



NOAA RESEARCH & DEVELOPMENT

NOAA is the single federal agency with operational responsibility to protect and conserve ocean, coastal, and Great Lakes resources and to provide critical and accurate weather, climate, and ecosystem forecasts to support national safety and commerce. NOAA seeks to accomplish this mission by addressing the grand environmental challenges facing our nation today and in the decades to come.

The NOAA Research Council, an internal body composed of senior scientific personnel from every line office in the agency, developed the current NOAA 5-Year Research Plan for 2008-2012, which provides corporate oversight to ensure that NOAA's research activities are of the highest quality, meet long-range societal needs, take advantage of emerging scientific and technological opportunities, and shape a forward-looking research agenda. NOAA has identified the most pressing of these challenges as a set of six overarching questions in the NOAA 5-Year Research Plan. NOAA's research and development portfolio is structured around finding answers to these questions and providing the public and policy makers the understanding needed to make well-informed decisions now and in the future.

What factors, human and otherwise, influence ecosystem processes and impact our ability to manage marine ecosystems and forecast their future state?

MONITORING AND PREDICTING HARMFUL ALGAE EVENTS PROTECTS SHELLFISH INDUSTRY AND CONSUMERS

NOAA is working to establish a national harmful algal bloom (HAB) monitoring and forecasting system to protect shellfish consumers around the country and the recreational and commercial economies that depend on them. This year, NOAA completed a HAB forecast system in the western Gulf of Mexico which provided Texas shellfish managers with algal toxins warnings, preventing potential threats to consumers' health. In the Northeast, NOAA offices teamed up to warn remote Maine shellfish harvesters over NOAA Weather Radio for the first time. In Oregon, a two-pronged HAB monitoring effort warned Oregon's recreational shellfishery of elevated toxin levels faster than ever. Blooms of toxic or unsightly algae are responsible for nearly \$82 million in lost income each year to communities around the country.¹ Predicting

¹ Hoagland, P., Scatasta, S. 2006. *The economic effects of harmful algal blooms*. In E. Graneli and J. Turner, eds., *Ecology of Harmful Algae*. Ecology Studies Series. Dordrecht, The Netherlands: Springer-Verlag, Chap. 29.



where and when these blooms arrive can save money and keep consumers safe.

ECOLOGICAL SEA NETTLE FORECASTING

With the aid of NOAA's National Weather and Oceans Services, the National Environmental Satellite Service's (NESS) Center for Satellite Applications and Research (STAR) led a project to make experimental ecological sea nettle forecasts for the Chesapeake Bay operational. High concentrations of sea nettles, a type of stinging jellyfish, seasonally inhabit the Chesapeake Bay from late spring to early autumn. Their sting is painful, and knowing where and when to expect these jellyfish helps people avoid them. Daily and three-day forecasts are now generated by using real-time and forecast data that predicts the probability of encountering sea nettles. This prediction system can also be easily modified to predict other important ecological variables in the Bay, such as the likelihood of waterborne pathogens. Knowing this type of information will provide direct benefits to the many people who live and play on and around the Chesapeake Bay.

COLLABORATIVE MULTI-AGENCY MONITORING OF REEF FISH IN THE FLORIDA KEYS

Coral reef fish are conspicuous and important components of coral reef ecosystems in south Florida and the Caribbean; however, populations of many of these species have been declining in recent decades. Solid quantitative information on the status and trends of coral reef fish populations is needed to better understand the factors leading to species declines and to suggest management strategies to reverse these trends.

To generate this information, NOAA and a wide array of other local organizations have been monitoring coral reef fish populations for many years. NOAA and its partners in the Florida Keys have been developing a standardized coral reef fish monitoring protocol to better coordinate these efforts to reduce costs and improve sampling efficiency. In 2010, a first-of-its-kind, multi-agency, collaborative, standardized reef fish monitoring protocol was published, representing an unprecedented collaboration between federal and state agencies including NOAA's Southeast Fisheries Science Center, the U.S. National Park Service, the Fish and Wildlife Research Institute of the Florida Fish and Wildlife Conservation Commission, and the University of Miami's Rosenstiel School of Marine and Atmospheric Science. The program is fully scalable as management priorities may change in the future. This coral reef fish monitoring program will serve as the model for how to conduct essential science-based ecosystem monitoring that integrates the needs and resources of a variety of federal, state, and academic partners.



