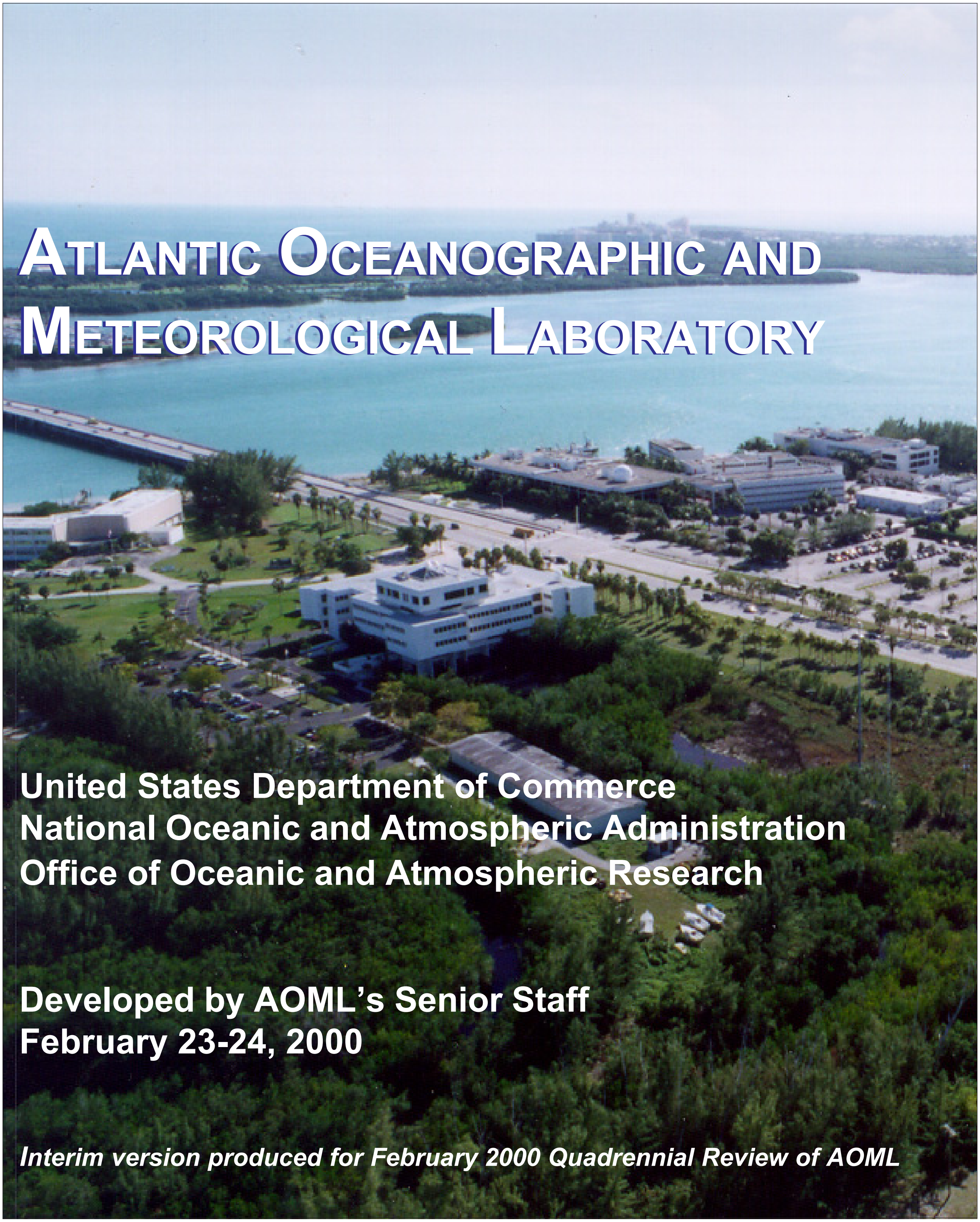
Strategic Plan



Atlantic Oceanographic and Meteorological Laboratory

United States Department of Commerce
National Oceanic and Atmospheric Administration
Office of Oceanic and Atmospheric Research

Developed by AOML's Senior Staff
February 23-24, 2000

Interim version produced for February 2000 Quadrennial Review of AOML

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Cover photograph: *Aerial view of the Virginia Key science community. Building to the left is the National Marine Fisheries Service/Southeast Fisheries Center, building in the center is the Atlantic Oceanographic and Meteorological Laboratory, and to the right is the University of Miami's Rosenstiel School of Marine and Atmospheric Science campus and the Cooperative Institute for Marine and Atmospheric Studies (photograph courtesy of Dr. David Palmer, AOML Remote Sensing Division).*

Page layout and document production by Gail Derr, Technical Editor, AOML Office of the Director

Preface

This document has been created for the benefit of the NOAA/OAR hierarchy, partners in other NOAA line offices, for academic and industry partners nationally and internationally, and for the whole population of the Laboratory to have a clear vision of AOML, a context for interaction and a plan for the future. However, this version will be distributed to reviewers and guests participating in the Quadrennial Review of AOML on February 23-24, 2000 and does, therefore, have a different slant than the final version that we expect to produce this spring when reviewers' comments can be incorporated.

It is intended to provide background material for our esteemed reviewers. It includes sections on our organization, current work, our plans, and some detail on issues of concern. We appreciate your presence at this review, your interest, and your comments concerning this strategic plan and the future of our Laboratory.

Sincerely yours,

Kristina B. Katsaros

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Mission

The mission of the Atlantic Oceanographic and Meteorological Laboratory is to conduct a basic and applied research program in oceans and climate, regional and coastal research, and tropical meteorology. The program seeks to understand the physical, chemical, and biological characteristics and processes of the ocean and the atmosphere, both separately and as a coupled system.

The principal focus of these investigations is to provide 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 controlling climate and affecting environmental quality, and improved ocean and weather services for the nation.

Table of Contents

Vision

We envision an Atlantic Oceanographic and Meteorological Laboratory (AOML)[1] *of 2004 and beyond with increasingly interdisciplinary research and even stronger links between the three major themes of our current research:*

- *Oceans and climate*
- *Regional and coastal waterways*
- *Tropical meteorology*

We envision an AOML whose role as a leader for research in all three theme areas is not only firmly established, particularly for research focused in the Atlantic Ocean, including the Intra-Americas Sea (Caribbean and Gulf of Mexico) and Florida coastal areas, but also includes custodianship of major data sets and a center for their dissemination. AOML's leadership will include forging of partnerships and initiation of new research directions.

Introduction

The work of the Atlantic Oceanographic and Meteorological Laboratory covers a broad range of environmental research contributing to all three themes of the Office of Oceanic and Atmospheric Research (OAR), namely, climate, atmospheres, and ocean resources research. There is substantial synergy and overlap between these themes in many of AOML's research projects, which will become clear in what follows. There are also several cross-cutting issues and opportunities

For each theme area we provide the current mission and a tentative and suggestive vision for the next 5-10 years An AOML Strategic Plan is also being developed. An important aspect of AOML's work is the extensive partnership network developed over the years which is continually growing supported by NOAA program offices, *e.g.,* the Office of Global Programs and the Coastal Ocean Program, other federal agencies, and even local or regional authorities. Sections on the partnership network and sources are also included. Our main partners on Virginia Key are the Cooperative Institute of Marine and Atmospheric Studies (CIMAS), the University of Miami's Rosenstiel School of Marine and Atmospheric Science (RSMAS), the National Marine Fisheries Service/Southeast Fisheries Science Center (NMFS/SEFSC), and two functions of the National Environmental Satellite, Data and Information Service (NESDIS) which are housed at AOML. In 1999, we participated in initiating the Cooperative Institute for Climate and Ocean Research (CICOR), located at the Woods Hole Oceanographic Institution, as one of our partners. A few proposals are currently funded with CICOR, and we anticipate CICOR to grow substantially. Before we describe the research under the three scientific theme areas, we present preliminary information about the operation and structure of AOML.

AOML participates on three strategic planning teams of NOAA (Predict and Assess Decadal to Centennial Change, Implement Seasonal to Interannual Climate Forecasts, Sustain Healthy Coasts) and on Dr. Baker's Climate and Marine Services Steering Committee. All four teams currently are developing initiatives for the 2002 funding cycle. The interests of AOML in these initiatives are also presented below. In the past three fiscal years, AOML has published 162 peer-reviewed articles, 40 book chapters/technical reports, and 177 conference proceedings/abstracts.

AOML Administrative Structure

AOML has approximately 108 full-time equivalent federal employees and about 61 contractors and affiliated scientists. The Laboratory is organized along three main research divisions (Hurricane Research, Ocean Chemistry, and Physical Oceanography), plus a fourth division (Remote Sensing) that is linked to the other three but is also an in-house resource for high-technology developments in remote sensing. A fifth division can be thought of as the Office of the Director. Individual scientists and technicians are assigned to the four scientific divisions, but are increasingly working in teams on projects that frequently involve personnel from one, two, three, or all four of the science divisions. Budget accounting by division and also by projects for salaries, as well as equipment, makes this structure function well for us. Three to five NOAA Corps officers are employed in various capacities throughout the Laboratory. In addition, AOML has numerous committees such as the Computer Committee; Engineering Committee; Space Committee; Morale,

[1]All acronyms are defined as they first appear in the text and are also compiled at the end of this document in a List of Acronyms.

Welfare, and Recreation Committee; Equal Employment Opportunity (EEO) Committee; Diversity Committee; and the newly formed Employee Association, that gather employee input and recommendations. AOML participates in OAR's EEO, Diversity, and Outreach Councils and in NOAA's Diversity Council. Figure 1 outlines the operational structure of the laboratory; a brief description of each functional unit follows.

Hurricane Research Division

The Hurricane Research Division (HRD) has a staff of 35 individuals, roughly one-third of whom are Ph.D.-level scientists. Its missions are improvement of forecasts and advancement of basic physical understanding of hurricanes and tropical meteorology. A key aspect of HRD's research is its annual program of research flights aboard reconnaissance aircraft (two WP-3D turboprops and the Gulfstream-IV SP jet) flown by NOAA's Aircraft Operations Center.

Ocean Chemistry Division

The diverse Ocean Chemistry Division's (OCD) scientific staff of 29, including nine Ph.D.-level scientists, is comprised of marine, atmospheric, and geological chemists, as well as chemical, biological, and geological oceanographers. OCD is, therefore, able to use multidisciplinary approaches to solve scientific research questions devoted to helping NOAA fulfill its scientific mission. The Division's work includes projects that are important in assessing the current and future effects of human activities on our coastal to deep ocean and atmospheric environments.

Physical Oceanography Division

The Physical Oceanography Division (PhOD) has a staff of approximately 45 research scientists and technicians, including 13 Ph-D.-level scientists. Its primary mission is to provide and interpret oceanographic data by conducting research relevant to the following NOAA Strategic Goals: Predict and Assess Decadal to Centennial Climate Change, Implement Seasonal to Interannual Climate Forecasts, and Sustain Healthy Coastal Ecosystems. PhOD houses and manages the Global Ocean Observing System (GOOS) Center and is responsible for coordinating NOAA's global and regional observing network efforts to maximize the quality and quantity of data available to users, among which are NOAA's weather and climate forecast groups. Included in the GOOS Center are the Global Drifter and Data Assembly Center, which manages the global collection, processing, and distribution of drifting buoy data, and the Upper Ocean Thermal Center, which does the same for data collected from expendable bathythermographs (XBTs). GOOS Center data are critical to understanding and predicting seasonal to decadal shifts in weather patterns and are used in empirical and statistical studies to understand dynamical processes in the global ocean/atmosphere coupled system.

Remote Sensing Division

The Remote Sensing Division (RSD) has a staff of 13, including four Ph.D.-level scientists. RSD uses electromagnetic and acoustic-based remote sensors for research on climate and oceans, tropical meteorology, and coastal stewardship/coastal ecosystem health. RSD principal projects include studies of anthropogenic discharges (*e.g.,* sewage effluent, dredged material) in the coastal ocean, measurement of oceanic precipitation, observations of oceanic wind fields and turbulent fluxes, and synthetic aperture radar (SAR) studies of coastal phenomena, tropical storms, and oceanic circulation.

Office of the Director

AOML's Office of the Director (OD) oversees all of the Laboratory's scientific programs, as well as its administrative, financial, computer, outreach/education, and facility management services for AOML's staff of approximately 169 individuals. OD has a staff of 25.

AOML also houses a National Environmental Science, Data, and Information Service (NESDIS) regional library and a National Oceanographic Data Center (NESDIS/NODC) Liaison Office (see section on Affiliates).

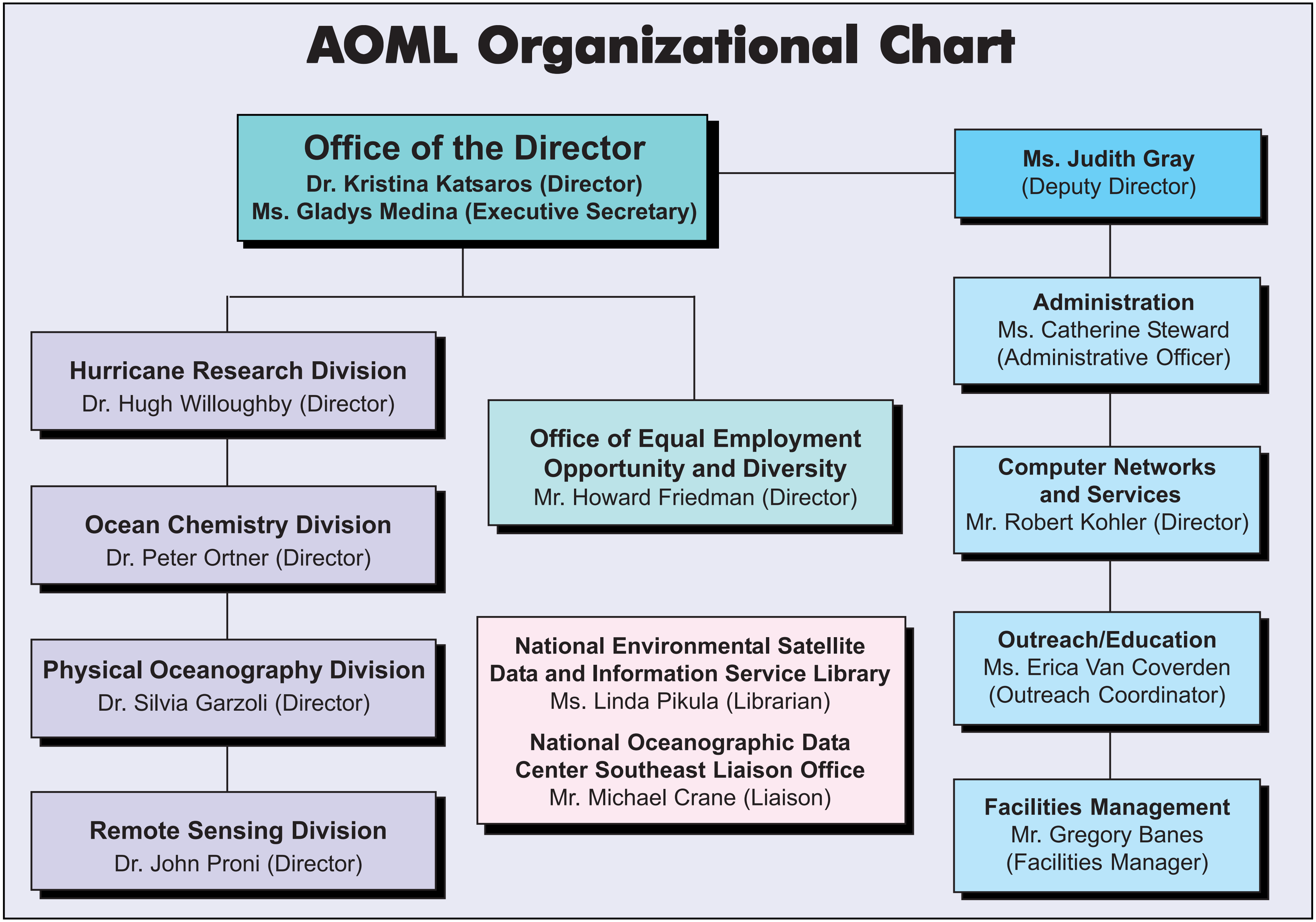

Figure 1. *AOML organizational structure.*

AOML Scientific Theme Areas

Oceans and Climate

Global Studies:

AOML is conducting climate studies with global scope in order to better understand the global setting for regional signals, and how the regional signals contribute to global phenomena. Even strongly regional phenomena such as El Niño-Southern Oscillation (ENSO) have clear and important expressions in the Atlantic and Indian Oceans. Other signals previously thought to be regional, such as the North Atlantic Oscillation (NAO), are linked to the opposite side of the Northern Hemisphere through polar vortex fluctuations. The role of the ocean in the control and modulation of compounds influencing climate (carbon dioxide [CO_2], water) or ozone levels (methyl bromide [CH_3Br], CO) requires both assessment of surface fluxes and changes in inventories over time. Analysis of sensitivity of the relevant fluxes to seasonal and interannual variability in hydrographic properties is critical to make future projections of atmospheric changes of chemical species. Finally, the evolution of a global observation system to support these and other such studies, and operational climate prediction, requires the active participation of research entities such as AOML in partnership with operational centers such as NOAA/ National Center for Environmental Prediction (NCEP). The AOML-based Global Ocean Observing System (GOOS) Center achieves this by assuring efficient acquisition and quality control of real-time data, and by developing and implementing new technologies for operational use.

<u>Physical climate studies</u>: Using data diagnostics, we have statistically separated and indexed global climate signals such as ENSO and the NAO (OC1) (Figure 2). We have found that within the equatorial Pacific region called NINO3, the interannual, global

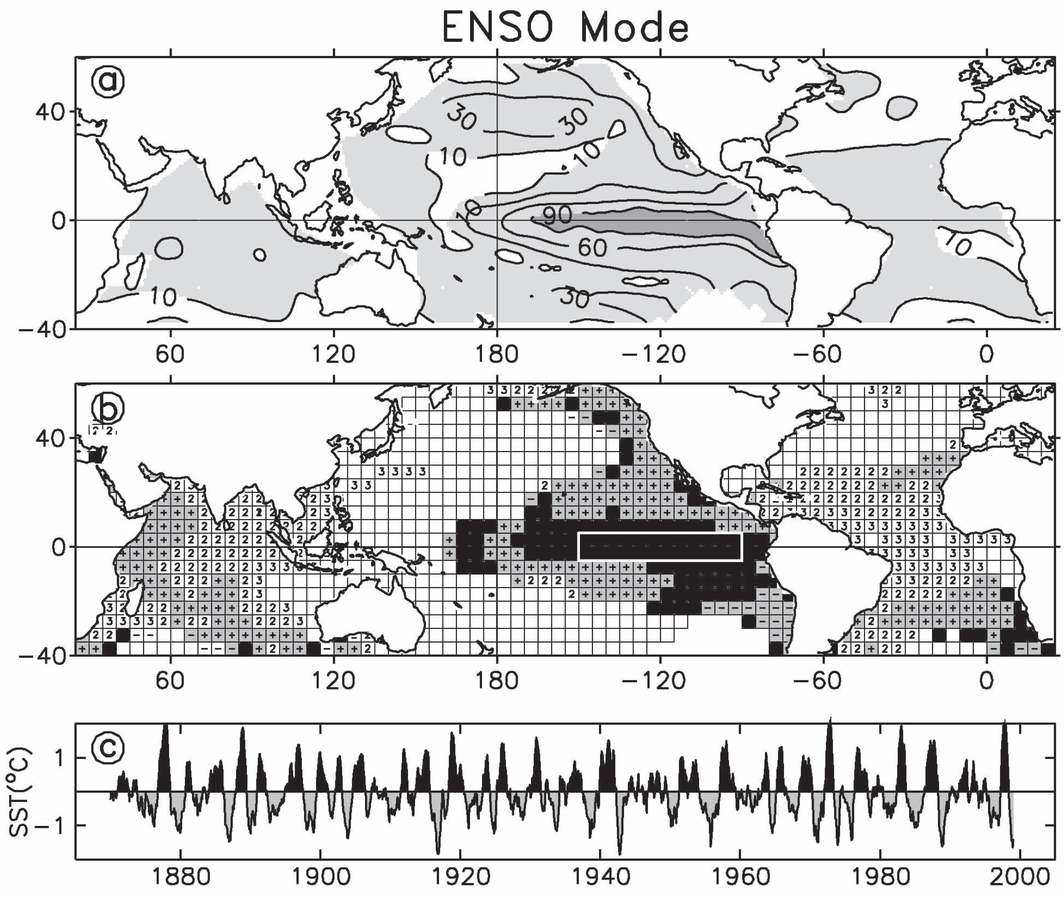

***Figure 2**. The global ENSO mode: Upper Panel: Relative weighting for various regions. The highest (dark gray) amplitudes are in the equatorial Pacific, but significant amplitudes (light gray) also appear in the tropical Atlantic and Indian Oceans and elsewhere in the Pacific. Middle Panel: Represents how the global mode captures the lags of the ENSO signal in various regions (+, 2, 3 = 1, 2, 3 seasons). Note the 1-3 season lags of the ENSO signal in the Atlantic and Indian Oceans and the negative numbers off Chile indicating a one-season precursor. Bottom Panel: The time series shows the global ENSO reconstruction for the NINO3 index region. Note that 1972-1973 has a higher amplitude than 1982-1983, the opposite to what a simple average of the data indicate.*

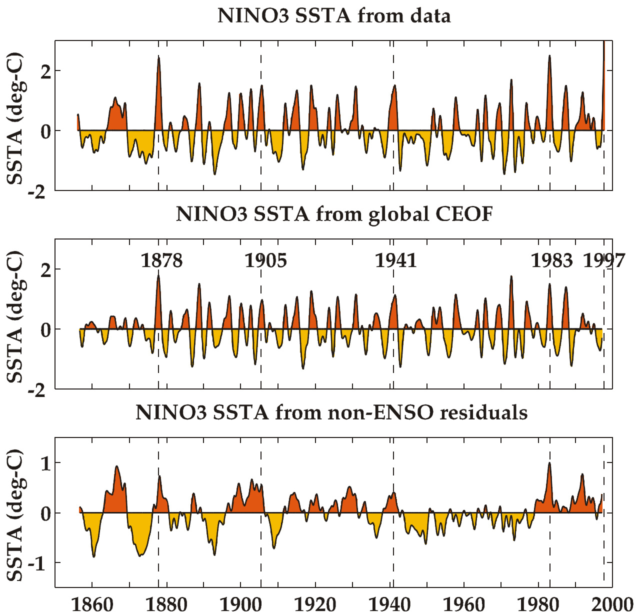

Figure 3. Top Panel: Monthly averages of sea surface temperature (SST) data for the NINO3 region in the equatorial Pacific. Note that 1997-1998, 1982-1983, and 1878-1879 have the largest peaks in the record and that they are all larger than the peak of 1972-1973. Middle Panel: Monthly averages of the global ENSO mode projected onto the NINO3 region. Note that peaks are generally smaller than in the data index and that 1972-1973 is now the largest peak in the series. Bottom Panel: Monthly averages of the residual SST variability in the NINO3 region after removing the global ENSO component from the data. Note that the series is predominantly decadal-to-multidecadal in character and accounts for the differences in the above two series.

