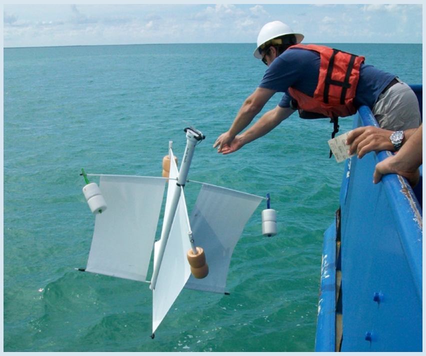
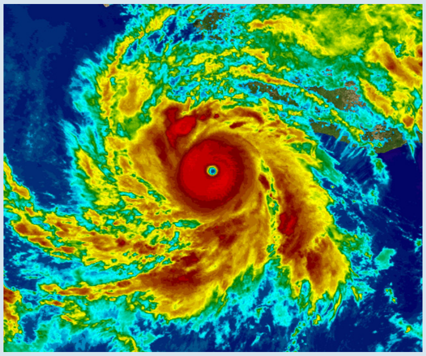
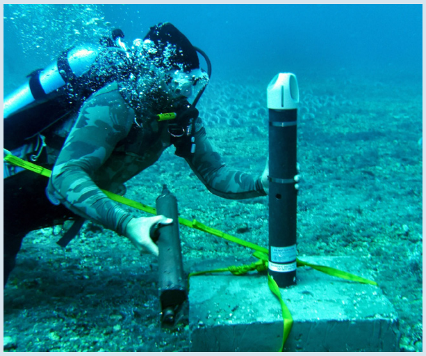
AOML is an environmental laboratory of NOAA's Office of Oceanic and Atmospheric Research in Miami, Florida







Strategic Plan

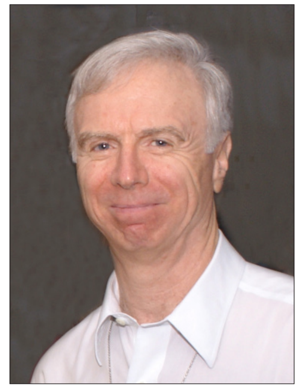
Atlantic Oceanographic and Meteorological Laboratory

FY2010-2015

www.aoml.noaa.gov

U.S. DEPARTMENT OF COMMERCE
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
Office of Oceanic and Atmospheric Research

A Message from the Director



Dr. Robert Atlas, AOML Director

Research conducted by the Atlantic Oceanographic and Meteorological Laboratory (AOML) encompasses three major scientific themes: oceans and climate, hurricanes and tropical meteorology, and coastal oceans and ecosystems. The Laboratory's research is recognized as first rate and significant for the evolution of these theme areas on both national and international scales. The close proximity of scientists with expertise in these three theme areas is an advantage for the Laboratory that naturally leads to interdisciplinary research with significant outcomes. One example is the analysis of the relationship between ocean surface temperature variability and frequency and intensity of hurricanes over many decades; other examples include the relationship between physical properties in the ocean with carbon fluxes and coastal chemistry and biology. The specific research areas addressed by AOML are the result of a three-decade evolution that began with the establishment of AOML between 1967 and 1973.

AOML's research benefits greatly from partnership with the University of Miami's Rosenstiel School of Marine and Atmospheric Science, the Cooperative Institute for Marine and Atmospheric Studies, and NOAA's Southeast Fisheries Science Center, all of which are in close proximity to AOML on Virginia Key. The Laboratory also has a wide net of collaborators in several of the other NOAA research laboratories and centers and with numerous universities and other federal, state, and local agencies.

The future provides tremendous challenges to meet the accelerating demands for new knowledge and instant information as increasingly complex science questions are asked. Our charge is to improve scientific understanding and capabilities to help protect the population of Florida and the nation from the vagaries of severe weather, climate effects, and ecological deterioration. These concerns are all becoming more urgent as the population moves to coastal areas and increases in number. Nurturing the relationship of the Laboratory with our constituency, NOAA service line offices (National Weather Service, National Marine Fisheries Service, National Ocean Service, and National Environmental Satellite, Data and Information Service) and other agencies, as well as the general population, is a significant part of our work. We meet these challenges with confidence and enthusiasm.

This version of the AOML Strategic Plan was updated in March 2012 to include images and sidebar text. For more information about AOML or the content of this strategic plan, please contact AOML's Communications Office at 305-361-4451 or visit us on the web at www.aoml.noaa.gov.

Vision

A NOAA research laboratory recognized as a center of excellence in atmospheric and oceanic research and a sought-after resource to the community and the nation for expertise on hurricanes, coastal ecosystems, and the role of oceans in climate.

Aerial view of AOML on Virginia Key in Miami, Florida.

Mission

Conduct research 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 leads to more accurate forecasting of severe storms, better utilization and management of marine resources, better understanding of the factors affecting both climate and environmental quality, and improved ocean and weather services for the nation.

List of Acronyms

ADCP	Acoustic Doppler Current Profiler
AMOC	Atlantic Meridional Overturning Circulation
AOAT	Atlantic Ocean Acidification Testbed
CHAMP	Coral Health and Monitoring Program
CIMAS	Cooperative Institute for Marine and Atmospheric Studies
CREWS	Coral Reef Early Warning System
CTD	Conductivity-Temperature-Depth
DWBC	Deep Western Boundary Current
GDP	Global Drifter Program
GRIP	Genesis and Rapid Intensification Processes
HEDAS	Hurricane Ensemble Data Assimilation System
HFIP	Hurricane Forecast Improvement Project
HWRF	Hurricane Weather Research and Forecasting
ICON	Integrated Coral Observing Network
IFEX	Intensity Forecast Experiment
MOC	Meridional Overturning Circulation
MOCHA	Meridional Overturning Circulation and Heatflux Array
OAR	Office of Oceanic and Atmospheric Research
OSE	Observing System Experiment
OSSE	Observing System Simulation Experiment
PIRATA	Prediction and Research moored Array in the Tropical Atlantic
PMEL	Pacific Marine and Environmental Laboratory
PREDICT	Pre-Depression Investigation of Cloud systems in the Tropics
SAL	Saharan Air Layer
SEAS	Shipboard Environmental data Acquisition Software
SFP	South Florida Program
SHIPS	Statistical Hurricane Intensity Prediction Scheme
SOOP	Ship of Opportunity Program
TAO	Tropical Atmosphere Ocean
TSG	Thermosalinograph
UAS	Unmanned Aerial System
XBT	Expendable Bathythermograph

Table of Contents

NOAA's Mission

Science, Service, and Stewardship:

- To understand and predict changes in climate, weather, oceans, and coasts.
- To share that knowledge and information with others.
- To conserve and manage coastal and marine ecosystems and resources.

NOAA's Vision

Resilient Ecosystems, Communities, and Economies:

- Healthy ecosystems, communities, and economies that are resilient in the face of change.

AOML's Role in NOAA and OAR

AOML aligns its research goals and activities with those of the broader NOAA mission and its Office of Oceanic and Atmospheric Research. The Laboratory conducts research in support of the following long-term goals as outlined in NOAA's Next-Generation Strategic Plan:

- Climate Adaptation and Mitigation
- Weather-Ready Nation
- Healthy Oceans
- Resilient Coastal Communities and Economies

AOML strives to facilitate the protection of natural resources and sustainable economic growth through better forecasting of climate (seasonal to decadal scales), weather, and ecological conditions as the basis of informed decision making by local managers and regional to national political entities.

This strategic plan outlines AOML's leadership in providing this expertise and vision for the next five years. It forms the basis for our research agenda and is intended as a guide for our partners, colleagues, and constituency as we work together to meet the scientific, societal, and environmental challenges of the 21st century.

The Laboratory employs a cross-disciplinary approach in conducting its research programs, which are carried out through collaborative interactions with national and international research entities and environmental forecasting institutions.

The Laboratory's research provides reliable information based on oceanic and atmospheric measurements and analysis. Core elements of the AOML mission include stewardship of those measurements, development and deployment of new sampling methods and analysis tools, and implementation of long-term consistent environmental observation programs. While much of our research focuses on the Atlantic Ocean, Caribbean Sea, and waters adjacent to Florida, the Laboratory's research enterprise is global in scope and includes research in nearly all ocean basins.

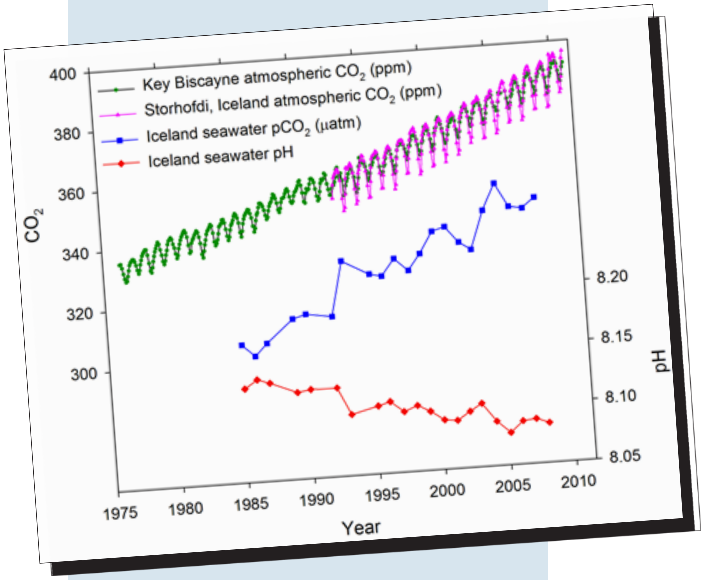
OAR's Mission

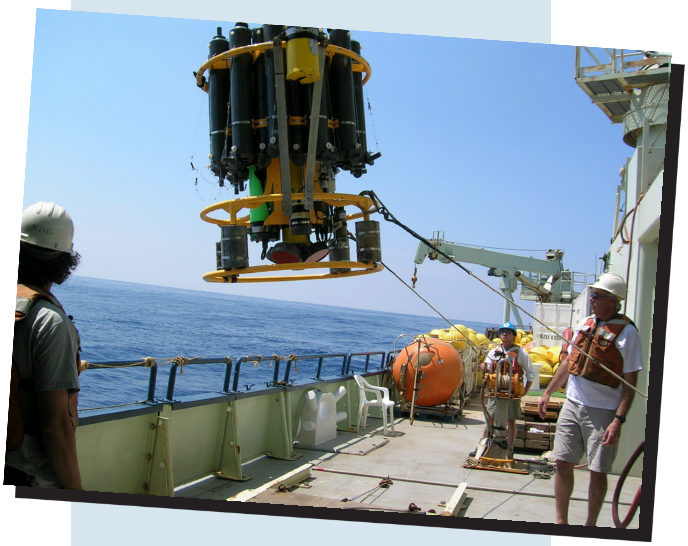
To conduct environmental research, provide scientific information and research leadership, and transfer research into products and services to help NOAA meet the evolving economic, social, and environmental needs of the Nation.

OAR's Vision

A society that uses the results of our research as the scientific basis for more productive and harmonious relationships between humans and the environment.

How AOML Meets NOAA's Goals and Objectives





Top image: The atmospheric time series of CO_2 as measured on Key Biscayne has been documented and maintained by researchers at AOML for more than 30 years and closely resembles data from other parts of the world. As atmospheric CO_2 levels have increased, oceanic pH levels have declined due to formation of carbonic acid as more and more CO_2 is absorbed into the oceans. Ocean acidification challenges reef-forming coral and other marine organisms dependent upon calcium carbonate to build the structures in which they live.

Bottom image: Ocean observing systems are a key component of NOAA's regional, national, and global climate services. Ship-based observations obtained from conductivity-temperature-depth (CTD) sensors and water samples collected using the CTD rosette play a critical role in monitoring the salinity, oxygen, nutrient, and heat content of the ocean.

Research at AOML is conducted in support of NOAA's Strategic Plan. We meet the objectives of our mission through multi-disciplinary investigations in three theme areas—oceans and climate, hurricanes and tropical meteorology, and coastal oceans and ecosystems—each of which corresponds to a long-term goal described in NOAA's Next Generation Strategic Plan. Specific AOML objectives for each theme area are described below.

We also serve NOAA's Science and Technology Enterprise objective through our dedication and support of ocean observing systems. We meet NOAA's Engagement Enterprise objective through our public outreach and collaboration with regional, national, and international partners in academia, other governmental agencies, and non-governmental organizations.

Climate Adaptation and Mitigation

An informed society anticipating and responding to climate and its impacts.

- Understand the physical processes and mechanisms that control the pathways, water mass transformations, and inter-ocean/interhemispheric exchanges of the Meridional Overturning Circulation and its related climate impacts.
- Study the variability of the Atlantic Warm Pool and tropical Atlantic Ocean and their interactions with the Pacific Ocean to better understand the oceanic influence on the climate and weather of surrounding continents.
- Determine how regional and basinwide ocean circulation are affected by long-term global ocean variability.
- Improve our understanding of the role of small-scale phenomena in climate dynamics and improve their parameterization in numerical models.
- Assess the impact and feedback mechanisms of the ocean on the global carbon cycle and anthropogenic carbon dioxide increases and quantify the rates and magnitude of ocean acidification at basinwide, regional, and local scales.

Weather-Ready Nation

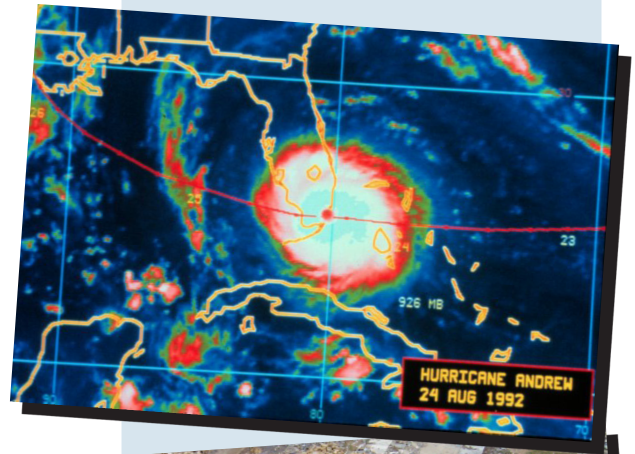
A society prepared for and responsive to weather-related events.

- Improve the basic physical understanding and model forecasts of tropical cyclone intensity/structure change, with a focus on rapid intensity change. Develop experimental model systems tested with actual observations to improve these models.
- Accelerate improvements to numerical and operational forecasts of tropical cyclone tracks, which are the basis of all other tropical cyclone forecasts (e.g., intensity, structure, waves, and rainfall).
- Improve understanding and modeling of the forcing that produces rainfall and storm surge flooding, damaging waves, and winds using conventional and unique hurricane measurement systems.
- Determine the influence of climate change on hurricane activity and improve our seasonal hurricane forecast skill.

Healthy Oceans and Resilient Coastal Communities and Economies

Marine fisheries, habitats, and biodiversity sustained within healthy and productive ecosystems/Coastal and Great Lakes communities that are environmentally and economically sustainable.

- Improve the capability to measure and understand the sources of degradation in coastal ecosystems and their impact on ecosystem health and resilience including the relationship of the oceans to human health.
- Enhance and increase the incorporation of science into ecosystem restoration and ecosystem-based management decisions, and provide tools for the integration of knowledge about both human and natural ecosystem components.



Top image: Satellite image of category 5 Hurricane Andrew making landfall in south Florida on August 24, 1992.

Middle image: Aerial view of Biloxi, Mississippi following the passage of Hurricane Katrina on August 29, 2005. AOML microbiologists studied the fate of fecal contaminants and other pathogens in the floodwaters of Katrina to assess impacts on water quality in the New Orleans area and Lake Pontchartrain.

Bottom image: View of a low-pressure system (formerly Hurricane Frank) over the eastern Pacific Ocean on August 28, 2010 as seen from NASA's Global Hawk unmanned aircraft at an altitude of 60,000 feet. The joint effort between NOAA and NASA was conducted in conjunction with AOML's hurricane field program and marked the first successful unmanned aerial flight above a tropical cyclone.

Top image: Coral reef in Lao Lao Bay off the island of Saipan, one of the Northern Mariana Islands in the Pacific Ocean. AOML researchers installed a coral observing station nearby in 2011 to monitor and provide early warnings of coral bleaching events. Seventy-five percent of the world's coral reefs are currently threatened by local and global pressures, according to a 2011 analysis. The most immediate challenges arise from local sources, which threaten more than 60% of coral reefs. Local threats include impacts from fishing, coastal development, and pollution. Left unchecked, the percentage of threatened reefs is expected to rise to more than 90% by 2030.

Bottom image: AOML researchers work with colleagues from NOAA's Southeast Fisheries Science Center to swap bongo and neuston nets during an interdisciplinary study of connectivity between ecosystems in the Caribbean. On the 19-day cruise aboard the NOAA Ship *Nancy Foster,* data were gathered to improve understanding of larval recruitment pathways of economically important reef fish in the U.S. Virgin Islands. In addition to the U.S. Caribbean coral reef ecosystem, offshore areas of the Caribbean support economically important pelagic fisheries. For example, white marlin and blue marlin spawn north of Puerto Rico and in the Mona Passage, and white marlin larvae have been collected in the area.

How AOML Meets NOAA's Goals and Objectives

Healthy Oceans and Resilient Coastal Communities and Economies (continued)

- Quantify the coastal air-sea flux of carbon dioxide and determine its spatial and temporal variability.
- Provide the science required to assess the impacts of ocean acidification, climate change, and sea level rise on coral reefs and assist in the application of this science to management decision-making.
- Improve understanding of the role of climate change on the health of coastal and regional marine ecosystems.
- Determine the degree to which the coastal ecosystems of the Intra-Americas Sea are physically and biologically interconnected and the degree to which they are affected by remote oceanographic and meteorological forcing.
- Determine the degree to which coastal ecosystems are affected by the landfall of tropical cyclones and conduct long-term studies on how these ecosystems respond to such stresses. Determine the factors that contribute to ecosystem resiliency in response to tropical cyclones.