What is the current state of biodiversity in the oceans, and what impacts will external forces have on this diversity and how we use our oceans and coasts?

EXPLORING BIODIVERSITY: AN EXPANDED BOTTOM TRAWL SURVEY IN THE BERING SEA

In the summer of 2010, the Alaska Fisheries Science Center completed the most comprehensive bottom trawl survey ever conducted in the Bering Sea. Three commercial fishing vessels were chartered to scientifically sample a standard set of stations ranging in bottom depth from 30 to 4,000 feet (1200 m) in an area about the size of the state of Texas. The vast survey area extended from the Alaska Peninsula in the south to the Bering Strait and to the U.S.-Russia Convention Line in the north. The primary purpose for conducting scientific bottom trawl surveys in the Bering Sea is to gather information for managing and conserving some of the United States' most valuable commercial fish stocks; such as, walleye pollock and red king crab. Scientists also use data from scientific bottom trawl surveys to learn about the marine communities within the Bering Sea. Basic questions asked by scientists are: What is the biodiversity within the different types of marine communities? How do the various members of a community interact? How do marine communities as a whole respond to varying environmental conditions such as climate change?

Scientists collected biological specimens in order to develop a comprehensive list of all species residing in the Bering Sea, along with information about their geographic range and what bottom depths they prefer. During the survey, biologists documented 233 different fish species and 529 different invertebrate species, some of which are very uncommon and unnamed. The diversity of species encountered demonstrates the diverse habitats that stretch across the Bering Sea including deep water canyons, islands, shallow coastal bays, and a gently sloping shelf. Each of these habitats can be affected by a variety of environmental forces that can fluctuate from season to season, year to year, and decade to decade. Examples of some of these environmental forces are oceanic and tidal currents, meteorological events, winter ice cover, and a subsurface layer of cold water ($<2^{\circ}\text{C}$) running down the middle shelf during the summer called the "cold pool" (Fig. 1). Fishes like the Arctic cod and Alaska plaice have an antifreeze substance in their blood that allow them to live in subzero water temperatures; however, temperate fishes, like walleye pollock, that lack an antifreeze substance appear to avoid the extremely cold temperatures. Fluctuations in the size of the cold pool each year can affect the species distribution of the marine community and thus, the interactions among them. The expanded survey effort in 2010 provided a valuable snapshot of the biological communities in the Bering Sea as they exist today. This snapshot will be useful for monitoring and compar-

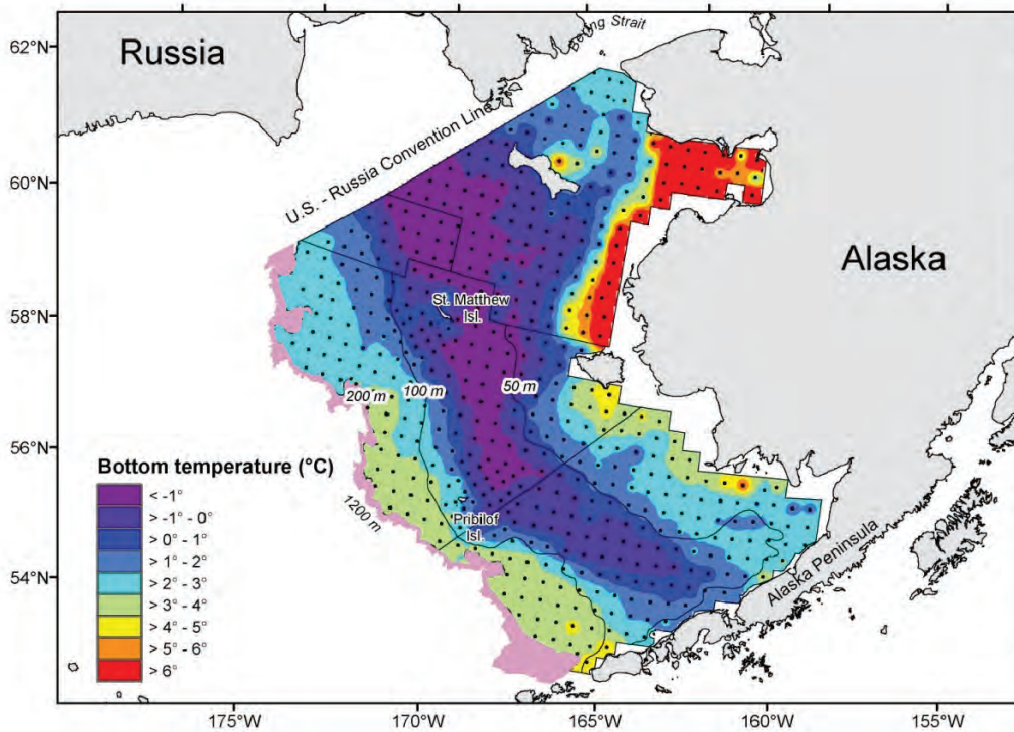
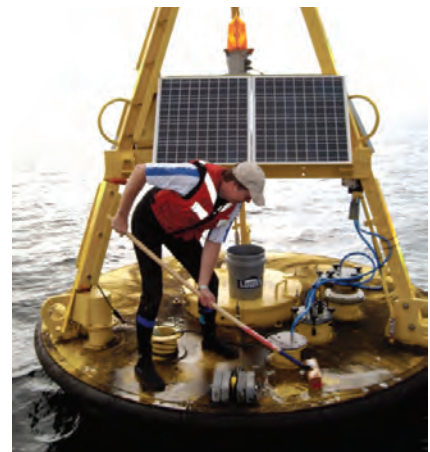


