHZADEH, and D.W. BEHRINGER. Computational studies of the effect of an El Nino/Southern Oscillation event on underwater sound propagation. In *Computational Acoustics: Algorithms and Applications*, D. Lee, R.L. Sternberg, and M.H. Schultz (eds.). Elsevier Science Publishers B.V. (North-Holland), Amsterdam, 335-356 (1988).

Computer simulations of underwater sound propagation in the equatorial Pacific have been undertaken using a recently-developed program called ULETA. This program was developed to exploit the characteristics of modern computing systems including the clustering of processors, command languages that permit interactive processor communication, and the availability of color graphics hardware and software. It has three modes of operation: a ray-tracing mode; a continuous-wave mode in which transmission loss as a function of depth and range is obtained for a source radiating a single acoustic frequency; and a pulsed mode in which the pressure resulting from a pulsed source is obtained at selected locations as a function of time. The input data for the simulations consisted of a series of sound-speed profiles which reflect the onset, evolution, and cessation of the most recent El Nino/Southern Oscillation (ENSO) event. The results of the computations indicate the presence of a layer of ray-path instability in the ocean, extending from about 50 m to 280 m in depth, which suddenly became very quiet during the ENSO event. Sound which entered this layer or was generated within it could not have traveled on for more than a few tens of kilometers in range without striking the bottom and experiencing the usual severe losses in intensity. While the existence of this layer provides an opportunity to monitor ENSO events using underwater sound, it prevents the straightforward application of the techniques of acoustic tomography to study the dynamics of the ocean in the layer. This is unfortunate since the major temperature anomalies occur within it.

AO-049

PAZOS, M.C. Drifting buoy data from the equatorial Pacific for the period January 1, 1984 through May 31, 1985. NOAA Data Report ERL AOML-11 (PB88-212824), 100 pp. (1988).

No abstract.

AO-050

POWELL, M.D. Boundary-layer structure and dynamics in outer hurricane rainbands. Ph.D. dissertation, Florida State University, Tallahassee, 227 pp. (1988).

Results of hurricane boundary-layer experiments conducted in outer rainbands of Hurricanes Josephine (1984) and Earl (1986) are presented. Comparisons of precipitation, kinematic, and thermodynamic structures in these storms indicate that principal rainbands have common characteristic mesoscale and convective-scale features in the boundary layer. The two-dimensional mesoscale structure suggests that rainbands are made of a linear aggregate of cellular reflectivity elements (on the inner, upshear side of the band) and stratiform rain (on the outer downshear side). The band is oriented perpendicular to the shear above the boundary layer and cells move downband at about 80% of the

maximum wind. Alongband and crossband wind and equivalent potential temperature maxima are located on the outer side of the band axis. Updrafts and downdrafts are preferentially located on the inner side of the band axis. Downdraft transport of cool and dry air from middle levels on the inner side of the rainband was responsible for modifying mixed-layer structure adjacent to the band on alongband scales of 100 km. An undisturbed mixed layer of 500 m was present on the outer side of the band. Application of a mixed-layer model to low-level flow trajectories from the outer rainband to the eyewall indicates that under some conditions, the mixed layer may not recover sufficiently and low surface equivalent potential temperature air may reach the eyewall. These conditions are associated with suppressed flow in a region of positive divergence with moderate rainfall from a middle level anvil cloud. Differential evaporation cooling over the transition layer drives entrainment of dry air, resulting in a drier mixed layer (with lower surface equivalent potential temperature). The model results suggest that incomplete recovery may be responsible for transitional changes in hurricane intensity.

AO-051

POWELL, M.D., and P.N. Georgiou. Response of the Allied Bank Plaza Tower during Hurricane Alicia (1983). *Journal of Wind Engineering and Industrial Aerodynamics* 26:231-254 (1987).