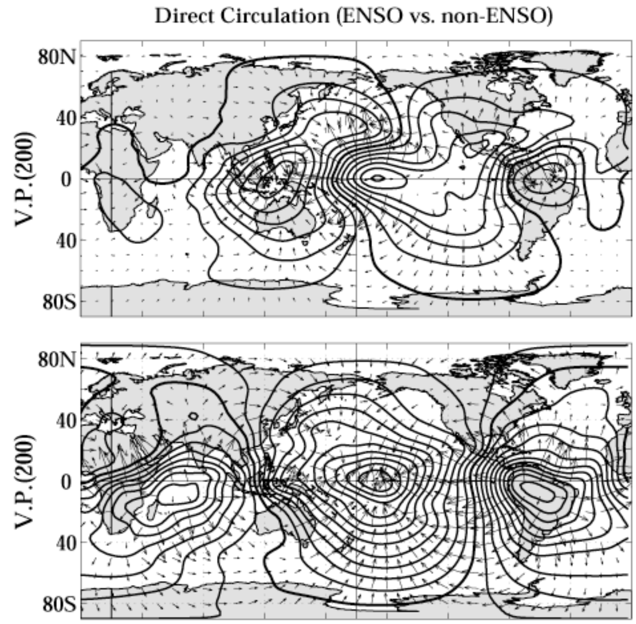

***Figure 4**. Anomalous distributions of the tropospheric direct circulation associated with the global ENSO (top) and non-ENSO (residual) variabilities in the equatorial Pacific. Top Panel: Composite average of 200 hPa velocity potential and irrotational velocity associated with positive-minus-negative phases of the global ENSO variability in the NINO3 region (see Figure 3, middle panel). Features to note are (1) the lateral convergence and implied suppressed convection west of the dateline and over northern South America, plus (2) the enhanced (suppressed) Hadley circulation in the central North Pacific (North Atlantic). Bottom Panel: Composite average of 200 hPa velocity potential and irrotational velocity associated with the change in the residual NINO3 SST between two multidecadal periods: 1978-1999 minus 1950-1977 (see Figure 3, bottom panel). Features to note include: (1) convergence (divergence) just east of the dateline (over South America), where the global ENSO shows divergence (convergence); and (2) anomalous Hadley circulations in the central North Pacific and North Atlantic that are opposite to those of the global ENSO mode.*

ENSO signal can be discriminated from the mainly interdecadal "non-ENSO" component (POC2)[2] (Figure 3). When these components are separately projected onto the global atmospheric variability (NCEP reanalysis), surprising differences can be seen in the Walker and Hadley circulation anomalies as they relate to the ENSO and non-ENSO variability (POC3) (Figure 4). The decadal to multidecadal (D2M) variability in the NINO3 region has anomalous Walker and Hadley associations (in the troposphere) that are nearly opposite to those of ENSO, over the global tropics. This raises some transcendental questions for future research regarding the relationships between ENSO and D2M, and suggests that the predictabilities emanating from ENSO and D2M must be considered separately and combined with care. In newly proposed work, we hope to combine modeling and data diagnostics in an attempt to see how the Atlantic sector is affected by, and feeds back on, such distinct climate modes. Why is the tropical North Atlantic variability quasi-independent of the tropical South Atlantic variability (non-dipole)? Does this follow from separate forcings by larger scale, independent tropospheric modes of variability? How is the tropospheric direct circulation altered in each case and how are those patterns related to known phenomena such as the NAO?

<u>Global atmospheric chemistry and carbon cycle</u>: Research on the global ocean carbon cycle has

[2]Posters are identified by the red letters "P," followed by OC (oceans and climate), RC (regional and coastal), TR (tropical meteorology), OD (Office of the Director), AC (Affiliates/Customers) and a number. They are listed after the section in the text where they are referenced.

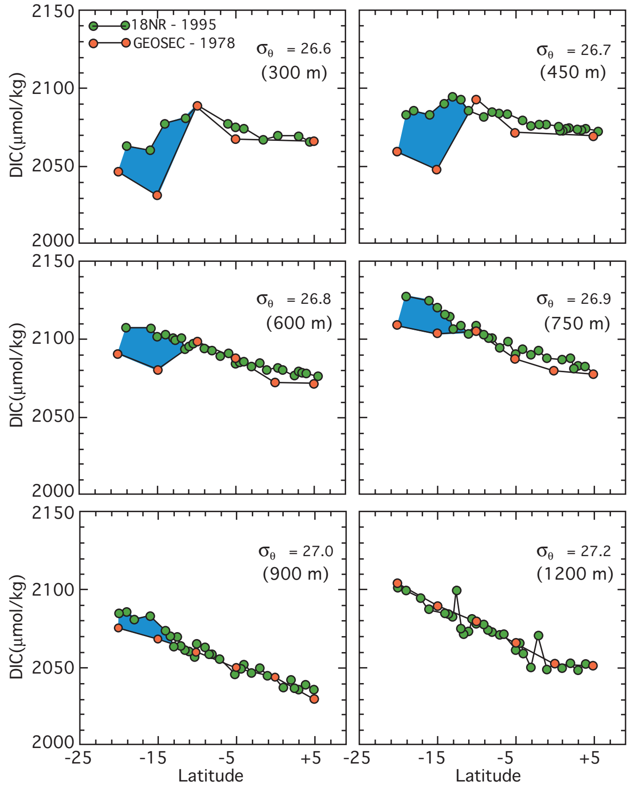

***Figure 5**. Anthropogenic CO_2 inventory is based on differences of dissolved inorganic carbon (DIC) over time. It is a comparison of salinity-normalized DIC, corrected for AOU (apparent oxygen utilization) and alkalinity changes over time, along an isopycnal surface in the upper thermocline of the Indian Ocean along 80°E longitude for a latitude zone ranging from 20°S to 5°N at two different times: GEOSECS in 1978 (red circles) and I8NR in 1995 (green circles). Six panels represent six density surfaces at sigma = 26.6, 26.7, 26.8, 26.9, 27.0, and 27.2. These surfaces correspond to a depth range of 300-1200 m. The I8NR is a CO_2 survey cruise performed by the NOAA Ocean-Atmosphere Carbon Exchange Study (OACES) program in concert with the Joint Global Ocean Flux Study (JGOFS) and the World Ocean Circulation Experiment (WOCE) repeat hydrographic survey. It shows that more anthropogenic CO_2 has been absorbed in the temperate ocean (south of about 15°S) than in the equatorial ocean. It also shows higher amounts of anthropogenic CO_2 in the shallower density layers (i.e., nearer to its source in the atmosphere) than in deeper layers.*

been collaborative work in estimating the anthropogenic carbon inventory based on hydrographic observations during the global CO_2 survey sponsored by NOAA and the Department of Energy, and air-sea CO_2 fluxes from observations of surface water pCO_2 on NOAA research ships. The high quality data, together with innovative methods to correct historical data (POC4), has led to robust estimates of the penetration of anthropogenic carbon into the ocean (Figure 5, from Peng *et al.,* 1998, *Nature*, 396, 560-563)[3]. This figure shows change between the surveys of 1978 and 1995 in the Indian Ocean at latitudes south of about 15°S. These methods are now being applied to make global anthropogenic carbon inventory estimates. To gain better understanding of shorter-term variations in air-sea CO_2 fluxes, we've instituted an active program of measurements of pCO_2 on ships and contributed to the first global monthly climatology of air-sea CO_2 fluxes (POC5). The climatology was subsequently used to estimate the interannual variability in air-sea fluxes, suggesting significantly smaller year-to-year changes than from atmospheric inference (POC6). This issue of variability and trends is of importance to determine the controls of carbon sequestration by the ocean. A new technique has been developed to measure trace level nutrients in oligotrophic waters (POC7), and the new production can be estimated based on the diel cycle of nitrate in the euphotic zone (POC8) on diurnal time scales.

The atmospheric chemistry effort at AOML has included an effort to measure and characterize the reactive nitrogen oxide gases in the marine environment. These gases play a critical role in the control of ozone formation in the troposphere, and their source/sink and concentration distributions are a critical input for global tropospheric chemical models. Recent field programs include the pre-Indian Ocean Experiment (INDOEX) and INDOEX cruises aboard the NOAA ships *Malcolm Baldrige* and *Ronald H. Brown* in 1995 and 1999, respectively. Results obtained in the former cruise have been incorporated into a photochemical box model which indicated the unexpected role of halogens (BrO, HOBr, HBr) in constraining the budget of ozone in the remote marine boundary layer. Preliminary results from the 1999 INDOEX cruise (http://www-indoex/ucsd.edu) showed a significant impact of air pollutants in this region (POC9).

Atmospheric methyl bromide (CH_3Br), which is of both natural and anthropogenic origin, has been identified as a Class I ozone-depleting substance in the amended and adjusted *Montreal Protocol on Substances that Deplete Stratospheric Ozone*. With the role of the ocean in regulating the atmospheric burden of this and other halocarbons still uncertain, recent field, laboratory, and modeling studies

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[3]This paper was awarded the 1999 ERL Outstanding Scientific Paper Award.

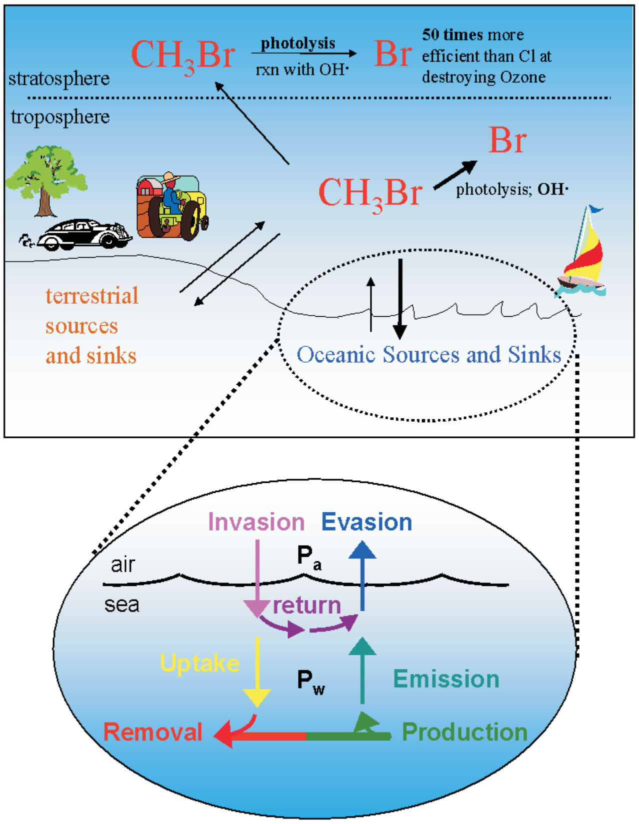


Figure 6*. Upper panel: Processes involved in the biogeochemical cycling of methyl bromide (CH_3Br). This trace gas, responsible for over half of the ozone depleting bromine delivered to the stratosphere, has both anthropogenic and natural sources and sinks. Lower panel: Coupled ocean-atmosphere system in more detail. P_a and P_w are the partial pressures of the species of interest in the air and in the water. The net flux is calculated as the difference between evasion and invasion, emission and uptake, or production and removal. Investigators at AOML conduct field studies on NOAA research vessels measuring P_a, P_w, net production, and depth profiles of CH_3Br and other halocarbons. Laboratory studies are currently underway at AOML to examine the ability of bacteria to degrade CH_3Br and other halocarbons. The results from both field and laboratory studies are being used in an in-house global model of this coupled ocean-atmosphere system that calculates global uptake rates and the partial lifetime of this and other atmospheric trace gases with respect to irreversible oceanic loss. The ocean is a significant source and sink of CH_3Br and other low molecular weight halocarbons involved in ozone depletion, global warming, and marine boundary layer chemistry. Warming of the ocean, changes in ocean currents, or altered surface winds resulting from global warming are likely to alter the flux of these gases across the air-sea interface, with concommitant effects on their contributions to important atmospheric processes. At this time, however, there are insufficient data to assess or predict how climate forcing will affect or be affected by the processes controlling the oceanic saturation or net flux of these trace gases.*

conducted in collaboration with investigators from the Climate Monitoring and Diagnostics Laboratory (CMDL) and universities have been designed to help improve our understanding of this role (Figure 6). We are improving our understanding of how biological (POC10) as well as chemical processes are important in the assessment of the ocean's ability to regulate atmospheric CH_3Br and other halocarbons (POC11).

In 1995-1996, the biological oceanography group at AOML led an Arabian Sea expedition under the aegis of Global Ecosystem Dynamics and Coupling (GLOBEC), one of the National Science Foundation's Global Climate Change programs (POC12). Using a range of acoustic frequencies, fish and zooplankton signals were distinguished, permitting rigorous quantitative analysis of the effect of monsoonal upwelling upon plankton biomass. Recent investigations of local upwelling and current structure have focused upon the relationship between temperature and local production processes and have highlighted eddy processes and local topographic effects (http://www.aoml.noaa.gov/ocd/globec).

Future AOML research will support the objectives of national and international research programs. In particular, we will contribute to the objectives of the Carbon Cycle Science Plan and the Surface Ocean Lower Atmosphere Study (SOLAS) through continued examination of the role that the ocean plays in regulating climatically important trace gases. Improved surface trace gas flux estimates requires expanded monitoring of surface water pCO_2 and halocarbon saturations, improved methods of interpolation, and better parameterization of air-sea gas fluxes. Understanding the processes controlling the surface water trace gas concentrations, such as improved understanding of nutrient dynamics, vertical diffusion, biological productivity, and biological degradation, are high priorities.

NOAA Global Ocean Observing System (GOOS) Center: NOAA is developing a new paradigm for operational oceanography by placing operational activities within research laboratories (POC13). A study using data provided by the global expendable bathythermograph (XBT) network illustrates how the synergy between operations and research functions (NOAA collects approximately 50% of the total global XBT profiles). Analysis such as the space-time diagram of subsurface temperature (Figure 7) was used to determine which transects should be continued until a global profiling float array is deployed (an operational goal) and continues to be used to study

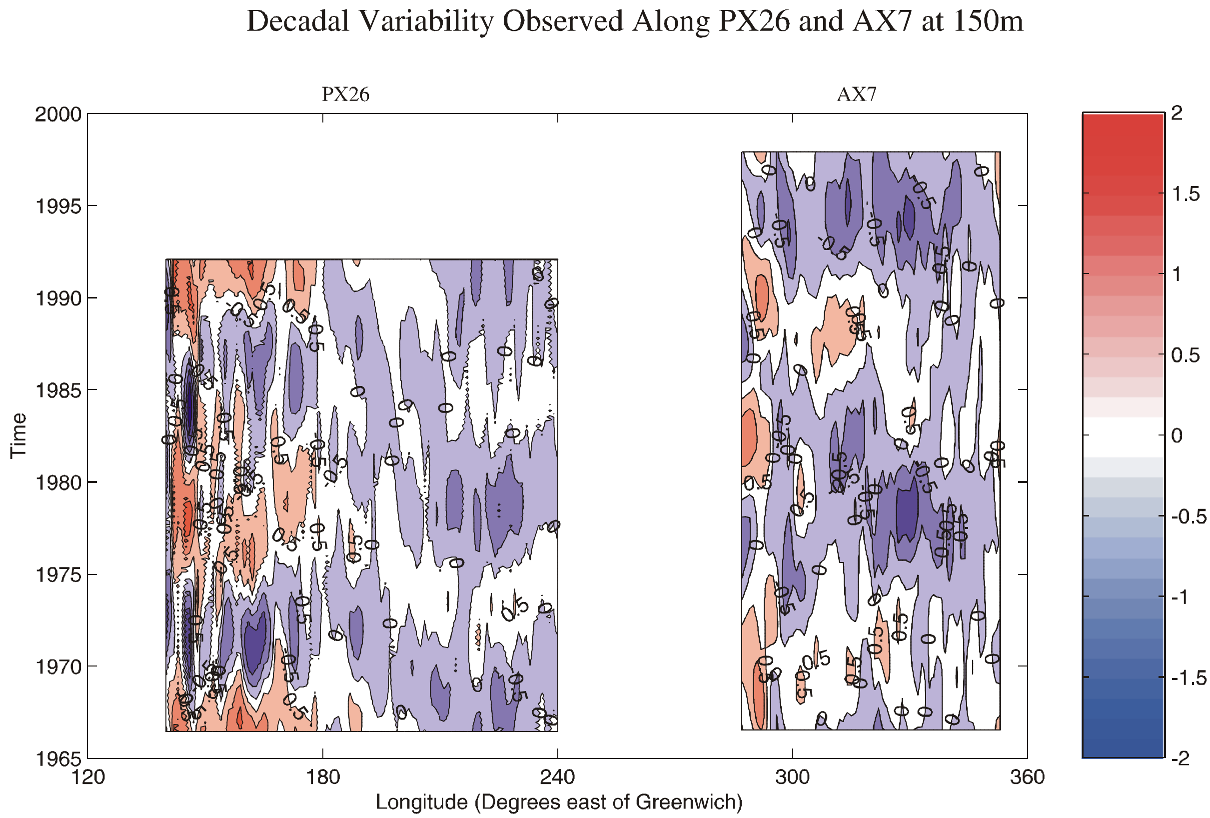


Figure 7*. As part of an international evaluation of the XBT network, AOML generated time-distance plots of subsurface temperature properties for transects through the subtropical gyres of the Pacific and Atlantic Oceans. The plots show very similar decadal signals, as do similar plots from transects crossing other regions of the northern hemisphere basins (not shown). Time-longitude variability from trans-oceanic Volunteering Observing Ship/XBT transects in the Pacific (PX26) and Atlantic (AX7). Monthly temperature anomalies at the thermocline depth are binned to one degree of longitude and filtered to remove variability at periods of less than seven years. Both oceans show strong decadal variability, intensified near the western boundaries.*

decadal signals in the ocean and possible interactions with atmospheric climate (POC14, POC15) (a research goal).

The GOOS Center incorporates the activities of the Global Drifter Program, which provides leadership and services from instrument procurement to data delivery for the global drifter array (GDA) of about 800 surface drifters (POC16). Sea surface temperature (SST) observations from the GDA are essential for creating SST analyses which are used in the initialization of National Center for Environmental Prediction (NCEP) ENSO predictions. Winds and sea-level pressures from the GDA are increasingly used for marine, regional, and global forecasts. Surface currents from the GDA are used in ocean global circulation models verification and in climate research. Products from the Global Drifter Program include a surface current climatology for the tropical Pacific Ocean for ENSO studies. Higher resolution surface current climatologies are in the works for the California Current and the world for oil spill mitigation efforts by the Minerals Management Service and for search and rescue operations of the Coast Guard.

The GOOS Center is working to improve the use of data in ocean models for predicting seasonal-to-interannual climatic variability. Recent research has led to a widespread realization that ocean models can be greatly improved with the addition of salinity-depth information (POC17). In the absence of an adequate observing system for salinity, it is necessary to leverage other types of data. In and below the thermocline, temperature-salinity correlations can be used to exploit XBT data. Near the surface, sea surface salinity could be monitored inexpensively. Additional information is available from satellite altimetric inferences of dynamic height. Our examination of NCEP's model-based reanalysis has revealed that the salinity of the equatorial undercurrent is generally too fresh, a fact that might be attributable to the treatment of the Indonesian throughflow. A related activity is our National Oceanographic Partnership Program collab-

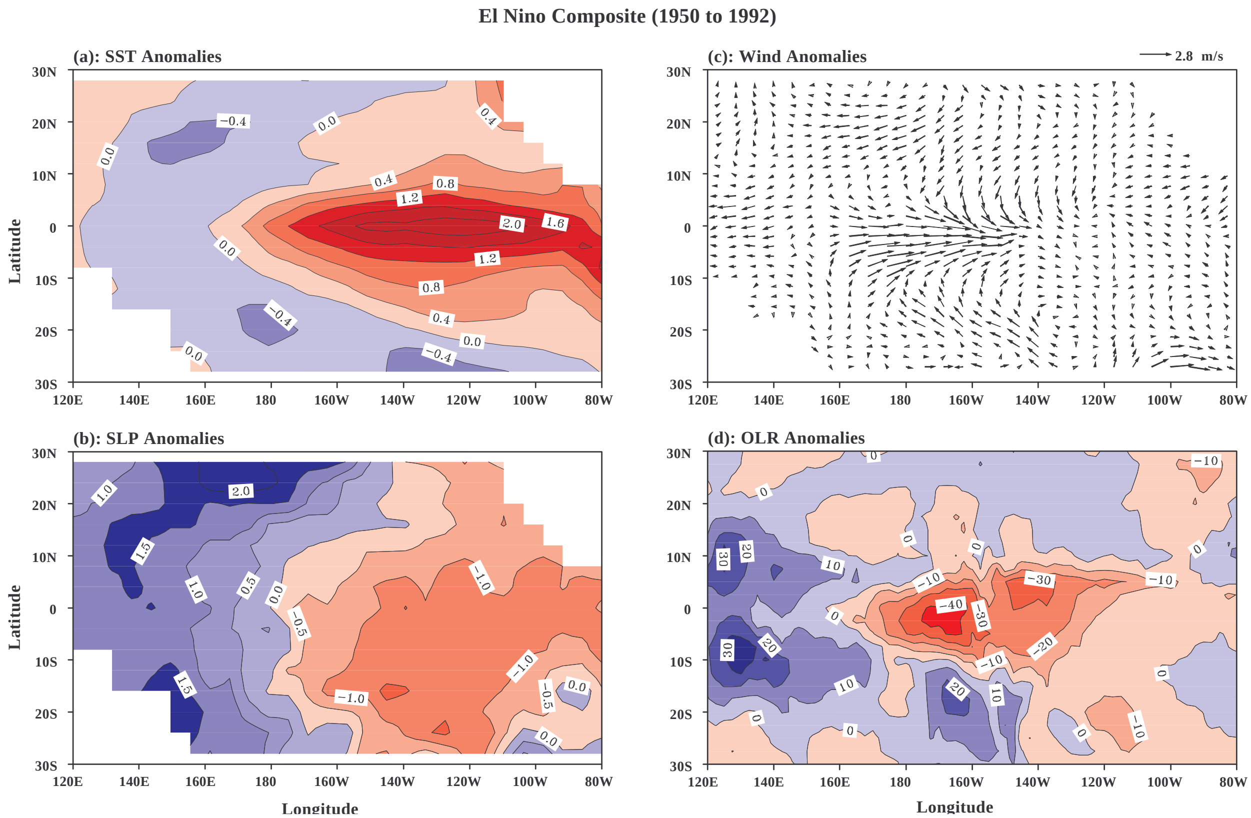


Figure 8. *The El Niño composite of (a) SST anomalies, (b) SLP anomalies, (c) surface wind anomalies, and (d) OLR anomalies (Wang et al., 1999). El Niño displays western Pacific anomaly patterns in addition to eastern Pacific anomaly patterns. During the peak phase of El Nino, warm SST and low SLP anomalies in the equatorial eastern Pacific and low OLR anomalies in the equatorial central Pacific are accompanied by cold SST and high SLP anomalies in the off-equatorial western Pacific and high OLR anomalies in the off-equatorial far western Pacific. Also, while the zonal wind anomalies over the equatorial central Pacific are westerly, those over the equatorial far western Pacific are easterly. AOML is studying these neglected western Pacific relationships and is consolidating them into a unified theoretical model that combines them with the postulated mechanisms of other ENSO scientists.*

oration (AOML, University of Miami, Los Alamos National Laboratory, Naval Research Laboratory) for assimilating data into HYCOM, a model that is distinctly different from that used by NCEP, to produce an alternative 30-year reanalysis.