Figure 1: Map of the expanded 2010 bottom trawl survey in the Bering Sea showing stations sampled and mean bottom temperatures.

ing with future surveys to determine what changes have taken place, and suggesting possible reasons as to why.

GRAY'S REEF SEAFLOOR OBSERVATORY TRACKS OCEAN ACIDIFICATION

In an ongoing effort to better understand and monitor the effects of ocean acidification throughout the National Marine Sanctuary System, researchers at Gray's Reef National Marine Sanctuary partnered with the University of Georgia in 2010 to develop and install a scientific "observatory" on the seafloor of the sanctuary. Sensors on the remote station record measurements like seawater pH, temperature, salt content and dissolved oxygen levels, helping create a baseline for tracking changes in the ocean conditions in the sanctuary. Along with data collected by the National Data Buoy Center and the Pacific Marine Environmental Lab, scientists will be able to use this information to learn more about how ocean acidification and other climate-related shifts affect marine ecosystems over time.



Researcher from the University of Georgia services the NOAA buoy and sensors currently deployed to document many environmental parameters including CO₂ in the water column at Gray's Reef National Marine Sanctuary.
Photo Credit: Gray's Reef National Marine Sanctuary

DIVERS RETURN TO CORDELL BANK AFTER 30 YEARS

A technical dive team from NOAA's National Marine Sanctuaries and the Cooperative Institute for Ocean Exploration, Research and Technology completed a series of deep dives in rigorous conditions on Cordell Bank, just off Northern California. Working from the NOAA research vessel FULMAR, the team completed a series of dives down to 190 feet in strong current. This was the first dive expedition to Cordell Bank since Cordell Expedition divers



Technical divers from the Office of National Marine Sanctuaries document biological communities on Cordell Bank for the first time in 30 years.
Photo Credit: Joe Hoyt/NOAA/CBNMS

explored the Bank between 1977 and 1985. Divers returned to the boat astonished at the pristine nature and spectacular diversity of life covering the Bank's upper reef areas. The team was able to accomplish all the mission's science objectives including photo and video documentation and sample collection. This information will allow sanctuary staff to evaluate changes that have occurred on the Bank since the original survey 30 years ago, and establish species composition and reef conditions in 2010. The 2010 data will also provide sanctuary staff the opportunity to analyze future changes that may be associated with climate, in particular effects of ocean acidification on deep corals.

What are the causes and consequences of climate variability and change?