As Hurricane Alicia passed over Houston on August 18, 1983, a record lasting approximately 90 minutes was obtained of the wind-induced accelerations of the tallest building in the downtown area, the Allied Bank Plaza. Coincidentally, the building had been the subject of a detailed wind tunnel model study several years earlier, the results of which included the prediction of building accelerations as a function of wind speed and wind direction. From the many wind observations made during Alicia's passage inland, it was possible to reconstruct the wind speeds and directions experienced at the Allied Bank Plaza site which overlapped the period of the acceleration record. This reconstucted wind history was combined with the wind tunnel test data to compute a time series of estimated accelerations sustained by the building during Alicia's passage inland. The resulting favorable comparison of actual and predicted accelerations provides a valuable case study, illustrating the reliability of wind tunnel modeling within the design process for tall buildings.

AO-052

ROFFER, C., and D.W. BEHRINGER. CTD/0_2 data collected in 1985 and 1986 for EPOCS. NOAA Data Report ERL AOML-9 (PB88-160775), 266 pp. (1987).

A summary of CTD measurements collected during four cruises in 1985 and 1986, as part of the Equatorial Pacific Ocean Climate Studies (EPOCS), is presented. These cruises continued the EPOCS program efforts along 110°W and 85°W, and extended the research area southeast along 15°S. Station locations and profiles of temperature, salinity and sigma-T are plotted for each cast. Dissolved oxygen bottle values, theta-s diagrams, and temperature and salinity sections are shown.

AO-053

RONA, P.A. Hydrothermal processes at the Mid-Atlantic Ridge: Recent developments. *Deep Sea Newsletter* 13 (1987).

The present year, 1987, is a time of consolidation and planning after the first submersible investigation of black-smoker-type vents, massive sulfide deposits and vent biota at the Mid-Atlantic Ridge made with *Alvin* in 1986, as reported in *Deep Sea Newsletter* 12. A partial bibliography of the numerous reports resulting from the three dives made at the TAG site at 26°N and the one dive made at the Snake Pit site at 23°N, which were presented at the December 1986 Annual Meeting of the American Geophysical Union and are in various stages of publication, is included in this report. Work on hydrothermal processes at the Mid-Atlantic Ridge planned for 1988 include submersible dives in March at the Snake

Pit site by a French group with the submersible *Nautile* (Dr. Catherine Mevel, Petrologie Metamorphique, Universite Pierre et Marie Curie, Tour 26.3–EME Etage, 4 Place Jussieu, 75252 Paris Cedex 05, France); a surface ship cruise in September to the TAG site by a British group with the R/V *Discovery* (Dr. Henry Elderfield, Department of Earth Sciences, University of Cambridge, Bullard Laboratories, Madingly Rise, Madingly Road, Cambridge CB3 OEZ, England); and a surface ship cruise to the TAG site and other potential sites by American and French groups with the NOAA Ship *Oceanographer* (Dr. Peter Rona, NOAA, 4310 Rickenbacker Causeway, Miami, Florida 33149, USA).

AO–054

RONA, P.A. Review: The geology of North America, Volume M: the western North Atlantic region. *Economic Geology* 83:666–667 (1988).

No abstract.

AO–055

RONA, P.A. The Gorda Ridge and the Mid–Atlantic Ridge: New frontiers for undersea research. Proceedings, Undersea Science Symposium, Groton, CT, October 21–23, 1987. NOAA Undersea Research Program, 16 (1987).

No abstract.

AO–056

RONA, P.A., and G. Thompson. Hydrothermal mineralization at the TAG area, Mid–Atlantic Ridge: Cyprus–type massive sulfide? Proceedings, Troodos–87 Symposium, Nicosia, Cyprus, October 5–10, 1987. Cyprus Geological Survey, 156 (1987).

No abstract.

AO–057

Sanford, T.B., P.G. BLACK, J.R. Haustein, J.W. Feeney, G.Z. Forristall, and J.F. Price. Ocean response to a hurricane. Part I: Observations. *Journal of Physical Oceanography* 17(11):2065–2083 (1987).