Future GOOS Center activities will include: (1) continued evaluation of the XBT network and identification of important climate signals; (2) new World-Wide Web products using the GOOS Center data to market the data and to monitor the state of the upper ocean; and (3) increased interactions with NCEP to improve data management methodology, efficacy of the observing network, and the forecast models.

Pacific Studies:

Phenomena important for tropical Pacific climate variability include interannual variability of the El Niño-Southern Oscillation (ENSO) and Pacific decadal variability. Since the Pacific Ocean is the largest ocean on the Earth, its climate phenomena largely affect weather around the world. Better description and understanding of these Pacific phenomena and their associated mechanisms are important steps toward finally providing reliable climate prediction for the general public. AOML has been conducting observational, numerical modeling, and theoretical studies of ENSO, Pacific decadal variability, ocean-related processes in the inter-tropical convergence zone/cold tongue region, impact of NCEP model initializations on ENSO prediction, and response of greenhouse gases to El Niño.

Observational studies performed at AOML show that ENSO displays western Pacific anomaly patterns in addition to eastern Pacific anomaly patterns (Figure 8). During the warm phase of ENSO, warm SST and low sea level pressure (SLP) anomalies in the equatorial eastern Pacific and low outgoing longwave radiation (OLR) anomalies in the equatorial central

The Western Pacific Oscillator

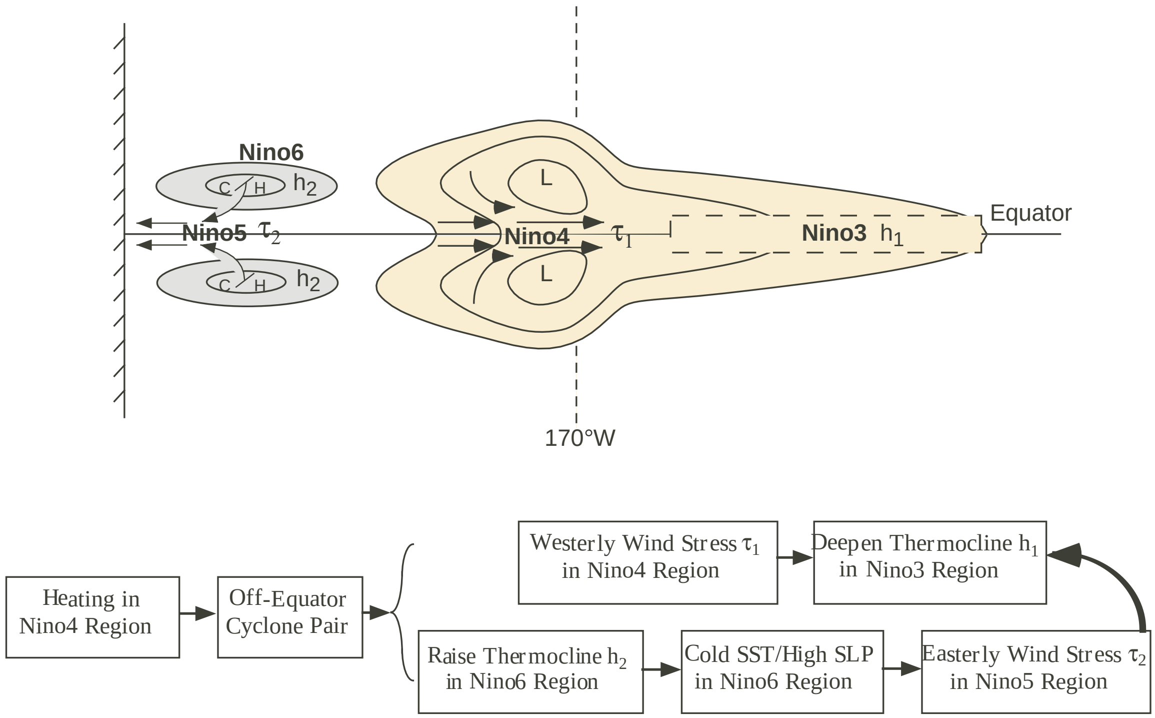


***Figure 9**. Schematic diagram of the western Pacific oscillator for ENSO. Condensation heating in the western central Pacific induces a pair of off-equatorial cyclones with westerly wind anomalies on the equator. These equatorial westerly wind anomalies act to deepen the thermocline and increase SST in the equatorial eastern Pacific, thereby providing a positive feedback for anomaly growth. On the other hand, the off-equatorial cyclones raise the thermocline there via Ekman pumping. Thus, a shallow off-equatorial thermocline anomaly expands over the western Pacific leading to a decrease in SST and an increase in SLP in the off-equatorial western Pacific. During the mature phase of El Niño, this off-equatorial high SLP initiates equatorial easterly wind anomalies in the western Pacific. These equatorial easterly wind anomalies cause upwelling and cooling that proceed eastward as a forced ocean response providing a negative feedback for the coupled ocean-atmosphere system to oscillate. Scientists at AOML are continuing to work on ENSO mechanisms by developing a unified ENSO oscillator model that includes the delayed oscillator, the western Pacific oscillator, the recharge-discharge oscillator, and the advective-reflective oscillator.*

Pacific are accompanied by cold SST and high sea level pressure anomalies in the off-equatorial western Pacific and high outgoing longwave radiation anomalies in the off-equatorial far western Pacific. Also, while the zonal wind anomalies over the equatorial central Pacific are westerly, those over the equatorial western Pacific are easterly. The nearly out-of-phase behavior between the eastern and western tropical Pacific is also observed during the cold phase of ENSO, but with anomalies of opposite sign. The western Pacific anomaly patterns are important for the evolution of ENSO since equatorial easterly (westerly) wind anomalies in the western Pacific produce ocean responses that proceed eastward to terminate (initialize) El Niño (POC18) (Figure 9).

AOML performed a theoretical study toward understanding why ENSO occurs on interannual time scales, or why the Earth has the interannual phenomenon of ENSO. A new, unified ENSO theory was developed at AOML. This unified ENSO theory includes the physics of the delayed oscillator, the western Pacific oscillator, the recharge-discharge oscillator, and the advective-reflective oscillator that have been previously proposed to interpret the oscillatory nature of ENSO (POC19). All of these oscillator models assume a positive ocean-atmosphere feedback in the equatorial eastern and central Pacific. The delayed oscillator assumes that the western Pacific is an inactive region, and wave reflection at the western boundary provides a negative feedback for the coupled system oscillate. The western Pacific oscillator emphasizes an active role of the western Pacific in ENSO. The recharge-discharge oscillator argues that discharge and recharge of equatorial heat content make the coupled system oscillate. The advective-reflective oscillator emphasizes the importance of zonal advections associated with wave reflection at both the western and eastern boundaries.

Motivated by the existence of these different oscillator models, a unified oscillator model is formulated and derived from the dynamics and thermodynamics of the coupled ocean-atmosphere system. All of the different oscillators can be extracted as special cases of the unified oscillator. This unified oscillator model shows an ENSO-like oscillation. As suggested by this new ENSO theory, all of the previous ENSO mechanisms may be operating in nature.

We investigated the impact of tropical Pacific decadal/interdecadal variability on ENSO variability and the interactions between the tropical and extratropical Pacific Oceans. Coupled ocean-atmosphere model runs performed at AOML show both tropical Pacific interannual and decadal/interdecadal variability. The slow decadal/interdecadal variation in the model mean thermocline affects the intensity and frequency of ENSO events. The model ENSO shows modest-amplitude oscillations between large-amplitude oscillations, an increase in frequency of El Niño, and an absence of La Niña during some periods. The studies at AOML pointed out that the atmospheric meridional Hadley Circulation may also serve to link the tropical and extratropical Pacific Oceans, in addition to the oceanic linkage by the influx of ocean water from high latitude. Both the oceanic and atmospheric processes, as well as local ocean-atmosphere coupling, are responsible for the observed climate variability of the coupled tropical-extratropical ocean-atmosphere system.

Scientists at AOML will continue to investigate Pacific climate variability by a combination of observational and numerical modeling studies. We will be interested in seeing how coupled global climate models perform in the western Pacific. If the western Pacific anomaly patterns are not in the models, then our analyses will provide directions for improving the coupled model and, hence, improving dynamically-based predictions. If they are in the models, we can quantify to what extent they play a role in ENSO evolution.

We use observations to describe and diagnose the ocean-related processes which control the evolution of heat content in the mixed-layer (and therefore SST) for several regimes within the inter-tropical convergence zone/cold tongue region. We also make direct comparisons with the NCEP ocean reanalysis to assess the ability of ocean global circulation models to adequately simulate the observed processes (POC20).

The NCEP ENSO predictions rely on initializations of the ocean state. We have found large differences between the initialized ocean states and observations in the western tropical Pacific, usually between about 150°E and 180°. These differences propagate eastward from about 150°E in mid 1996 to 160°W in mid 1997 and to about 110°W by early 1998. Recall that mid 1996 precedes the development of the 1997 El Niño while mid 1997 corresponds to the time during which the event developed into one of the largest events of the century. We hypothesize that these large differences result from times when westerly wind bursts cause the ocean to respond in a way that the model system cannot capture. We need to check this out by correlating the occurrence of westerly wind bursts with the development of these strong model/observation differences. Ultimately, we hope to assess the impact of this error on the ENSO predictions.

The equatorial Pacific upwelling supplies approximately 0.3-1.2 PgC (=Gton C) CO_2 to the atmosphere annually. During non-El Niño years, upwelling of waters enriched in nutrients and CO_2 extends from the coastal waters west of South America to approximately 160°E. The large area affected by the upwelling process makes this region the largest oceanic source of CO_2 to the atmosphere. A comprehensive set of atmospheric and surface ocean pCO_2 measurements and supporting hydrographic data were obtained from 1992 through 1999 on NOAA research ships servicing the Tropical Atmosphere Ocean (TAO) array. The 1992-1994 cruises occurred during a prolonged mild El Niño, the 1995-1996 cruises occurred during the well developed cold tongue conditions, and the 1997-1998 cruises occurred during the strongest El Niño of this century (POC21) (Figure 10). This was followed by a strong La Niña contrasting the effect of the ENSO on the CO_2 cycling. During El Niños, the subsurface supply of CO_2 diminishes and fluxes decrease dramatically, while during La Niñas enhanced upwelling brings more waters enriched with CO_2 to the surface. Quantification of these fluxes is critical if we are to improve understanding of atmospheric CO_2 trends and projection of future atmospheric CO_2 levels.

Future work will include increasing data coverage by utilizing floats and additional ships of opportunity, and improved spatial and temporal interpolation techniques to better quantify the flux. Remote sensing of SST, chlorophyll, and surface wind will be a critical

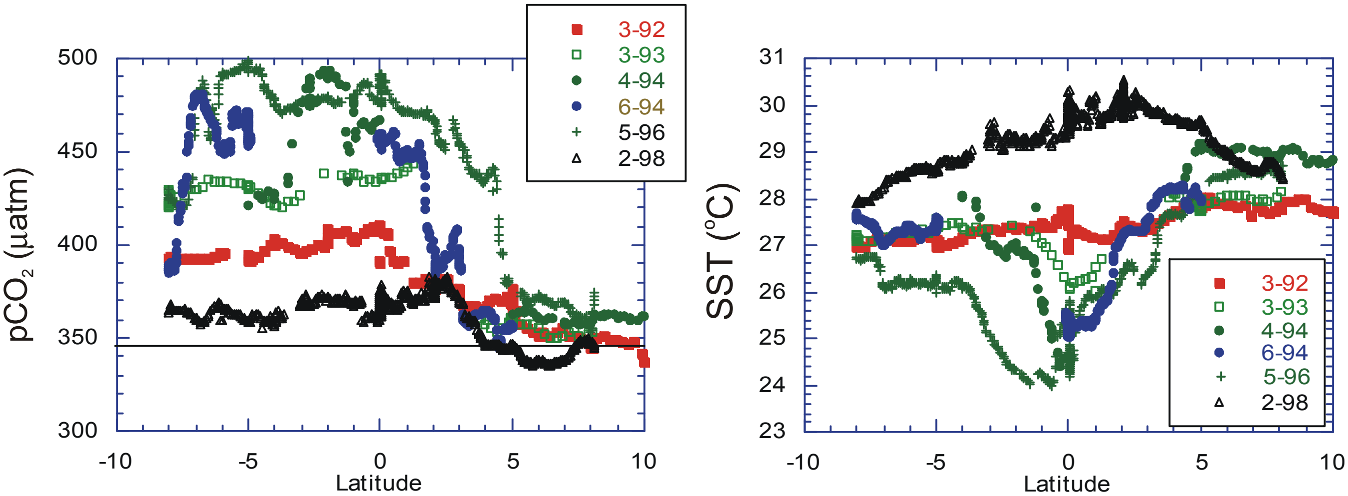


***Figure 10**. Changes of pCO$_2$ (left) and SST (right) over time along 110°W in response to the ENSO cycle. During El Niños, the efflux of CO$_2$ is depressed. The dates in the panel, denoted by the month followed by the year (e.g., 6-94), give the dates when the data were collected.*

component. To improve our mechanistic understanding, shipboard measurements of pCO$_2$ will be augmented with those of chlorophyll, oxygen, and total carbon. This work will continue in strong collaborative fashion with Dr. R. Feely at PMEL, Dr. F. Chavez at the Monterey Bay Aquarium Research Institute, and investigators in Japan (Drs. Inoue and Ishii) and France (Drs. Boutin, Etcheto, and Dandonneau).

Atlantic Studies:

Studying the seasonal to interannual variability in upper ocean thermal energy content, transport, and property fluxes of heat, fresh water, and carbon is important in order to monitor and understand how the ocean influences climate fluctuations, and to improve our ability to predict important climatic signals such as the North Atlantic Oscillation (NAO) and tropical Atlantic variability. The thermohaline circulation is known to occur at long time scales in equal importance or even more importance than the wind-driven circulation because it couples the full volume of the global ocean to the atmosphere, forming a global circulation network of mass and heat transports. The classical picture of the "conveyor belt" indicates that the North Atlantic exports cold deep water and imports warm upper ocean water from the South Atlantic. This thermohaline overturning cell is composed of northward transports of warm surface- and intermediate-layer waters in the upper 1000 m, southward transport of North Atlantic Deep Water (NADW), and at the bottom northward flowing Antarctic Bottom Water. The net balance is to the north and, as a result, the Atlantic is a peculiar ocean because it is the only ocean that transfers heat northward across the equator.

Some intriguing and yet unanswered questions are: How much heat is transported into the North Atlantic and from where does it come? What are the main passages from the South to the North Atlantic? How is the upper limb of the "conveyor belt" circulation supplied? How do changes in the strength of the lower limb affect the atmosphere away from the poles? And what is the ocean's role in modifying the atmospheric circulation on interannual and decadal time scales?

Key questions in the North Atlantic focus on the forcing of decadal signals in the NAO through heat content/flux variability and changes in the overturning circulation. Through observational programs, AOML has been conducting studies into the variability of the ocean circulation in the center of the Atlantic subtropical gyre. Some of the key findings have been: (1) decadal signals in subsurface temperatures and transport that are correlated with atmospheric patterns such as the NAO (Figure 11); (2) seasonal variability in poleward heat flux, suggesting the importance of high frequency variability on important climate forcing agents; (3) long-term changes in deep water mass characteristics such as Labrador Sea Water (Figure 12); and (4) a major reduction in Southern Ocean deep water production during the 20th century that may be explained by chemical tracers analysis (POC22). Contributing observational programs that have resulted in advancing our understanding of the

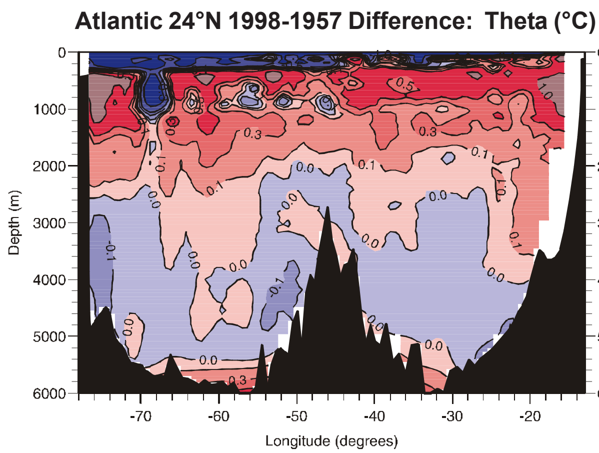


***Figure 11**. Decadal variability in surface heat fluxes can most clearly be seen from high quality hydrographic sections sufficiently accurate enough to measure the small changes in temperature seen between sections taken during different epochs. The ocean effectively integrates small changes in surface heat flux that result in small biases in sea surface temperature which become subducted and overturned into the deep water. Repeat hydrographic measurements taken at the same location through time can then be differenced to get indicators of climate change. Shown here is the temperature difference along pressure surfaces between the Ronald H. Brown (1998) and Discoverer (1957) hydrographic sections. Large warming of the water column from 300-2500 m is seen, suggesting increased surface heating in the northern North Atlantic over these decades. The strong negative temperature difference above 300 m is due to the fact that the 1957 data was taken during summer and the 1998 data was taken during winter.*

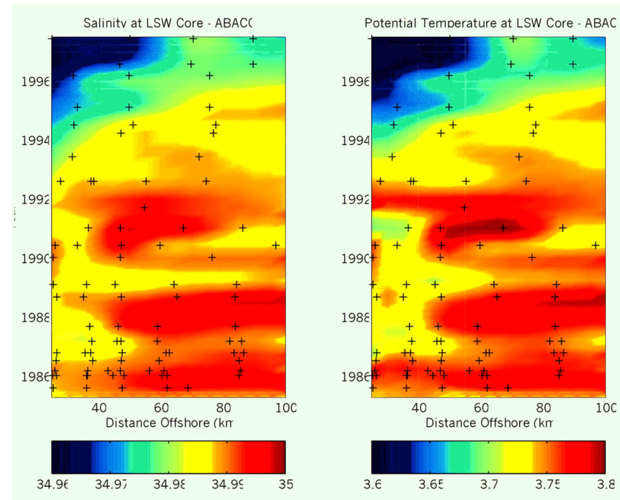


***Figure 12**. Time series of temperature and salinity at the depth of Labrador Sea Water obtained from data collected east of Abaco Island, the Bahamas (26.5°N). Crosses represent station positions. The section is taken across the axis of the Deep Western Boundary Current. The Deep Western Boundary Current transports Labrador Sea Water from its source region in the Labrador Sea to south of the equator and is an important component of the global meridional overturning circulation. Prior to 1993, temperature and salinity characteristics are relatively uniform. After 1993, temperature and salinity begin decreasing dramatically, beginning at the boundary and then extending offshore. This change in water mass characteristics indicates the arrival of Labrador Sea Water formed some 10 years earlier, indicating that the Deep Western Boundary Current advects waters from the Labrador Sea at faster rates than previously thought. These findings have important implications in studies of the ocean's ability to uptake atmospheric gases such as carbon dioxide.*

ocean's role in forcing climate fluctuations include: (1) long term and repeated measurements of the deep water properties off the coast of Florida (Abaco Island, Bahamas) and transatlantic sections along 24°N (POC23); (2) high frequency sampling of the upper ocean temperature through the Volunteer Observing Ship (VOS) program using expendable bathythermographs (XBTs) in both high horizontal resolution and low resolution mode; and (3) sustained transport observations of the Florida Current using low cost voltage measurement supplied from undersea telephone cables (Figure 13) (POC24). A new project for FY-00 is the analysis of historical hydrological data sets for the Black Sea with the goal of studying the response of an enclosed sea to changes in the Europe-North Atlantic climate system (POC25).

In the tropical and South Atlantic, key questions center on the pathways of the upper limb of the overturning circulation: How much warm and salty upper layer water enters the Atlantic from the Indian Ocean? How much is colder and fresher water

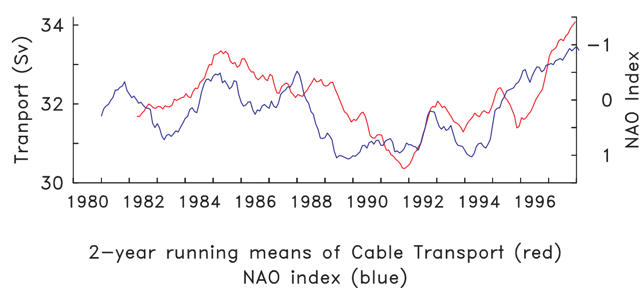


***Figure 13**. Florida Current transports are measured from West Palm Beach, Florida to the Bahamas via a submerged submarine cable. Voltage differences are measured at either end of the cable coupled with simple electromagnetic theory that says charged particles (water) moving through earth's magnetic field will create a current (voltage) which gives a measure of how fast the water is moving through the Straits of Florida. Measurements taken since 1982 show a high correlation (0.9) with the NAO Index. The NAO is a measure of variability in atmospheric surface pressure difference between Portugal and Iceland which has been shown to be correlated with the climate of the continental U.S. and hurricane formation. Continued measurements of Florida Current transport may help unravel the mystery of coupling between the ocean and atmosphere at decadal time scales.*

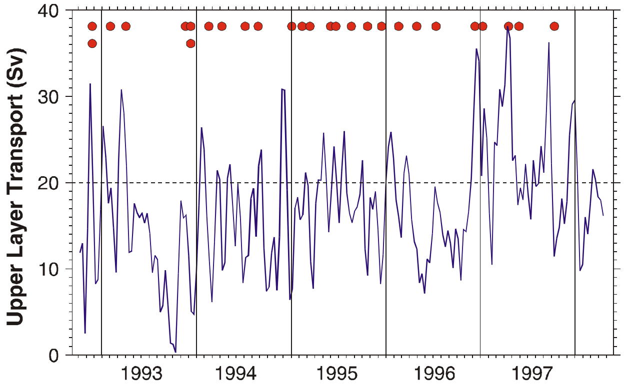


Figure 14. Another area that requires special attention because of its role in the thermohaline circulation is the southern tip of South Africa where exchange between the Indian and Atlantic Oceans takes place. One of the key questions still to be answered is how much heat and salt is transferred from the Indian to the Atlantic Ocean and what are the processes involved in this exchange. This figure shows the time series of the upper layer, westward baroclinic mass transport from the Indian to the Atlantic Ocean (solid line), and times when Agulhas rings were shed (circles). The transport was calculated using a combination of hydrographic and altimeter data and a simple model that relates the sea height anomaly with the depth of the upper layer. A strong interannual variability is observed. During 1997, the average transport of the Agulhas Current is significantly higher (23 Sv) than the long term mean (15.7 Sv). In spite of the high transport in 1997, the number of rings shed at the retroflection (4) was smaller than the other years (4 to 7), but each one of the rings transported twice the average volume of mass and heat. Variability of the strength of the retroflection and number and size of the eddies shed have a direct implication on the thermohaline circulation. Further observational and theoretical studies are needed to fully understand the process and its role in the global climate.