MONITORING SEA ICE THICKNESS USING CRYOSAT-2 SATELLITE ALTIMETRY: THE FIRST VALIDATION

The NESS Center for Satellite Applications and Research Laboratory for Satellite Altimetry, Sea Ice Team organized a critically important aircraft flight close to the North Pole and directly under the path of the European Space Agency's CryoSat-2 satellite on April 20, 2010, just 12 days after launch. This flight was an early opportunity to validate CryoSat-2's new radar technique for measuring the thinning of Arctic sea ice, a trend which is believed to be an early indicator of climate change. This activity provided support for the CryoSat mission through the efforts of three agencies, thereby setting an excellent example of what can be accomplished through international collaboration.

NEW STUDY SHOWS SOME CLIMATE CHANGE IMPACTS LARGELY IRREVERSIBLE

A study led by NOAA's Earth System Research Laboratory in Boulder, CO, published in the *Proceedings of the National Academy of Sciences* shows that changes in surface temperature, rainfall, and sea level are largely irreversible for more than 1,000 years after carbon dioxide (CO₂) emissions are completely stopped. If atmospheric CO₂ concentrations rise to 450-600 parts per million from the current value of 385 parts per million, the results would include persistent decreases in rainfall comparable to the 1930s North American "Dust Bowl" in zones including southern Europe, northern Africa, southwestern North America, southern Africa, and western Australia. The scientists emphasized that increases in CO₂ that occur in this century essentially "lock in" the sea level rise that would slowly follow over the next 1,000 years. Support for these findings was robust enough to quantify some irreversible climate impacts, including rainfall changes in certain key regions, and global sea level rise. This study demonstrates that some climate change impacts resulting from increases in atmospheric CO₂ concentrations are largely irreversible, and will have large consequences for agriculture, ecosystems, and coastal environments.



Jeremy Potter sampling the water during the 2005 NOAA-sponsored "Hidden Ocean" cruise to study marine life in all realms of the Canada Basin, one of the deepest parts of the Arctic Ocean.



What improvements to observing systems, analysis approaches, and models will allow us to better analyze and predict the atmosphere, ocean, and hydrological land processes?

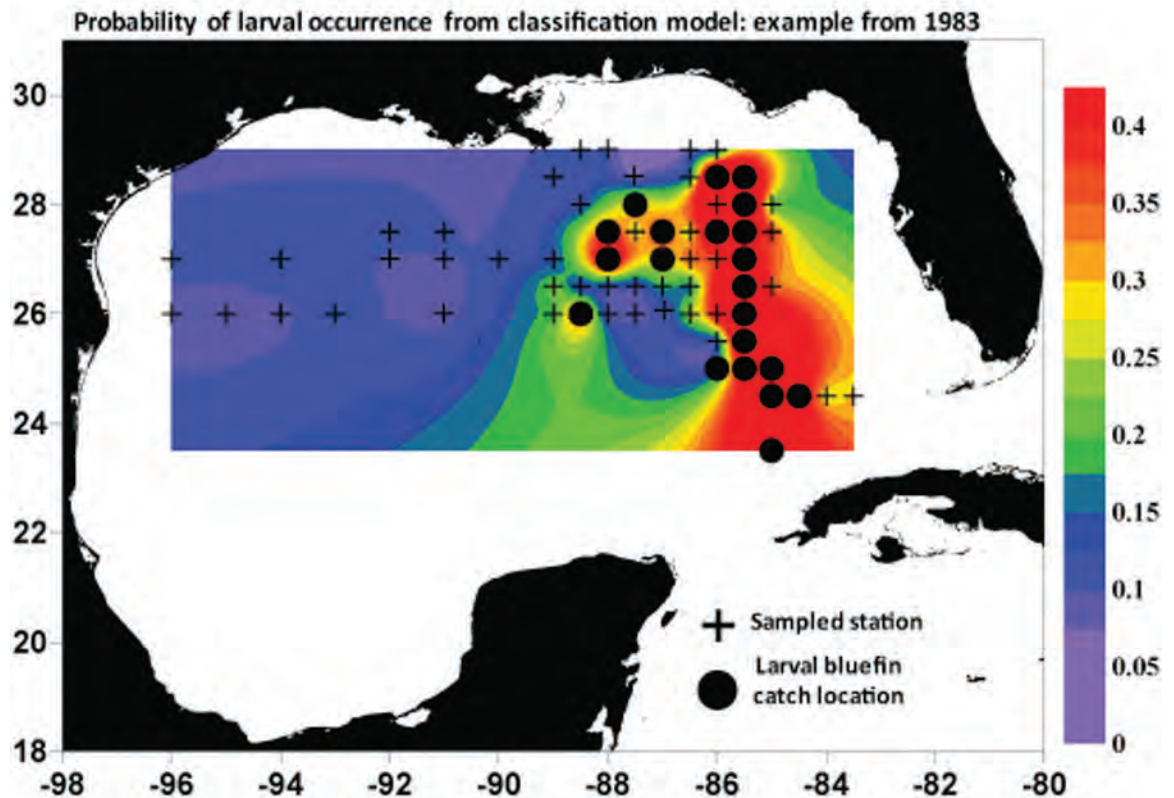
DIRECT ASSIMILATION OF GOES IMAGER RADIANCES TO IMPROVE COASTAL PRECIPITATION FORECASTS