Science and Technology Enterprise

- A holistic understanding of the Earth system through research, integrated Earth observing systems, and environmental modeling.
- Maintain and support the Global Drifter Program, Ship of Opportunity Program, Western Boundary Time Series Program, the PIRATA Northeast Extension Program, CLIVAR CO_2 Repeat Hydrography Program, and the Argo Program as directed and funded by the NOAA Climate Service, and the ICON/CREWS network as directed and developed by NOAA's Coral Reef Conservation Program.

- Develop the next generation of methodologies, instruments, sensors, sensor platforms, and integrated environmental monitoring systems required to monitor ecological, physical, and chemical processes in the coastal marine ecosystem.

- Employ new technology in biosensors, monitoring technologies, autonomous in situ monitoring, remote sensing, and modeling to develop observation systems that include biological and chemical components and which can be used to understand the impacts of climate change, pollutants, and other stressors on marine ecosystems.

Engagement Enterprise

- An engaged and educated public with an improved capacity to make scientifically informed environmental decisions, and full and effective use of international partnerships.

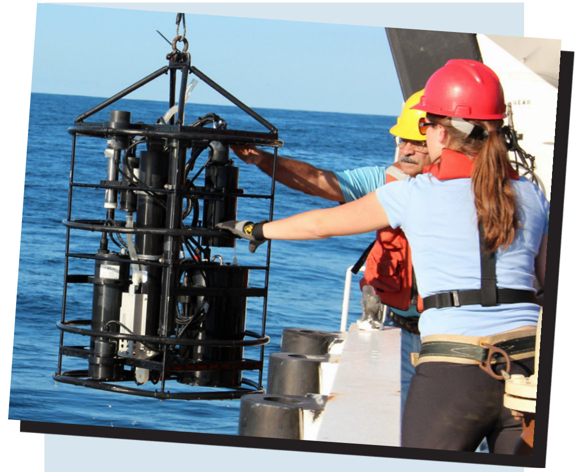
- Effectively communicate the findings from AOML's observations and scientific research to resource managers, stakeholders, and policy makers.

- Project to the public a sense of a vital AOML enterprise whose scientific accomplishments are important and relevant to society's needs.

- Improve AOML's Internet world-wide web presence to better serve colleagues and the general public.

- Foster an environment of collaboration, exchange, and leadership with our university, federal, and international partners by serving on scientific boards, steering and advisory committees, and by supporting a robust visiting scientist program.

- Reach out to under-represented groups in science.



Top image: Optical packages such as this one being recovered in the Virgin Passage, U.S. Virgin Islands, provide data on inherent and apparent optical properties of the water, contributing to AOML's rapidly developing program in ocean optics and remote sensing. A special effort is being made to improve algorithms for satellite-derived ocean color products in tropical waters through collaboration with scientists from NOAA's National Environmental Satellite, Data and Information Service, the University of South Florida, University of Puerto Rico, the Southeast Fisheries Science Center, and the Naval Research Laboratory/Stennis Space Center.

Bottom image: AOML researcher Gustavo Goni (far left) poses with students and teaching staff aboard the MV *Explorer* prior to the deployment of a surface drifting buoy. The *Explorer* serves as a floating university campus for the Semester at Sea Program and regularly houses more than 700 students per semester during its voyages around the world. In exchange for the *Explorer* assisting NOAA in gathering oceanographic observations as a volunteer observing ship, AOML researchers presented classes aboard the *Explorer* on oceanography, global ocean circulation patterns, NOAA's ocean observing efforts, and satellite oceanography applications. Students also attended training sessions with AOML researchers and then helped to deploy and track surface drifting buoys and Argo profiling floats.

Oceans and Climate Research

Top image: The PIRATA (Prediction and Research Moored Array in the Tropical Atlantic) program seeks to monitor the upper ocean and near surface atmosphere of the tropical Atlantic via an array of moored buoys, such as the one pictured here with the NOAA *Ship Ronald H. Brown*.

Bottom image: Deployment of a satellite-tracked surface drifting buoy.

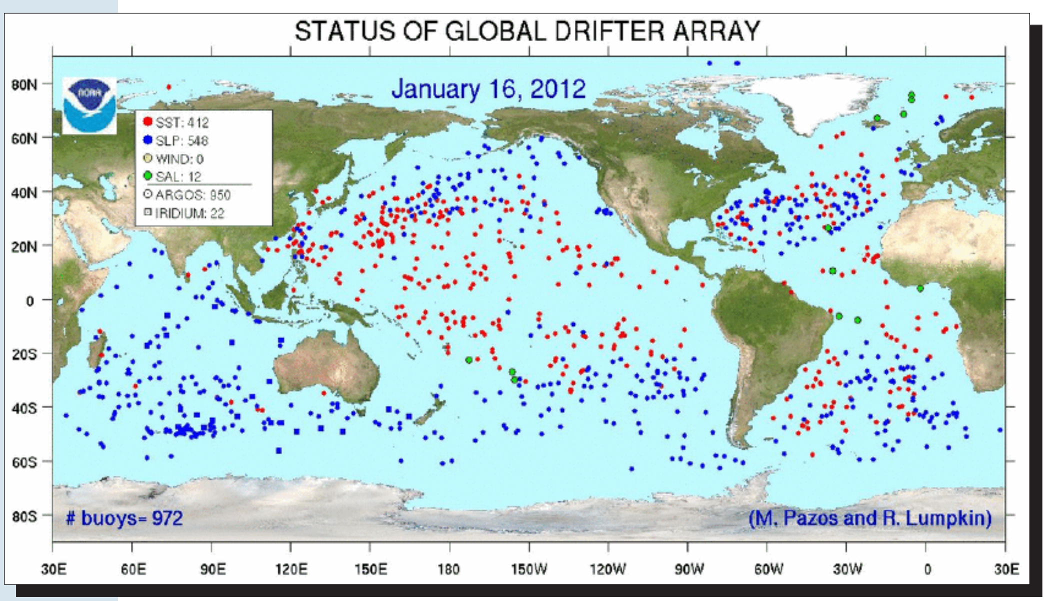
Right: The global drifter array on January 16, 2012. The size of the array varies according to regional deployments and fluctuations in "death" rate, while the annual average is maintained at close to 1,250 drifters. NOAA's Global Drifter Program (GDP) is the principal component of the global drifter array. AOML houses two vital components of the Global Drifter Program: the Drifter Data Assembly Center and the Drifter Operations Center. These components of the GDP coordinate deployments of surface drifting buoys around the world, process and archive the data, maintain metadata files for each drifter deployed, develop and distribute data-based products, and maintain the GDP website.

Background

AOML conducts research based on models and observations to understand and characterize the role of the oceans in climate variability and change. Techniques vary from shipboard-conducted process studies, models, long-term continuous time series, and satellite-derived products. In support of these studies, AOML presently manages all or significant portions of the following NOAA contributions to the internationally coordinated Global Ocean Observing System activities:

- Global Drifter Program
- U.S. Argo Consortium
- Global Ship of Opportunity Program (for deployment of XBTs and underway surface ocean observations)
- CLIVAR CO_2 Repeat Hydrography Program
- PIRATA (Prediction and Research Moored Array in the Tropical Atlantic) Program
- Western Boundary Time Series Program

These activities include the design, implementation, maintenance, and enhancement of the observational network, real time quality control of the data for use by operational forecast agencies, delayed mode quality control of the data for use in scientific projects, and the production and provision of ocean products used by operational and research communities in their ocean activities. AOML scientists serve on the international committees that provide guidance for all of these projects to ensure alignment with NOAA requirements.



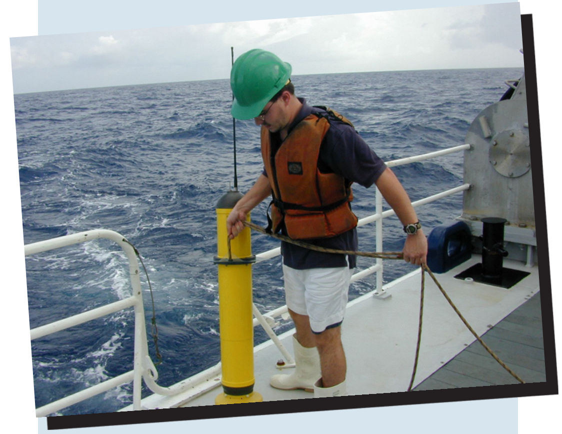
Furthermore, AOML scientists play an innovative role in establishing deployment opportunities by enhancing their interaction with commercial ship companies, the international community, and foreign universities and laboratories. The above programs supply data to NOAA and to national and international institutions that provide operational climate forecasts and conduct climate variability research.

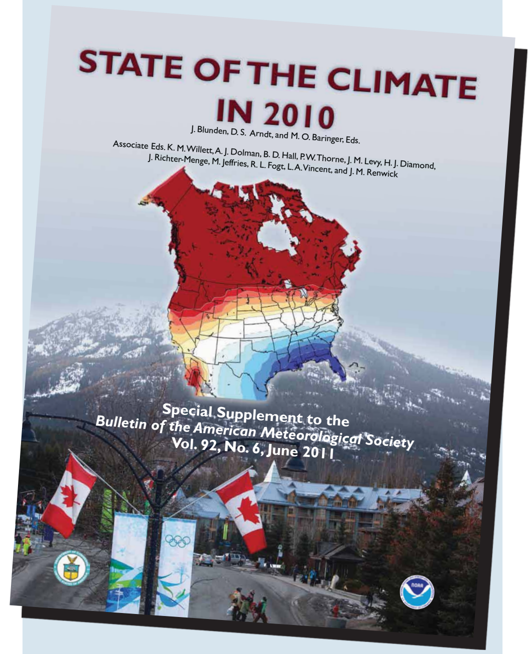
AOML's research related to ocean dynamics includes the Meridional Overturning Circulation (MOC), western boundary currents (e.g., Gulf Stream, Deep Western Boundary Current, Brazil Current, and surface and intermediate depth circulation in the Atlantic Ocean), and Gulf of Mexico and Caribbean Sea oceanography. In addition to global in situ and hydrographic observations, satellite observations and numerical modeling also complement and augment our research.

AOML participates in international research projects directed at developing new methods to observe the ocean for climate studies. Specifically, AOML provides variability measurements of the northward-flowing Florida and Antilles currents and the southward-flowing Deep Western Boundary Current; this unique long-term program is now the foundation for the internationally coordinated Meridional Overturning Circulation and Heatflux Array (MOCHA) and RAPID-MOC programs. These programs are focused on observing the intensity of the Atlantic MOC near 27°N to evaluate the ocean's natural variability and to test and validate ocean-only and coupled ocean-atmosphere models.

In addition, AOML collaborates with NOAA's Pacific Marine Environmental Laboratory (PMEL) to augment and maintain the PIRATA array (the Atlantic's counterpart to the very successful TAO [Tropical Atmosphere Ocean] array in the Pacific). The PIRATA moorings provide surface atmospheric data for weather forecasts and oceanographic data for studies of the oceanic conditions in the Main Development Region for tropical cyclones. Long-term maintenance of these moorings will provide important data on the ocean's role in tropical climate and the possible telecommunications between the tropics and subtropics, along with opportunities for shipboard observations and drifter/float deployments.

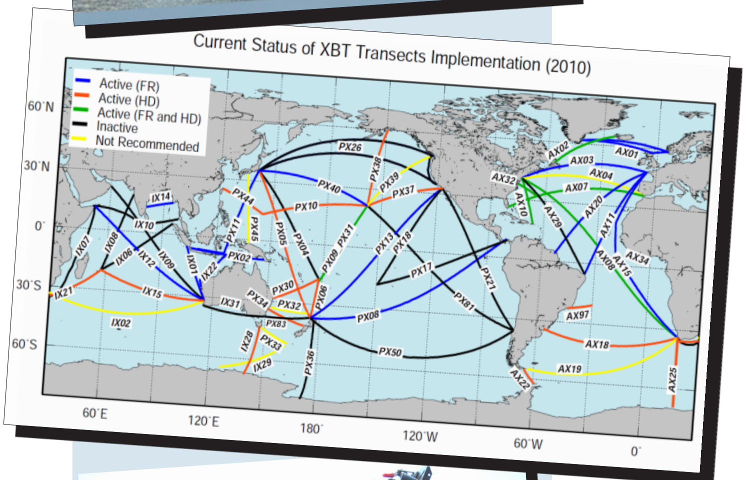
AOML also develops new instrumentation for observing the ocean. For example, the Shipboard Environmental data Acquisition Software





Top image: An Argo profiling float prior to deployment. Argo floats spend the majority of their life cycle drifting beneath the ocean's surface, sinking to depths as great at 2000 m to gather temperature and salinity measurements. At regular intervals, typically every 10 days, they rise to the surface, transmit their data, and descend once again to drift with the currents. Argo floats began being deployed worldwide in 1999 and, by 2007, the program reached its target goal of 3,000 floats. The Argo array provides an estimated 100,000 temperature/salinity profiles annually, which document seasonal to decadal shifts in climate. They also provide information on the changing patterns of heat and freshwater storage in the global ocean, as well as their transport. Argo has improved estimates and forecasts of sea level rise, played a key role in improving seasonal climate forecasts, and has provided new insights on hurricane activity.

Bottom image: Cover image of the *Bulletin of the American Meteorological Society* 2010 State of the Climate article coedited by Molly Baringer of AOML with contributions by nine AOML authors.



Top image: Merchants ships provide a cost-effective means for gathering environmental data over broad, often undersampled, expanses of the ocean and aid AOML's climate research efforts by participating in the Ship of Opportunity Program (SOOP). SOOP is a global network of commercial and research vessels that collect surface and subsurface oceanographic data from instruments such as expendable bathythermographs (XBTs), underway pCO_2 systems, thermosalinographs (TSGs), surface drifters, and Argo floats.

Middle image: Global map that depicts the oceanic transects currently used by research vessels and ships of opportunity to gather XBT and TSG data in support of NOAA's ocean-observing efforts.

Bottom image: Kyle Seaton of AOML on the stern of the cargo ship *Horizon Navigator*, next to a mounted XBT auto-launcher developed at AOML. XBTs measure the thermal structure of the upper ocean and are needed to help increase understanding of the dynamics of the ocean's variability on seasonal to interannual and decadal time scales. They also provide data for model validation studies.

Oceans and Climate Research

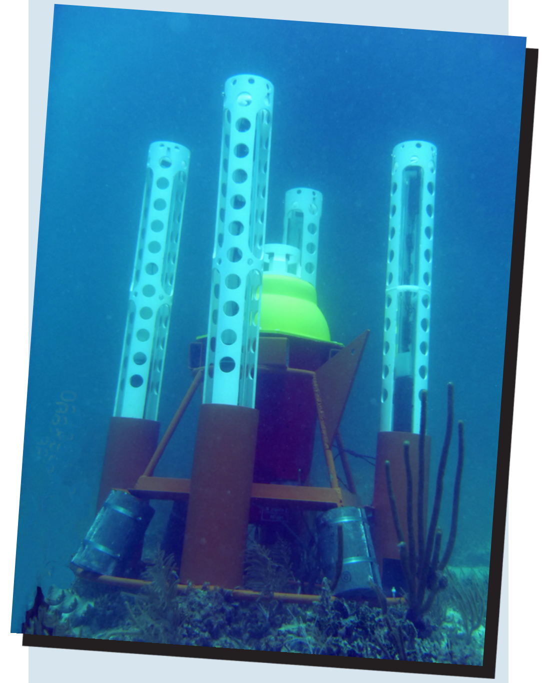
(SEAS) system was developed to improve communications between land stations and the merchant ships that collect marine meteorological and oceanographic data for NOAA. SEAS additionally provides data to the U.S. Coast Guard for their search and rescue operations at sea. A surface mini-drifter, developed at AOML for deployment in very shallow regions such as the coastal zone, measures currents that could play a significant role in climate change. AOML also designed and built the oceanographic instrument package for a real-time transmission system deployed at underwater observatories.

The ocean plays a key role in regulating and modulating atmospheric levels of climate-forcing trace gases such as carbon dioxide (CO_2). This is particularly pertinent because of the rapidly increasing CO_2 levels in the atmosphere due to anthropogenic activity. Understanding the role of the ocean is paramount for any possible CO_2 mitigation strategies.

The magnitude of CO_2 exchange and the quantification of uptake of CO_2 by the ocean are two key processes that are studied at AOML in collaboration with academic and NOAA partners, in particular, the Ocean Carbon Group at PMEL. The Ocean Carbon Group at AOML addresses key issues pertaining to the global carbon cycle through observations, analysis, and interpretation. This work is performed as part of NOAA's long term Climate Adaptation and Mitigation goal, including cross-cutting activities in ocean acidification that intersect with NOAA's Healthy Oceans goal.