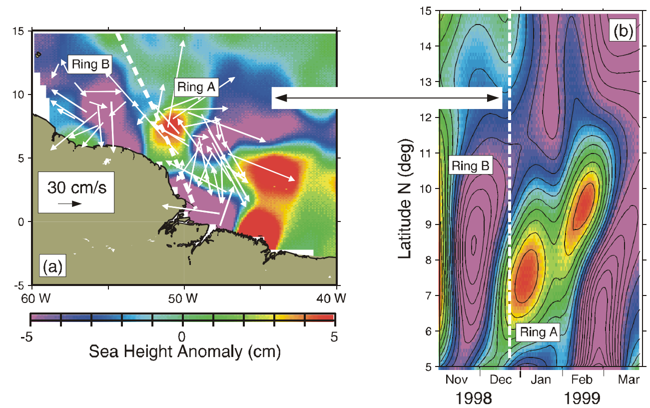


Figure 15. The North Brazil Current is responsible for a large part of the cross-equatorial transport of waters from the South Atlantic into the North Atlantic basin. This current retroflects to the east 2 degrees north of the equator, shedding warm rings which ultimately reach the Windward Islands and the Caribbean Sea. From TOPEX/Poseidon-derived sea height, this figure shows the conditions for December 10-20, 1998: (a) Regions of higher sea height anomalies (yellows and reds) are associated with warm anticyclonic features. There is a warm ring (Ring A) at approximately 7.5°N, and the North Brazil Current retroflection at approximately 5°N. The acoustic Doppler current profiler-derived velocity vector field at 150 m depth is superimposed and shows that west of Ring A there is an anticyclonic feature, with no surface signature, undetected by altimetry. The dotted white line shows the TOPEX/Poseidon groundtrack d311. (b) A space-time diagram of the TOPEX/Poseidon-derived sea height anomaly field for groundtrack d311 shows Ring A and a second ring that crosses this groundtrack during February 1999. Although altimetry represents a very useful tool to detect these warm features, the need for continuous hydrographic surveys is clearly shown in this example.

originating out of the Drake Passage? What are the main pathways of the two competing sources and the mechanisms that originate the transfers? Studies at AOML have already shown: (1) the important role of the Benguela Current and Agulhas rings shed at the retroflection in supplying the tropical Atlantic with warm, near-surface waters as part of the upper limb of the overturning circulation (Figure 14); (2) that boundary current variability of the North Brazil Current creates between five to eight eddies a year that transport water from the Southern Hemisphere northward (Figure 15); (3) that near the equator and in the interior, the circulation pathways follow complicated patterns and contain substantial seasonal variability (Figure 16); and (4) that the upper limb of the overturning circulation once across the equator enters the Caribbean Sea through the southernmost passages of the Caribbean Island chain (Figure 17).

Observational programs that have answered some of these questions include: (1) the PALACE floats experiment, to study the pathways of the intermediate water in the equatorial region and to measure the upper ocean thermal field in the tropical Atlantic (POC26); (2) the Benguela Current Experiment, to understand the interocean exchanges of heat and mass and to follow the path of the intermediate water from the Indian to the Atlantic Ocean (POC27); (3) the North Brazil Current Rings Experiment, to determine and quantify the role of the rings shed at the retroflection of the North Brazil Current on the transfer of heat and mass from the South Atlantic to the North Atlantic (POC28); and (4) The Windward Island Passage Monitoring Experiment to study the partition and variability of upper ocean transport along the Caribbean Island Chain (POC29).

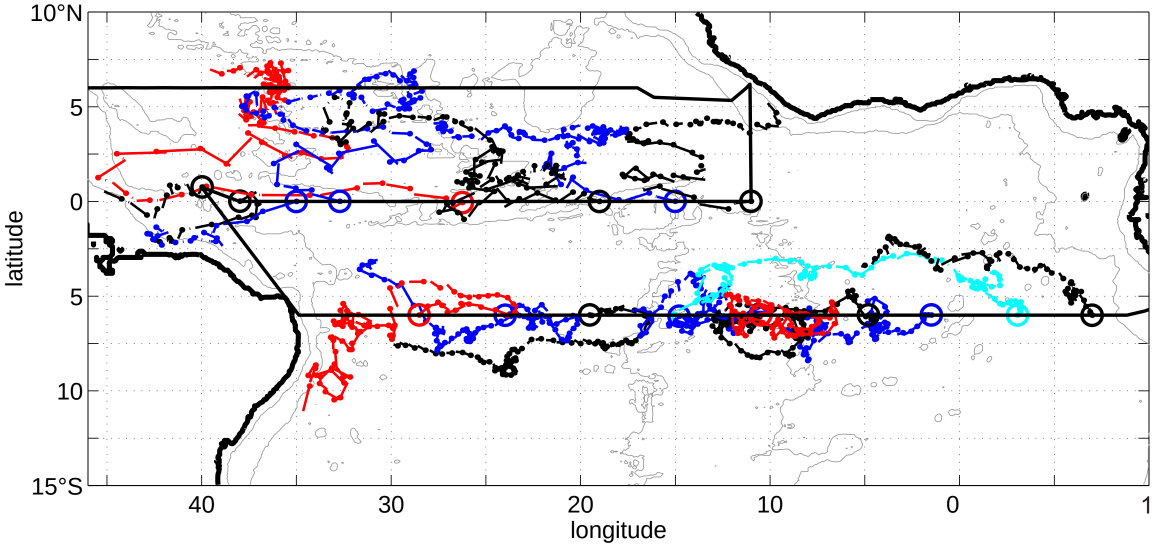
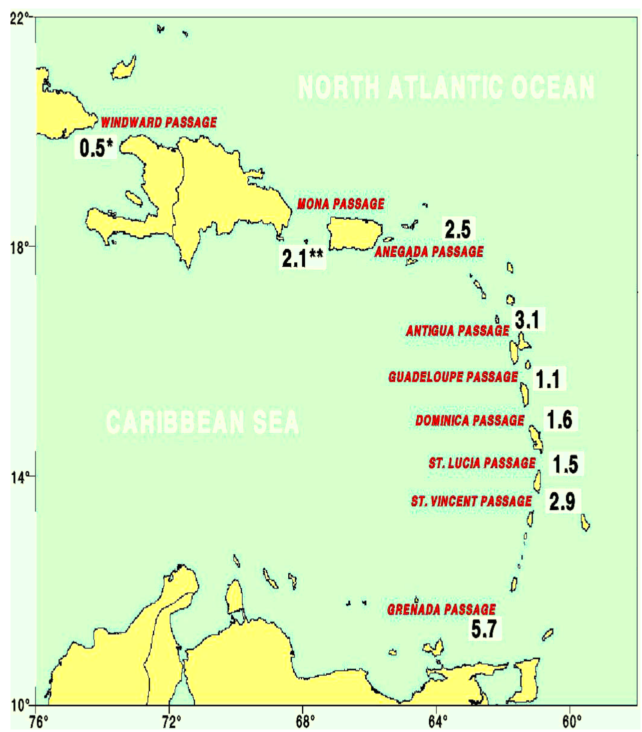


Figure 16. Trajectories of PALACE floats in the tropical Atlantic during the period July 1997 through November 1999 ballasted to drift at 1000 dbar and programmed to surface every 10 days to transmit in real time, via satellite, the profile obtained while rising to the surface. The instruments were deployed during the 1997 R/V Seward Johnson cruise (solid black lines). Each submerged trajectory segment is shown as a line starting at a dot. The trajectories reveal three regions of different flow characteristics. The equatorial band is characterized by high velocities (long trajectory segments), with a mean speed between 1°S and 3°N of about 10 cm/s. Further north, 3-8°N, and further south, 2-8°S, the speed is about half as large (shorter trajectory segments). Another difference between the high and the low energy regimes is that, in the latter, some of the PALACE floats tend to stay a long time in a small area, e.g., the three red trajectories are more than two years long. The one near 5°S, 10°W does not reveal much displacement whereas the trajectories at and north of the equator cover large distances. Several zonal currents can be identified in the trajectories. These are the westward Equatorial Intermediate Current between about 1°S and 1°N, the Northern Intermediate Countercurrent in 2-3°N west of 25°W and at about 1°N further east, as well as the central branch of the intermediate South Equatorial Current between 2°S and 4°S (black and light blue trajectories starting at 6°S, 0-10°E). The flow pattern between 4°S and 8°S does not show persistent zonal currents over longer periods of time; instead, typical periods are shorter than four months.

Figure 17. Direct measurements of transport in the Atlantic-Caribbean Passages from 1991-1998 have produced mean transports shown. Around 20 Sv of the approximately 32 Sv that flows through the Florida Straits enters the Caribbean south of the Virgin Islands, where southern hemisphere water masses dominate. A pilot program is underway (Caribbean Inflow Variability, with RSMAS and PMEL) to continuously measure the transport through the Grenada Passage via telephone cable and sea level to better understand the mesoscale transport variability and discern long-period changes in transport.



A Vision for the Future:

AOML will be a major NOAA center for the collection, dissemination, and use of global oceanographic and surface marine atmospheric data needed to increase the agency's ability to:

• Accurately forecast weather and climate,

• Increase confidence in global warming and climate change scenarios,

• Improve our understanding of the role of the oceans in the cycling of climatically important trace gases, and

• Increase understanding of air sea interactions.

To achieve these objectives, AOML research and operational efforts during the next five years will be expanded in the following areas:

• Continue and intensify large scale climate research: It is our plan to (a) intensify our research on ocean-atmosphere interactions in the Atlantic sector with an eye to extracting maximum value from the evolving Atlantic observation system; (b) continue to study the meridional overturning circulation in the Atlantic Ocean; and its relation with the North Atlantic Oscillation and the role of the ocean in modifying the atmospheric circulation on interannual and decadal scales with particular emphasis in the tropical Atlantic; and (c) continue to explore the interactions between Pacific and Atlantic variability, and between the interannual and decadal time scales, and their impacts on climate variability of the western hemisphere, including Pacific ENSO variability.

• Constrain the oceanic carbon sink on seasonal to decadal time scales as part of the U.S. carbon cycle science plan: On seasonal time scales we will improve the estimates of air-sea fluxes by leading process studies to parameterize the gas transfer velocity with new methodology, and by increasing spatial and temporal coverage of surface ocean CO_2 measurements using autonomous instruments from ships of opportunity and drifters. This work will closely dovetail into the GOOS activities at AOML. On decadal timescales we will reoccupy a critical subset of WOCE cruise lines and perform hydrographic, tracer, and CO_2 system measurements to quantify the anthropogenic CO_2 increase in the ocean.

• Assess the role of oceanic uptake and emission of halocarbons and hydrocarbons on atmospheric ozone levels on atmospheric ozone and climate change: AOML will improve the oceanic source/sink functions used by chemical and climate models by mapping the oceanic saturations for these trace gases using automated instruments on ships of opportunity. This work ties in well with the GOOS objectives. We will continue to examine the processes controlling these saturations through intensive field and laboratory studies built on the framework of the global mapping project. The combination of continuous ocean monitoring and intensive studies will allow us to establish forcing functions for uptake and emission fluxes to include in models, both in-house and extramural, that can examine the potential feedback that may affect and be affected by climate change.

• Fortify research on the climate of the Intra-Americas Sea (IAS) region: The emergence of multiple programs for climate research and applications in the Americas (PACS, IAI, IRI), AOML's natural interests and contacts in the Caribbean and surrounding region, and AOML's pioneering research and participation in IAS initiatives, all point to the future strategic importance of the IAS climate for both the U.S. and our neighbors to the south. AOML can play a key role in this process, and we will continue to increase our efforts to understand the regional ocean-atmosphere interactions, the IAS linkages to global climate patterns, and the effects of IAS ocean variability on pollutants and marine resources. We will also cooperate with concerned regional and international entities to improve the applications of our research to the regional needs of agriculture, energy, and marine resources.

In what concerns operations, it is our plan to:

• Strengthen the GOOS Center activities: Global sustained observations of the ocean and overlying atmosphere are needed to satisfy NOAA's weather and climate missions and for use in major research programs (*e.g.,* CLIVAR). The NOAA GOOS Center will participate in activities to (1) improve instrumentation, (2) increase the quality and quantity of required data, (3) increase accessibility to our data, and (4) generate products that will characterize the present state of the ocean.

• Formulate and participate in the design and operations of a Climate Observing System for the Tropical Atlantic: Research conducted at AOML and other institutions has shown that the tropical Atlantic Ocean plays an important role in the climate of the eastern United States and the Caribbean. There is a need for additional observations both to support climate studies and to enhance forecast capabilities. AOML has played a leading role in planning and implementing the Tropical Observing System and will continue to use the data to study the interactions between the tropical Atlantic and global climate.

To achieve our vision, it will also be necessary for AOML scientists to be more proactive in the generation of new programs that will attract support from the Executive Branch and Congress. AOML scientists are actively working on obtaining this support through the planning and development of major scientific (GODAE, CLIVAR, COSTA, PACS, ACVE, SOLAS, COAG) and operational (GCOS, GOOS) programs. AOML scientists also participate in the NOAA strategic planning activities. We plan to continue and reinforce those activities.

Scientists from AOML include: Molly Baringer, Hugo Bezdek, David Bitterman, Robert Castle, Steven Cook, Shailer Cummings, David Enfield, Oleg Essenkov, John Festa, David Forcucci, Silvia Garzoli, Gustavo Goñi, Kelly Goodwin, Donald Hansen, Elizabeth Johns, Kitack Lee, Dennis Mayer, Alberto Mestas-Nuñez, Robert Molinari, Peter Ortner, David Palmer, Tsung-Hung Peng, Claudia Schmid, Derrick Snowden, Mark Swenson, Carlisle Thacker, Chunzai Wang, Rik Wanninkhof, Douglas Wilson, Shari Yvon-Lewis, and Jia-Zhong Zhang.

Collaborating scientists include: James Butler (Climate Monitoring and Diagnostics Laboratory); Dean Roemmich (Scripps Institution of Oceanography); Scott Doney (NCAR); Sydney Levitus (NODC), John Bullister, Richard Feely, Greg Johnson, James Larsen, Calvin Mordy, Chris Sabine (PMEL); Paty Matrai (Bigelow Laboratory for Ocean Sciences); Rana Fine, William Johns, Jiangang Luo, Frank Millero, Peter Minett, Eric Saltzman, Sharon Smith (RSMAS); Van Holliday (TRACOR); Russell Dickerson (University of Maryland); Robert Weisburg (University of South Florida); Paul Quay (University of Washington); Dennis Hansell (Bermuda Biological Station for Research); David Fratantoni, Larry Madin, Michael McCartney, Wade McGillis, Phillip Richardson, Ray Schmitt (WHOI); Wallace Broecker, Taro Takahashi (Lamont-Doherty Earth Observatory, Columbia University); Alexander Suvorov (Marine Hydrophysical Institute).

Collaborating institutions: Bigelow Laboratory for Ocean Sciences; Climate Monitoring and Diagnostics Laboratory (NOAA); Environmental Technology Laboratory (NOAA); Monterey Bay Aquarium Research Institute (MBARI); PMEL (NOAA); Princeton University; RSMAS; University of California at San Diego; University of Maryland; University of South Florida; WHOI.

Laboratory Review Posters:

POC1 *Patterns of Variability in Global Sea Surface Temperatures* (David Enfield and Alberto Mestas-Nuñez)

POC2 *Equatorial Pacific SST Variability: ENSO and Non-ENSO Components* (Alberto Mestas-Nuñez and David Enfield)

POC3 *Tropospheric Direct Circulations Associated with the Climatic Components of SST Variability in the Equatorial Pacific* (David Enfield and Alberto Mestas-Nuñez)

POC4 *Reevaluation of Historical Carbon Data Based on Recent High Quality Measurements* (Tsung-Hung Peng and Rik Wanninkhof)

POC5 *Do We Really Know the Oceanic CO_2 Uptake to 0.5 Gigaton C?: The Effect of the Gas Transfer Velocity on CO_2 Fluxes* (Rik Wanninkhof, Wade McGillis [WHOI], and Taro Takahashi [Lamont-Doherty Earth Observatory, Columbia University])

POC6 *Interannual Variability in the Global Oceanic CO_2 Sink from 1979-1998: Diagnostic Studies using a Global Surface pCO_2 Climatology* (Kitack Lee, Rik Wanninkhof, Taro Takahashi [Lamont-Doherty Earth Observatory, Columbia University], Richard Feely [PMEL], and Scott Doney [NCAR])

POC7 *Shipboard Automated Determination of Trace Concentrations of Nitrite and Nitrate in Oligotrophic Water by Gas-Segmented Continuous Flow Analysis with a Liquid Waveguide Capillary Flow Cell* (Jia-Zhong Zhang)

POC8 *New Production Estimated from the Diel Cycle of Nitrate in Oligotrophic Waters* (Jia-Zhong Zhang, Rik Wanninkhof, and Kitack Lee)

POC9 *Trace Gases in the Marine Boundary Layer* (Thomas Carsey, Russell Dickerson [University of Maryland], Alexander Pszenny [MIT], and Michael Farmer)

POC10 *The Role of Biology in the Biogeochemistry of Halocarbons* (Kelly Goodwin)

POC11 *The Role of the Ocean in Regulating Atmospheric Halocarbons* (Shari Yvon-Lewis)

PCO12 *Arabian Sea: Global Ecosystem Dynamics and Coupling (GLOBEC)* (Peter Ortner, Shailer Cummings, David Forcucci, Sharon Smith [RSMAS], Jiangang Luo [RSMAS], Van Holliday [TRACOR], and Larry Madin [WHOI]

POC13 *The Global Ocean Observing System (GOOS) Center* (Steven Cook, Robert Molinari, and Derrick Snowden)

POC14 *Information Content in Low Resolution Expendable Bathythermograph Transects* (Derrick Snowden and Robert Molinari)

POC15 *The Role of XBTs in Understanding the Dynamics of Upper Ocean Variability from Interdecadal to Annual Cycle Time Scales and Interpreting Satellite Altimetric Observations* (Dennis Mayer, John Festa, Molly Baringer, Robert Molinari, and Gustavo Goñi)

POC16 *Drifting Buoy Data Assembly Center* (Mark Swenson, Mayra Pazos, Claude Jodoin, Oleg Esenkov, Daniel Mendoza, and John Stadler)

POC17 *Estimating Salinity Profiles for Climate Prediction* (Carlisle Thacker and Donald Hansen)

POC18 *The Role of the Western Pacific in ENSO* (Chunzai Wang, Robert Weisberg [University of South Florida], and Dennis Mayer)

POC19 *A Unified ENSO Theory* (Chunzai Wang)

POC20 *Observed Seasonal Cycle of Mixed-Layer Heat Advection in the NECC* (Mark Swenson and Donald Hansen)

POC21 *Underway pCO_2 Measurements on the NOAA Ship Ronald H. Brown* (Rik Wanninkhof, Richard Feely [PMEL], Robert Castle, and Betty Huss)

POC22 *Possible Thermohaline Circulation Changes in the Last Millennium* (Tsung-Hung Peng and Wallace Broecker [Lamont-Doherty Earth Observatory, Columbia University])

POC23 *Deep Water Hydrography in the Subtropical North Atlantic* (Molly Baringer, Douglas Wilson, Robert Molinari, Elizabeth Johns, Rik Wanninkhof, and Kitack Lee)

POC24 *Florida Current Transport Variability* (Douglas Wilson, Elizabeth Johns, and Molly Baringer)

POC25 *Oceanographic Characteristics of the Black Sea: Regional Classification, Season, and Interannual Variability - Construction of a Data Base and Digital Atlas* (David Palmer, Alexander Suvorov [Marine Hydrophysical Institute], and Sydney Levitus [NODC])

POC26 *Intermediate Depth Circulation in the Tropical Atlantic* (Claudia Schmid, Silvia Garzoli, and Robert Molinari)

POC27 *Benguela Current Experiment* (Silvia Garzoli, Philip Richardson [WHOI], and Gustavo Goñi)

POC28 *Rings of the North Brazil Current Experiment* (Silvia Garzoli, Gustavo Goñi, Douglas Wilson, William Johns [RSMAS], Philip Richardson [WHOI], David Fratantoni [WHOI], and Amy Ffield [Lamont-Doherty Earth Observatory, Columbia University])

POC29 *Transport through Major Caribbean Passages* (Douglas Wilson, William Johns [RSMAS], Elizabeth Johns, and Ryan Smith)

Regional and Coastal Environmental Research

Regional and coastal environmental problems have been a focus of AOML activities for more than two decades. Prior major interdisciplinary, multi-institutional efforts have included *inter alia*: Nutrient Enhanced Coastal Ocean Productivity; New York Bight Study and a series of fisheries oceanography-related studies (Fisheries Oceanography Cooperative Investigations, South Atlantic Bight Recruitment Experiment, Southeast Florida and Caribbean Recruitment). At present, our principal field efforts range from physical, biological, and chemical studies related to South Florida Ecosystem Restoration (SFER) and the underlying health of this ecosystem (PRC1) to the regional Intra-Americas Sea and the status and health of coral reef ecosystems worldwide. At the same time, we are seeking to develop the next generation of instrumentation and data assimilation tools necessary to provide the nowcast and forecast products required by the coastal ocean resource management community.