NESS developed a fast radiative transfer model, which is an efficient method for calculating the transfer of electromagnetic radiation through the Earth's atmosphere. The model will allow imager data from NOAA's next generation of geostationary weather satellites (GOES-R) to be used directly in numerical weather prediction systems for the first time. This data assimilation technique has the potential to improve forecasts of heavy precipitation near the coasts, thus protecting lives and property.

MAPPING BLUEFIN TUNA SPAWNING SITES IN THE NORTHERN GULF OF MEXICO

Atlantic bluefin tuna is one of the most valuable and sought-after fish species, capable of fetching thousands of dollars per pound on the Japanese sushi market. The National Marine Fisheries Service (NMFS) has surveyed the northern Gulf of Mexico bluefin spawning sites each spring since the late 1970s, recording abundances and distributions of bluefin tuna larvae which are only days to weeks old. These abundances are formulated into a larval index, which is currently the only fishery-independent input to the bluefin tuna stock assessment. Surveys have shown spatial distributions for bluefin larvae vary markedly from year to year; however, scientists do not fully understand the processes driving these spawning behaviors. To address this knowledge gap, scientists from the NMFS Southeast Fisheries Science Center developed a habitat model to predict spawning behavior. The model uses data collected both at the time of sampling, from oceanographic instrumentation, and data collected remotely from earth-orbiting satellites. Results from the model showed that bluefin tuna larvae were found within low-productivity waters of a defined temperature range, and outside of the warm Loop Current and large warm-core rings.

In the short term, these real-time model predictions will be used to improve the accuracy of the larval bluefin tuna index. Predictions of larval distributions during spring 2010 will also contribute to a better understanding of the potential impacts of the Deepwater Horizon oil spill on eggs and larvae of bluefin tuna. In the longer term, defined temperature tolerances of adults and larvae will be combined with climate models, to predict future changes in bluefin tuna spawning behaviors under climate change conditions, through the end of the 21st century. The products will provide valuable information to stock



A habitat model using eight temporal and spatial variables, collected over 25 years of cruises. Results for each year were displayed as a map of predicted suitable habitat, with bluefin tuna larvae catch locations overlaid.

assessment scientists, and to the national and international management communities.

How can the accuracy and warning times for severe weather and other high-impact environmental events be increased significantly?