The response of the ocean was investigated using aircraft–deployable expendable current profilers (AXCP). The goals were to observe and separate the surface wave and surface mixed–layer velocities under the storms and to map the across–track and along–track velocity and temperature response in the mixed layer and thermocline. Custom instrumentation was prepared, including slower falling AXCPs, and the AXCP equipment was installed on NOAA WP–3D aircraft. Research flights were made into two 1984 hurricanes: Norbert, in the western Pacific off Baja, California (19°N, 109°W); and Josephine, off the west coast of the U.S. (29°N, 72°W). Thirty–one probes were deployed in each hurricane. All but four AXCPs survived the 220–knot launch and wave–zone impact (surface winds up to 75 knots) and produced basic RF transmissions. About half the AXCPs provided temperature and velocity profiles. Most velocity profiles exhibited strong surface wave contributions, slab–like velocities in the SML, strong shears beneath the SML, and only weak flows in the upper thermocline. Separation of the surface gravity wave velocities from the steady and inertial motions was obtained by fitting the profiles to steady flows and shears in three layers and to a single surface wave at all levels. The velocity profiles displayed large divergences to the horizontal SML velocities in the wake of the hurricanes. The observations show a strong enhancement to the right of the storm as expected from numerical simulations. The largest SML velocities were 1.1 m s^{-1} in Norbert and 0.73 m s^{-1} in Josephine. Numerical simulations will be compared with the observations in Part II.

AO-058

SHAPIRO, L.J. Month-to-month variability of the Atlantic tropical circulation and its relationship to tropical storm formation. *Monthly Weather Review* 115(11):2598-2614 (1987).

Monthly mean winds have been derived from 200 mb and Analysis of the Tropical Oceanic Lower Layer (ATOLL) winds over the southern North Atlantic, Caribbean, Gulf of Mexico and eastern Pacific during the hurricane seasons (June-November) of 1975 through 1985. After removal of the seasonal cycle, the winds are expressed in terms of empirical orthogonal functions. The dominant mode of variability for the combined 200 mb/ATOLL circulation strongly resembles part of a Walker cell confined near the equator. This mode is strongly correlated with an El Nino index (Weare, 1986) and is associated with the El Nino/Southern Oscillation. A positive (El Nino-like) index tends to be associated with more anticyclonic vorticity at the ATOLL level in the tropics and increases in the vertical shear between about 10° and 30°N. This circulation is unfavorable for tropical storm formation. Correlations are derived between the monthly mean winds and monthly tropical storm frequency in the Atlantic basin. Contemporaneous correlations in August, September and October, the three most active months, as well as correlations between winds and tropical storm formation one and two months later, are computed. Predictability of monthly tropical storm frequency at the two-month lead is statistically significant, with true skill approximately 45% of the variance. Only one-sixth of this skill is associated with the El Nino/Southern Oscillation. A favorable environment for storm formation is apparently established at least two months before the given month of formation. The results extend and complement seasons of tropical storm activity and previous hypotheses concerning the influence of El Nino on storm formation.

AO-059

SHAPIRO, L.J., D.E. Stevens, and P.E. Ciesielski. A comparison of observed and model-derived structures of Caribbean easterly waves. *Monthly Weather Review* 116(4):921-938 (1988).