South Florida Ecosystem Restoration science activities at AOML include a number of interdisciplinary projects. Specific subject areas were determined and priorities assigned based in conjunction with NOAA's federal, state, and regional partners cooperating in the multi-agency SFER effort. Projects include: delineating and monitoring the circulation and exchange between Florida Bay and adjacent waters (PRC2, PRC3) (Figure 18), the physical component supports the Bay Circulation Model and the biological and chemical monitoring component supports the Quality and Ecological Models; paleoecological studies of the history of the Bay ecosystem (PRC4) (Figure 19) that have been instrumental in setting restoration objectives by elucidating the salinity history of Florida Bay prior to extensive water management; kinetic and field studies quantifying the critical relationship between dissolved phosphorous and calcium carbonate chemistry (PRC5) which determines the availability of this essential nutrient to phytoplankton and seagrass primary producers; measuring for the first time within the Bay the atmospheric deposition of plant nutrients (PRC6), the absence of which has been one of the major uncertainties in Bay nutrient budgets; development and testing of a new rainfall algorithm for the Next Generation Radar (NEXRAD) (PRC7), which is absolutely critical to determining the pattern and intensity of precipitation over Florida Bay and the South Florida peninsula given the highly convective nature of tropical rainfall; multi-investigator plankton bloom dynamics field experiments (PRC8), which have characterized growth processes, nutrient pathways, and grazing loss in both the diatom blooms and blue-green algal blooms (the two dominant modes in Florida Bay); adaptation and parameterization of the Advance Regional Prediction Simulation (ARPS) model to the South Florida Peninsula to improve prediction of the rainfall, wind, and evaporation fields under various restoration scenarios and initial conditions (PRC9) (Figures 20 and 21); and, most recently, an exploratory investigation of the distribution

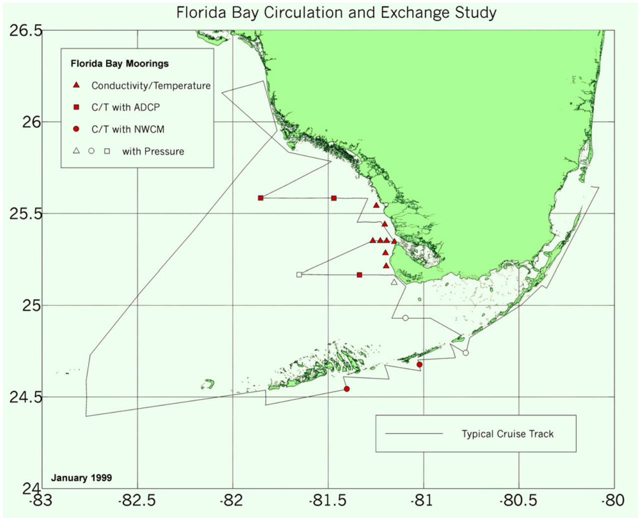


Figure 18. *Map of physical fixed array plus cruise tracks.*

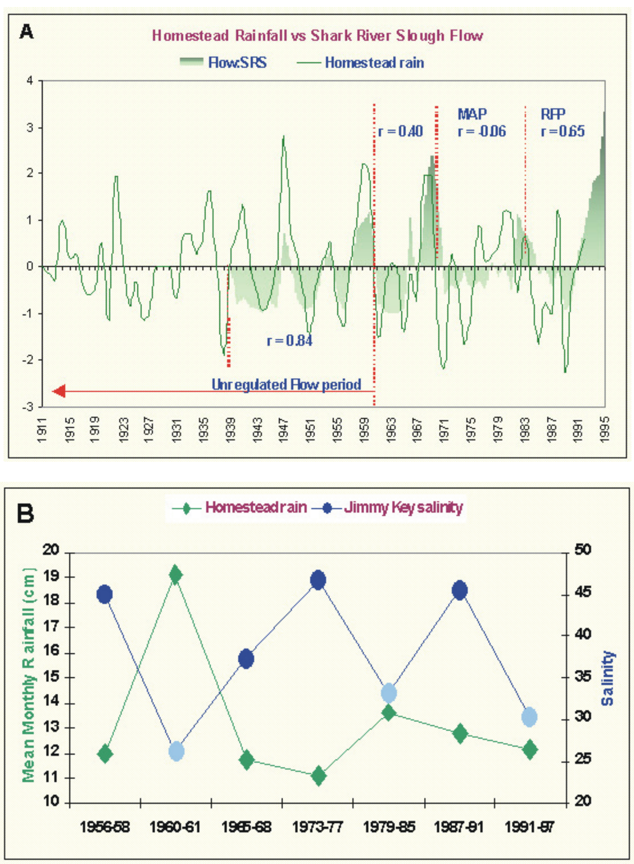


Figure 19. *Natural and anthropogenic influences on overland freshwater flow and historical Florida Bay salinity. Upper panel (A): Trend analysis (0 = average conditions) of historic Homestead rainfall and Shark River Slough flow (1911-1995) shows varying degrees of correlation for pre-management (0.84), construction period (0.40) through changing water management strategies (-0.06 for MAP = Monthly Allocation Plan; 0.65 for RFP = Rainfall Plan). Lower Panel (B): A strong inverse correlation between long-term salinity changes at Jimmy Key, in central Florida Bay, and long-term rainfall patterns indicate a natural forcing function dominates.*

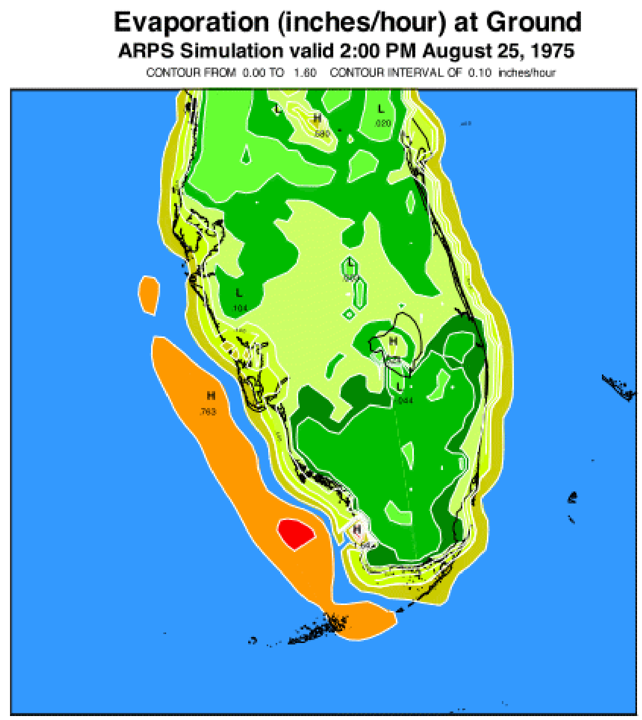


Figure 20. *Evaporation valid at 2:00 p.m., August 25, 1975 from an ARPS mesoscale atmosphere model simulation over the Florida Area Cumulus Experiment (FACE) mesonet region. The evaporation pattern correlates well with the strongest divergent and initially driest surface wind fields, in the vicinity of the greatest surface-to-air temperature/humidity differences. Moisture was picked up by the atmospheric flow over Lake Okeechobee and by the organized offshore downdrafts associated with the west coast sea breeze circulation, while the Florida Everglades "muck" soil in the interior of the state tended to resist evaporation due to its high water retention and strong capillary forces. Thus, a significant north-south mesoscale gradient in evaporation was simulated across Florida Bay.*

and degradation rate of an important class of anthropogenic pollutants (polycyclic aromatics - PAH) in South Florida (PRC10).

The Intra-Americas Sea is a developing area of collaboration between AOML and RSMAS and several Caribbean countries. An operational and expanding data collection network has been established which has been incorporated into an analysis of regional change and contributed to global scale heat transport estimates (PRC11). In addition, an industry (Royal Caribbean Cruise Lines), government (AOML), and university partnership has been formed to obtain oceanographic and meteorological data during weekly Miami-based cruises of the *Explorer of the Seas*, the world's largest cruise ship. The cruise track will transit the Florida Current and three northern Caribbean passages weekly, yielding a unique long-term, high-

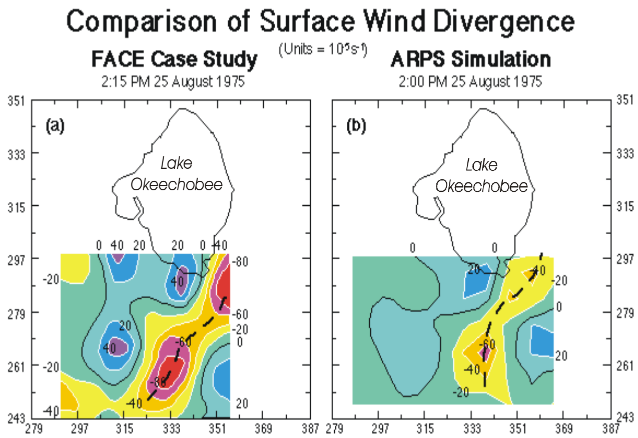


Figure 21. *The divergence of the surface winds diagnosed from (a) real observations from the Florida Area Cumulus Experiment (FACE) mesonet region, and (b) and ARPS mesoscale atmospheric model simulation for the same case. When realistic land surface characteristics are incorporated into the model, the porous, cultivated land south of Lake Okeechobee causes enhanced diurnal surface heating, which results in more abrupt divergent deflections of the surface winds over the lake. This increases the convergence of the wind field over the agricultural land (heavy dashed line) and causes a thunderstorm complex to develop immediately south of the lake, similar to the convective cells diagnosed in the real data. Thus, the crescent-shaped band of maximum rainfall associated with the lake breeze shifts from east of Lake Okeechobee to its southern shore.*

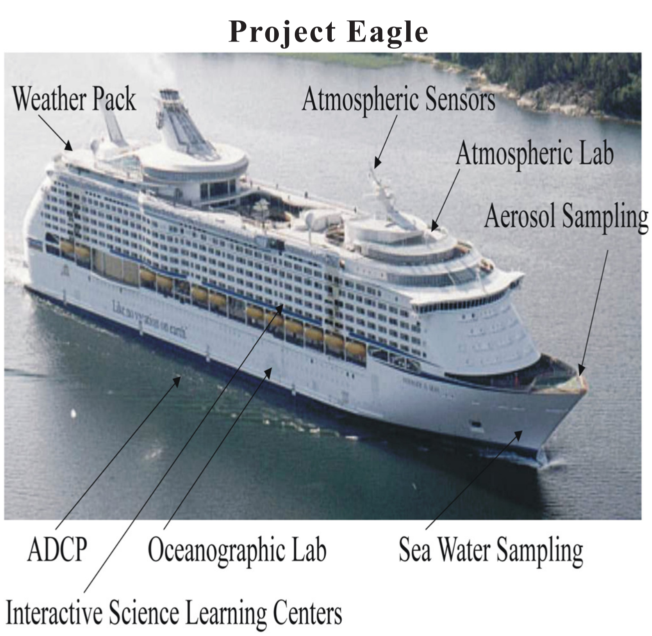


Figure 22. *Location of laboratories, learning centers, and sensor/instrumentation aboard the Explorer of the Seas (Royal Caribbean Cruise Lines).*

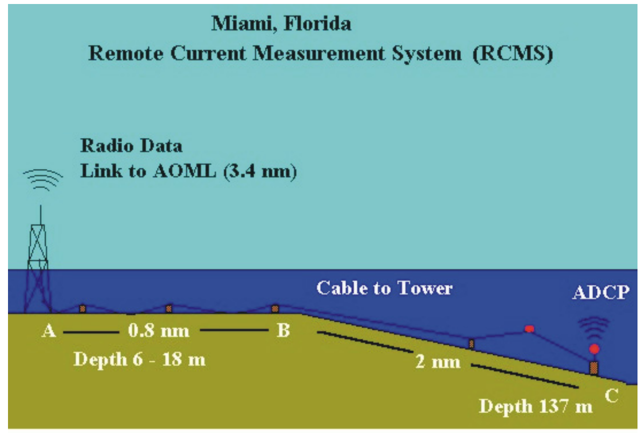


Figure 23. *Discharge monitoring at the Port of Miami.*

resolution data set for interdisciplinary climatological studies. The ship has already been substantially outfitted and will arrive in Miami in October 2000 (PRC12) (Figure 22). It is one component of our collaborative effort to move shipboard oceanographic sampling into the New Millennium (PRC13).

Anthropogenic activities near delicate coral reefs are being monitored and regulated using data and technologies pioneered at AOML. Offshore of Miami, the realtime data stream is permitting daily regulation of discharge activity by the Army Corps of Engineers (PRC14) (Figure 23). Meteorological and oceanographic parameters along the Florida Keys Marine Sanctuary reef tract are monitored from a series of fixed platforms (PRC15) (Figures 24 and 25), and

Figure 24. *C-MAN station.*

Figure 25. *Underwater diver on sensors.*

these data are assimilated by an artificial intelligence-based program (Coral Reef Early Warning System) that automatically issues warnings of coral reef bleaching and other deleterious conditions to the coral reef research and management community. The same system of hardware and software has been developed for the Great Barrier Reef in collaboration with the Australian Institute of Marine Science (AIMS).

A Vision of the Future:

AOML's role in regional and coastal environmental research will expand in the coming years, both in regard to basic research and integrated operational monitoring/modeling. There is no question that the problems coastal managers and planners face require information on processes at both shorter and smaller time and space scales than previously studied but over longer periods than previously available. In our view, progress requires time series Eulerian data sets which are best and most cost-effectively obtained from fixed platforms and buoys nested within remotely sensed wider fields (PRC16). Process work is still essential but will in the future no longer be exploratory in nature but rather limited and carefully targeted at elucidating ambiguity in these time series data. Recent advances have been made and will continue to be made both in regard to in-situ sensor technology, *e.g.,* in regard to continuously measuring and recording the dissolved and marine boundary layer concentration of significant chemical species like ammonia (PRC17) and adapting and integrating commercially available sensors into instrument packages tailored to our questions of interest. Real-time data assimilation and creative analysis are now possible and will become practical due to advances in both computer hardware and software. All of these information sources will have to be integrated into end-to-end information systems to deliver the products relevant to our future.

Scientists from AOML include: Shailer Cummings, Charles Fischer, Kelly Goodwin, James Hendee, Elizabeth Johns, Frank Marks, Craig Mattocks, Terry Nelsen, Peter Ortner, John Proni, Paul Willis, Douglas Wilson, and Jia-Zhong Zhang.

Collaborating scientists include: Michael Dagg (Louisiana Universities Marine Consortium); John Ogden (Florida Institute of Oceanography); Alan Strong (NESDIS); Pai-Yei Whung and Tilden Meyers (Air Resources Laboratory), Suyi Liu (World Precision Instruments, Inc.); C. Tomas (University of North Carolina); Gabriel Vargo (USF); Joanne Arthur Joseph Pachut, Catherine Souch, Lenore Tedesco, (Indiana University/Purdue University at Indianapolis); Bruce Albrecht, C. Alvarez-Zarikian, Patricia Blackwelder, Otis Brown, Jonathan Gottschalk, Hans Graber, Gary Hitchcock, T. Hood, Kevin Leaman, Hal Maring, Frank Millero, Christopher Mooers, David Powell, Sharon Smith, Peter Swart, Thomas Lee, Harold Wanless, Elizabeth Williams, Rod Zika (RSMAS); John Trefry (Florida Institute of Technology); Paul Trimble (South Florida Water Management District); M. Xue (Center for the Analysis and Prediction of Storms).

Laboratory Review Posters:

PRC1 *South Florida Ecosystem Restoration Prediction and Modeling: NOAA's Contribution to the Interagency Florida Bay Science Program* (DawnMarie Welcher and Peter Ortner)

PRC2 *Surface Salinity Variability of Florida Bay and Southwest Florida Coastal Waters* (Elizabeth Johns, Douglas Wilson, and Thomas Lee [RSMAS])

PRC3 *Interaction of Freshwater Riverine Discharges from the Everglades with the Gulf of Mexico and Florida Bay: Preliminary Results from a Moored Array and Shipboard Surveys* (Douglas Wilson, Elizabeth Johns, Ryan Smith, Thomas Lee [RSMAS], and Elizabeth Williams [RSMAS])

PRC4 *Understanding Long-Term Rainfall, Freshwater Flow, and Salinity Patterns with Concomitant Responses of Benthic Microfauna, Stable Isotopes, and Pollen in Oyster and Florida Bays* (Terry Nelsen, Charles Featherstone, Patricia

Blackwelder [RSMAS], T. Hood [RSMAS], C. Alvarez-Zarikian [RSMAS], Peter Swart [RSMAS], Harold Wanless [RSMAS], Lenore Tedesco [IU/PU], John Trefry [FIT], Catherine Souch [IU/PU], Joseph Pachut [IU/PU], and Joanne Arthur [IU/PI])

PRC5 *Role of Sediment Resuspension on the Phosphorous Cycle in Florida Bay* (Jia-Zhong Zhang, Charles Fischer, Christopher Kelble, and Frank Millero [RSMAS])

PRC6 *Atmospheric Deposition of Nitrogen and Phosphorous in Florida Bay* (Pai-Yei Whung and Tilden Meyers [Air Resources Laboratory], and Charles Fischer)

PRC7 *Tuning and Evaluating NEXRAD (WSR-88D) Data as a Measure of Fresh Water Flux into the Florida Bay/Everglades System* (Paul Willis, Frank Marks, and Jonathan Gottschalk [RSMAS])

PRC8 *Plankton Bloom Dynamics in Florida Bay* (Peter Ortner, David Forcucci, Shailer Cummings, Michael Dagg [LUMCON], C. Tomas [UNC], Gabriel Vargo [USF], Gary Hitchcock [RSMAS])

PRC9 *Simulations of Anthropogenically Generated Microclimates which Impact the Florida Bay Water Cycle* (Craig Mattocks, Paul Trimble [SFWMD] and M. Xue [Center for the Analysis and Prediction of Storms])

PRC10 *Pollutant Monitoring and Remediation: Polycyclic Aromatic Hydrocarbons (PAH)* (Kelly Goodwin, Daniel Voss, and Rod Zika [RSMAS])

PRC11 *Intra-Americas Sea Cooperative Advances* (Douglas Wilson, Christopher Mooers [RSMAS], and Kevin Leaman [RSMAS])

PRC12 *Project Eagle: An Industry, Academia, and Government Collaboration* (Shailer Cummings, Douglas Wilson, Rik Wanninkhof, Otis Brown [RSMAS], and Hal Maring [RSMAS])

PRC13 *Oceanography Entering the New Millennium* (Shailer Cummings, David Forcucci, Otis Brown [RSMAS], and David Powell [RSMAS])

PRC14 *Environmental Studies of Anthropogenic Discharges in the Coastal Zone* (John Proni and Terry Nelsen)

PRC15 *Coral Reef Monitoring and Information Services* (James Hendee, Terry Nelsen, John Proni, John Ogden [Florida Institute of Oceanography], and Alan Strong [NESDIS])

PRC16 *Submesoscale Vortices Shoreward of the Florida Current* (Peter Ortner, Thomas Lee [RSMAS], Sharon Smith [RSMAS], Hans Graber [RSMAS], and Gary Hitchcock [RSMAS])

PRC17 *Development of an In-Situ Ammonia Sensor Based upon a Fluorescence Technique and a Novel Liquid Waveguide Capillary Cell* (Jia-Zhong Zhang, Peter Ortner, and Suyi Liu [World Precision Instruments, Inc.])

Tropical Meteorology

Tropical cyclones move with the surrounding wind and draw their energy from the sea. The hurricane problem has historically been framed in terms of track forecasts and emphasis on forcing by the synoptic-scale atmosphere. As society has begun to ask meteorologists to predict variations in intensity or seasonal levels of activity, ocean thermal structure emerged as a key, perhaps dominant, factor. When one takes account of storm-induced cooling of the surface, it is upper ocean heat content that controls intensity fluctuations. Annual to decadal changes in the Atlantic thermohaline circulation correspond to variations of the numbers of hurricanes, most especially of the most intense "major hurricanes" that cause greatest damage. Hurricane wind and rain impacts on the built (Figure 26) and natural environments make human and economic effects an emerging field of study that spans architecture, engineering, sociology, economics, biology, chemistry, and even geology, in addition to meteorology and oceanography. Scientists at AOML, working with colleagues at Florida International University, RSMAS, the National Hurricane Center (NHC), the Environmental Modeling Center, and elsewhere, are in a unique situation to pursue all aspects of the hurricane problem.

Hurricane Track Forecasting:

Hurricane track forecasts are the success story of tropical meteorology. If current trends continue, early in the new century vector errors at all forecast periods will be half what they were in 1970. Motion is a combination of propagation due to the vortex's

Figure 26. *Widespread f1 damage in southern Miami-Dade County in the wake of Hurricane Andrew (1992).*

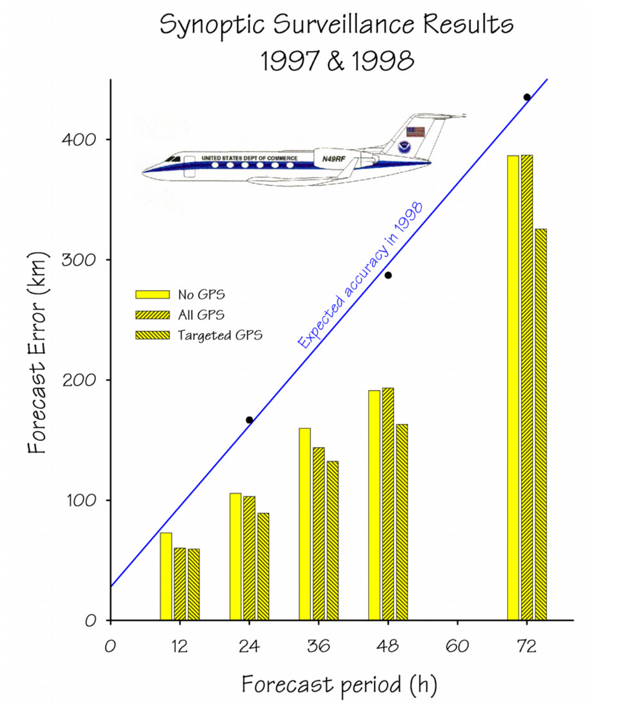


Figure 27. Results of data denial experiments with synoptic surveillance observations, illustrating ~15% improvement of already very good forecasts.

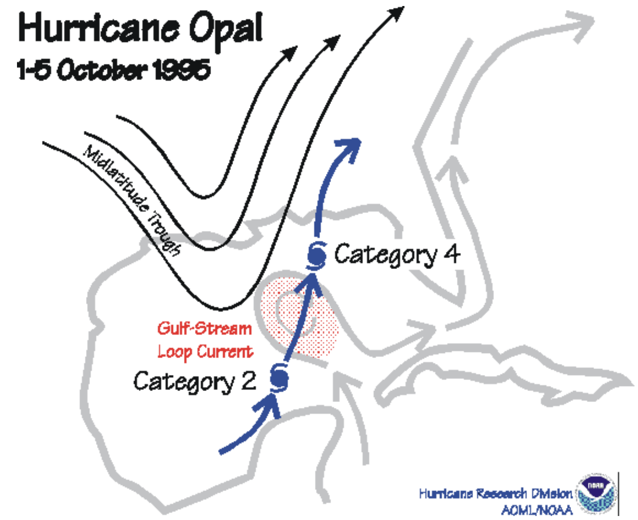


Figure 28. Hurricane Opal intensified rapidly under the influence of a "digging" mid-latitude trough as it careened northward across a warm eddy spun off from the Gulf Stream toward the U.S. coast.

asymmetric structure and advection by the surrounding winds (PTM1). Synoptic surveillance missions in which aircraft observe this "steering flow" with dropsondes deployed around hurricanes are HRD's contribution to the improvement of operational forecasts (PTM2). These flights, which began in 1982, provided the justification for procurement of NOAA's high-level Gulfstream IV jet aircraft. In their present form (PTM3), they incorporate targeting based upon NCEP's ensemble forecasts and reduce track errors by 10-15% in data-denial simulations (Figure 27). This improvement is equivalent to about a decade of business-as-usual progress in the forecaster's art.