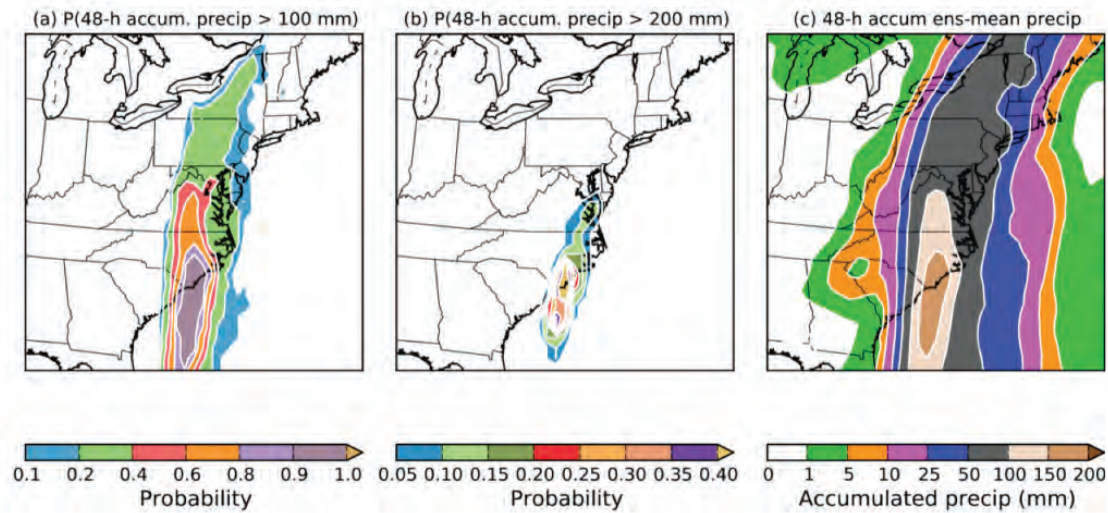
THE NOAA HURRICANE FORECAST IMPROVEMENT PROGRAM

In 2008, NOAA established the Hurricane Forecasting Improvement Project (HFIP), a 10-year project designed to accelerate improvements in one to five day forecasts for hurricane track, intensity, storm surge and to reduce forecast uncertainty, with an emphasis on rapid intensification of storms. In 2010, the project posted a series of impressive accomplishments that improved understanding of hurricane track and intensity, which include the following:

The Developmental Testbed Center (DTC), a facility for the weather prediction community to test and evaluate new models and forecasting techniques, developed a free, shared resource called the Hurricane Weather Research and Forecast (WRF) Model. Significant effort in the last year has also been



T254 GFS/EnKF 12-60 hour forecast from 2010092900

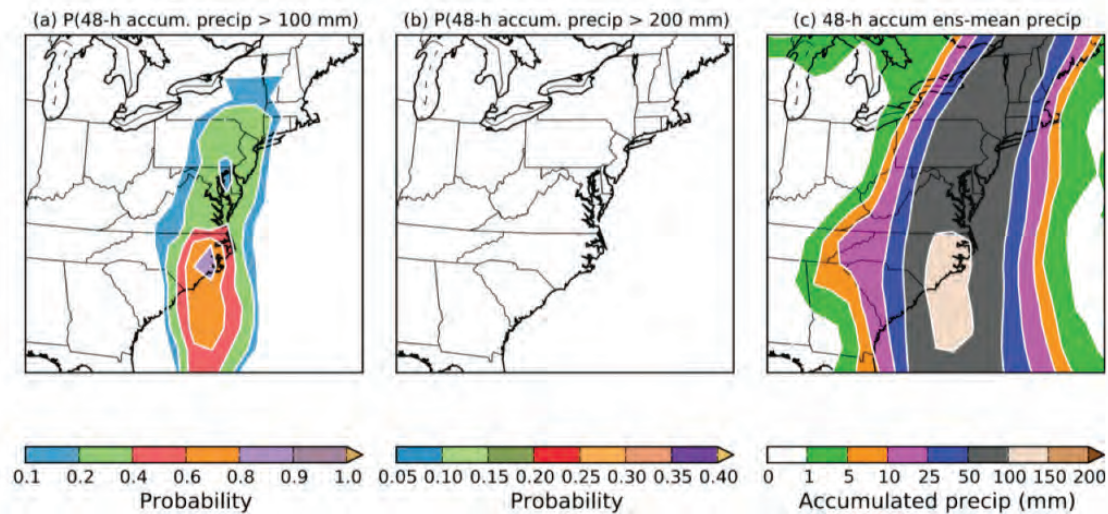


(Figure 2) Experimental Forecast: 12-60 h precipitation forecasts from the experimental Global Forecast System/Ensemble Kalman Filter (GFS/EnKF) system (a) Probability of greater than 100 mm total precipitation during the period. (b) Probability of greater than 200 mm. (c) Ensemble-mean precipitation amount.

focused on transitioning to operation, testing, and preparing the National Centers for Environmental Prediction (NCEP) HRRF modeling system for release to the community. In addition to offering tutorials, the DTC provides support to the research community through online scientific documentation, a users' guide, and a virtual help desk.