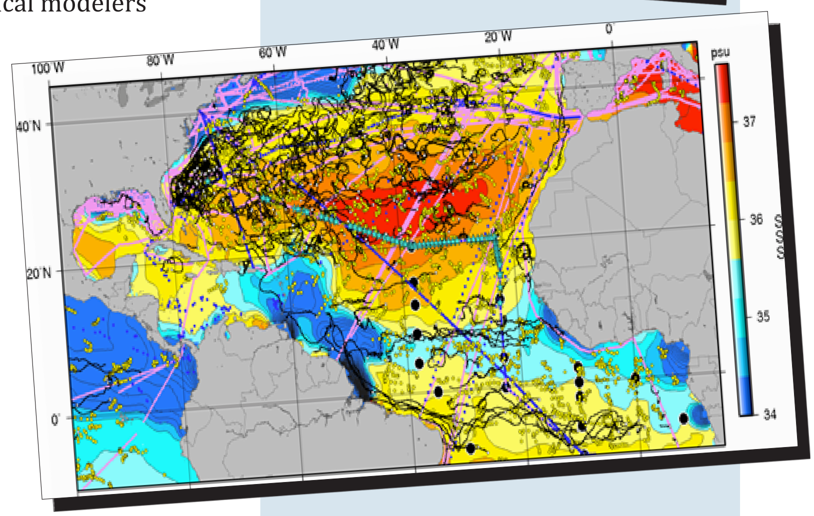
Challenges

A major challenge for AOML in maintaining the various global observing systems is the difficulty in obtaining merchant and research ship time. Volatility in the commercial shipping industry greatly complicates the ability to maintain stability in deployment opportunities on volunteer platforms (e.g., expendable bathythermographs, Argo floats, surface drifters, etc.). Reductions in research vessel funding has already caused delays and, in some cases, cancellations of cruises, a critical problem when instruments are to be recovered. AOML must continue to capitalize upon the resources it has developed over the years to ensure seagoing operations are not impacted (e.g., the use of shipping lines for sensor deployments and collaborations with other countries for research cruises).



Currently, international groups govern the deployment of the particular instrument type that they oversee (e.g., the international Argo Steering Committee, the Global Drifter Program, etc.). Obtaining a truly integrated observing system requires research on the integration of satellite and in situ networks to minimize duplication and maximize both information content and spatial and temporal resolution. Observing System Simulation Experiments (OSSEs) that use tested and validated numerical models have the potential to provide an excellent guidance tool to help achieve these efficiencies. Statistical and empirical studies provide additional tools to work towards achieving these same goals.

Historically, there has been a virtual wall between numerical modelers and observational oceanographers, and this disconnect greatly hampers both the evolution of observing systems and the improvement of forecast models. Most of the work conducted on model-data comparison has been completed on an ad-hoc basis with little detailed planning and follow through. It is a goal of AOML to increase modeler-observationalist interactions. Consequently, AOML is increasing its in-house ocean modeling capabilities to enhance the scientific analysis of ocean observations and develop an ocean OSSE system. This capability will be used to evaluate the impact of the present ocean observing system and design the enhancements required to achieve our stated goals.



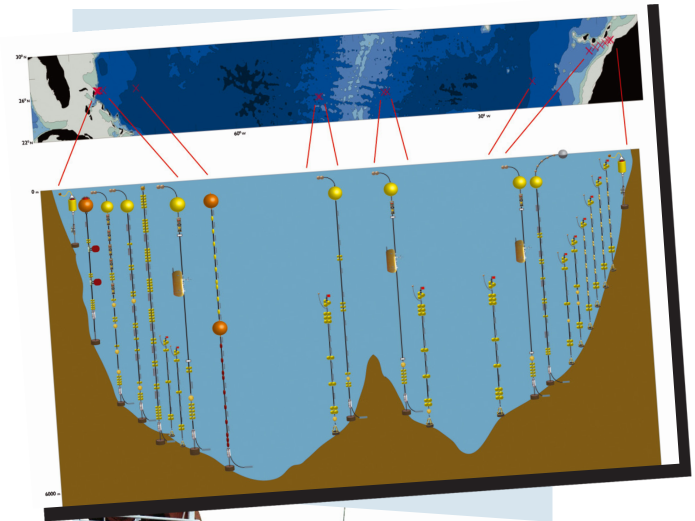
Another major challenge is the search for new indices and enhanced observing systems that will allow us to better understand long-term climate changes and the role that the ocean plays in driving these changes. Observations are the backbone of all the data analysis conducted at AOML. By collecting and analyzing long-term, research-quality observations from the ocean and the atmosphere, AOML will be able to confirm or modify the results derived from model predictions.

New instrument technologies and improved observing system designs will also allow us to enhance existing observing systems with increased efficiency. Additionally, the distribution of these data in real time, with appropriate metadata and support for the associated archiving centers, must be addressed. Timely distribution of quality-controlled data is crucial for more accurate forecasts. Therefore, AOML intends to

Top image: Four prototype data pods developed by the Instrumentation Group at AOML deployed in the Straits of Florida. The Adaptable Bottom Instrument Information Shuttle System, ABIISS, enables scientific instruments on the ocean floor to send their data to the surface via expendable data pods. The pods are released on a programmable schedule and rise to the surface to transmit their data via satellite. ABIISS has the potential to save significant amounts of financial and personnel resources by reducing the amount of ship time needed to support and maintain ocean time series measurement sites.

Bottom image: Location of typical sustained ocean observations during a three-month period in the Atlantic Ocean, some of which AOML plays a key role in implementing and maintaining: XBT transects (blue lines), TSG observations (purple lines), surface drifters (black lines), PIRATA moorings (black lines), underway CTD (blue circles), and Argo floats (yellow circles).

Oceans and Climate Research



AOML researchers have been at the forefront of investigating the Meridional Overturning Circulation (MOC) since 1982 when they joined colleagues from NOAA's Pacific Marine Environmental Laboratory and the University of Miami to monitor key components of the MOC at 27°N east of Florida. This NOAA program, presently called the Western Boundary Time Series project, is also the cornerstone of an international effort between the United States and United Kingdom to measure the MOC and ocean heat transport in the North Atlantic Ocean at 26.5°N from Florida to Africa. The basin-wide program, denoted as MOCHA (Meridional Overturning Circulation and Heatflux Array) by U.S. National Science Foundation and NOAA-funded contributors and RAPID-MOC by U.K. Natural Environment Research Council contributors, has been in place since early 2004 and has the goal of providing daily estimates of the basinwide MOC for at least ten years.

Top image: Diagram of the MOCHA/RAPID-MOC monitoring array along 26.5°N latitude stretching from southeast Florida to the northwest coast of Africa. The instrument array provides continuous measurements of water flow, salinity, temperature, and water pressure (graphic courtesy of Darren Rayner, National Oceanography Centre, Southampton, UK).

Bottom image: A conductivity-temperature-depth (CTD) rosette is deployed to gather data about the physical properties of the water column during a research cruise aboard the NOAA Ship *Ronald H. Brown* with colleagues from the University of Miami and National Oceanography Centre.

continue improving the current technology and data acquisition systems, as well as its quality control methods and distribution of data.

Priorities

The continuation of AOML's established role as a preeminent research center is our priority. This priority can be met through emphasis upon the design, implementation, and maintenance of the ocean observing system's critical components and the collection of high-quality observations for use in climate diagnostics, analysis, modeling, and forecasting. Climate-related observations and data collection activities must be end-to-end, from sensor deployment through data transmission and product generation, and the development of new generations of measurement systems. Equally important, the data collected must be used in analysis efforts to increase understanding of climate dynamics and in design studies directed at maximizing the efficiency of the observing systems. Plans to achieve these priorities are presented in the specific actions below.

AOML's oceans and climate researchers use scientifically-recognized techniques and products and develop new applications that benefit society including, for example, improved understanding of the ocean's impact on droughts, hurricane genesis and intensification, and long term climate change.

Science Objectives and Actions

Objective: Understand the physical processes and mechanisms that control the pathways, water mass transformations, and interocean/interhemispheric exchanges of the MOC and its related climate impacts.

Actions:

- Make critical contributions to the design, implementation, maintenance, and enhancement of the current MOC observing system.
- Develop deep ocean observing systems in conjunction with international partners to characterize the strength and spatial structure of the MOC in the North and South Atlantic oceans.
- Evaluate the current state of the MOC, its connectivity and coherence, and determine the MOC's influence on climate through analysis of observational data and models.

- Analyze model outputs to assess the overall effectiveness of observing systems that monitor the heat, mass, and fresh water transports of the MOC and develop optimized observing systems.

Objective: Study the variability of the Atlantic Warm Pool and tropical Atlantic Ocean and their interactions with the Pacific Ocean to better understand the oceanic influence on the climate and weather of surrounding continents.

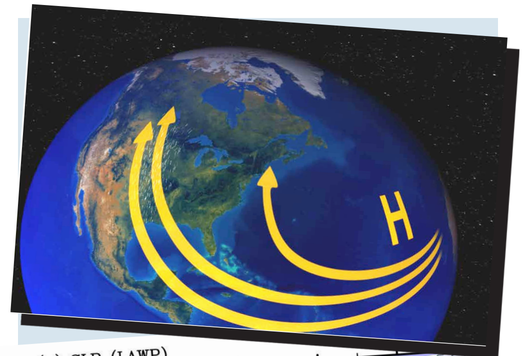
Actions:

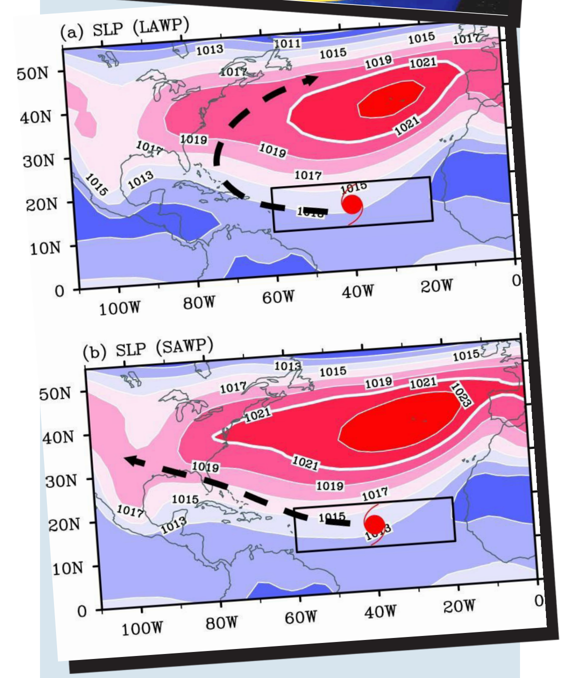
- Perform diagnostic and modeling studies on the impacts, mechanisms, and predictability of the Atlantic Warm Pool.
- Determine the influence of the Atlantic Warm Pool on extreme events such as tornados, droughts, and floods in the United States and their relationship with moisture transport from the Atlantic Warm Pool region.
- Identify processes and/or parameterizations in coupled ocean-atmosphere models that are responsible for generating model biases in the tropical Atlantic Ocean and in the Atlantic Warm Pool.
- Design, propose, and implement extensions of the Global Ocean Observing System in the Intra-Americas Sea.
- Continue to play a leading role in international programs linked to the Intra-Americas Sea and its links to climate processes.

Objective: Determine how regional and basinwide ocean circulation are affected by long-term global ocean variability.

Actions:

- Develop new techniques to analyze in situ ocean measurements with satellite remote observations.
- Study the variability of ocean gyres, particularly in the South and North Atlantic oceans.
- Improve understanding of the changes and locations of major surface currents that are key components of the MOC.
- Determine the regional impacts of sea surface height, sea surface temperature, surface currents, ocean color, and heat content.
- Map the sea height trend derived from satellite altimetry during 1993-2007, showing regions where sea level has risen and decreased.





Climate researchers at AOML have studied the Atlantic Warm Pool for a number of years to better understand its role in bringing summer rainfall to the central portion of the United States and its impact on Atlantic hurricane activity. The Atlantic Warm Pool is a large body of warm water found in the region of the Gulf of Mexico, Caribbean Sea, and western tropical North Atlantic with sea surface temperatures above 28.5°C.

Top image: Schematic diagram of the North Atlantic subtropical high and its associated low tropospheric flows. The atmospheric flows carry moisture from the Atlantic Warm Pool to North America, which helps bring summer rainfall to the central United States.

Bottom image: A study by AOML researchers (Wang et al., 2011, *Geophysical Research Letters*, 38:19702) identified a relationship between the Atlantic Warm Pool and the likelihood of hurricanes making landfall in the United States. Hurricanes that form in the Main Development Region (shown as a black box) appear to be influenced by the Atlantic Warm Pool. The top image (a) depicts the influence of a large Atlantic Warm Pool, which recurves storms into the Atlantic away from the United States. The bottom image (b) depicts the influence of a small Atlantic Warm Pool, which steers storms in a more westwardly direction towards the United States.

Top image: Amidst 18-foot waves and wind gusts greater than 50 knots, a ship-mounted camera photographs the sea washing over the rear deck of the Ice Breaker *Nathaniel B. Palmer* during the first week of sampling operations in the Southern Ocean. An AOML researcher participated in the cruise as part of an ongoing effort to determine changes in global ocean carbon content and transport in support of the U.S. contribution to the World Climate Research Program's CLIVAR Repeat Hydrography Program and the International Ocean Carbon Coordination Project.

Middle image: Researchers pose with a CTD rosette during a repeat hydrography cruise across the Pacific Ocean aboard the RV *Melville*.

Bottom image: The U.S. Global Ocean Carbon and Repeat Hydrography Program carries out a systematic and global re-occupation of select hydrographic sections to quantify changes in the storage and transport of heat, fresh water, carbon dioxide, and related parameters.

Oceans and Climate Research

Objective: Improve our understanding of the role of small-scale phenomena in climate dynamics and improve their parameterization in numerical models.

Actions:

- Observe the structure and energy levels of ocean turbulence at scales from meters to tens of kilometers to characterize the lateral and depth variations in dispersion driven by features at these scales.
- Observe the dynamics of ocean fronts and cross-frontal fluxes in regions of strong mean sea surface temperature gradients. These fronts can be associated with equatorial cold tongues, midlatitude western boundary currents, or high latitude circumpolar currents and are often maintained by a complex balance of two- and three-dimensional processes that provide a rigorous test for numerical models.
- Determine the impact of small-scale features and cross-frontal eddy transports upon large scale air-sea heat fluxes, background circulation, precipitation patterns, and oceanic transport of salt via studies of regional ocean heat and salt budgets on intraseasonal to decadal time scales.
- Improve the parameterization of dispersion in ocean numerical models by documenting how dispersion can be represented over various scale ranges.
- Characterize the observed distribution of near-inertial energy in the ocean and document the effect of background mesoscale and large-scale vorticity on this distribution.

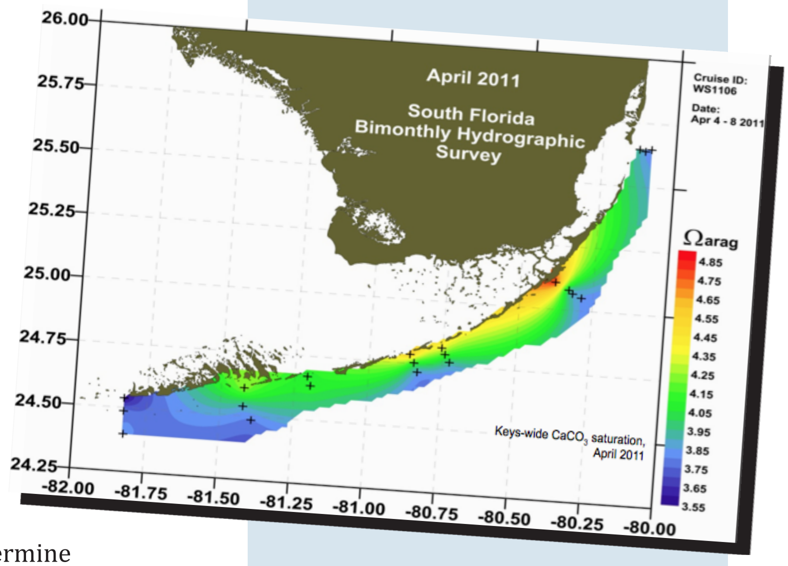
Objective: Assess the impact and feedback mechanisms of the ocean on the global carbon cycle and anthropogenic CO_2 increases and quantify the rates and magnitude of ocean acidification at basinwide, regional, and local scales.

Actions:

- Quantify the air-sea CO_2 flux in near-real time through modeling and increased observations of the partial pressure of CO_2 at the sea surface.
- Determine the change in ocean carbon inventory through continued observations of the inventory and transport of CO_2 with global surveys from the CLIVAR/CO_2 Repeat Hydrography Program. Attribution of these changes in the ocean's biogeochemical cycles through

multi-species measurements and modeling are an important part of the interpretation, along with improved modeling efforts performed with collaborators.

- Assess the impacts of increasing inorganic carbon concentrations on ocean chemistry and biology (ocean acidification). Through its long involvement in ocean carbon research and its state-of-the-art facilities for inorganic carbon measurements, AOML is uniquely positioned to quantify these changes and determine their response in subtropical waters, including coral reefs. AOML will be a key contributor to a coastal ocean acidification monitoring system for the Gulf of Mexico and U.S. eastern seaboard.
- In partnership with NOAA's Coral Reef Conservation Program, PMEL, and academic partners, AOML will lead the implementation of a coral reef ocean acidification monitoring network to document changes in carbonate chemistry within coral reef environments. This network will enable AOML researchers and others to assess natural variability and better constrain biological feedbacks that can augment the rate and impact of ocean acidification within local environments.



Ocean acidification poses a growing threat to coral reefs worldwide. As carbon dioxide levels increase in the ocean, changes in carbonate chemistry make it more difficult for organisms such as coral to build the calcium carbonate structures in which they live. Monitoring carbonate chemistry at reef sites thus holds the promise of advancing understanding of a marine environment in transition and its overall affect upon coral reefs.