A linear primitive equation model has been used to test the hypothesis that the vertical structure of observed Caribbean easterly waves is determined by the interaction between convective heating and the environmental wind. The model determines the response to a propagating heat source in a specified basic state. The model allows for the inclusion of diffusion and cumulus momentum transports. The linear perturbations are assumed to have the form of a single Fourier component in the zonal direction. The frequency and zonal wavelength of the disturbance are taken from observations of the three-dimensional structure of a series of Caribbean easterly waves made by Shapiro. The structure of the basic state zonal wind, assumed to be a function of height, is based on observations near the latitude of largest observed wave amplitude. The maximum heating rate is 5 K day^{-1}, centered at about 19°N. Very good agreement is found between the model-derived vertical structure of the waves and that observed by Shapiro (1986). In particular, the observed 90° westward phase shift between the 200 mb and near-surface troughs, and the westward tilt of the trough axis with height, are reproduced in the model solutions. Although linearization is not strictly valid for the observed wind amplitudes of about 5 m s^{-1}, the model's linear dynamical framework appears to represent the wave's structure well. The westward phase shift is found to depend on the downward flux of wave energy toward a near-critical layer near the ground. Experiments also suggest that the latitude of the disturbance may be as important a factor in the determination of the westward tilt of the trough axis as is the structure of the basic state zonal wind. An eastward tilt of the trough axis in the lower troposphere, such as that in the classical model of a Caribbean easterly wave, can occur at low latitudes, when the westward phase shift is in a narrow layer near the level of maximum heating. Cumulus momentum transports do not substantially change the structure of the forced wave disturbance. The model solutions are compared with similar experiments of Holton, and are related to results of Stevens, Lindzen and Shapiro.

AO-060

Tappert, F.D., M.G. Brown, D.R. PALMER, and H.F. BEZDEK. Chaos in underwater acoustics. *Journal of the Acoustical Society of America* 83:S36 (1988).

The problem of predicting sound propagation in range-dependent ocean environments has been investigated, in which it is supposed that the environment (volume and/or boundary) varies smoothly in range and is exactly known with arbitrary precision. Although this problem as stated is deterministic and not intrinsically stochastic, it has been discovered from numerical and analytical studies of physically realistic examples drawn from deep ocean propagation, shallow-water propagation, and surface duct propagation, that ray path solutions exhibit "classical chaos," namely, unpredictable and stochastic behavior. Ray paths are found to have a continuous spectrum characteristic of noisy stochastic processes, and ray paths are found to have an exponentially sensitive dependence on initial conditions and environmental parameters characteristic of chaotic processes. This phenomenon of chaos in underwater acoustics is caused by the exponential proliferation of catastrophes (caustics) due to the loss of control implied by the nonseparability of variables in the eikonal equation. As a consequence, even when the ocean environment is known exactly, there exists a "predictability horizon" that limits the range to which acoustic fields can be predicted.

AO-061

THACKER, W.C. A cost-function approach to the assimilation of asynoptic data. *Journal of Scientific Computing* 2(2):137-158 (1988).

This paper describes a method for reconstructing a synoptic state by fitting dynamics to asynoptic data. The best fit is defined by the minimum of a quadratic cost function and dynamics are enforced through the use of a penalty term. When the coefficient of the penalty term is identified as the inverse of the variance of model error, the method yields the same results as Kalman filtering, and in the limit of infinitely large coefficient, the same as strong-constraint formalisms. The self-adjoint nature of the equations for the best fit motivated the use of a relaxation method for their solution. The method is illustrated within the context of one-dimensional, linear, shallow-water wave dynamics, where computational examples indicate that a synoptic state is properly determined only if the asynoptic data are equivalent to complete initial conditions.

AO-062

THACKER, W.C., and R.B. LONG. Fitting dynamics to data. *Journal of Geophysical Research* 93(C2):1227-1240 (1988).

A formalism is presented for fitting dynamic forecast models to asynoptic data. Because of the importance of wind stress forcing in oceanic models and of the inadequacies of wind stress observations, the formalism allows an oceanic model to be fit to both oceanographic and meteorological data. Within the context of this formalism the important question of whether an asynoptic data set contains sufficient information to determine the model state completely and unambiguously is discussed. Because the information travels along wave characteristics, it is clear that for the data to be sufficient to determine the model state, they must be distributed so that every feature of the flow is seen at some time or another. Such widespread coverage of the oceans requires a data collection system that relies heavily on satellites. The formalism is illustrated using a highly truncated model of the wind-driven equatorial ocean and computational examples demonstrate how surface elevation and wind stress observations might be used to recover the model state.