Oceanic Forcing:

By contrast, Hurricane Opal of 1985 illustrates the limited progress in intensity forecasting (PTM4). Opal intensified rapidly overnight as it accelerated toward the United States Gulf Coast (Figure 28). It would have been a repeat of Hurricane Camille's devastating landfall if it had not weakened equally abruptly. Neither the intensification nor the weakening were forecast with enough lead time to permit appropriate response by emergency managers. A simple air-sea interaction model developed at Massachusetts Institute of Technology[3] appears to demonstrate a dominant role for oceanic forcing relative to atmospheric forcing or the cyclones' internal dynamics. As impressive as this result is, it is accurate only to about one Saffir-Simpson category. One possible improvement is replacement of the climatological representation of upper ocean structure with one observed through satellite altimetry (PTM5). Detailed observations of ocean response from aircraft (PTM6), combined with buoy and dropsonde observations of the hurricane's atmospheric boundary layer, also show promise for further improvement (PTM7).

Shear of the environmental wind appears to be the mechanism by which atmospheric teleconnections modulate Atlantic hurricane activity and it is generally thought to have a significant role in day-to-day intensity changes of individual storms. Airborne Doppler and reflectivity radar show that an environmental shear >10 m s^{-1} imposes a wavenumber-one structure on the eyewall convection (Figure 29). Individual cells form ~45° to the right of the down-shear direction, reach maturity with reflectivities >45 dBZ on the left side of the shear vector, and have largely rained out by the time they detach from the eyewall as they advect back to the right side of the shear (PTM8). Observations of chemical tracers offer an opportunity to validate meteorological theories of hurricane development (PTM9). Already, these

[3]Emmanuel, K.A., 1999: Thermodynamic control of hurricane intensity. *Nature*, **401**, 665-669.

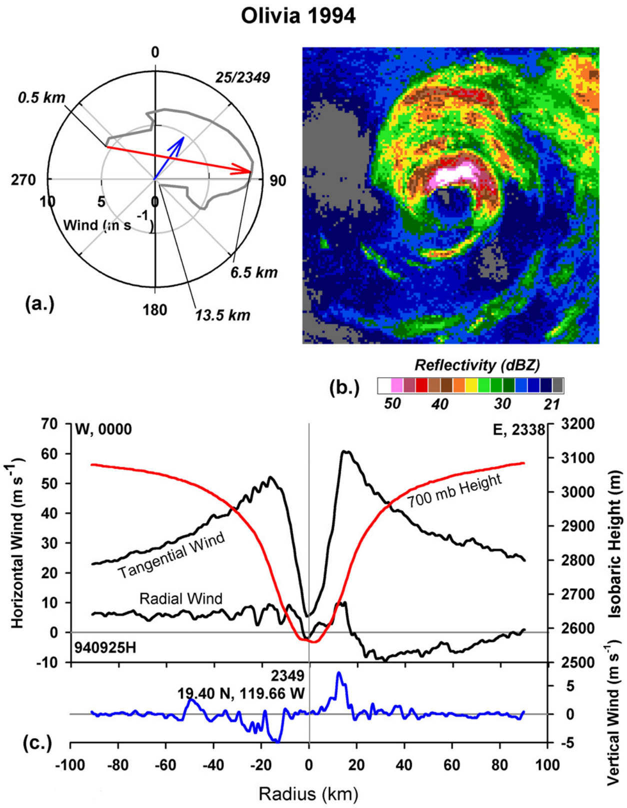


Figure 29. *Eastern-Pacific Hurricane Olivia in westerly shear: (a) "environmental" hodograph; (b) radar reflectivity; and (c) flight-level wind and 700 mb height.*

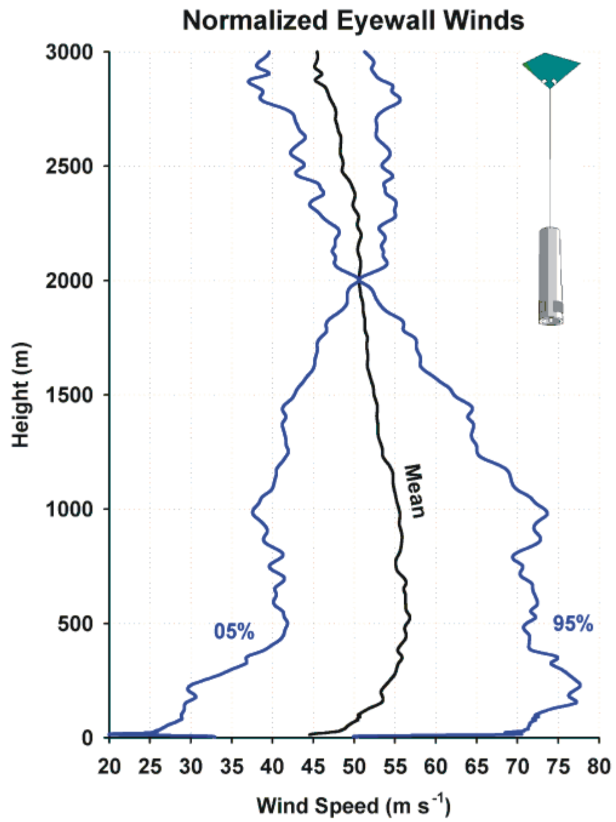


Figure 30. *Mean of 61 eyewall GPS soundings, normalized to the same speed at 2 km, illustrating the large variability about the mean, which approximates a logarithmic profile.*

insights have led to a reevaluation of hurricane eye thermodynamics in which air has a long residence time inside the eye, in contrast with the rapid recycling through the eye postulated earlier.

The boundary layer is the place where hurricanes impact people and property. Hurricane surface winds are the main emphasis of the Hurricanes at Landfall (HaL) focus of the United States Weather Research Project (USWRP). Since the mid-1980s, HRD has provided forecasters with quasi-operational analyses that are based on data from reconnaissance aircraft and surface anemometers (PTM10). Recent addition of satellite cloud-drift winds and surface winds deduced from both spaceborne and airborne remote sensing extends the domain and accuracy of this product. It is used routinely as guidance for watches and warnings and is proving useful for early evaluation of insurance losses and impacts on infrastructure during individual landfalls.

The GPS-based dropsondes developed for synoptic surveillance are superb boundary layer probes (Figure 30) because they report independent wind and thermodynamic observations every 5 m as they fall to the surface (PTM11). In the convective regions of hurricanes, GPS sondes have revealed previously unsuspected low-level jets at 100-300 m altitude with winds 20-40% stronger than those at 3 km or the surface. Another operationally important property of hurricanes is the onset of gale-force winds (17 m s^{-1}) after which preparations for landfall generally must cease. The surface wind analyses provide forecasts and validation of this key parameter, particularly so since their augmentation with remote sensing (Figure 31). Dedicated aircraft missions (PTM12) and detailed radar observations (PTM13) in hurricanes as they pass onshore, combined with land-based intercept teams from universities such as Texas Tech, Clemson, and the University of Oklahoma, and careful post-storm damage assessments (PTM14) will produce increasingly refined quantitative models of hurricane wind impacts. Evacuation in response to effective and timely warnings have reduced deaths from storm surge to the point that inland flooding is the primary cause of U.S. mortality, as the somber experience of Hurricane Floyd this past season dramatizes.

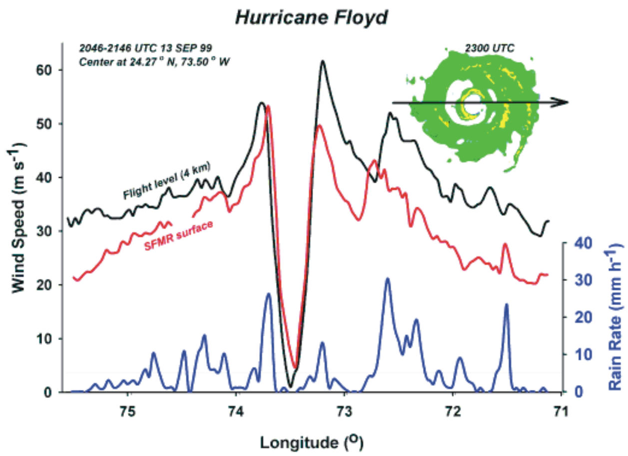


***Figure 31**. A west-to-east pass across Hurricane Floyd when it was a Category 4 hurricane east of Miami, heading west. This graph compares wind measured at 6 km with that sensed at the surface by the stepped-frequency microwave radiometer (SFMR). The rain rate is also measured by SFMR.*

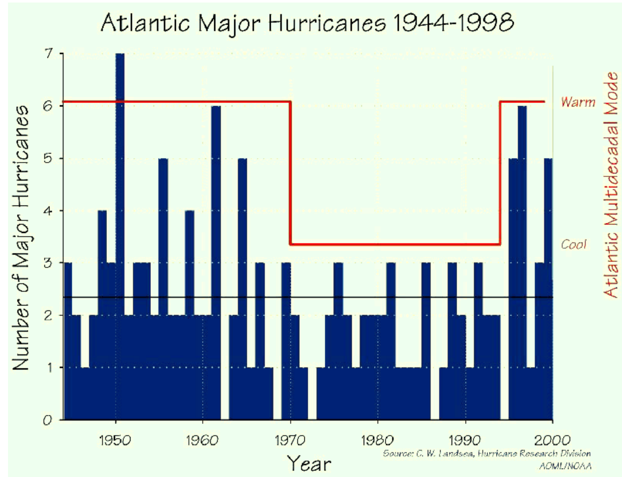


***Figure 32**. Occurrence of major hurricanes and the phase of the Atlantic multidecadal model since 1944.*

Tropical Rainfall:

Tropical rainfall is a key element of tropical weather both in hurricanes and generally. At sea, airborne radar and passive radiometers can measure the distribution of rainfall (PTM15). In-situ measurements of precipitation microphysics are essential to understanding the remotely sensed observations (PTM16). Acoustic sensing of wind and rainfall at sea (PTM17) is an extremely promising avenue of investigation. Collaboration with NASA through their Third Convection and Mesoscale Experiment (CAMEX3) with planned follow-on in 2001 or 2002 directs extensive resources at this important problem. The Tropical Rainfall Measuring Mission (TRMM), which measures rainfall from orbit worldwide, is finding application to hurricane rainfall distribution (PTM18). Another powerful tool is the National Weather Services' fully deployed network of operational Doppler radars, the WSR-88D, which is proving invaluable for measurement of precipitation in hurricanes (PTM19). Numerical modeling also has a vital role in understanding (PTM20) and prediction of rainfall processes and amounts both for tropical cyclones (PTM21) and for ecological impacts (PTM22).

Remote Sensing:

Recent satellite measurements promise additional information, both for real-time analysis and forecasting and for research. The 1400-km wide swath of the SeaWinds instrument aboard QuikSCAT, which was launched into polar orbit in June 1999, provides surface winds at 25 km resolution that can aid in the early detection of Atlantic Ocean tropical depressions (PTM23) and provide data for assimilation into the AOML real-time surface wind analysis for the Hurricanes at Landfall (HAL) project (PTM24). Features in the surface winds observed at about 100 m resolution by the Canadian RadarSat Synthetic Aperture Radar (SAR) during four storms in the 1998 hurricane season provide evidence of deep secondary flows in the hurricane boundary layer (PTM25).

Climatic change modulates hurricane activity. Hurricane landfalls on the U.S. east coast were common during the 1940s through the mid 1960s. In the 1970s and 1980s, landfalls were few (Figure 32). The 1995-1999 seasons inclusive have been the five most active in the >100 year quantitative record (PTM26). The fluctuations in activity are most pronounced for major hurricanes, the strongest 20% of hurricanes with winds >50 m s^{-1} that account for 80% of U.S. economic loss. They also correlate with the observed "North Atlantic Mode" of global sea-surface temperatures (PTM27).

Geological cores from Florida Bay show clear indications of historical hurricanes (PTM28). "Paleotempestology" is a propitious avenue for extension of the climatological record into the past. The pressing need to understand human and economic impact of hurricanes should not obscure the role of high winds and huge influxes of fresh water on the fragile South Florida ecosystem.

A Vision of the Future:

There is a reasonable expectation that the elevated level of hurricane activity that has characterized the late 1990s will continue into the second decade of the new century. The Hurricane Research Division will formalize and extend collaborations with the National Weather Service, the media, universities and other government agencies. If it is to be a viable organization, it will need to hire young PIs and secure stable funding for a staff of approximately 35. Hurricane track forecasts will continue to improve until they reach a plateau with errors about half of those achieved in the late 20th century. Hurricane intensity forecasting will come to show considerable skill, achieving accuracies of less than one Saffir-Simpson category at 48 h and beyond, contingent upon knowledge of the cyclone's track. Similarly, forecasts of seasonal activity will become more precise and useful. Knowledge of oceanic forcing and response will prove essential to these advances. Meteorological progress will be converted to neighborhood-level forecasts through quantitative understanding of the surface boundary layer and precipitation processes. Finely-tuned appreciation of hurricanes' impacts on humans and their property will make forecasts more useful. Meteorological advances notwithstanding, damage (corrected for inflation) will double about every 30 years and a few tens of U.S. citizens will die, primarily by drowning in fresh water, each year. There remains a small, but nonzero, probability that a poorly forecast hurricane striking a vulnerable shore might kill thousands.

Scientists from AOML include: Sim Aberson, Michael Black, Peter Black, Robert Black, Thomas Carsey, Joseph Cione, Peter Dodge, Evan Forde, John Gamache, Gustavo Goñi, Samuel Houston, Robert Jones, John Kaplan, Kristina Katsaros, Frank Marks, Christopher Landsea, Craig Mattocks, Terry Nelsen, Alberto Mestas-Nuñez, Katsuyuki Ooyama, Mark Powell, John Proni, Robert Rogers, and Eric Uhlhorn.

Collaborating scientists include: Bruce Albrecht (RSMAS), David Atlas (formerly at NASA), Gary Barnes (University of Hawaii), Jack Bevin (TPC/NHC), Lance Bosart (SUNYA), James Carswell (University of Massachusetts), Shuyi Chen (RSMAS), Mark DeMaria (CIRA), Russell Dickerson (University of Maryland), Matthew Eastin (Colorado State University), Kerry Emanuel (Massachusetts Institute of Technology), William Frank (Pennsylvania State University), James Franklin (TPC/NHC), William Gray (Colorado State University), Robbie Hood (NASA), Michelle Huber (TPC/NHC), Stephen Leatherman (FIU/International Hurricane Center), Steven Lord (NCEP/Environmental Modeling Center), John Molinari (SUNYA), Michael Montgomery (Colorado State University), Roger Pielke (NCAR), Edward Rappaport (TPC/NHC), Wayne Schubert (Colorado State University), Nick Shay (RSMAS), Paul Trimble (South Florida Water Management District), Paris Vachon (Canada Centre for Remote Sensing), M. Xue (Center for the Analysis and Prediction of Storms), Chi-Dong Zhang (RSMAS), Edward Zipser (University of Utah).

Collaborating institutions: Aircraft Operations Center, International Hurricane Center at Florida International University, National Center for Atmospheric Research, National Centers for Environmental Prediction/Environmental Modeling Center, National Hurricane Center, National Weather Service generally, Rosenstiel School of Marine and Atmospheric Science, 53rd Weather Reconnaissance Squadron.

Laboratory Review Posters:

PTM1 *Linear Motion of a Two-Layer, Baroclinic Hurricane in Shear* (Robert Jones and Hugh Willoughby)

PTM2 *Targeted Observing Strategies to Improve Tropical Hurricane Track Predictions* (Sim Aberson)

PTM3 *The First Penetration into the Hurricane Eye by the NOAA Gulfstream-IV Aircraft* (Michael Black, A. Barry Damiano [AOC], and Sean White [AOC])

PTM4 *Large-Scale Characteristics of Rapidly Intensifying Tropical Cyclones* (John Kaplan and Mark DeMaria [CIRA])

PTM5 *Estimates of Hurricane Heat Potential in the Western North Atlantic Ocean, Caribbean Sea, and Gulf of Mexico using TOPEX/POSEIDON-Derived Sea Height Anomaly Data* (Gustavo Goñi, Lynn Shay [RSMAS], and Peter Black)

PTM6 *Sensitivity of Hurricane Intensity Change to Air-Sea Interaction Processes* (Peter Black, Lynn Shay [RSMAS], Daniel Jacob [RSMAS], Samuel Houston, Eric Uhlhorn, James Carswell [UMASS], Edward Walsh [Environmental Technology Laboratory], and Eric D'Asaro [University of Washington])

PTM7 *Observed Upper Ocean Thermal Structure in Hurricane Erika (1997)* (Joseph Cione and Eric Uhlhorn)

PTM8 *Response of the Hurricane Core to Environmental Wind Shear* (John Gamache, Hugh Willoughby, and Michael Black)

PTM9 *Reactive Trace Gases in the Marine Boundary Layer* (Thomas Carsey and Russell Dickerson [University of Maryland])

PTM10 *A Distributed Real-Time Hurricane Analysis Wind System (*Mark Powell, Nirva Morisseau-Leroy, Sonia Otero, Samuel Houston, Nicholas Carrasco, and George Soukup)

PTM11 *Wind Structure of the Hurricane Eyewall as Observed by GPS Dropsondes* (Michael Black and James Franklin [NHC])

PTM12 *Dual-Doppler Analyses of Mesovortices in a Hurricane Rainband* (Peter Dodge, Scott Spratt [NWS], Frank Marks, David Sharp [NWS], and John Gamache)

PTM13 *Recent WSR-88D Observations of Hurricane Atmospheric Boundary Layer Structure at Landfall* (Frank Marks, Peter Dodge, and Carl Sandin [MAST Academy])

PTM14 *HRD's Hurricane Winds at Landfall Missions: A Collaborative Effort to Measure Extreme Winds near the Coast* (Samuel Houston, Peter Dodge, Mark Powell, and Frank Marks)

PTM15 *A New Era in Hurricane Reconnaissance: Real-Time Measurement of Surface Wind Structure and Intensity via Microwave Remote Sensing* (Eric Uhlhorn, Peter Black, Mark Goodberlet [Quadrant Engineering], and James Carswell [UMASS])

PTM16 *Electrical Development of the Mesoscale Convective Complex: Influence of Ice Particle Growth and Advection* (Robert Black and Terry Schuur [NSSL])

PTM17 *A Methodology for Validating Satellite Estimates of Rainfall Over the Ocean Using Underwater Sound* (John Wilkerson [NESDIS], Jeffrey McCollum [NESDIS], and John Proni)

PTM18 *Study of the Rain Distribution in Tropical Cyclones using TRMM Microwave Imager* (Manuel Lonfat [RSMAS], Frank Marks, and Shuyi Chen [RSMAS])

PTM19 *WSR-88D Derived Rainfall Distributions in Hurricane Danny (1997)* (Frank Marks, John Gamache, and Lauren Selevan [MAST Academy])

PTM20 *The Nested Spectral Model with Classical Thermodynamics and Parameterized Microphysics* (Katsuyuki Ooyama)

PTM21 *Using a Numerical Model to Investigate the Factors Controlling Rainfall Distribution in Hurricanes* (Robert Rogers, Shuyi Chen [RSMAS], Joseph Tenerelli [RSMAS], and Manuel Lonfat [RSMAS])

PTM22 *Simulations of Anthropogenically Generated Microclimates over the Florida Peninsula and their Impact on the Florida Bay Water Cycle* (Craig Mattocks, Paul Trimble [South Florida Water Management District], and M. Xue [Center for the Analysis and Prediction of Storms])

PTM23 *QuikSCAT is First to Identify Tropical Depressions in 1999 Hurricane Season* (Kristina Katsaros, Evan Forde, Paul Chang [NESDIS], and Timothy Liu [JPL])

PTM24 *Assimilation of Scatterometer-Derived Winds into Real-Time Tropical Cyclone Wind Analysis* (Eric Uhlhorn, Kristina Katsaros, and Mark Powell)

PTM25 *Wind Fields from SAR: Could They Improve our Understanding of Storm Dynamics?* (Kristina Katsaros, Paris Vachon [Canada Centre for Remote Sensing], Peter Black, Peter Dodge, and Eric Uhlhorn)

PTM26 *The Atlantic Hurricane Database Re-Analysis Project* (Christopher Landsea, Craig Anderson [CDC], Noel Charles [FIU], Gilbert Clark [FIU], Jose Fernandez-Partagas [deceased], Paul Hungerford [FIU], Charles Neumann [Science Applications International Corporation], and Mark Zimmer [FIU])

PTM27 *Patterns of Variability in Global Sea Surface Temperatures* (David Enfield and Alberto Mestas-Nuñez)

PTM28 *The Signature of Hurricane Sedimentation in the Lower Everglades/Florida Keys Ecosystem: Recognition of Sedimentologic, Geochemical, and Microfaunal Indicators* (Lenore Tedesco [IU/PU], Catherine Souch [IU/PU], Joseph Pachut [IU/PU], Terry Nelsen, John Trefry [FIT], Simone Metz [FIT], Harold Wanless [RSMAS], T. Hood [RSMAS], Patricia Blackwelder [RSMAS] and C. Alvarez-Zarikian [RSMAS])

Office of the Director Services

Office of Equal Employment Opportunity

AOML's Equal Employment Opportunity program focuses on community and educational outreach, recruitment, and enhancement of opportunities for employees to maximize their skills and careers through education, training, and merit. AOML is represented on the NOAA and OAR EEO Councils and the Greater Miami Federal Executive Board's Black Program Council, Federal Women's Program Council, and Hispanic Employment Council. AOML's EEO Director/Laboratory EEO Manager is a member of the NOAA EEO Council and also serves on the Council's Subcommittee on Under-Representation. At AOML, he is responsible for:

• Developing and coordinating the EEO-related activities of AOML's program managers.

• Coordinating with other NOAA organizations (*e.g.,* the National Weather Service and National Marine Fisheries Service in the Miami area).

• Providing guidance on EEO-related issues to AOML management and staff and to the OAR EEO manager.

AOML's EEO Director/Laboratory EEO Manager also participates in the Speakers Bureau, a joint activity of AOML's OEEO and the Miami Chapter of the American Meteorological Society.

Activities include, but are not limited to, conducting tours of NOAA-Miami facilities; participating in career days and science awareness programs; and judging local, regional, national, and international science and engineering fair events in Miami-Dade and Broward Counties. AOML supports several programs of the Miami-Dade County Public Schools, including a year-round intern program with the MAST Academy and other high schools; Weather-On-Wheels (an outreach program of the MAST Academy); and the Community Laboratory Research Program. The AOML/OEEO and AOML supervisors and rating officials conduct numerous career counseling sessions for employees, applicants, and women's and minority organizations.