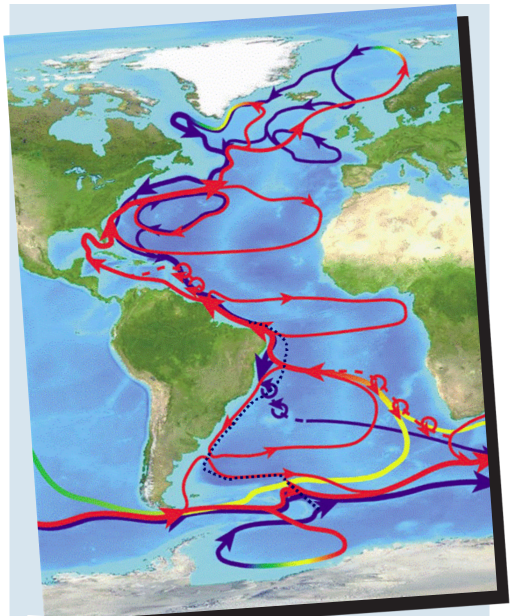
Top image: Calcium carbonate saturation levels observed in the Florida Keys during an AOML/South Florida Program bimonthly cruise.

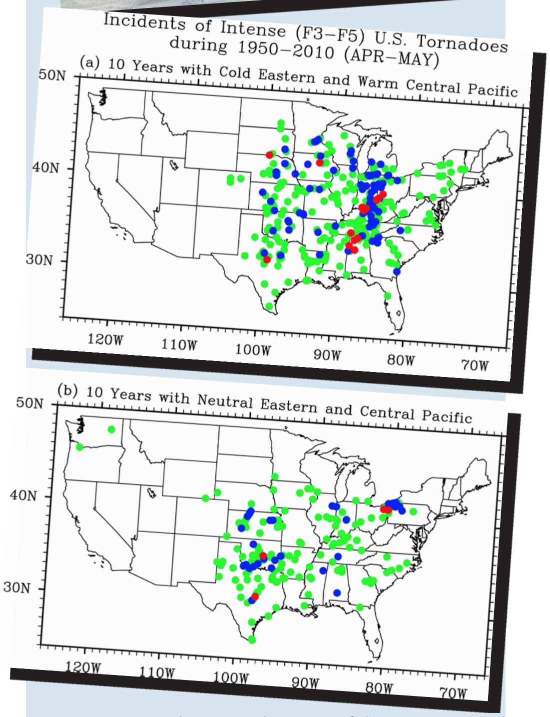
Bottom image: AOML researchers with the Ocean Carbon Group received the Department of Commerce's highest honor, the Gold Medal, in 2006 as part of a group award with colleagues from NOAA's Pacific Marine Environmental Laboratory. The award recognized their 15 years of meticulous research and observations that showed the oceans were becoming more acidic as a result of the uptake and storage of anthropogenic carbon dioxide.

Anticipated Impacts

The key participation of AOML in the design, implementation, maintenance, and enhancement of the ocean observing system will lead to studies that significantly improve our understanding of the global ocean's role on seasonal to decadal and longer time scales of climate variability and, in particular, the role of ocean circulation in redistributing heat, fresh water, and carbon globally. One such example will be our focus on the Atlantic MOC. We expect to continue gathering measurements on the variability of the northward-flowing Florida and Antilles currents and the southward-flowing Deep Western Boundary Current (DWBC). AOML has continuously monitored the DWBC since 1982. The extensive data set acquired from this long-term effort is now the cornerstone of internationally-coordinated programs with the National Science Foundation and AOML's European partners.

The evaluation of numerical models and implementation of OSSEs will lead to the design and implementation of improved observing systems. AOML, in collaboration with national and international partner institutions, will complete a re-survey of the global oceans and obtain the first





Top image: Schematic diagram of the overturning circulation in the Atlantic Ocean that represents the large-scale conversion of surface waters (red arrows) to deep waters (blue arrows in the Southern Ocean; dashed blue line arrows for the North Atlantic Deep Water). AOML researchers are monitoring the AMOC's variability to improve their knowledge of important climate processes that are critical to assessing future climate changes.

Bottom images: AOML researchers discovered a relationship between conditions in the Pacific Ocean and the occurrence of strong tornado outbreaks in the United States. Cold eastern Pacific waters and warm central Pacific waters create conditions that are favorable for intense tornado outbreaks over the U.S. The number of intense tornados (F3, F4, and F5) nearly doubles during these conditions when compared to neutral temperatures.

direct estimates of carbon sequestration over the past decade in the Atlantic, Pacific, and Indian oceans. AOML will lead the Atlantic alliance on surface pCO_2 measurements and will establish a comprehensive observing plan to determine basinwide air-sea CO_2 fluxes on seasonal time scales. We will also be at the center of a new frontier in oceanography, one in which ocean variability is sampled in real time and analyzed and predicted operationally, much in the way that the atmosphere is currently sampled.

Beyond 2015

As our understanding of climate processes and their indices, precursors, and impacts improve, as real-time in situ and satellite measurements become the standard, and as we learn how to simulate and predict global ocean variability, we will move into exciting new areas of climate research and societal-driven applications. Future research will likely continue to target the Atlantic MOC and its role in climate variability and will focus on ways to predict its regime shifts and regional impacts.

For our study of the ocean's impact on global CO_2, we envision a continuation of the main projects outlined above with the following augmentations:

- A major expansion of efforts to improve our understanding of increasing CO_2 levels on ocean ecosystems under the banner of ocean acidification.
- An increase in the efficiency and scope of the main projects outlined above by capitalizing on the rapid developments occurring in sensor technology and ocean infrastructure. A particular challenge to be addressed is the ability to sample (inorganic carbon) properties at depths greater than 2 km with means other than the current Niskin/rosette sampling approach.
- Greater collaborative effort to address key research issues related to the ocean carbon cycle including quantifying the uptake of anthropogenic carbon on seasonal to decadal time scales, understanding the variability of inorganic carbon and nutrient cycling in the (deep) ocean, and learning more about its natural, anthropogenic, and climate-forced components.
- Quantification and understanding of the rapidly-observed changes in the carbon cycle at high latitudes.

Hurricanes and Tropical Meteorology

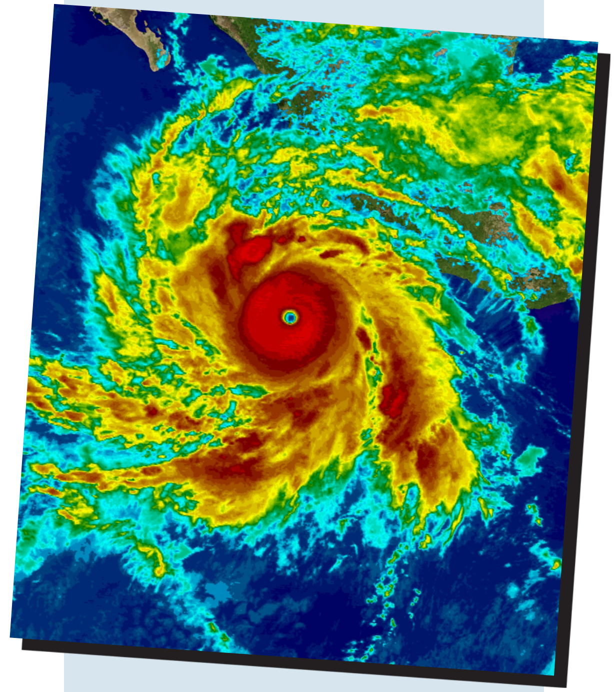
Background

The mission of AOML's hurricane research is to advance the understanding and prediction of hurricanes and other tropical weather. AOML's hurricane research is based on a combination of observations, models, and theories with particular emphasis on using data obtained from research aircraft to improve our understanding of tropical cyclones and to drive improvements in numerical model system development. The goals of this research are to:

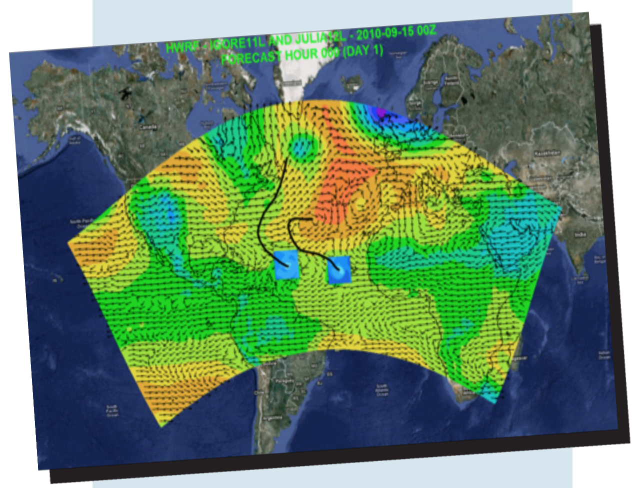
- Advance the prediction of tropical cyclone intensity and structure during the life cycle from genesis to decay or extratropical transition by improving the understanding of processes that modulate internal storm dynamics and storm interactions with the atmosphere, ocean, and land.
- Improve the prediction of tropical cyclone tracks by enhancing the understanding of interactions between a tropical cyclone and its environment.
- Enhance the ability to assess and predict the impact of tropical cyclones on life and property.

These goals are accomplished through:

- Design of research experiments conducted in the environment of tropical cyclones and incipient disturbances to collect and provide data for research and operational applications.
- Development and testing of high-resolution hurricane model and data assimilation systems to improve their ability to simulate nature, track, and intensity forecasts and optimize hurricane observing.
- Development and testing of tools to evaluate and quantify the value of tropical cyclone forecasts.
- Development of new technologies, observational tools, and applications to improve tropical cyclone track, intensity, and structure forecasts.
- Analysis of these data sets, communication of findings at conferences and meetings, and publication of our research in the refereed literature.



AOML is recognized internationally for its knowledge of tropical cyclones, as well as its expertise in technological areas such as airborne Doppler radar, cloud microphysics, dropwindsondes, and air-sea interaction, to name a few. These assets make AOML unique worldwide and provide NOAA a unique capability.



AOML's Hurricane Weather Research and Forecasting model is providing tropical outlooks beyond the current operational five-day forecast to meet the next generation need for forecasts out to seven days.

Hurricane researchers at AOML have routinely gathered data from the inner core and surrounding environment of tropical cyclones for more than 30 years from aboard NOAA's hurricane hunter aircraft. These data are acquired annually in concurrence with the Atlantic and Pacific basin hurricane seasons.

Top image: Low-level clouds swirling in the center of Hurricane Floyd in September 1999, as viewed from the window of one of NOAA's WP-3D hurricane hunter aircraft. The WP-3D's wingtip appears in the upper left corner.

Bottom image: AOML hurricane researchers Kathryn Sellwood and Shirley Murillo process dropwindsonde data aboard one of NOAA's WP-3D aircraft before transmitting the data to operational forecast centers.

Hurricanes and Tropical Meteorology

Much of our hurricane research is based on analysis of in situ and remotely-sensed observations in the core of tropical cyclones and their surrounding environment. These analyses are used to improve our general understanding of tropical cyclones and provide valuable information for the initialization and evaluation of the next-generation of numerical models.

Observations are primarily collected as part of the NOAA Intensity Forecast Experiment (IFEX) during hurricane season using the fleet of U.S. Air Force Reserve WC-130J aircraft and the two NOAA WP-3D turboprop aircraft and Gulfstream-IV jet operated by NOAA's Aircraft Operations Center. The goal of IFEX is to collect observations that directly aid in the development and evaluation of the next generation tropical cyclone forecast modeling system under the new NOAA Hurricane Forecast Improvement Project (HFIP).

Challenges

AOML's traditional strength in tropical meteorology has been its collection and analysis of observations to improve understanding of the physical processes that drive tropical cyclone behavior. AOML is now leveraging this strength by developing numerical models and techniques to more effectively use these observations to improve and evaluate numerical forecasts.

In-house modeling and data assimilation capabilities, combined with AOML's observational leadership in the areas of air-sea interaction, atmospheric and oceanic boundary layers, vortex evolution, and convective structure, have afforded the laboratory a direct and unique connection between scientists who understand what hurricanes look like through observations and researchers assimilating these observations into high-resolution modeling systems.

This strategy is an ideal fit for the new HFIP approach focused on improving numerical models, observing strategies, and products for forecasters. It also provides a corps of talent NOAA can capitalize upon to accelerate improvements into hurricane forecasts. AOML is the only entity within NOAA where all these challenges can be simultaneously addressed under one roof.

Priorities

AOML is addressing the following priorities from NOAA's Five-Year Research Plan under the umbrella of HFIP by developing higher resolution global and regional models. These models make full use of the higher resolution data already being collected to assess uncertainties in the forecast guidance.

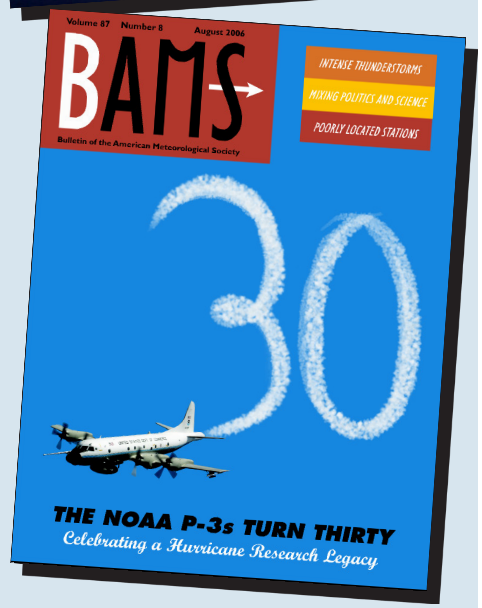
- Determine the degree to which accuracy and warning times for severe weather and other high-impact environmental events can be increased significantly.
- Improve and develop observing systems, analysis approaches, and models that will allow us to better understand, analyze, and predict the atmosphere, ocean, and hydrological land processes.
- Better estimate and communicate the uncertainties in our analyses and predictions.

Science Objectives and Actions

Objective: Improve the basic physical understanding and model forecasts of tropical cyclone intensity/structure change, with a focus on rapid intensity change. Develop experimental model systems tested with actual observations to improve these models.

Actions:

- Lead the IFEX field program to conduct aircraft experiments designed to address the physical processes that drive tropical cyclone intensity and structure change.
- Provide real-time feedback on model intensity and wind field structure forecast performance via our unique analysis tools: the Hurricane Ensemble Kalman Filter (EnKF), hurricane ensemble data assimilation system (HEDAS), H*Wind, Editsonde/ASPEN, and real-time airborne Doppler analyses.
- Develop and evaluate a high-resolution Hurricane Weather Research and Forecasting (HWRF) model system to study the hurricane intensity problem at the cloud-resolving scales of 1-3 km, with particular emphasis on rapid intensity change.



Top image: NOAA's two WP-3D turboprop Orion aircraft have served as airborne observing platforms for tropical cyclone research for more than 30 years during AOML's annual hurricane field program.

Middle image: AOML's hurricane researchers led the effort to acquire the Gulfstream-IV high altitude jet for synoptic surveillance missions around tropical cyclones, which has led to more accurate track forecasts.

Bottom image: Cover of the August 2006 issue of the *Bulletin of the American Meteorological Society* featuring an AOML-authored article about the NOAA WP-3D aircraft and its 30 years of service as an observing platform. Hurricane researchers first used the WP-3D aircraft to observe a tropical cyclone on June 27, 1976 as Hurricane Bonny churned in the eastern Pacific. The article documents the instruments aboard the WP-3Ds that have enabled HRD scientists to study numerous aspects of hurricane structure over the years. This instrumentation continues to evolve.

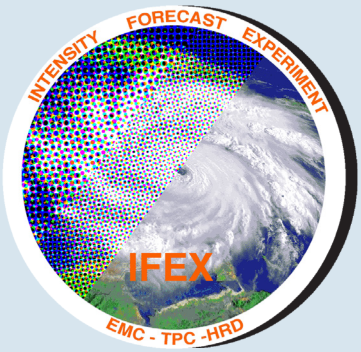
Hurricanes and Tropical Meteorology

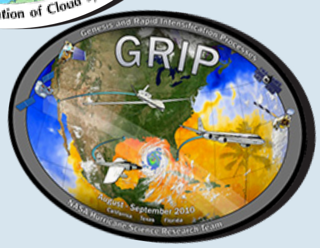
- Develop and evaluate a high-resolution HWRF data assimilation system and observing strategy analysis. AOML's efforts are focused on building an EnKF data assimilation system for HWRFX (HEDAS) capable of assimilating high resolution vortex-scale observations.
- Develop evaluation tools for the high-resolution HWRF modeling system that can examine large-, vortex-, and convective-scale aspects of simulated storms.
- Develop and improve statistical-dynamical intensity guidance such as the Statistical Hurricane Intensity Prediction Scheme (SHIPS and Decay-SHIPS), the Logistic Growth Equation Model, and the Rapid Intensity Change Index (RI-Index).
- Continue to improve satellite-derived products and aircraft sampling strategies that can monitor and detect atmospheric moisture in the tropical cyclone environment. Data from these efforts will be used to advance our general understanding of how dry air (e.g., the Saharan Air Layer, or Saharan dust storms) impacts hurricane intensity and will be integrated into statistical-dynamical models such as SHIPS and the RI-index.

Objective: Accelerate improvements to numerical and operational forecasts of tropical cyclone tracks, which are the basis of all other tropical forecasts (e.g., intensity, structure, waves, and rainfall).

Actions:

- Develop a high-resolution HWRF modeling system to produce improved intensity and structure forecasts and advance scientific understanding of the nature of tropical cyclone rapid intensity and structural changes.
- Evaluate the high-resolution HWRF modeling system's track forecasts to advance our understanding of the large scale tropical cyclone environment and its interaction with a tropical cyclone.
- Develop an ensemble forecasting system for use in predicting the uncertainty in track and intensity forecasts as a general "spread" of intensity forecasts and a probability density function of forecast uncertainty for track (along-track and cross-track), intensity, and structure (asymmetries).