AO-063

Thayer, V.G., B.G. McDonald, J.M. Ellingson, C.W. Oliver, D.W. BEHRINGER, and S.B. Reilly. Report of ecosystem studies conducted during the 1986 eastern tropical Pacific dolphin survey on the research vessel *McArthur*. NOAA Technical Memorandum NMFS NOAA-TM-NMFS-SWFC-104 (PB88-215199), 112 pp. (1988).

No abstract.

AO-064

Thayer, V.G., R.L. Pitman, K.A. Rittmaster, G.G. THOMAS, D.W. BEHRINGER, and S.B. Reilly. Report of ecosystem studies conducted during the 1986 eastern tropical Pacific dolphin survey on the research vessel *David Starr Jordan*. NOAA Technical Memorandum NMFS NOAA-TM-NMFS-SWFC-105 (PB88-214630), 106 pp. (1988).

No abstract.

AO-065

Thayer, V.G., S.B. Reilly, P.C. Fiedler, C.W. Oliver, and D.W. BEHRINGER. Report of ecosystem studies conducted during the 1987 eastern tropical Pacific dolphin survey on the research vessel *McArthur*. NOAA Technical Memorandum NMFS NOAA-TM-NMFS-SWFC-114 (NTIS number not yet available), 114 pp. (1988).

No abstract.

AO-066

Thayer, V.G., S.B. Reilly, P.C. Fiedler, R.L. Pitman, G.G. THOMAS, and D.W. BEHRINGER. Report of ecosystem studies conducted during the 1987 eastern tropical Pacific dolphin survey on the research vessel *David Starr Jordan*. NOAA Technical Memorandum NMFS NOAA-TM-NMFS-SWFC-115 (NTIS number not yet available), 94 pp. (1988).

No abstract.

AO-067

Van Dover, C.L., B. Fry, J.F. Grassle, S. Humphris, and P.A. RONA. Feeding biology of the shrimp *Rimicaris exoculata* at hydrothermal vents on the Mid-Atlantic Ridge. *Marine Biology* 98:209-216 (1988).

A newly described species of shrimp, *Rimicaris exoculata*, Williams and Rona, 1986, dominates the megafungal community at two hydrothermal sites on the Mid-Atlantic Ridge. Behavioral observations and gut-content analyses indicate that these shrimp ingest large amounts of sulfide particles from black smoker chimneys. We found no evidence for chemoautotrophic endosymbionts in *R. exoculata*, based on analyses of morphology, stable isotopes, lipopolysaccharides, and ribulose-1,5-bisphosphate carboxylase (RuBPCase) activity. Instead, we suggest that the shrimp are normal heterotrophs, grazing on free-living microorganisms associated with black smoker chimneys. We infer that high bacterial productivity is required to sustain populations of *R. exoculata* at these vent sites.

AO-068

WILBURN, A.M., E. JOHNS, and M. BUSHNELL. Current velocity and hydrographic observations in the Straits of Florida, the Caribbean Sea and offshore of the Antillean Archipelago: Subtropical Atlantic Climate Studies (STACS), 1984 and 1985. NOAA Data Report ERL AOML-8 (PB88-149299), 194 pp. (1987).

No abstract.

AO-069

WILBURN, A.M., E. JOHNS, and M. BUSHNELL. Current velocity and hydrographic observations in the Straits of Florida, the Caribbean Sea and offshore of the Antillean Archipelago: Subtropical Atlantic Climate Studies (STACS), 1986. NOAA Data Report ERL AOML-10 (PB88-160767), 247 pp. (1987).

No abstract.

AO-070

WILBURN, A.M., E. JOHNS, and M. BUSHNELL. Current velocity and hydrographic observations in the southwestern north Atlantic Ocean: Subtropical Atlantic Climate Studies (STACS), 1987. NOAA Data Report ERL AOML-12 (NTIS number not yet available), 86 pp. (1988).

No abstract.

AO-071

WILLIS, P.T., and A.J. Heymsfield. Melting-layer structure in MCC stratiform precipitation. Preprints, 10th International Cloud Physics Conference, Bad Homburg, Federal Republic of Germany, August 15-20, 1988. American Meteorological Society, Boston, 699-701 (1988).