A typical year's EEO, educational outreach, and diversity activities is shown in Figure 33. Additional information about AOML'a EEO program can be found at World-Wide Web Internet site http://www.aoml.noaa.gov.eeo/ and POD1, POD2, POD3.

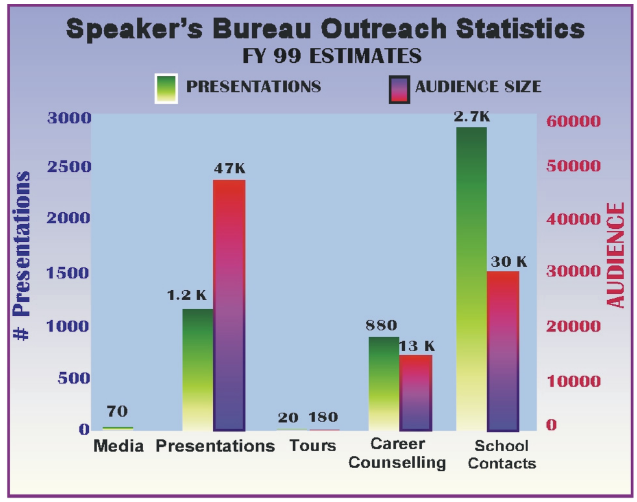


Figure 33. *AOML equal employment opportunity, diversity, and educational outreach activity statistics for a typical year.*

Diversity Program

AOML's management strongly endorses the value and importance of diversity in the workplace. An organization that accepts diversity and recognizes the contributions of all employees is a healthy and productive organization. Understanding and recognizing diversity enables AOML to capitalize on the differing views and contributions that each of its employees brings to the workplace. As such an organization, AOML provides for a richer work environment and ensures that employees work more closely with one another in carrying out organizational goals. Understanding and recognizing the contribution of a diverse workforce enables AOML to adapt better to changes.

In addition, AOML has taken part in the NOAA-wide Survey-Feedback-Action (SFA) cultural assessment so that various diversity issues can be addressed to improve the workplace. The AOML NOAA library has started a collection of books and other materials which address the management of diversity issues. AOML is represented on both the NOAA and OAR Diversity Councils, and has started a brown-bag lunch series concerning the management of diversity issues. Other diversity events, such as the Meyers-Briggs Type Indicator and Diversity Training are planned during fiscal year 2000.

Administration

The Administration staff is comprised of three federal and four contract and student employees. It develops annual budget plans for each of the science divisions and the Office of the Director, provides monthly reviews of each Division's budget, interacts with OAR budget offices and the Central Administrative Support Center (CASC) Finance Office, monitors all electronic fiscal transactions, provides oversight of external grants and contracts, and submits the Laboratory's invoices for payment. The Administrative Office also provides a link for human resources to the centralized operations at the Mountain Administrative Support Center (MASC) Personnel Office.

Computer Networks and Services

The Computer Networks and Services Division (CNSD) staff consists of four federal and two student employees. CNSD maintains and supports AOML's computer networks, telecommunications equipment, and color and laser printers. CNSD assists AOML staff with application and network problems and issues and provides support for Unix, Microsoft Windows-based, and Macintosh-based software systems. The number and type of computers maintained by CNSD and by the scientific Division staff is in a constant state of flux and is continually growing. A recent count showed that AOML has an installed base of at least 111 PCs, 40 Macintoshes, two Compaq/Digital Equipment VAX 4000/100 minicomputer servers, 32 Sun Solaris Unix workstations and servers, and six Hewlett-Packard (HP) workstations and servers. Compare these numbers with those from October 31, 1991, when AOML reported 15 networked PCs, seven Macintoshes, 15 Unix workstations and one Unix server, seven microcomputers, and two clustered VAX servers. In addition, the Hurricane Research Division maintains a number of HP workstations and servers, and the Physical Oceanography Division a cluster of VAX and Alpha workstations.

A variety of office automation software and scientific compilers, graphic, and statistical applications are maintained on the various computers, including MicroSoft Office, Corel WordPerfect Office, Fortran, Matlab, IDL, S-Plus, IMSL, and the NAG Fortran Libraries. AOML also uses Informix, Oracle, and GemStone database management systems.

A Vision of the Future:

In the very near future, hardware will be in place so that AOML will be able to connect to the University Corporation for Advanced Internet Development (UCAID) Internet II project Abilene. This will make AOML part of a larger Metropolitan Area Network (MAN) that will encompass AOML, NMFS/SEFC, the University of Miami, Florida International University, NWS/NHC, the International Hurricane Center, and Miami-Dade Community College. Since Internet II has peering arrangements with other national high-speed Internet backbones such as DREN, AOML scientists will be able to take better advantage of supercomputers for models and graphical representation of large data sets. As part of this process, SEFC, RSMAS, and AOML will be connected at Gigabit Ethernet speeds, which is many orders of magnitude improvement over the current connections.

AOML is also planning on having its Web pages mirrored at the NOAA NIC in Silver Spring and at other existing NOAA mirror sites. This is especially critical during hurricane season when AOML researchers are actively involved in collecting and making available on the Web large amounts of data gathered in tropical cyclones and elsewhere. Another issue AOML plans to address is that of a backup facility on the mainland so that AOML scientists can continue to communicate via email and access data during times when the Laboratory is shut down during a mandatory hurricane evacuation.

All of these improvements will enable AOML to better display its work and enhance cooperative efforts with NOAA, other government agencies, universities, and the private sector.

Outreach and Education

In recognition of the need for publicity, both locally and nationally, AOML has invested in a dedicated outreach coordinator to focus on raising the awareness of the laboratory through greater presence at local activities and an increased level of publicity in the news. In the past year, AOML, scientists were mentioned in over 100 newspapers nationwide, in which AOML research was the focus of the majority of the articles.

AOML has a well established and active outreach and education program that includes direct contact with students in mentor programs, answers to inquiries sent via mail and the Internet, coordination with national education programs, volunteer time in school activities, and school or on-site laboratory visits. In the past year, AOML came in contact with an estimated 77,000 members of the general public. This past summer, 26 high school and college students worked with scientists at AOML through internships or as contract employees. Additionally, AOML often coordinates with the Rosenstiel School on education projects such as high school science competitions and marine science education weeks for the community (POD4).

Facilities Management

The beautiful AOML building belongs to NOAA. It was inaugurated on February 9, 1973. The Facilities Management Group (three federal and two contract employees) maintains, repairs, and improves the physical environment of the AOML facility and the grounds surrounding the facility. They provide road and grounds maintenance, custodial services, facility operations services (heating, ventilation, air conditioning, electricity, plumbing, painting, carpentry, construction, etc.), special events set up (tents, tables, chairs), and vehicle maintenance.

Laboratory Review Posters:

POD1 *Women in Meteorology before World War II* (Sim Aberson)

POD2 *Women and Minorities in Meteorology since 1950* (Sim Aberson)

POD3 *World War II and the Broadening of Opportunities* (Sim Aberson)

POD4 *AOML's EEO and Outreach Programs* (Erica Van Coverden)

Research Initiatives

Increases in our NOAA funding are required for the health of our research programs. Many of our programs provide long-term monitoring of climate, coastal, or weather phenomena and are not conducive to proposal-driven, short-term support. The leadership of AOML has made a concerted effort in the last several budget cycles to participate in the NOAA budget initiative process. NOAA has seven strategic planning teams related to its mission. We have membership on some of these teams and other planning councils relevant to our research: Predict and Assess Decadal to Centennial Change (Molly Baringer); Implement Seasonal to Interannual Climate Forecasts (David Enfield); NOAA Informal Climate Council (Rik Wanninkhof); and Coastal Ecosystems Health (John Proni); plus an overall initiative on Climate and Marine Services (Robert Molinari and Kristina Katsaros). In addition, AOML has been represented on the interagency U.S. Weather Research Program (USWRP) planning teams for years (Hugh Willoughby, Frank Marks, and others). Below we describe some current efforts for FY 2002 which we will update, if possible, at the time of the review.

An Ocean System for Improved Climate and Marine Services: A Ten-Year Implementation Plan

A steering group for preparing major initiatives has been formed by the Undersecretary for Atmospheres and Oceans, Dr. D. James Baker. It consists of the Assistant Administrators of the Weather Service, the National Environmental Satellite, Data, and Information Service, and OAR, the head of Office Global Programs, three laboratory directors, including from AOML K. Katsaros and a few working scientists. R. Molinari from AOML has a pivotal role in this major initiative, working closely with W. Nowlin of Texas A&M University, who is a lead author from outside of NOAA. The Committee is formulating NOAA's policy in regard to observing, modeling, and forecasting the ocean for climate and marine services. The important aspect is that NOAA is offering to take a lead role with Dr. Baker intending to get this program off to a good start so it can flourish beyond the current governmental administration.

Objective: Implement an ocean system that includes data collection, management, and analysis to improve NOAA's ability to deliver climate and marine services.

Support requested that is relevant to AOML activities includes (1) increased coverage from AOML operated global observing networks, (2) increased data management efforts including quality control and data accessibility, and (3) increased network evaluation studies. The final disposition with respect to NOAA's strategic planning teams has not been settled.

COASTS

AOML is requesting funds for two projects under the COASTS umbrella: hurricane research and coastal data access and distribution. NOAA has incorporated hurricane-related items that were previously considered explicitly as part of USWRP under the Advance Short-Term Warnings and Forecasts strategic plan element into the COASTS initiative. For FY 2002 these include:

(1) USWRP/Hurricanes at Landfall (HaL) $6.0M/year increase to base: $2.5M for base restoration in OAR laboratories ($800K to AOML), cooperative institutes, and NCEP (EMC and Tropical Prediction Center [TPC]) and $3.5 M for NOAA/NSF grants to university PIs. This item incorporates the HaL performance measures from earlier underfunded initiatives. It is directed at improvement of forecasts through basic science and transfer of existing technology. OAR laboratories, NWS, and university collaborators are the main partners.

(2) Deployment of the Stepped Frequency Microwave Radiometer (SFMR) on Air Force Reserve (AFRES) reconnaissance aircraft to sense surface wind speed and rainfall rate operationally from 3-7 km flight level. This initiative will cost $2.25M over five years, mostly for instruments and integration into AFRES WC-130Js. AFRES, NWS, and the Office of the Federal Coordinator for Meteorological Services and Supporting Research (OFCM) are the main partners.

(3) Upgrade the Gulfstream-IV jet aircraft to a "next-generation reconnaissance platform." This initiative will cost $6.5M over five years. It will develop instruments: a Dopplerized nose radar, vertically scanning Doppler radar, fast-falling dropsonde, improved flight-level sensors, and integrate them into the Gulfstream-IV aircraft. AOC and NWS are the main partners.

Another AOML interest for the COASTS initiative is gaining access to the large amount of coastal oceanic and atmospheric data being collected and used by a broad community of government, academic, and private enterprises. *Project ACCESS* is being designed as a cooperative effort to pull together as much coastal data as possible and make it available. *Project ACCESS* will identify data that is already being collected (historical and contemporary), identify mechanisms for gaining access to that data, identify mechanisms for redistributing these data (existing mechanisms and those to be developed), and create the process(es) by which we can work together to combine sampling efforts and expand the network of measurements. Proposed by AOML and NOAA's National Oceanographic Data Center, groups with scientific and economic interests in marine/coastal areas are invited to join the effort. The initial geographic region of focus is the east coast of Florida, from the Georgia State line to the boundary of the Florida Keys National Marine Sanctuary near Key Largo and from the head of the estuaries to the Gulf Stream. To date, four workshops have been held to assess community interest in (a) coordinating data access and distribution and (b) developing future cooperative ocean monitoring projects.

Coastal Ecosystem Health

AOML's John Proni participates on this theme in the subgroup on habitat. AOML's interests relate to coral reef health, hypoxia issues, and coastal community concerns (infrastructure such as sewage and dredge issues). This team is just beginning its meeting (February 2000).

U.S. Weather Research Program

The United States Weather Research Program (USWRP) is a multi-agency (NOAA, NASA, NSF, Navy) cooperative program to advance the science of weather forecasting. As the result of a series of workshops in the mid 1990s, the meteorological community advanced three focused research directions: Hurricanes at Landfall (HaL), quantitative precipitation forecasting (QPF), and the mix of observations needed to support improved synoptic forecasts. Because the subject matter of HaL spanned the other two and because it was deemed easy to promote, it was chosen as the main emphasis for the late 1990s. HaL produced a small amount of new money in the 2000 budget cycle, but its legislative success has been so limited that the other agencies are reconsidering their commitment.

Budget, Personnel and Infrastructure Issues

The financial support for our research programs is in serious trouble. It is our "mega" issue. AOML has not received increases in its budget for research over a period of 10 years, even though several compelling initiatives have been proposed.

Meanwhile, Congress mandates annual cost of living (COLA) salary increases, 4.2% and 5.2% during the past two cycles. In addition, we are required to allot merit-based pay increases to a total amount of about 2% of our federal salaries per year. This value is the average of the increase paid over several years under the GS-pay scale. However, since 1998 AOML has participated in the Performance Personnel System or so-called "Demonstration Project," under which pay raises are strictly tied to performance. The same average percentage is still assigned to pay increases for our personnel.

Both the net loss in funds (at year 2000 dollar values) and the pressures of the new evaluation system have added a stress factor to AOML's scientific and administrative personnel. Employees are asked to perform more duties and write more proposals. The future is an uncertain prospect with the decade-long history of absolutely level base funding. It puts extra pressure on support services that do not have any new sources of "program" funds from which they could be supported via proposals. For the scientific programs, there is also a limit to available sources of outside funding. The Office of Global Programs and the Coastal Ocean Program within NOAA have provided some relief, as has the U.S. Weather Research Program (although the latter has been sorely underfunded).

In the section entitled "Research Initiatives," we describe our participation in the NOAA Congressional Initiatives process, where we are actively attempting to remedy the funding dilemma. We do not feel that any of our programs should be eliminated wholesale to alleviate the budget pressures, but it will be necessary to cut back certain aspects if the pattern does not change in the next few years.

For the present, we have instituted some efficiencies in better sharing of services from secretaries, technicians, and computer experts. We are finding new research opportunities through multi-disciplinary proposals with numerous partners. However, we strongly urge our OAR hierarchy to recover at least the losses due to mandated salary increases and the equivalent inflation-related increases in our other operating costs.

If the pressure is not relieved soon, the greatest loss to the enterprise will come from the loss of our most talented scientists who will find greener pastures, and from the loss of the freedom to occasionally explore new, risky projects because the data and someone's intuition suggests that it has promise. Even a set-aside discretionary fund for such a purpose would not be a solution since it is the deeper effect on employee morale that must be repaired. The continued lack of financial support for our accomplished researchers translates into a recognition that either (a) they are not respected for what they do, or (b) the hierarchy is of the opinion that only programs and proposal-driven research could have merit. We don't believe that there is any conscious decision made to this effect at any level, but rather that the consequences of the tension between the Executive Branch and Congress, between the Department of Commerce and NOAA, and between the line offices in NOAA has resulted in simple neglect of the need for some stability in the funding of the important research of NOAA's Office of Oceanic and Atmospheric Research.

Currently, we hire new workers mainly through our cooperative institutes or via contractors. Most new hires are supported on external funds received through competitive proposals. The unfortunate aspect of this situation is that there are very few agencies that will entertain proposals from a national laboratory of another agency. The personnel history of the laboratory for the past three years is presented in Table1.

Table 1. Laboratory personnel history.

	Full-Time Equivalent	CIMAS	Contract	Total
1997	98	50	9	157
1998	107	53	11	171
1999	108	49	12	169

The FTE increase in 1998 reflects the addition of the SEAS group from NOS to our Physical Oceanography Division. The large proportion of CIMAS and contract support personnel reflects the budget situation. In recent years, some employees have been replaced under student cooperative agreements (counted as NOAA employees) and as temporary NOAA employees, since stable funding in inflation-adjusted dollars is not assured. The overhead rate is less for these student and temporary positions than for non-NOAA employees, so this strategy allows some savings.

We only hire into temporary positions with the "soft" (proposal) driven support. The presence of CIMAS has allowed us to attract talented post-doctoral research assistants who add important breadth and energy to the Laboratory's work. It would be appropriate for a healthy research organization, however, if at least about one-third of new hires were in permanent FTE positions.

In spite of the level number of employees, we make a strong effort to broaden our population diversity with each new hire. Not reflected in the personnel table above are the high school and college interns from the local community that we employ each year. In 1999, there were 26 interns, many of Hispanic and African American heritage. A few past interns have become AOML employees.

The following three figures illustrate: (a) the distribution of funds for research in the three theme areas plus the Laboratory infrastructure over the past five years (Figure 34) ; (b) the function of the sources of funds for each of the five years (Figures 35a and 35b); and (c) the funding by theme within each of the five functional units within the Laboratory (Figure 36).

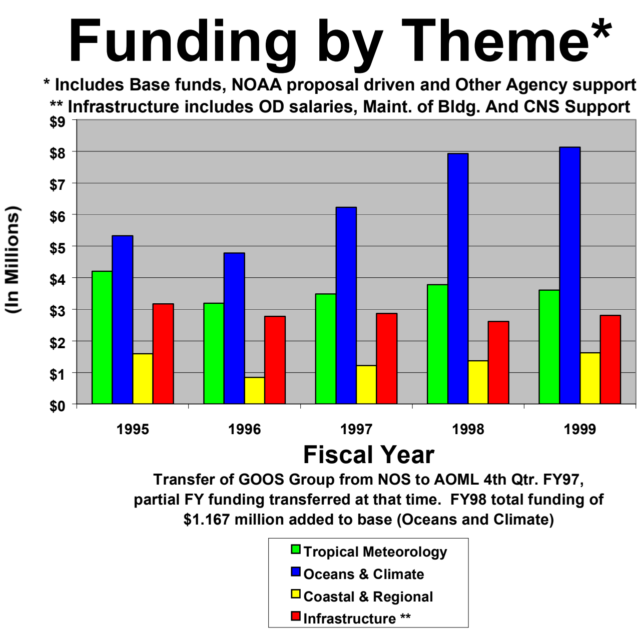


Figure 34. *Total funding from all sources for the three scientific themes and for the total cost of Laboratory infrastructure. In the climate and ocean category, we see an increase in 1997 and a further increase in 1998. These are the result of the transfer of personnel with accompanying base funds from the National Ocean Service in August 1997 and do not reflect a real budget increase. In fact, this figure amply illustrates the steady state of the AOML research budget. AOML's infrastructure costs include the salaries of the whole administrative team, computer and network services, and facilities maintenance personnel, as well as operational expenses such as electrical (mainly cooling), water, and complete maintenance of our building.*

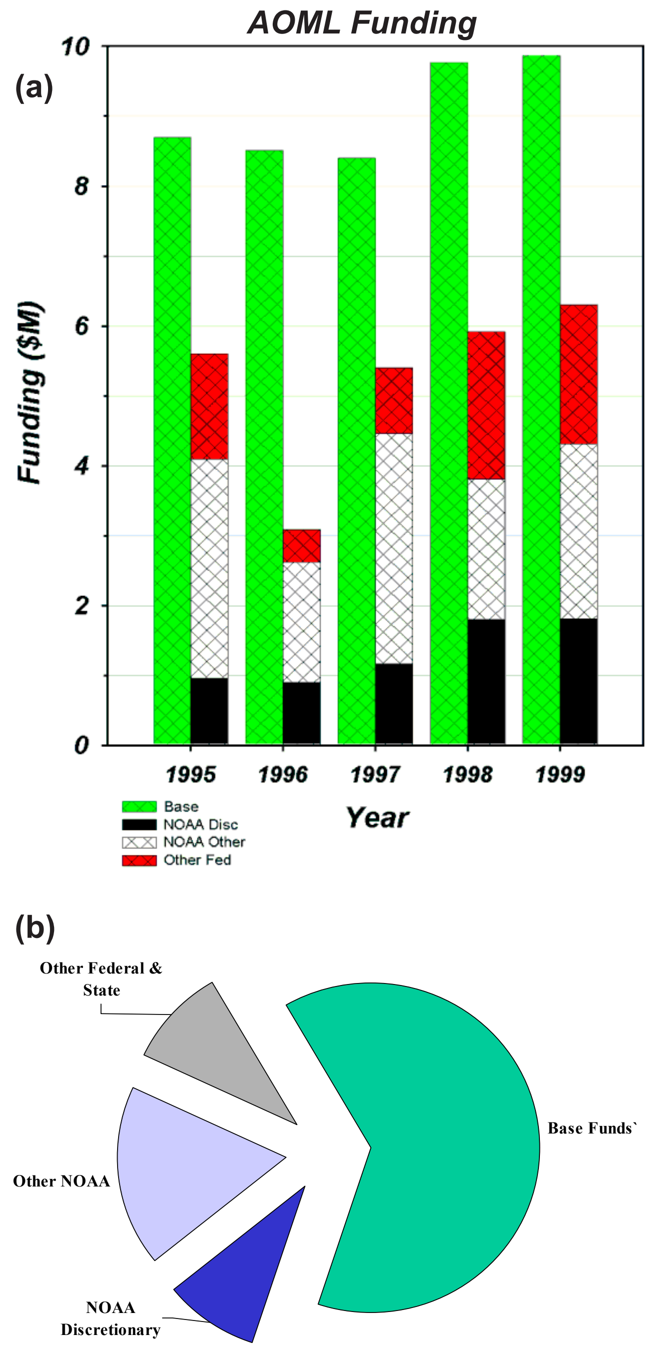
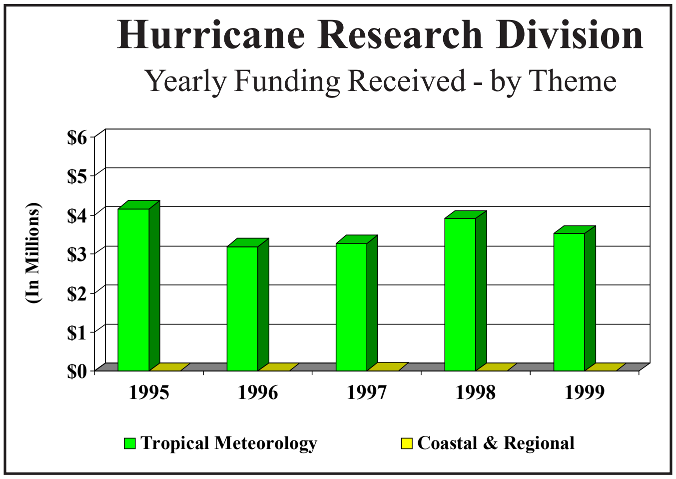
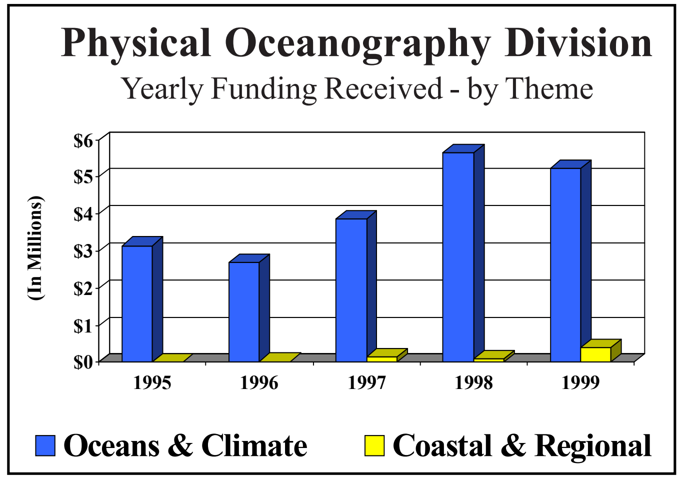
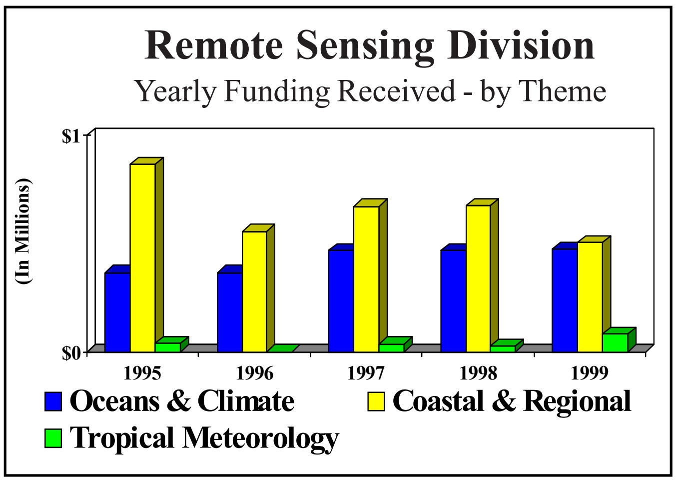
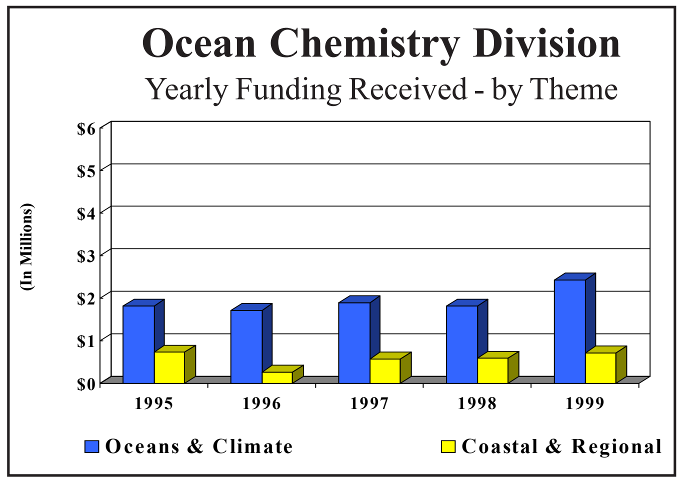