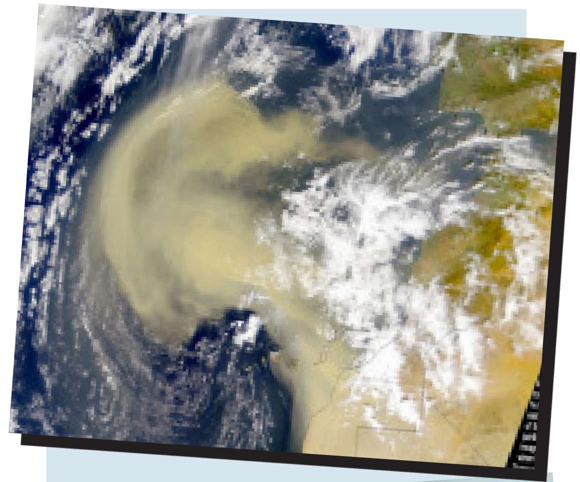


Top image: Since 2005, a major component of HRD's annual field program has been focused on the Intensity Forecast Experiment, or IFEX, conducted in collaboration with NOAA's National Hurricane Center, Aircraft Operations Center, Environmental Modeling Center, and other partners. IFEX is a multi-year effort to improve operational forecasts of tropical cyclone intensity, structure, and rainfall by obtaining high-quality observations from the atmosphere and ocean in and around tropical cyclones during all stages of their life cycle.

Bottom and middle images: In addition to AOML-led experiments related to IFEX, AOML's hurricane researchers have also partnered with the National Space and Aeronautical Administration (NASA) and the National Science Foundation (NSF) for other IFEX experiments:

The Pre-Depression Investigation of Cloud systems in the Tropics was a collaborative effort of AOML and NSF to better understand the processes governing the transition of easterly waves into tropical depressions.

NASA's Genesis and Rapid Intensification Processes (GRIP) campaign was a collaborative effort of NOAA, NASA, and academic partners to better understand how tropical storms form and intensify. During the GRIP science missions in 2010, several systems, including hurricanes Earl and Karl, were sampled from as many as seven aircraft, including NASA's Global Hawk unmanned drone. The GRIP missions documented both the rapid intensification and decay of Hurricane Earl, making its life cycle the most intensively sampled to date.



Top image: Satellite image of a massive dust storm migrating off the west coast of Africa. In the summer and early fall, dust storms generally develop in the arid Saharan Desert every three to five days. These dry, mineral-laden dust clouds, also known as the Saharan Air Layer or SAL, can be transported thousands of miles across the Atlantic Ocean by trade winds.

Middle image: Dust associated with the Saharan Air Layer as viewed from NOAA's Gulfstream-IV jet northeast of Barbados. Cumulus clouds poke through the tops of the dust layer, which is seen as a milky white haze.

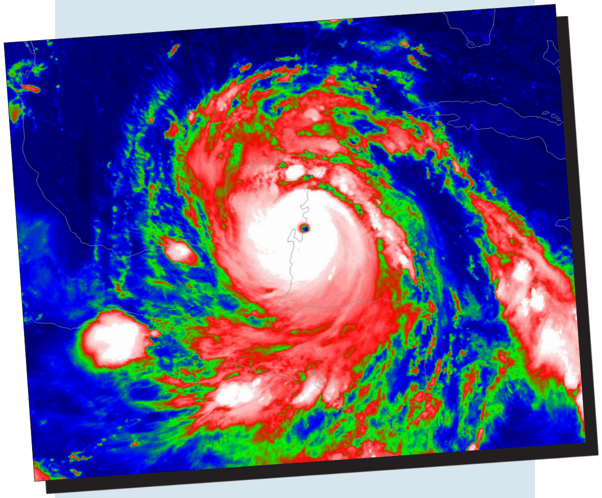
Bottom image: Flight crew from a SALEX (Saharan Air Layer Experiment) mission. The SAL is one of many factors being investigated by AOML's hurricane researchers for its potential impact on tropical cyclogenesis and intensity change. The extremely warm, dry air of the SAL reduces atmospheric moisture and has been found to suppress the development of tropical cyclones in the Atlantic.

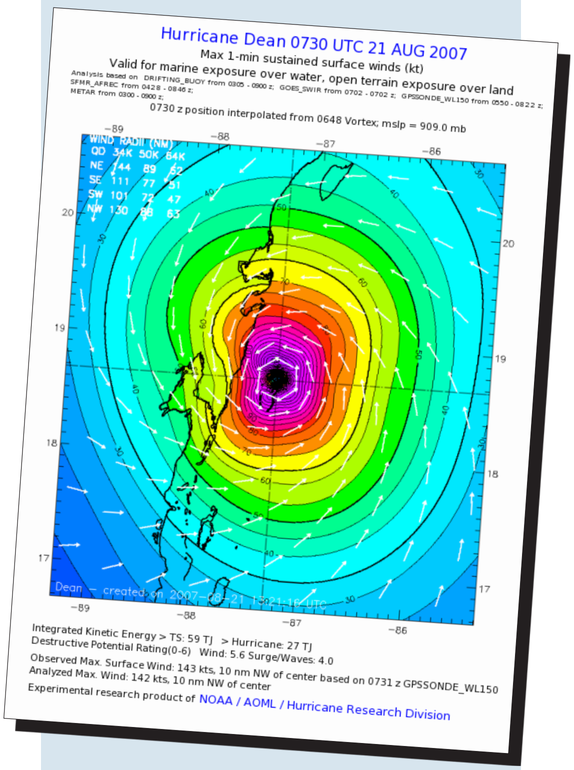
- Develop improved track, intensity, and structure forecast guidance products (e.g., an ensemble mean and spread of track and intensity forecasts; the radius of maximum wind, precipitation, and wind asymmetry; and a four-dimensional evolution of a storm's structure).
- Develop and test new guidance products for forecasters and emergency managers to apply in their decision-making.
- Evaluate forecast errors relative to the coastal extent of watches and warnings and the ultimate landfall location and time.
- Develop a data assimilation and modeling framework to test observing strategies (e.g., OSSE, OSE) that incorporate synoptic-scale, in situ, and remotely-sensed observations to improve track, intensity, and structure forecasts. The framework should address:
    1. Evaluation of sampling strategies for manned and unmanned aircraft;
    2. Improvements to assimilation of current data types into numerical models;
    3. Evaluation of sampling strategies for new satellite and airborne remote sensing tools (e.g., Lidar, GOES-R sounders); and
    4. Evaluation of spatial and temporal densities of observations for in-situ data combined with existing satellite data coverage.

Objective: Improve understanding and modeling of the forcing that produces rainfall and storm surge flooding, damaging waves, and winds using conventional and unique hurricane measurement systems.

Actions:

- Prepare real-time analyses of hurricane surface winds based upon remotely sensed, airborne, and conventional observations that are accessible to forecasters at the Tropical Prediction Center/National Hurricane Center as guidance for warnings. Extrapolation of the winds onshore can provide a vital preview of damage patterns for emergency managers and other officials and provide initial conditions for storm surge simulations.
- Develop guidance for tropical cyclone rainfall forecasts and model evaluation.





Top image: GOES-12 satellite infrared image of Hurricane Dean making landfall along the Yucatan Peninsula region of Mexico on August 21, 2007 with sustained surface winds of 165 mph. Dean became the first category-5 storm to make landfall in the Atlantic basin following Hurricane Andrew's devastating south Florida impact on August 24, 1992.

Bottom image: Surface wind analysis of Hurricane Dean approaching the Yucatan Peninsula on August 21, 2007 as generated by AOML's H*Wind project. H*Wind products were developed at AOML to improve understanding of the extent and strength of the tropical cyclone wind field and to improve the assessment of hurricane intensity. The H*Wind "snapshot" products are provided in image and gridded form for research purposes and have been especially useful for storm surge and wave forecasting applications.

Hurricanes and Tropical Meteorology

- Employ in-situ data collected in landfalling hurricanes by ground-based research teams to evaluate the capability of numerical and statistical models to accurately forecast the rate of decay of hurricane winds after landfall.
- Investigate new metrics to convey the potential of wind field forcing and rain to inflict damage through the action of wind, waves, storm surge, and fresh water flooding.
- Develop guidance for tropical cyclone impacts through improved modeling and evaluation.
- Develop guidance for the engineering community to help mitigate tropical cyclone impacts through improved understanding, observations, and model evaluation.

Objective: Determine the influence of climate change on hurricane activity and improve our seasonal hurricane forecast skill.

Actions:

- Understand how and why global ocean warming and natural climate variability affect Atlantic hurricane activity.
- Investigate the relationship between tropical cyclone activity in the North Atlantic and the eastern North Pacific.
- Improve ocean model predictability of the Atlantic Warm Pool and other ocean indices as a means of improving seasonal forecasts of hurricane activity.
- Provide oceanic data for improved hurricane forecast skill including hurricane intensification.
- Improve upper ocean heat content estimates for tropical cyclone intensification studies and forecasts.
- Collaborate with other laboratories and universities to evaluate and improve ocean model performance within coupled hurricane prediction models.

Anticipated Impacts

As HFIP progresses, our emphasis will shift from improving numerical models through improved initialization and physical representation to more emphasis on improving the model guidance products through a better understanding and use of model uncertainty in the guidance. A single "deterministic" forecast by a particular numerical model has an inherent but unknown level of uncertainty. If the forecast is reproduced many times, each time introducing small initial differences, the result is called an ensemble, and the different model forecasts can potentially provide information on the confidence one should place in a particular forecast. Frequently, but not always, the highest probability is that the correct forecast is near the mean, median, or mode of the ensemble, although other ensemble realizations have a finite probability of being correct. Because the various forecasts diverge with time, decision makers should be able to make more effective decisions when provided with ensemble guidance as compared to being provided with a single forecast.

Ensembles will need to be produced in a number of ways, including changing the initial conditions of a single model to form the various members of the ensemble, altering the physical parameterizations within a single model to form an ensemble of slightly different models, or combining the results from several model systems where the core, physics, and initialization would all be different. This configuration is known as a multi-model ensemble and currently provides the best operational guidance for both track and intensity at this juncture.

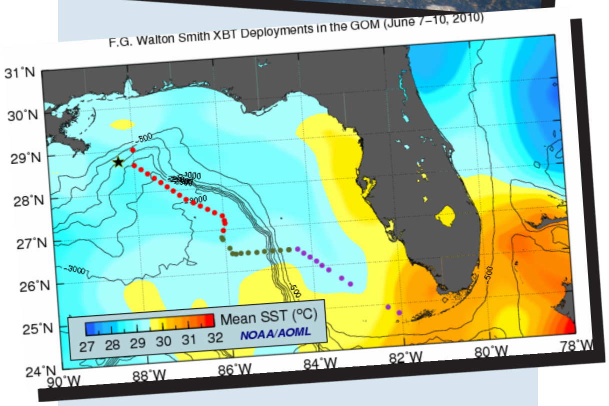
Beyond 2015

The goal of HFIP is to develop an improved operational tropical cyclone prediction system that is implemented by the end of 2014. This system will employ:

- 20-40 member ensembles: 10 km global and 3 km regional resolution
    - o two global model cores/physics
    - o three regional model cores/physics
- Statistical post processing of both track and intensity from a 10-year reforecast from the various models rerun each year.
- At least one member of each model in the ensembles will be computed using a fully three-dimensional ocean. Others may use parameterized ocean coupling.
- Both global and regional models will use an advanced hybrid (4DVAR/Ensemble) data assimilation system.
- Regional models will use all available satellite and aircraft-derived data for inner core initialization, with an emphasis upon ensemble and model products that maximize their value to forecasters.

Top image: View of Biscayne Bay during the passage of Hurricane Wilma over south Florida on October 24, 2005. Wilma, the 22nd named storm of the record-breaking 2005 Atlantic hurricane season, was the most intense tropical cyclone observed to date in the Atlantic basin, with top winds reaching 185 mph.

Middle and bottom images: Damage to a screened patio area and the parking lot at AOML following the passage of Hurricane Wilma. Wilma came ashore in southwest Florida as a major category-3 storm but weakened on its trek across the state, impacting southeast Florida as a category-2 storm.



Following the unexpected explosion and sinking of the Deepwater Horizon oil rig in the Gulf of Mexico on April 20, 2010, millions of gallons of crude oil entered the region, imperiling countless marine and wildlife species, as well as marine and coastal ecosystems. AOML researchers were actively involved in NOAA's early response efforts to monitor, characterize, and measure the extent of the environmental disaster.

Top image: Nelson Melo of AOML deploys a satellite-tracked drifting buoy in Gulf waters to monitor surface currents.

Middle image: Oil from the Deepwater Horizon spill floats in the Gulf of Mexico as observed by AOML researchers during a cruise aboard the University of Miami's RV *F.G. Walton Smith.*

Bottom image: Location of expendable bathythermographs (XBTs) deployed by AOML scientists from the RV *F.G. Walton Smith* to collect data on the oceanic thermal structure of the Gulf of Mexico at a time when oil was actively flowing from the damaged Macondo well.

Coastal Ocean and Ecosystems Research

Background

Oceanic and atmospheric monitoring of the Gulf of Mexico, the wider Caribbean, and the Atlantic Ocean have been a focus of AOML activities for more than three decades. AOML's coastal ocean and ecosystem research has studied organisms from the smallest microbes to the largest whales and areas from the intertidal zone to deep-sea hydrothermal vents.

In recent years, AOML's coastal ocean and ecosystem research has focused on quantifying the impact of anthropogenic activities and management decisions on the health of tropical and subtropical coastal ecosystems. More recently, our research has expanded to include comparative studies with more temperate coastal systems to enhance the context within which climate-induced changes in ecosystems can be interpreted. This research is conducted through a suite of sustained monitoring projects, targeted process studies, and both heuristic and mechanistic ecological models. The unifying goal of this research is to improve our management of coastal ecosystems, thereby maximizing ecosystem health and economic yield.

Overall, AOML ecosystem research supports NOAA's Next Generation Strategic Plan goals for Healthy Oceans, Resilient Coastal Communities and Economies, and Climate Adaptation and Mitigation. Considerable expertise and effort are directed toward programs that apply new technology to monitoring and forecasting the impact of human activities upon the coastal ocean. These efforts have often dove-tailed with global projects, such as those for ocean carbon characterization and integrated ocean observing, and support the NOAA mission areas related to sustainable resource management, marine protected areas, and fisheries.

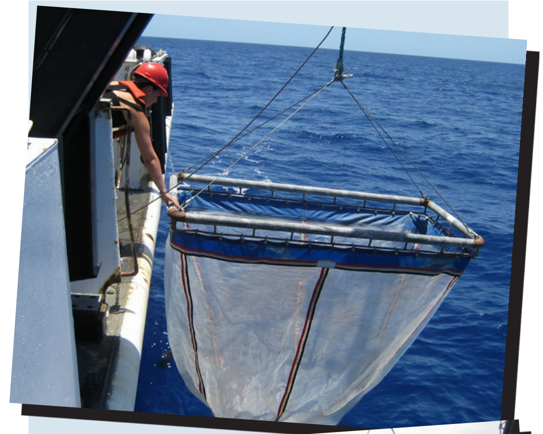
AOML's current interdisciplinary field efforts include: physical, biological, and chemical studies that support the south Florida Ecosystem Restoration effort and the underlying health of this ecosystem; the interconnectivity of ecosystems throughout the regional Intra-Americas Sea; land-based sources of pollution to coastal waters; the relationship between oceans and human health; the status and health of coral reef ecosystems worldwide; and the influence of climate change, ocean acidification, and anthropogenic activities on coastal and coral reef ecosystems.

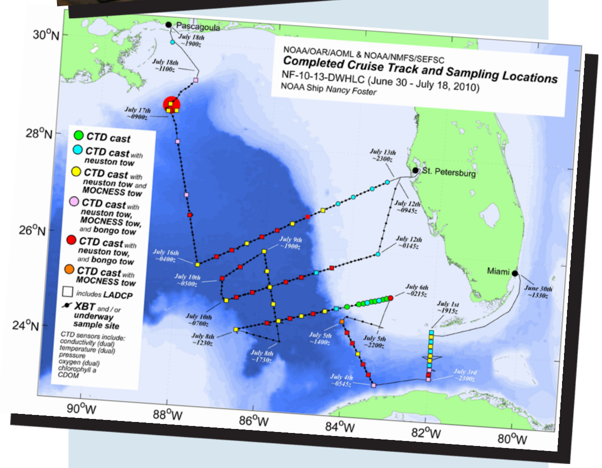
To further these investigations, we seek to develop the next generation of sensors, instrumentation, methodologies, models, and data assimilation tools necessary to provide nowcast and forecast capabilities required by the coastal resource management community. For example, biosensing capability coupled with traditional oceanographic data will enhance efforts in research, modeling, and forecasting and will aid in the ability to make informed management decisions, even under a changing climate.

A 2008 issue of the *Journal Coastal Management* (V36) focused on the economic benefits of regional ocean observing systems. The economic benefits were estimated to be $274.7 M/yr for recreational waters and $150.5 M/yr for recreational and commercial fisheries. For recreational water management, the estimated benefit was contingent upon development and implementation of technologies for rapid and direct measurement of pathogens. If the estimated beach and fisheries benefits are calculated to be, respectively, 70% and 5% dependent on the types of molecular technologies being developed at AOML, the yearly benefits would be $200 M/yr. The molecular technologies explored and developed at AOML include detection assays to rapidly detect fecal contamination in coastal waters and beach sands and source tracking diagnostics to help identify the cause(s) of microbial contamination. These efforts strive to protect human health and to better inform remediation efforts.