No abstract.

AO-072

WILLOUGHBY, H.E. Linear motion of a shallow-water, barotropic vortex. *Journal of the Atmospheric Sciences* 45(13):1906-1928 (1988).

A shallow-water barotropic model of tropical cyclone motion allows calculation of linear wavenumber one perturbations on a maintained, moving axisymmetric vortex. The perturbations are Rossby waves that depend upon the radial gradient of axisymmetric relative vorticity rather than the meridional gradient of absolute vorticity. Although the motion of the vortex is a parameter for calculation of the perturbations, the motion in a particular situation is determinate, because it minimizes the Lagrangian of the system. The motion in an environmental current matches the current, except at frequencies where the vortex is barotropically unstable. Imposed sources and sinks of mass simulate the effects of convection. The "convectively-induced" motions excite the barotropic instability plus a mode that depends upon forcing at the Rossby wave critical radius. This mode has largest amplitude and fastest vortex motion at the orbital frequency of the axisymmetric flow where forcing is imposed. It seems to correspond with the trochoidal motion of real tropical cyclones. For cyclonic frequencies only, perturbation in the streamfunction field resembles a solitary Rossby wave and exhibits counterrotating gyres isolated from the relative flow due to the vortex motion. The vortex motion on a beta plane is largely meridional with speed proportional to the total relative angular momentum of the vortex. When the vortex has cyclonic circulation throughout, the northward motion is much too fast. This unreasonable result highlights the importance of nonlinear processes in tropical cyclone motion.

Addendum

AO–073

DeMARIA, M. Tropical cyclone track prediction with a barotropic spectral model. *Monthly Weather Review* 115(10):2346–2357 (1987).

A barotropic spectral model (BSM) is developed to investigate the possibility of forecasting tropical cyclone tracks with global, general circulation models. The model is governed by a barotropic vorticity equation in spherical coordinates which is solved using a spectral method with spherical harmonic basis functions. The model was run with a triangular truncation of 128 on half of the northern hemisphere (180°W–0°W), and was initialized using horizontal winds from the NMC analyses vertically averaged from 1000 to 100 mb. The storm circulation is represented by a specified axisymmetric vortex and the model was tested by making 30 track forecasts of Atlantic tropical cyclones (13 storms) which occurred from 1979 to 1984. The skill of the model was assessed by comparing the track forecasts to forecasts from a model based on climatology and persistence (CLIPER). The BSM has statistically significant skill for 24 and 36 h track forecasts, and longer range skill for forecasts of low-latitude storms. For low-latitude storms, the BSM had greater skill than the operational SANBAR and movable fine mesh (MFM) models. The sensitivity of the model to the horizontal resolution is tested. These results suggest that track forecasts could be made with a global spectral model with a triangular truncation of about 96. It might then be feasible to make track forecasts with a global model similar to the operational model at the European Centre for Medium Range Weather Forecasts which uses a triangular truncation of 106. The sensitivity of the model to the domain size and to the specification of the initial vortex is also investigated. These results show that when simple lateral boundary conditions are used, the track forecast errors rapidly increase when the model domain is made smaller than half of a hemisphere. These results also show that the track errors are very insensitive to the size of the vortex, provided that the vortex is not unrealistically large. When the shape of the vortex profile is changed to include an anticyclonic circulation at large radii, the track errors are smallest when the total angular momentum of the vortex is close to zero. The errors rapidly increase as the total angular momentum becomes negative. The effect of modifying the initial analyses so that the deep-layer mean wind in the storm region is consistent with the previous storm motion is also studied. The track errors show the most reduction when the analyses with a radius of about 1000 km of the storm are modified.