Figure 35. *The relative importance of various sources of funds supporting the three science themes and the infrastructure over the past five years are presented as a bar graph (a) for each year and as a pie graph (b) for the sum of all five years. Again, it is clear that the NOAA base funds have remained level (except for the mentioned addition of personnel in August 1997). Other substantial sources of funds are from the Office of Global Programs and the Coastal Ocean Program within NOAA. Tropical meteorology has its only significant new source of funds from the U.S. Weather Research Program, which is a multi-agency supported program. Unfortunately, for reasons that seem inexplicable to us, this program, that has hurricanes at landfall and quantitative precipitation forecasts as its two main objectives, has received very weak Congressional funding over the past several years.*









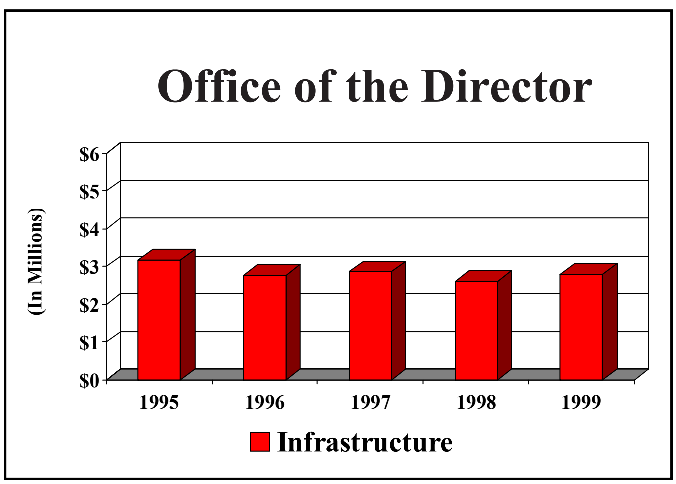


Figure 36. *Sources of funds for the five divisions of the Laboratory, here colored by the scientific theme that they represent (note that the y-axis is smaller for the Remote Sensing Division). It can be seen that each scientific division has its main source of funds from one theme area, but not exclusively, except for the Hurricane Research Division that has mostly tropical meteorology support. Thus, the multi-disciplinary nature of most of our research projects is evident in this figure. Some aspect of the tropical meteorology work is actually quite oceanographic in that the oceanic heat source represented by warm eddies in the Gulf of Mexico is now being measured under this heading. The labels simply have not caught up with the reality in this case.*

Affiliates/Customers and Partners

Affiliates

Aircraft Operations Center:

NOAA's Aircraft Operations Center (AOC), located at MacDill Air Force Base in Tampa, Florida, supplies mission-ready airborne platforms and personnel for NOAA programs and other activities and ensures availability of all services commensurate with a safe, efficient, and cost-effective aviation operation. AOC establishes, defines, and implements aircraft operations, safety, utilization, and engineering policies for NOAA aircraft and provides technical support to those NOAA Program Offices requiring aircraft operations. AOC also coordinates the charter of aircraft, special projects, and aircraft assignments of scientific and technical personnel required by projects and missions. AOML works closely with AOC in preparation and execution of reconnaissance and research flights during the annual Atlantic hurricane season (June 1-October 31).

Cooperative Institute for Climate and Ocean Research:

The Cooperative Institute for Climate and Ocean Research (CICOR), established in 1998, is a cooperative institute between NOAA and the Woods Hole Oceanographic Institution in Woods Hole, Massachusetts. CICOR provides a framework at WHOI for coordinating NOAA-funded research, for building ties between WHOI investigators and colleagues at NOAA laboratories, and for developing cooperative NOAA-funded research at academic institutions in the northeastern United States. The research activities of CICOR are organized around three themes: coastal ocean and near shore processes; the ocean's participation in climate; and climate variability and marine ecosystem process analysis. These theme areas, each of which has significant implications for human society, are interrelated. Scientific progress requires collaboration by scientists within and between disciplines. In each case, progress depends on a combination of fundamental process studies, the development and deployment of technological systems for sustained observation, and the development of predictive models that are based on an understanding of the underlying processes and that assimilate information from the observational systems. AOML's cooperation with CICOR is still in its first year with just one operating project, but others are in the proposal stage.

Cooperative Institute for Marine and Atmospheric Studies:

The Cooperative Institute of Marine and Atmospheric Studies (CIMAS) is a research institute between NOAA and the University of Miami (UM) located next to the Rosenstiel School of Marine and Atmospheric Science (RSMAS) on Virginia Key. CIMAS was established in 1977 through a Memorandum of Understanding and serves as a mechanism to bring together the research resources of the University of Miami with those of AOML, the National Marine Fisheries Service (NMFS), and other branches of NOAA to develop a center of excellence in research that is relevant to understanding the earth's oceans and atmosphere. The research activities of CIMAS are organized around three themes: climate variability, fisheries dynamics, and coastal ocean ecosystem processes. AOML's cooperation with CIMAS is extensive and very successful.

Florida Keys National Marine Sanctuary:

The Florida Keys National Marine Sanctuary (FKNMS) encompasses approximately 2800 square nautical miles of nearshore waters extending from just south of Miami to the Dry Tortugas, small islands west of Key West in the Gulf of Mexico. Research and monitoring are critical to achieving the Sanctuary's primary goal of resource protection. The Keys' ecosystem is diverse and complex, and many of its processes and their interrelationships are not well known. Also, while many resource impacts are obvious and severe, they are often not documented or quantified, and their causes may be even less clear or completely unknown. The purpose of research and monitoring is to establish a baseline of information on the resource and the various components of the ecosystem, and how they interact. In this way, research and monitoring can ensure the effective implementation of management strategies using the best available scientific information.

National Hurricane Center:

The National Hurricane Center (NHC) maintains a continuous watch on tropical cyclones over the Atlantic, Caribbean, Gulf of Mexico, and the eastern Pacific from 15 May through November 30. NHC prepares and distributes hurricane watches and warnings for the general public, and also prepares and distributes marine and military advisories for other users. During the "off-season," NHC provides training for U.S. emergency managers and representatives from many other countries that are affected by tropical cyclones. NHC also conducts applied research to evaluate and improve hurricane forecasting techniques, and is involved in public awareness programs. AOML tropical meteorologists participate with NHC during each year's hurricane season in aircraft reconnaissance missions and research for landfalling hurricanes.

NODC (Library Information Science Division) Miami Regional Library:

The NESDIS/NODC/LISD Miami Regional Library consists of two libraries, one located at AOML and the other at the National Hurricane Center (NHC). These libraries combined are staffed by three individuals who hold Masters degrees in their fields. The primary mission of the Miami Regional Library is to provide scientific information and data to support the AOML and NHC research programs. In addition, the library acts as a resource to the other NOAA southern libraries, government agencies, private research organizations, academic institutions, and the general public, providing traditional and electronic access to regional information and scientific journals through a Unix-based server.

National Oceanographic Data Center (NODC) Southeast Liaison Office:

The NODC has an officer stationed at AOML with a territory spanning the southeast region of the United States from Louisiana to Virginia. As the nation's primary oceanographic data center, the NODC maintains contact with users and investigators within the region to acquire and distribute data sets. Data acquisition is an important activity for the Liaison Office and acquisition will be expanded in the calendar year 2000 work plan.

Cooperative programs with AOML staff, such as *Project Access* (Accelerated Coastal Community Environmental Science Service), have been successful in promoting the unified mission of NOAA and in seeking participation by Florida coastal constituents (PAC1). The NODC Liaison Officer provides information about NOAA programs or data held at the NOAA facilities to the general public.

Regional data programs such as the NOAA GOOS program in Miami will generate significant new data sets, and NODC is eager to be an active partner in the management of the data with the advice of the NODC Liaison Officer.

Within the NODC structure is the NOAA Miami Regional Library. A joint activity with the Miami Regional Library is expanding the NOAA card catalogue to identify data sets held at the NODC. Any new data set delivered to the NODC will be catalogued in the library system using the MARC format established by the library community.

South Florida Ocean Measurement Center:

The South Florida Ocean Measurement Center (SFOMC) was founded through a partnership involving government and academia including the Naval Surface Warfare Center, Carderock Division, South Florida Testing Facility (SFTF); Florida Atlantic University (FAU); Nova Southeastern University; University of Miami (UM); University of South Florida (USF); Harbor Branch Oceanographic Institution (HBOI); and NOAA/AOML. This comprehensive in-water installation is located off shore in Dania, just south of Ft. Lauderdale, Florida in an area with a wide variety of environmental conditions. It also includes living reefs and is located where the continental shelf break is only three miles from shore.

SFOMC is being built, with the guidance of the Office of Naval Research, around the substantial existing in-water assets of the SFTF. Hundreds of miles of cables, sensors, and high-speed multiplexers are being supplemented with a large number of additional environmental sensors including several in-water USF multi-sensor arrays. When completed, real time environmental data covering the atmosphere through the air/ocean interface and down to the sub-bottom will be available. Sophisticated and extensive acoustic arrays and additional measurement sensors are being strategically located by the UM to support a variety of propagation measurements. Sensors will also be placed to support work of the NOAA/AOML. An autonomous underwater vehicle (AUV) docking station will be permanently installed, providing the ability to operate the ONR funded FAU AUVs in virtually any weather. Considerable shore based infrastructure will also be available including the

Navy's SFTF with a secured range house and new laboratory building, a small harbor and a 250 ft. pier capable of berthing and staging any one of the three HBOI ships, the Nova Southeastern University Oceanographic Center (NSUOC), FAU's Department of Ocean Engineering at SeaTech, and a new Navy engineering and administrative building. A variety of data packages will be available for use of the scientific community on the range.

The initial combined installations of the various environmental moorings; the various arrays and radars; and the existing SFTF sensors, results in a dense measurement system surrounding an AUV operations area extending from the western edge of the Florida Current to the inner reef tract. This system will provide a detailed look at physical processes taking place along the east coast of Florida. When coupled with the biological measurements conducted by NSUOC, there will also be a remarkable opportunity to examine interactions between biology and physics in the region. Environmental data will be available to the entire scientific community for long term monitoring as well as to investigators conducting experiments at this new natural laboratory.

Customers and Partners

The results of scientific research, of course, have numerous customers. We like to think that they include all future generations of Earth's inhabitants, as our work contributes to the advances in our common body of knowledge. Taking a narrower point of view, we present below the groups that benefit as collaborators and direct users of our products. Our customers can, in many cases, also be considered our partners, so we have them listed together. Figure 37 is a spider's web showing how AOML's partnerships range from local to international, including academic, intergovernmental, NOAA, and private industry. National and international customers of results from AOML research include:

• Climatic and oceanographic researchers (WOCE, and TOGA, GOALS, Decadal-Centennial Climate Variability, and Seasonal-Interannual Variability).

• Evaluators of the carbon cycle, ozone depletion, and heat storage climatology (*e.g.,* the Intergovernmental Panel for Climate Changes [IPCC], the World Meteorological Organization [WMO])

• Ocean modelers.

• The National Hurricane Center is aided directly by the aircraft flights and near real-time surface wind fields provided when hurricanes threaten landfall. AOML researchers benefit from the NHC data collection, analyses, and their particular expertise.

• National and international weather and climate prediction services (*e.g.,* NCEP, ECMWF, The Fleet Numerical Weather Prediction Center of the Navy).

• Insurance providers.

• Building engineers, and increasingly, the economic "futures" sector.

• Other Federal agencies. *e.g.,* Environmental Protection Agency, U.S. Army Corps of Engineers, U.S. Navy, and U.S. Coard Guard.

• The South Florida Ecosystem Restoration Consortium.

• Port authorities, sewage, dredge, and other public and private coastal infrastructure authorities.

• Satellite researchers working on algorithms for surface wind and precipitation benefit from AOML data. They include researchers from NASA, NESDIS, the European Space Agency, the Canadian Space Agency, and others.

• Satellite data researchers using, for instance, scatterometers, SAR, and the TRMM satellite, gain insights into how to interpret satellite measurements from in-situ data collected by AOML scientists such as aircraft dropsondes, radars, coastal rain radar, acoustical instruments, ocean buoys and drifters.

• The scientists of AOML support local educational activities in schools (K-12) and teach at several colleges and the University of Miami. We participate in local science fairs and the National Oceans Bowl and have an active intern program, drawing participants from local schools.

Laboratory Review Posters:

PAC1 *Project ACCESS (Accelerated Coastal Community Environmental Science Service): Coordinating Access to Coastal Oceanic and Atmospheric Data* (Michael Crane [National Oceanographic Data Center] and Judith Gray)

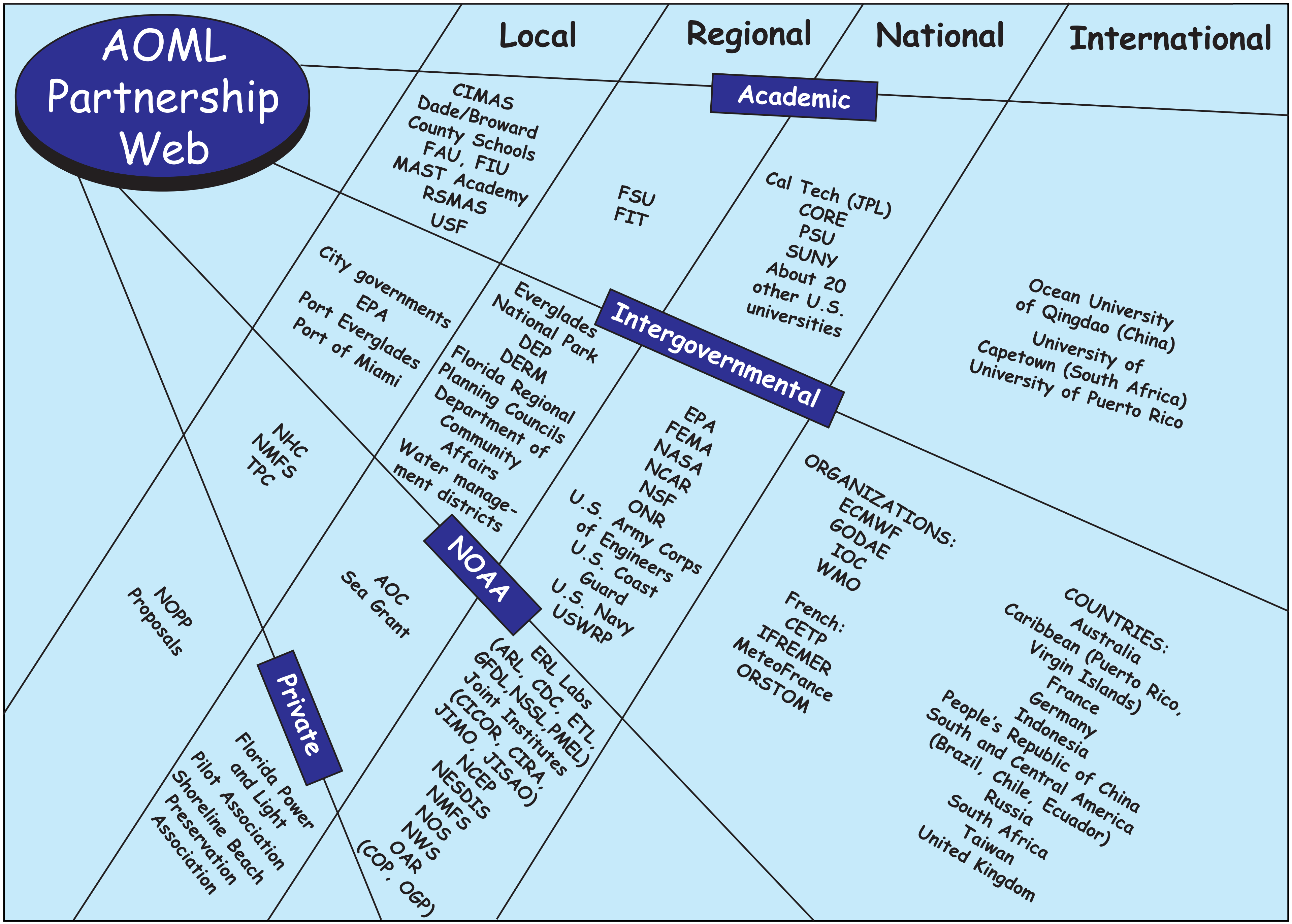


Figure 37. *AOML partners and customers.*

List of Acronyms

AIMS	Australian Institute of Marine Science
ARPS	Advanced Regional Prediction Simulation
ASTEX	Atlantic Stratocumulus Transition Experiment
AUV	autonomous underwater vehicle
AXBT	Airborne expendable bathythermographs
CAMEX3	Third Convection and Mesoscale Experiment
CH_3Br	Methyl bromide
CICOR	Cooperative Institute for Climate and Ocean Research
CIMAS	Cooperative Institute for Marine and Atmospheric Studies
CIRA	Cooperative Institute for Research in the Atmosphere
CMDL	Climate Monitoring and Diagnostics Laboratory
CNS	Computer Networks and Services (AOML)
CO_2	Carbon dioxide
D2M	Dedacal to multidecadal
ECMWF	European Centre for Medium Range Weather Forecasts
EMC	Environmental Modeling Center
ENSO	El Niño-Southern Oscillation
FAU	Florida Atlantic University
FIT	Florida Institute of Technology
FIU	Florida International University
FKNMS	Florida Keys National Marine Sanctuary
FTE	Full-time equivalent
GDA	global drifter array
GLOBEC	Global Ecosystem Dynamics and Coupling
GOOS	Global Ocean Observing System
GPS	global positioning system
HaL	Hurricanes at Landfall
HBOI	Harbor Branch Oceanographic Institute
HRD	Hurricane Research Division (AOML)
IAS	Intra-Americas Sea
IPCC	Intergovernmental Panel for Climate Changes
INDOEX	Indian Ocean Experiment
IU/PU	Indiana University/Purdue University
JGOFS	Joint Global Ocean Flux Study
JPL	Jet Propulsion Laboratory
LUMCON	Louisiana Universities Marine Consortium
OACE	Ocean-Atmosphere Carbon Exchange Study
PhOD	Physical Oceanography Division (AOML)
MASC	Mountain Administrative Support Center
MAST	Maritime and Science Technology Academy
MBARI	Monterey Bay Aquarium Research Institute
NADW	North Atlantic Deep Water
NAO	North Atlantic Oscillation
NCAR	National Center for Atmospheric Research
NCEP	National Center for Environmental Prediction
NESDIS	National Environmental Satellite Data and Information Service
NEXRAD	Next Generation Radar
NMFS	National Marine Fisheries Service
NODC	National Oceanographic Data Center
NOS	National Ocean Service
NSF	National Science Foundation
NSSL	National Severe Storms Laboratory
NSUOC	Nova Southeastern University Oceanographic Center
NWS	National Weather Service
OAR	Office of Oceanic and Atmospheric Research
OCD	Ocean Chemistry Division (AOML)
OFCM	Office of the Federal Coordinator for Meteorological Services and Supporting Research
PhOD	Physical Oceanography Division (AOML)
PI	Principal investigator
PMEL	Pacific Marine Environmental Laboratory
QPF	quantitative precipitation forecasting
RSD	Remote Sensing Division (AOML)
RSMAS	Rosenstiel School of Marine and Atmospheric Science
SAR	Synthetic aperture radar
SEAS	Shipboard Environmental (Data) Acquisition System
SEFSC	Southeast Fisheries Science Center
SFA	Survey feedback action
SFER	South Florida Ecosystem Restoration
SFMR	stepped frequency microwave radiometer
SFOMC	South Florida Ocean Measurement Center
SFTF	South Florida Testing Facility
SFWMD	South Florida Water Management District
SLP	Sea level pressure
SOLAS	Surface Ocean Lower Atmosphere Study
SST	Sea surface temperature
SUNYA	State University of New York at Albany
TAO	Tropical Atmosphere Ocean
TOGA	Tropical Ocean Global Atmosphere
TPC	Tropical Prediction Center
TRMM	Tropical Rainfall Measuring Mission
UM	University of Miami
UNC	University of North Carolina
USF	University of South Florida
USWRP	U.S. Weather Research Program
VOS	volunteer observing ship
WHOI	Woods Hole Oceanographic Institution
WMO	World Meteorological Organization
WOCE	World Ocean Circulation Experiment
XBT	Expendable bathythermograph