Challenges

The primary challenges to ecosystem research globally are shared by the ecosystem science program at AOML. The lack of comprehensive, high temporal, and spatial resolution biological, physical, and chemical data sets severely limits our understanding of ecosystem processes and function. This scarcity of biological data is mainly due to the limitation of current sampling technologies to effectively quantify and identify biological populations and track them continuously over long periods of time. The inability for current whole ecosystem models to replicate observed patterns and abundances is likely an artifact of our lack of understanding of the complex processes that interact to produce ecosystem responses.



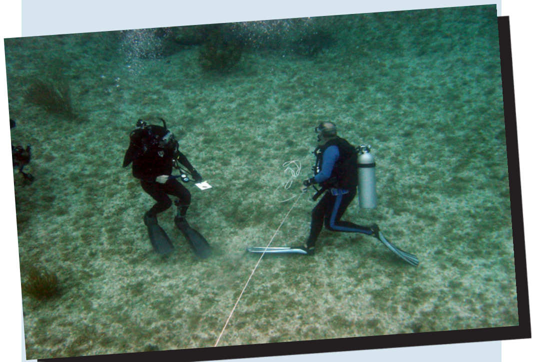


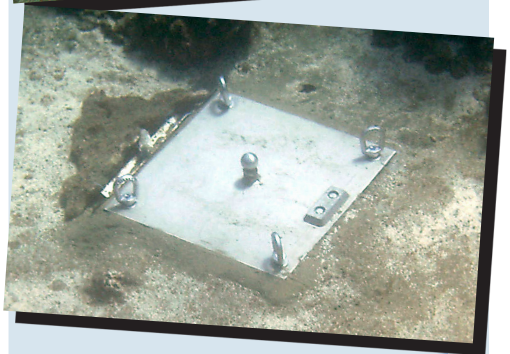
Of prime concern following the Deepwater Horizon oil spill was for the potential of oil to be transported from the Gulf of Mexico via the Loop Current to the coastal regions of south Florida, northern Cuba, and the Bahamas. AOML researchers gathered data to monitor and assess the ocean surface and subsurface circulation in the southern Gulf and Straits of Florida, as well as gathered physical, chemical, and biological samples.

Top image: A Neuston net is towed to sample surface waters for ichthyoplankton and tar balls.

Middle image: A MOCNESS (Multiple Opening/ Closing Net and Environmental Sensing System) net is deployed to sample ichthyoplankton at various depths.

Bottom image: The completed cruise track and sampling methods/locations for the Deepwater Horizon Loop Current cruise aboard the NOAA Ship *Nancy Foster*.





Top image: AOML divers conduct a site survey for the location of a new Coral Reef Early Warning System (CREWS) station offshore of Little Cayman Island.

Middle image: Anchored securely to the ocean floor, a CREWS bottom plate will support a coral monitoring platform equipped with an array of instruments positioned above and below the ocean surface along an upright, 38-foot long pylon.

Bottom image: The completed CREWS station located in Salt River Bay, St. Croix, U.S. Virgin Islands. CREWS stations gather data in near real-time to assess the health of coral reefs. The data are transmitted to AOML for processing by an expert system that uses artificial intelligence technology and then posted to the Coral Health and Monitoring Program web site. Early warning alerts are issued when parameters conductive to coral bleaching and other impact events for corals and coral reef ecosystems are met.

Coastal Ocean and Ecosystems Research

AOML's basic and applied research will expand in the coming years to meet the challenges of coastal managers and planners, both as timely needs (e.g., storm forecasting, identification, quantification and prediction of anthropogenic stressors, assessments of ecosystem health, pathogen detection, nutrient water quality, etc.) and in the understanding and characterization of long-term trends determined through our continued monitoring efforts. Data will be obtained through the best and most cost effective use of ship-based process studies, fixed platforms, moorings, buoys and remote sensors, drifting and autonomous sensors and biosensors, ships-of-opportunity, unmanned platforms, and manual sample collection.

Recent advances have been made and will continue to be made both in regard to in situ sensor technology and in the adaptation and integration of commercially-available sensors and biosensors into instrument packages tailored to our interests. Real-time data assimilation and creative analysis are now possible and will become practical due to advances in computer hardware and software. All of these information sources will be integrated into end-to-end information systems to deliver the products relevant to our future.

Priorities

AOML seeks to develop science-based management and monitoring systems that lead to sustainable ocean ecosystems, coastal communities, and human social systems, even with rapid changes occurring in land and ocean use, climate, and ocean chemistry. We are engaged in research to better understand and monitor sources of environmental degradation, document and predict changes in the global carbon budget, understand and mitigate the impact(s) of ocean acidification, and protect biodiversity.

While AOML's ecosystem research is conducted globally and internationally, our focus is on tropical and subtropical ecosystems, particularly coral reefs. A concerted effort is made to use the diverse ecosystems of south Florida, the Gulf of Mexico, and Caribbean as accessible model systems for the development of new understanding and technology that can be applied globally. Many of these ecosystems are in protected areas and of unique scientific and conservation interest. As part of our contribution to NOAA's Science and Technology

Enterprise goal, AOML's ecosystem research includes the development of sensors and sensor applications for ocean chemistry, nutrient detection, and microbial species identification (particularly for pathogen detection).

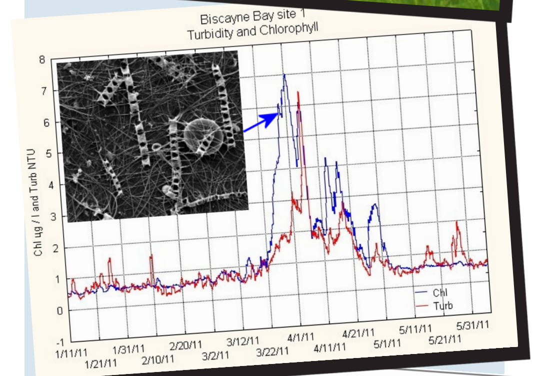
AOML's ecosystem research also includes the use of acoustic remote sensing techniques and the development of data and models for use in coastal marine spatial planning, assessment of biodiversity, and advanced water quality monitoring programs. Our work with regional, national, and international partners is aimed at integrating ecosystem data into management decision tools and improving the representation of biological and chemical properties in the suite of parameters included in ocean observation systems.

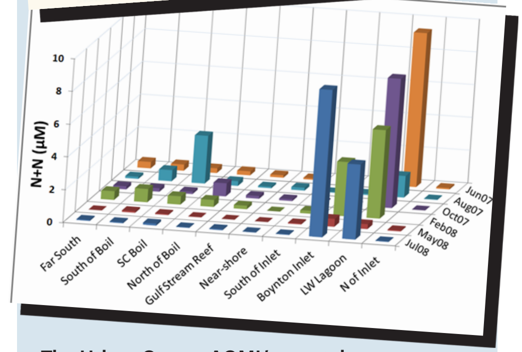
Science Objectives and Actions

Objective: Improve the capability to measure and understand the sources of degradation in coastal ecosystems and their impact on ecosystem health and resilience including the relationship of the oceans to human health.

Actions:

- Determine the origin(s) (natural and anthropogenic) of pollution from land-based sources into coastal waters, their impact on ecosystem nutrient budgets, and other impacts on ecosystem structure and function. Improve their detection and tracking through improved sensor development, observing strategies, and ecological modeling.
- Evaluate and improve methods for predicting coral bleaching and the impact of anthropogenic factors (including temperature rise) on coral reef ecosystems.
- Develop and deploy new and alternative indicators (particularly fecal pollution indicators) for measuring and tracking microbial pollution in coastal ecosystems, including fishery habitats, beaches, and recreational waters.
- Determine the prevalence, persistence, and risk of microbial indicators and pathogens in environmental matrices of coastal ecosystems, particularly those impacting human health such as fisheries, beaches, and recreational waters.



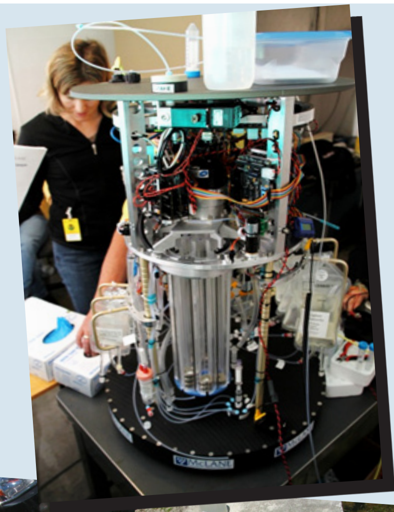


The Urban Ocean: AOML's coastal ocean program studies regional systems like Biscayne Bay, the Atlantic beaches, and nearshore reefs as model systems for development of sustainable coastal ecosystems and economies in south Florida and other urbanized coastlines of the tropical Atlantic and Caribbean.

Top image: Moored instrument used for continuous monitoring of turbidity in Biscayne Bay and its relationship to seagrasses. Studies of seagrass communities and mangroves by AOML scientists also contribute to NOAA's efforts to estimate and inventory "blue carbon" resources on U.S. coastlines.

Middle image: Concentrations of chlorophyll and turbidity during a bloom in Biscayne Bay in the spring of 2011. The inset is a scanning electron micrograph showing centric diatoms whose numbers increased dramatically during the bloom.

Bottom image: Concentrations of nutrients in Palm Beach County during a year-long survey. Note increased concentrations at the South Central treated-wastewater outfall (SC Boil), Boynton Inlet, and Lake Worth (LW) Lagoon. AOML studies nutrients and pollutants entering the coastal ocean, whether from land-based sources through ocean outfalls and coastal inlets or from offshore waters through coastal upwelling.



Researchers with AOML's Environmental Microbiology Program test nearshore and coastal waters, the water and sand of recreational beaches, and marine sentinel species such as sponges and corals for a variety of microbial indicators of human-sourced contamination, as well as for specific pathogenic organisms that can cause diseases in humans, marine animals, and corals. AOML researchers are also working to develop and validate new methods for water quality assessment and detection of pathogenic organisms.

Top image: National Research Council postdoctoral associate, Annie Cox, with NOAA's Environmental Sample Processor (ESP). The ESP is a fully automated platform for in-situ sampling and genetic analysis. It collects and concentrates water samples, extracts nucleic acids, applies molecular probes to identify microorganisms, and relays the results back to shore. AOML has developed new fecal source indicators and methods for improving yield extraction and quality nucleic acids for use in NOAA's implementation of ESP missions. ESP deployments will be used as observatories and early-warning systems.

Bottom image: AOML student interns collect water samples from the Little Venice neighborhood of Marathon in the Florida Keys. The samples were subsequently analyzed to measure the occurrence of enterococci bacteria to assess the health risks to marine and coastal waters posed by fecal contamination.

Coastal Ocean and Ecosystems Research

- Utilize new molecular source tracking methodologies to support epidemiological studies and better understand the risks to human health from exposure to microbial contaminants in coastal ecosystems.
- Develop and deploy alternative markers to track pollutants, especially those associated with increasing anthropogenic usage of the coastal zone (e.g., environmental detection of excreted pharmaceutical products, physico-chemical markers of sewage, nutrient markers, etc.)
- Utilize paleorecords from coral core archives to identify the historical impacts of coastal urbanization and land use changes on coral growth with a goal of understanding changes in water management practices on reef ecology.
- Develop and deploy methodologies to detect, track, and characterize algal bloom dynamics (particularly for harmful algal blooms such as *Karenia brevis* or "red tide") using molecular-based, species-specific assays and sensors.

Objective: Enhance and increase the incorporation of science into ecosystem restoration and ecosystem-based management decisions, and provide tools for the integration of knowledge about both human and natural ecosystem components.

Actions:

- Develop ecosystem models and predictive tools and integrate data and information to support integrated ecosystem assessments and coastal and marine spatial planning. Develop reliable ecological forecasts and incorporate these forecasts into management decision support.
- Improve understanding of the impact of the Comprehensive Everglades Restoration Plan and other restoration actions upon the south Florida coastal marine ecosystem, including Florida and Biscayne bays and the Florida Keys National Marine Sanctuary.
- Develop and maintain ecosystem restoration and monitoring projects to mitigate the impact of oil pollution and/or other unique stressors (e.g., hurricanes) in south Florida, the Gulf of Mexico, and the Caribbean.

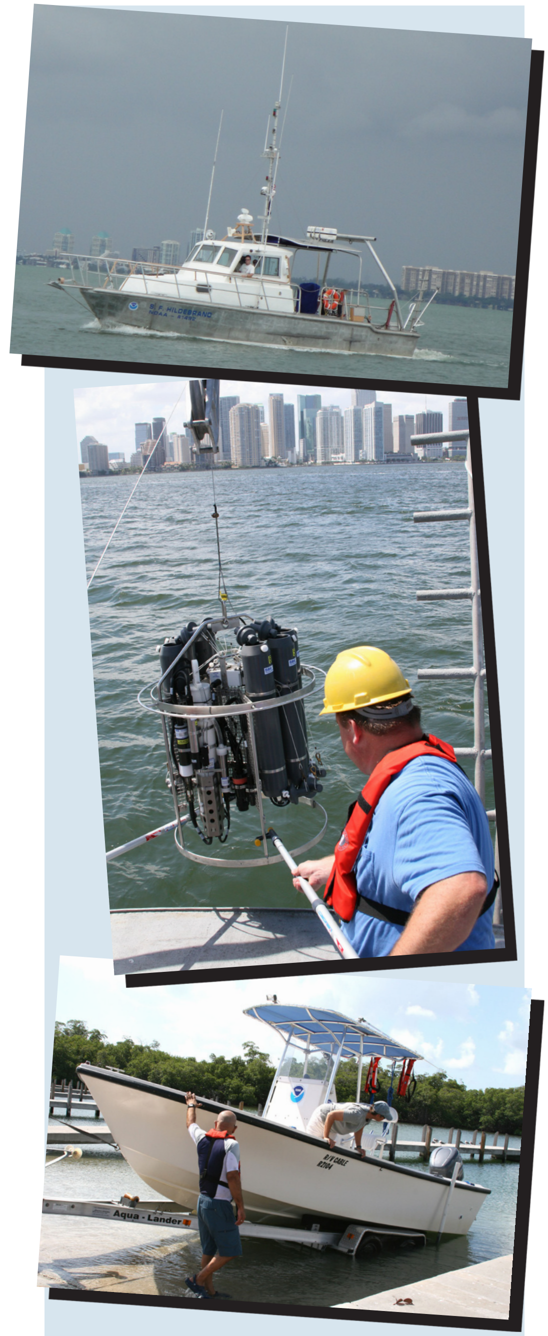
- Provide the physical, water quality, and biological data required to verify models and evaluate alternative management and restoration scenarios.
- Develop methodologies that integrate human and natural components of coastal ecosystems.
- Develop trade-off analysis tools for use by decision makers to examine trade-offs within and among natural and human ecosystem components.
- Develop indicators and set targets to guide management decisions toward a realistic and desirable ecosystem that is both ecologically and economically productive.
- Develop reliable indices of ecosystem health (e.g., resilience, fishery productivity, microbial and nutrient water quality, human health, and aesthetics).

Objective: Quantify the coastal air-sea flux of carbon dioxide and determine its spatial and temporal variability.

Actions:
- Develop a national coastal CO_2 observational network with a focus on the Gulf coast and U.S. eastern seaboard.
- Maintain automated underway pCO_2 systems on coastal research vessels and augment these measurements with nutrient and oxygen sensors.
- Conduct a synthesis of data obtained in the past to evaluate regional-scale CO_2 fluxes.
- Conduct a study on the seasonal and interannual variability in coastal carbon dynamics.
- Determine the relationship between physical and biological forcing on air-sea CO_2 exchange on regional scales.

Objective: Provide the science required to assess the impacts of ocean acidification, climate change, and sea level rise on coral reefs and assist in the application of this science to management decision-making.

Actions:
- Determine the historical and current regional dynamics of ocean acidification.



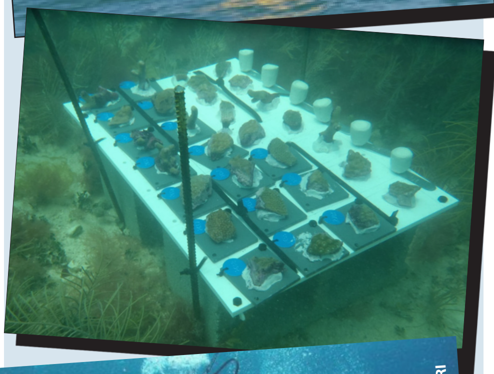
The RV *Hildebrand* and RV *Cable* are owned and operated by AOML as research platforms for sampling operations in the coastal ocean.

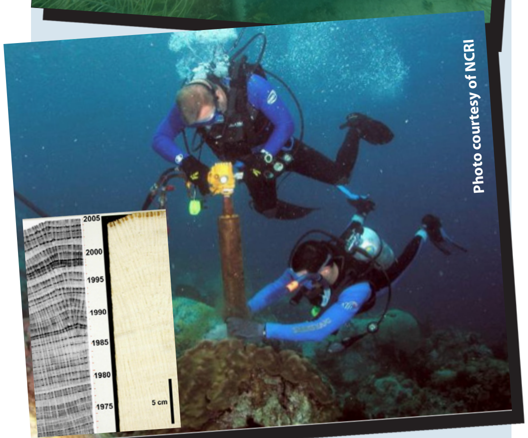
Top image: The 41-foot RV *Hildebrand* is equipped with an A-frame for net tows and instrument deployment and has the capacity for a flow-through water sampling system for underway sampling of surface water properties.