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GAMACHE, John F.	Meteorologist
GARCIA, Chely G.	Accounting Technician
GOONAN, Elizabeth A.	Library Technician
GRIFFIN, Joseph S., Jr.	Mathematician

NAME	TITLE
GRIFFIN, Nancy F.	Computer Programmer
HANSEN, Donald V.	Director, PhOD
HARRIS, Alan S.	Maintenance Mechanic
HARRIS, Jessie E.	Oceanographer
HARVEY, George R.	Oceanographer
HERMAN, Alan	Mathematician
HILL, Leonard C.	Oceanographer
HUDSON, Denise M.	Physical Science Technician
HUSS, Betty E.	Computer Programmer
JOHNS, Elizabeth	Oceanographer
JONES, Robert W.	Meteorologist
JONES, Stanley K.	Electronics Technician
KAPLAN, John	Meteorologist
KAVANAGH, Noemi	Translating Assistant (typing)
KOHLER, Robert E.	Computer Programmer
KRUG, Warren S.	Electronics Technician
LAUTER, Charles A., Jr.	Electronics Technician
LAUTER, Lois P.	Secretary (typing)
LEIGHTON, Paul A.	Computer Programmer
LIU, Paul C.	Oceanographer
LOCKETT, Gloria J.	Mathematician
LONG, Robert B.	Oceanographer
LORD, Jacqueline M.	Computer Programmer
LORD, Stephen J.	Meteorologist
LORENZO, Alejandra	Computer Programmer
MARKS, Frank D., Jr.	Meteorologist
MARQUES, Frank D.	Secretary
MAUL, George A.	Supervisory Oceanographer
MAYER, Dennis A.	Oceanographer
McLEISH, William L.	Oceanographer
MEDINA, Gladys C.	Secretary
MENDEZ, Antonio	Chemist
MEYER, Alvyn M., Jr.	Electronics Technician
MILLER, Thomas O.	Electronics Technician
MINTON, Sidney M.	Computer Systems Analyst
MOLINARI, Robert L.	Oceanographer
MOORE, Lloyd D.	Chemist
MORRISSEY, Barbara J.	Computer Operator
MORRISSEY, Thomas R.	Maintenance Mechanic
NELSEN, Terry A.	Oceanographer
NODAL, William J.	Mathematician
OOYAMA, Katsuyuki V.	Meteorologist
ORTNER, Peter B.	Supervisory Oceanographer
PALMER, David R.	Physicist
PARKER, Edmond L., Jr.	Wood Crafter
PAZOS, Mayra C.	Computer Programmer

NAME	TITLE
PIOTROWICZ, Stephen R.	Oceanographer
POWELL, Mark D.	Meteorologist
PRONI, John R.	Director, OAD
PSZENNY, Alexander P.	Oceanographer
PUIG, Antonio A.	Electronics Technician
PUTLAND, Gerald E.	Physical Scientist
REDMOND, Elizabeth H.	Computer Programmer
RODDY, Robert J.	Mechanical Engineer
ROFFER, Carol	Oceanographer
RONA, Peter A.	Geophysicist
ROSENTHAL, Stanley L.	Deputy Director, AOML
SABINA, Reyna	Mathematician
SHAPIRO, Lloyd J.	Physicist
SIMPKINS, Juanita A.	Secretary
SOUKUP, George A.	Physicist
SPECKERMAN, Bruce P.	Administrative Officer
STRUCK, John H.	Electronics Technician
SWEENEY, Dennis P.	Physical Science Technician
THACKER, William C.	Physicist
THOMAS, Gregg G.	Oceanographer
TIRADO, Pedro W., III	Student Trainee (physical science)
TROUT, James W.	Supervisory Meteorologist
TSAI, John J.	Physicist
WESTON, Dorothy L.	Secretary (typing)
WIGGERT, Victor	Meteorologist
WILBURN, Anne Marie	Oceanographer
WILLIAMS, Helen	Computer Operator
WILLIS, Paul T.	Meteorologist
WILLOUGHBY, Hugh E.	Meteorologist
WILSON, William D.	Oceanographer
WOOLDRIDGE, Anita L.	Oceanographer
WRIGHT, Robert E., Jr.	Meteorologist Technician
YOUNG, Margie S.	Oceanographer

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