Middle image: AOML scientist Chuck Featherstone deploys the *Hildebrand's* CTD rosette, which is equipped with temperature, conductivity, pressure, oxygen, and chlorophyll sensors, as well as Niskin water sampling bottles used to collect samples from different depths.

Bottom image: The 21-foot RV *Cable* is secured on its trailer after sampling operations.

Coastal Ocean and Ecosystems Research





Top image: AOML operates the Atlantic Ocean Acidification Testbed (AOAT), a long-term monitoring program that uses the Moored Autonomous pCO_2 (MAP) buoy pictured here to collect continuous data on chemistry, salinity, and temperature. These data are used as background information by academic and federal scientists studying the biological effects of ocean acidification at AOAT sites in the Florida Keys and La Parguera, Puerto Rico.

Middle image: Coral and bioerosion blocks deployed in the Florida Keys. Live corals are used to establish species-specific growth rates, and bioerosion blocks are used to determine rates of carbonate destruction by various eroding organisms under monitored environmental conditions.

Bottom image: AOML researcher Kevin Helmle obtains a core sample from a coral colony to recover skeletal records of coral growth over time. Much like the information revealed by tree rings, an X-ray of a coral core (inset) shows differences in the coral growth rate. When compared to data on runoff, precipitation, temperature, or other historical records, a picture of the way coral responds to environmental change can be constructed.

- Assess how coral calcification rates have changed over recent history and determine the relationships between reef calcification, photosynthesis, and environmental stress.
- Quantify local near-reef dynamics in relationship to ocean acidification through enhanced observing systems and targeted process studies and quantify the feedbacks and secondary processes affecting local carbonate chemistry.
- Quantify and monitor community-scale coral reef carbonate budgets at selected reef systems.
- Assess coral reef resiliency across a range of local carbonate chemistries based on recent acute stress events and rates of recovery and identify local management actions that foster the greatest resiliency to ocean acidification.
- Utilize paleorecords from coral core archives to reconstruct sea surface temperature, seawater pH, and their controls on coral growth and calcification.
- Develop regional models that describe the effects of ocean acidification to coral ecosystem services in collaboration with academic partners.
- Evaluate and classify the effects and range of susceptibilities across reef zones to ocean acidification and/or thermal stress.
- Conduct comparative experiments to delineate ecosystem differences between high carbonate systems in south Florida and those without elevated pCO_2 levels.

Objective: Improve understanding of the role of climate change on the health of coastal and regional marine ecosystems.

Actions:

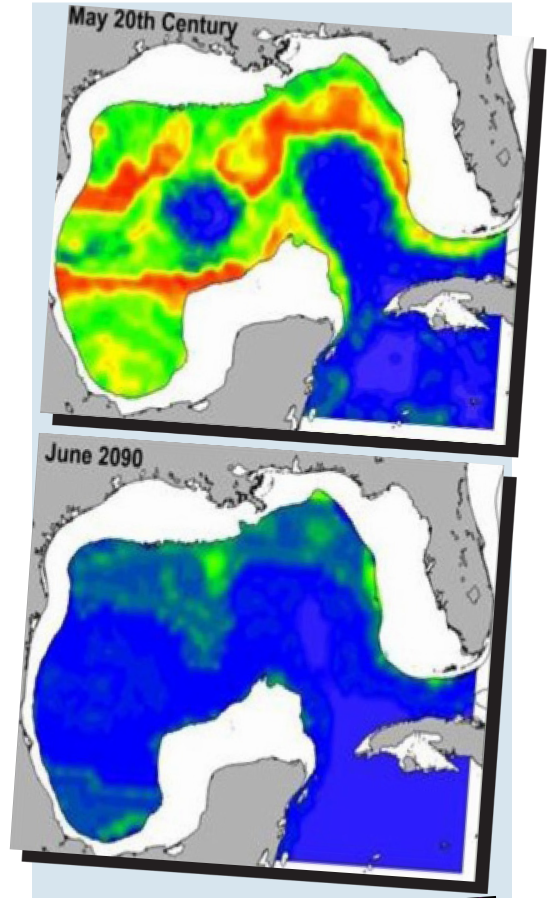
- Analyze available long-term observed and proxy data sets in collaboration with NOAA's Southeast Fisheries Science Center to determine the degree of climate variability and long-term changes in south Florida, the Gulf of Mexico, and Caribbean Sea and their impact on living marine resources.

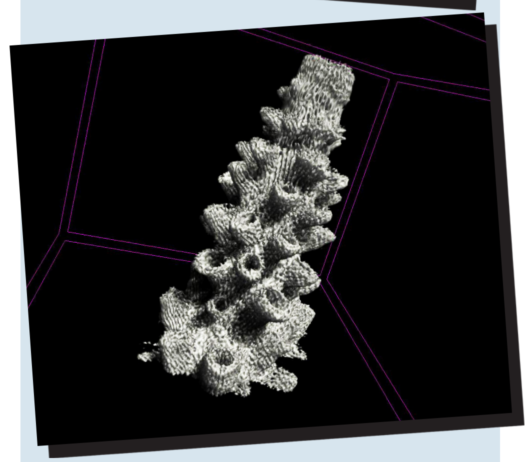
- Utilize numerical model products to assess expected changes in representative regional marine environments, particularly south Florida, the Gulf of Mexico, and the Caribbean, and provide science-based input to resource managers based on the possible range of climate change scenarios.
- Synthesize our current knowledge regarding the interplay between ocean circulation and biological processes with expected changes to develop a better expectation of future conditions.
- Develop comparative or integrative analyses, where possible, with investigators studying coastal ecosystems in other areas (e.g., the California Current ecosystem, Pacific Island ecosystems, and polar regions).
- Incorporate sea level rise and changing rainfall patterns into models and regional planning activities that address the fate of microbial contaminants and chemical pollution associated with storm water runoff and stream flow to the coastal ocean.

Objective: Determine the degree to which the coastal ecosystems of the Intra-Americas Sea are physically and biologically interconnected and the degree to which they are affected by remote oceanographic and meteorological forcing.

Actions:

- Conduct interdisciplinary observational studies and use numerical models to assess the degree to which large-scale oceanographic and meteorological forcing, local circulation, and water column properties affect the variety, abundance, and distribution of regional marine life.
- Synthesize and integrate all available data to provide concise, relevant, science-based products for use by regional resource managers in their decisions about marine protected areas and other resource conservation strategies.
- Serve in a leadership role within NOAA in the Caribbean and Coral Reef Conservation Program projects to facilitate capacity building in the region for utilizing oceanographic and meteorological data and information products to understand and manage marine ecosystems.

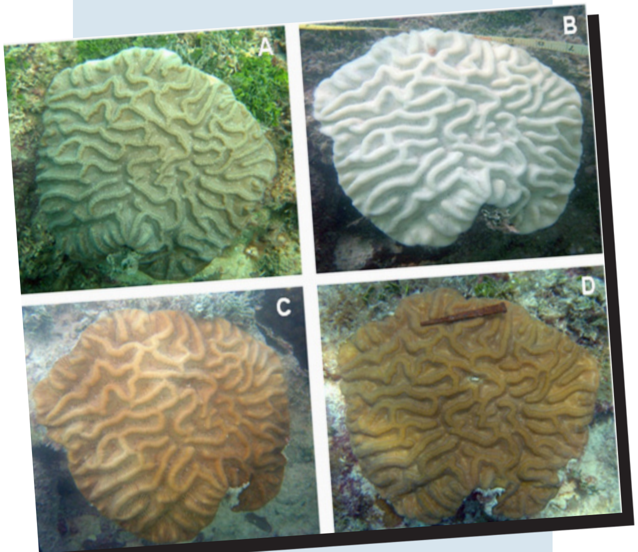


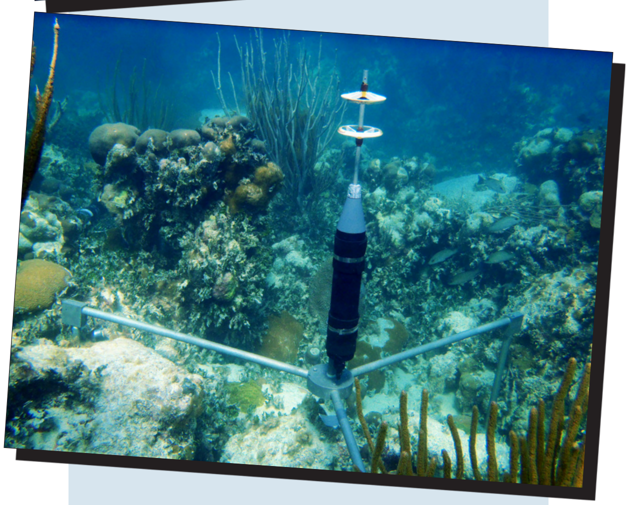


Top image: Probability of larval occurrence (red more likely, blue less likely) of Atlantic bluefin tuna in the late 20th century (top) and late 21st century (bottom). Atlantic bluefin tuna predominantly spawn in the northern Gulf of Mexico from April to June within an optimal temperature range. In response to projected warming, areas with high larval occurrence will decrease by more than 90% toward the end of the 21st century.

Bottom image: X-ray microtomography uses hundreds of high resolution x-ray images to digitally reconstruct three-dimensional objects with a resolution down to seven microns. This technology is being used by AOML researchers to study the effects of ocean acidification on the growth of threatened and endangered coral species such as this Staghorn coral (*Acropora cervicornis*).

Coastal Ocean and Ecosystems Research





Top image: AOML researchers with the Coral Health and Monitoring Program (CHAMP) have found that hurricanes may aid coral reefs in surviving and rebounding from bleaching events. In 2005, cooler ocean temperatures caused by the passage of a hurricane and the upwelling of deeper, colder water from the ocean floor enabled heat-stressed coral reefs in the Caribbean Sea to recover more rapidly. The four-panel image depicts the time-series of a coral (*Colpophyllia natans*) at Coral Gardens in the Florida Reef Tract before, during, and after a bleaching event: (a) prebleaching (August 11, 2005); (b) bleached (September 6, 2005); (c) nearly recovered (November 9, 2005); and (d) recovered with normal pigmentation (March 2, 2006). Corals in close proximity to hurricane-cooled waters rebounded faster than corals located farther away from the hurricane path (photo courtesy of the National Academy of Sciences).

Bottom image: A coral reef oxygen sensing system on the ocean floor at Cheeca Rocks in the Florida Keys is part of a new effort by AOML's coral researchers to improve understanding of the impacts of ocean acidification upon delicate coral reef ecosystems.

- Facilitate the implementation of a Caribbean-wide meteorological and oceanographic monitoring network under the leadership and collaboration of the Caribbean Community Climate Change Center in Belize.
- Conduct interdisciplinary studies on the impact of Brazil Current eddies upon coastal ecosystems in the lower Caribbean basin.
- Document the inherent variability of the Gulf Stream using ship-of-opportunity and remote sensing data.

Objective: Determine the degree to which coastal ecosystems are affected by the landfall of tropical cyclones and conduct long-term studies on how these ecosystems respond to such stresses. Determine the factors that contribute to ecosystem resiliency in response to tropical cyclones.

Actions:

- Conduct biological and chemical studies of coastal ecosystems before and after tropical cyclone landfall in conjunction with appropriately scaled wind field, tidal surge, and wave height studies.
- Identify characteristics of resilient coastal ecosystems that quickly recover from the impact of a tropical cyclone.
- Determine the role of tropical cyclones in driving ecosystem succession in subtropical coastal ecosystems.
- Quantify the effect of tropical cyclones on coastal mesozooplankton and phytoplankton communities.

Anticipated Impacts

AOML's coastal ocean and ecosystem research will support NOAA's Next Generation Strategic Plan goal of Resilient Coastal Communities and Economies by providing for more informed management of coastal marine resources and better prediction of the consequences of continued coastal development and global climate change. Our research will facilitate the implementation of rational, science-based decisions regarding NOAA's coastal stewardship obligations and interagency ecosystem and habitat restoration efforts. The resulting knowledge and information are essential in the mitigation and/or avoidance of unintended deleterious effects upon coastal environments.

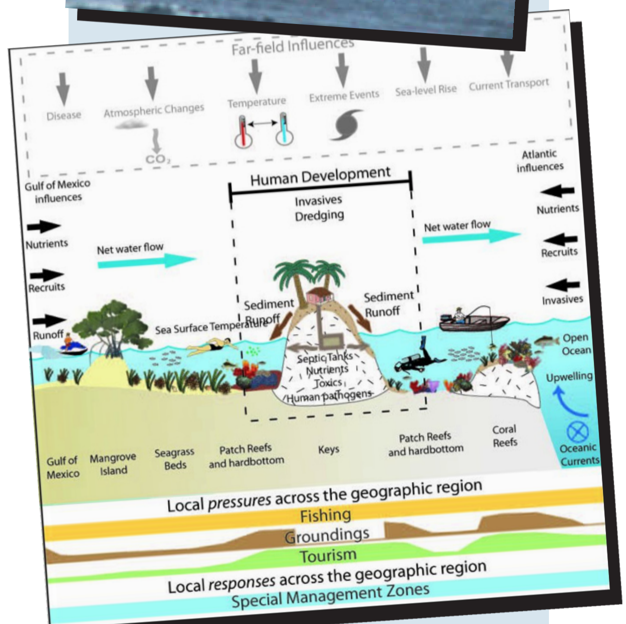
Beyond 2015

As our measurement, analytical, and modeling capabilities improve, our research is expected to contribute to more quantitative predictions of environmental change and to truly comprehensive and effective coastal and marine spatial planning. Additionally, with continued evolution in computing resources, sensor technology, and data assimilation strategies, we will be providing progressively more real-time information and complex models capable of simulating "real world" observations. These will be incorporated into early warning systems that can promote beach safety, coral reef conservation, human health, and ecosystem protection.

Our programs in coastal oceanography, marine spatial planning, and integrated ecosystem assessment are intended to become part of a larger multidisciplinary approach to coastal management that we hope to extend in the south Florida region as a model for integrated involvement of federal, state, municipal, academic, and other stakeholders.

Specific long-range objectives for such a coordinated effort to promote resilient coastal communities and economies, particularly for south Florida, the Gulf of Mexico, and Caribbean regions, as well as the nation, include the following:

- Conduct full, large-scale research projects with autonomous technology.
- Integrate biogeochemical and microbiological sensors into the technology supporting global and regional observing systems.
- Develop a standard methodology to measure and predict the effects of anthropogenic activities on the coastal ecosystem (e.g., land use changes, eutrophication, desalinization, and fishing pressure), especially as they affect coral reefs and other sensitive ecosystems of high value.
- Extend the range and scope of oceanographic measurements made in south Florida, especially the Florida Straits, to create an adaptive ocean observing system capable of supporting a rapid response to environmental threats originating from human and/or natural sources.



Top image: Photo from the *Miami Herald* newspaper of a fishing vessel and oil drilling rig in Cuban waters only 50-55 miles from the coast of Florida. Building on lessons learned from the Deepwater Horizon oil spill, AOML is partnering with the federal and university research community to prepare for potential impacts. This consortium of researchers is building a capacity for baseline oceanographic measurements, an early warning system, predictive modeling, and mitigation response.

Bottom image: Conceptual diagram of drivers and stressors impacting the ecosystem of the Florida Keys and Dry Tortugas reef track as part of the Marine and Estuarine Goal Setting (MARES) project coordinated by AOML and its CIMAS partners. The initiative is a model for applying science to management and restoration problems in a way that includes both economic and non-economic human dimensions with the goal of providing sustainable ecosystem services. MARES has developed similar models for both southeast and southwest Florida as separate management areas.

Coastal Ocean and Ecosystems Research

- Establish a science-based research plan for monitoring land-based sources of pollution and their impacts upon south Florida that include stakeholder engagement and a mechanism for direct use of data products in management decisions.

- Establish international partnerships for the application of environmental research on microbial contaminants, climate change, nutrients, and coral health and resilience to the generation of sustainable coastal ecosystems throughout the Caribbean.

- Develop research and data products to assist managers in planning for the interactive effects of climate change and increased urbanization of the coastal zone on the health and productivity of coastal ecosystems.

- Develop ocean acidification ecosystem risk and vulnerability maps delineating the range of predicted impacts to ecoservices anticipated by continued ocean acidification. These maps can be applied towards regional marine protected area planning and local efforts to foster increased resiliency.

AOML's South Florida Program (SFP), and its associated field operations, have enabled scientists and resource managers to keep a watchful eye on the sensitive marine habitats found in the region and have served as a sentinel during periods when the ecosystem has been subjected to extreme events such as hurricanes, harmful algal blooms and, more recently, potential oil spill contaminants. Additionally, the AOML SFP has produced a comprehensive, long-term baseline regarding regional circulation, salinity, water quality, and biology for the ecosystem. These data are the only regular, synoptic measurements of these inter-related parameters throughout the southwest Florida shelf, Biscayne and Florida bays, and the Florida Keys reef tract.

During the August 2011 SFP sampling cruise, AOML researchers documented the delivery of Mississippi River water to the Florida Keys using an onboard flow-through C6 seawater system. The Mississippi River reached record levels in the spring of 2011 as a result of the record flooding that occurred in the central United States. The large pulse of fresh water, possibly laden with contaminants such as fertilizers, pesticides, and other materials due to its terrestrial origin, began entering the Gulf of Mexico in May 2011. By July 2011, it had spread southward as a narrow, coherent plume along the eastern edge of the Loop Current.

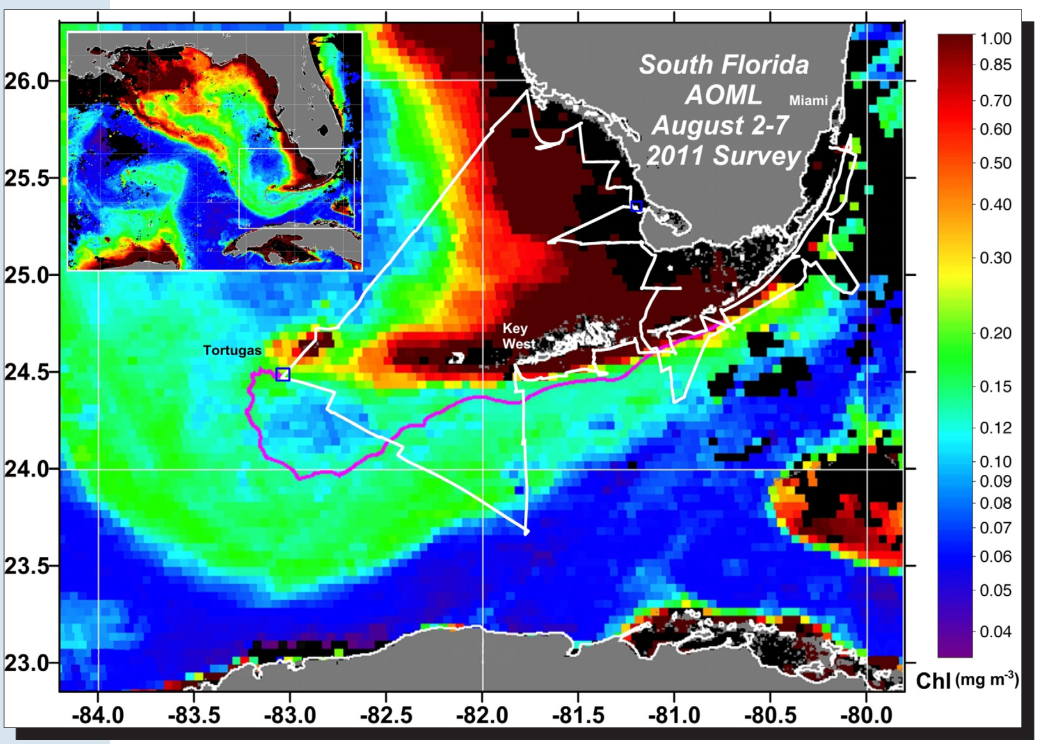


Image at right: Satellite-derived, three-day composite image of ocean color from NASA's MODIS Aqua satellite depicting surface chlorophyll levels in the Gulf of Mexico and coastal south Florida waters in August 2011. Higher values are seen originating from the discharge region of the Mississippi River and spreading down to south Florida along the eastern front of the Loop Current, ultimately reaching the Tortugas Gyre and the Florida Current along the Florida Keys. Also shown are the SFP cruise track (white line) and the trajectory of a satellite-tracked surface drifter (magenta line) deployed near the Dry Tortugas.

Science and Technology Enterprise

AOML's Ocean Observing Systems

AOML has invested substantially in gathering and analyzing data and in long-term oceanic and environmental monitoring efforts. These activities will continue to garner a significant portion of our research focus and expand to include environmental modeling. A portion of our efforts will also be directed towards high risk/high return applied research, such as prototype development of remote observing platforms, development of artificial intelligence techniques for integrating disparate data streams, and in ecological forecasting to facilitate public health and the preservation of fragile ecosystems. Within this context, the following research topics are projected to be the foci of our efforts in the coming years.

Objective: Maintain and support the Global Drifter Program, Ship of Opportunity Program, Western Boundary Time Series Program, PIRATA Northeast Extension Program, CLIVAR CO_2 Repeat Hydrography Program, and the Argo Program as directed and funded by NOAA's Climate Service, and the ICON/CREWS network as directed and developed by NOAA's Coral Reef Conservation Program.

Actions:

- Continue serving as a key international partner in the implementation and sustainability of the Global Ocean Observing System.
- Provide the scientific background for designing components of the ocean observing system geared to study, for example, the AMOC.
- Conduct numerical experiments to improve the current observing system.
- Develop capabilities for new instrumentation, data collection, and analysis such as from autonomous underwater vehicles.
- Expand the ICON/CREWS network in the Caribbean and American territories using alternative technologies, including moored buoys and new ecological forecasting algorithms.

Top image: AOML researchers prepare an underway conductivity-temperature-depth (UCTD) system for deployment off the stern of the NOAA Ship *Ronald H. Brown* during the 2011 PIRATA Northeast Extension cruise. The UCTD system collects high-resolution temperature and salinity profiles of the upper ocean without the need of a stationary cast, thereby reducing costs associated with time at sea. Measurements to depths of 500 m can be performed while underway at 10 knots, the standard speed of a research vessel while on transit between stations.

Bottom image: An inverted echo sounder deployed in the southwest Atlantic Ocean in 2009 is part of an instrument array that has enabled AOML researchers to better investigate the role of western boundary currents in the South Atlantic as components of the global Meridional Overturning Circulation (MOC). Variability in the Atlantic MOC has been shown in numerical models to have significant impacts on global climate signals such as air temperature and precipitation over large portions of the Northern Hemisphere.

Science and Technology Enterprise

Objective: Develop the next generation of methodologies, instruments, sensors, and integrated environmental systems required to monitor ecological, physical, and chemical processes in the coastal marine ecosystem.

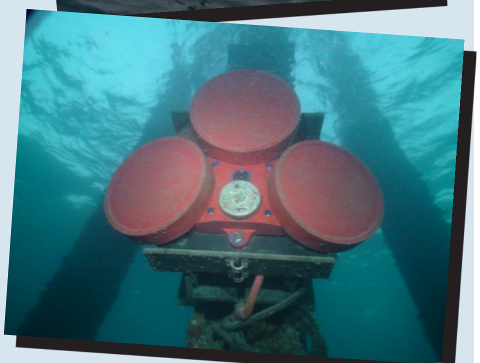
Actions:

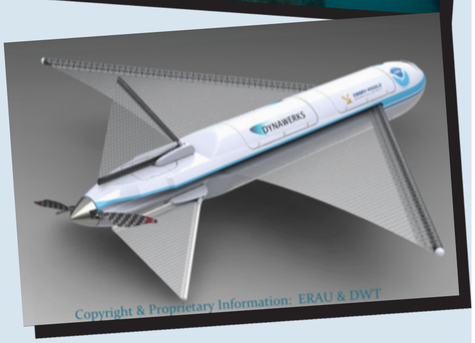
- Develop remote sensor systems based upon the molecular quantification of planktonic organisms, harmful algal bloom organisms, naturally-occurring pathogens, and the abundance of microbial contaminants (including indicators and pathogens).
- Extend the concentration range over which we can measure atmospheric ammonia in the marine boundary layer and develop an in situ dissolved ammonia sensor sufficient to assess air-sea fluxes in coastal environments.
- Adapt present and next generation sensors to a range of platforms, e.g., research ships, moorings, towers, airplanes, ships-of-opportunity, and/or automated underwater vehicles.
- Enhance ICON and other monitoring platforms with ocean acidification, nutrient, and other sensors to provide real-time information products that enable environmental managers to make better informed decisions.

Objective: Employ new technology in biosensors, monitoring technologies, autonomous in situ monitoring, remote sensing, and modeling to develop observation systems that include biological and chemical components and which can be used to understand the impacts of climate change, pollutants, and other stressors on marine ecosystems.

Actions:

- Expand the Integrated Coral Observing Network (ICON) to include more U.S. territories and coastal regions of south Florida and the Caribbean.



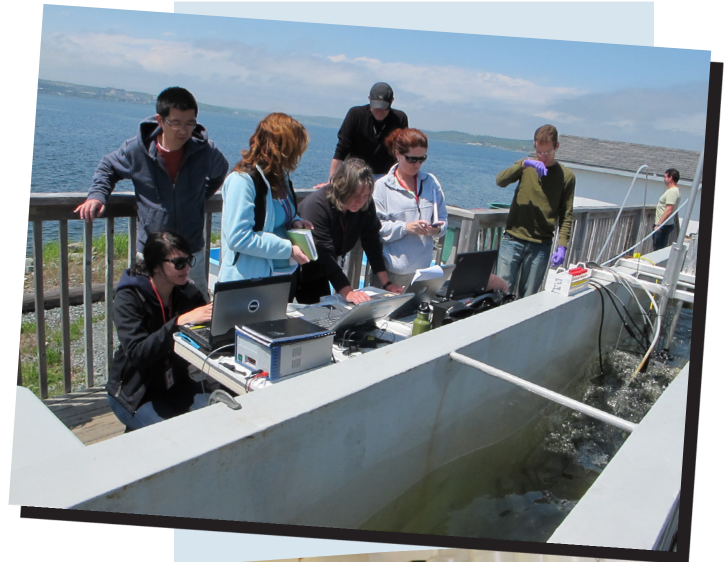


Top image: Wave gliders are cost-effective platforms for collecting ocean observations over broad expanses. The gliders are powered by batteries replenished by solar panels and can operate independently for extended periods in both the open and coastal oceans.

Middle image: An acoustic Doppler current profiler (ADCP) designed by AOML scientists to detect the currents across Port Everglades Inlet. The ADCP is used to estimate the flux of land-based sources of pollution from the coastal lagoon to the open ocean and nearby coral reefs through the Inlet. Port Everglades is one of the busiest cruise ship ports in the world, and Broward County among the most densely populated regions of south Florida.

Bottom image: AOML continues to test unmanned aerial systems (UAS) as platforms for low altitude hurricane observations (below 500 ft) to better observe air-sea interaction. Data sources such as this GALE UAS may be the key to continued improvements in intensity predictions.

- Evaluate hydrocarbon sensing systems for their application to coastal and deep-water environments and enhance monitoring for hydrocarbon impact in sensitive coastal waters.
- Adapt new technology developed at AOML for obtaining low-level nutrient measurements to use on autonomous platforms and in observing systems.
- Develop an optical water mass classification capability as a tool for management and ecosystem studies.
- Develop and deploy new and alternative indicators for detecting and determining the persistence of microbial pollution in coastal ecosystems, new molecular source tracking methodologies, and biosensors for use in integrated environmental monitoring systems to track pollutants associated with increasing anthropogenic usage of the coastal zone.
- Adapt laboratory-based methodologies for the detection of pollution sources and microbial contaminants to sensor technologies for deployment on autonomous or semi-autonomous platforms or vehicles.
- Adapt and utilize acoustic remote sensing technologies for the quantification of pollutant fluxes, detection of biological and physical quantities, and the estimation of dispersion of these quantities by physical processes.
- Develop comparative or integrative analyses, where possible, with investigators studying other coastal ecosystems that are strongly impacted by urban development and heavy recreational usage (e.g., southern California, Hawaii, coastal cities in South America, and the Caribbean).



Top Image: AOML scientists Michelle Wood (center) and Chris Kelble (not shown) participated in a two-week experiment to evaluate the performance of hydrocarbon sensors using the wave tank at Canada's Department of Fisheries and Oceans Center for Offshore Oil and Gas Energy Research. The sensors used to detect subsurface oil during the 2010 Deepwater Horizon oil spill, and several next-generation instruments, were exposed to different concentrations of weathered and unweathered Macondo oil (with and without dispersant) to determine their limits of detection and sensitivity for total oil and different components of oil.

Bottom Image: AOML researcher Natchanon Ammornthammarong with the autonomous ammonia sensor he designed to detect ammonium in natural waters in collaboration with Drs. Jia-Zhong Zhang and Peter Ortner. The system has three working ranges, sensitivity comparable to the most sensitive batch or flow-through methods, and the same accuracy as traditional manual calibration. Development of the autonomous sensor, which can be deployed from ships, moorings, and buoys, was developed at AOML with funding from the National Ocean Partnership Program.

Top image: AOML Director Dr. Bob Atlas appears on an evening broadcast of Miami's WSVN Channel 7 news program as part of its annual hurricane preparedness coverage. Atlas was part of a panel of experts that answered questions about hurricanes and addressed concerns posed by the general public.

Middle image: In support of the south Florida community, AOML staff participate in a job fair to answer questions and provide information about NOAA. The one-day event in Miami was hosted by U.S. Florida Congressman Lincoln Diaz-Balart and drew an estimated crowd of 2,000 job seekers.

Middle image: AOML microbiologist Dr. Chris Sinigalliano (far left) observes as a group of high school students participating in an environmental immersion day event listen as David Wanless of AOML (right bottom corner) discusses the results of their water quality sampling efforts. The students gathered water samples from the mangroves surrounding AOML, the beach, and other sites on Virginia Key to test for the presence of microbial pollutants using a molecular technique that measures specific DNA sequences.

Engagement Enterprise

AOML's Communications

AOML is part of an international community of research laboratories, educators, environmental decision makers, weather and climate forecasters, Congressional policy setters, and an ever-expanding public, all of whom benefit from our research. An essential element of AOML's mission is its communication with these diverse communities via the media, the sharing of data and research results, and publication of articles in professional and popular journals.

Priorities

AOML will continue to employ an expert in scientific communications to ensure a clear and professional message. Our communications and outreach coordinator provides the communities with whom we interact with a single point of contact for outreach activities.

Objective: Effectively communicate the findings from AOML's observations and scientific research to resource managers, stakeholders, and policy makers.

Actions:

- Distribute near-real-time, value-added integrated analysis products based upon coastal ocean measurements to coastal managers, emergency service managers, and environmental regulators.

- Produce analyses and communication tools that are useful and regularly employed to guide ecosystem-based management.

- Build a close partnership with non-government organizations, scientists, economists, managers, and the public to ensure all restoration goals are represented, that trade-offs are resolved to provide the maximum benefit, and uncertainties are clearly explained.

- Maintain contact with and respond to opportunities to provide briefings to local Congressional representatives and local government agencies.

Objective: Project to the public a sense of a vital AOML enterprise whose scientific accomplishments are important and relevant to society's needs.

Actions:

- Distribute press releases for each major journal article or field program endeavor.
- Educate and train our cadre of scientists in the most effective ways to personally communicate their research through professional meetings and media interactions.
- Use the AOML and NOAA web sites to communicate research related to environmental events of national and regional interest (e.g., the Deepwater Horizon oil spill and AOML's ocean monitoring efforts).
- Participate in public events that focus on the contributions of AOML research to societal issues.

Objective: Improve AOML's Internet world-wide web presence to better serve colleagues and the general public.

Actions:

- Develop web pages that can be easily navigated by the general public with no previous knowledge of our program titles and/or internal organization. Describe research in basic terms and include descriptive graphics.
- Employ web 2.0 capabilities such as blogs and social network sites and web-based software for meetings and collaborative activities to ensure our virtual presence is as vibrant and dynamic as our body of research.
- Develop and implement a common standard of communication excellence in all of our web-based content.

South Florida Congresswoman Ileana Ros-Lehtinen visited AOML to learn more about the Laboratory's science programs and how they support and protect life in south Florida.

Top image: Ileana Ros-Lehtinen listens and watches as AOML Director Dr. Bob Atlas demonstrates how recent advances in high-resolution computer models have led to more accurate tropical cyclone track forecasts.

Middle image: Ileana Ros-Lehtinen meets with Dr. Silvia Garzoli and Ulises Rivero to learn how satellite-tracked surface drifters designed at AOML are used to monitor currents in the shallow basins of Florida Bay.

Bottom image: Ileana Ros-Lehtinen listens as AOML microbiologist Dr. Chris Sinigalliano discusses efforts to investigate and assess land-based microbial contaminants discharged into the coastal environment and their impact on coral reefs, as well as on human and marine animal health.

Top image: AOML oceanographer Evan Forde demonstrates the use of chemistry to determine the acidity of seawater during a session of the OCEANS (Oceanographic Curriculum Empowering Achievement in Natural Sciences) program. Forde created and developed OCEANS to provide a supportive learning environment for middle school students to study the biology, physics, chemistry, and geology of the world's oceans.

Middle image: A group of AOML's summer student interns pose with NOAA Administrator Dr. Jane Lubchenco during a visit to AOML.

Bottom image: AOML coral researcher Dr. Jim Hendee (standing on bench wearing white shirt) joins volunteers for a beach cleanup event at Lauderdale-By-The-Sea, a coastal community 30 miles north of Miami that has living coral reefs within 100 feet of its shores. Before the event began, Hendee spoke to volunteers about the fragility of coral reef ecosystems and NOAA's long-term global efforts to assess environmental conditions at coral reefs through satellite data collection and monitoring stations that gather in situ observations.

Engagement Enterprise

Objective: Foster an environment of collaboration, exchange, and leadership with our university, federal, and international partners by serving on science boards, steering and advisory committees, and supporting a robust visiting scientist program.

Actions:

- Facilitate an understanding of coastal pollution and the oceanography of urban coasts through cooperative endeavors with academic, state, and federal partners.

- Participate with the EPA and other agencies, organizations, and stakeholders in the formulation of new water quality criteria that incorporate rapid molecular methods for greater sensitivity, accuracy, and response-time for improved environmental and public health.

- Facilitate rapid advancement in hurricane intensity prediction through broad collaboration with federal and university partners by hosting meetings, visits, and workshops through the Hurricane Forecast Improvement Project. Continue to host visiting scientists from other NOAA Research laboratories and federal institutions, as well as from the academic and international communities, and encourage their participation in seminars and joint publication opportunities.

Objective: Reach out to under-represented groups in science.

Actions:

- Partner with and make presentations at local schools to encourage students to choose educational curricula relevant to the marine and atmospheric sciences.

- Encourage employees of all races and gender to participate in outreach and educational activities.

- Encourage employees to work with student interns from under-represented groups, allowing for hands-on experience with researchers.

Environmental research from the heights...

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National Oceanic and Atmospheric Administration
Office of Oceanic and Atmospheric Research

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... to the depths