Along with the above research, NOAA made multiple upgrades to NCEP's operational models that showed promising results of a 20 percent improve-

T190 Operational GFS, GSI-ETR 12-60 hour forecast from 2010092900



(Figure 3) Operational Forecast: the current National Centers for Environmental Prediction Global Forecast System ensemble results for the same period. The results in the experimental system (Figure 7) show more refined data than the current NCEP system. Scientists hope these experimental systems will eventually lead to dramatic improvements in hurricane track forecasts in the future.



ment in hurricane track forecasting. Scientists at NOAA's Geophysical Fluid Dynamics Laboratory (GFDL) have been experimenting with a model ensemble for hurricane prediction that makes multiple predictions from the same hurricane start time, using different initial conditions. The model accounts for the uncertainties in the initial state of the atmosphere, often producing a more skillful forecast than any individual ensemble member.

During 2009 and 2010, Earth System Research Laboratory (ESRL) scientists designed a tropical cyclone experiment that showed a dramatic reduction in mean track errors (Figures 2 and 3) as compared to the NCEP operational forecast system. Researchers believe the improvements were due to better analyses of the steering wind environment around the tropical cyclone, resulting in better track forecasts.

NEW USER-FRIENDLY WIND WAVE FORECASTING TOOL MADE OPERATIONAL

Understanding waves associated with storms is essential to forecasting damage to coastal shorelines, which impacts coastal communities and marine habitats. NOAA's Wave Exposure Model is a free and easy-to-use tool that helps coastal managers, ecologists, and physical hydrologists alike by forecasting wave heights, wave energy and sediment erosion. Unlike more complicated, larger ocean-focused models, this tool was designed for use in smaller, more enclosed waterways where no similar tools have been made available – and where ever-increasing numbers of people are living and working. By placing the model on the popular Coastal Service Center's Digital Coast website, it is readily accessible to people worldwide. Furthermore, the tool is under evaluation for use by the National Weather Service for forecasting wave effects on shores of inland waters.

How are uncertainties in our analysis and predictions best estimated and communicated?

NWS DELIVERS IMPROVED WEATHER DATA TO THE FAA FOR MORE EFFICIENT MANAGEMENT OF THE NATIONAL AIR SPACE



Participants integrating cube data at FAA Tech Center Weather Laboratory.

The Next Generation Air Transportation System (NextGen) is a multi-agency effort to improve the efficiency and effectiveness of air traffic in the National Air Space System and ground traffic management at major airports. In 2008, a U.S. Congressional Economic Committee Report predicted that even a low-level implementation of improvements to air space management (~15 percent of recommended implementations) could reduce carbon loadings to the atmosphere by 1.15 million tons annually and have a \$2.7 billion positive impact on the U.S. economy. Because weather causes 70 percent of all air traffic delays, improved weather products and their use in managing the National Air Space is critical to achieve these goals.



In an effort to enable the reduction of aircraft delays, and improvements to the efficiency of air travel, NOAA's NextGen Weather Program in the National Weather Service's (NWS) Office of Science and Technology has designed, developed, installed, and currently operates a prototype for improved transfer of weather data and delivery of aviation weather products to the Federal Aviation Administration (FAA). This prototype, called the NextGen Environment for Testing (NET), is a system that takes legacy weather products from diverse locations across the United States, converts them to net-ready format, and expedites their delivery by making them automatically available through a single point of access. Expansion of these capabilities is expected to continue through the next several years as the NWS develops and deploys an initial operational capability for NextGen based on the concepts developed for this demonstration in the NET.

NOAA'S NATIONAL AIR QUALITY PREDICTION CAPABILITY

NOAA scientists extended smoke and ozone predictions for Hawaii and ozone predictions for Alaska in 2010. NOAA scientists also developed a new satellite observation product that delineates smoke aerosols in the atmospheric column for routine near-real time verification of smoke predictions. The new smoke predictions leverage wildfire emission information provided by the U.S. Forest Service (USFS). The new ozone predictions leverage efforts of NOAA's partners at the Environmental Protection Agency (EPA), in providing emission inventories, monitoring observations for near-real time verification, and coordinating with state and local air quality forecasters. Ozone and fine particle pollution are currently responsible for an estimated 60,000 premature deaths in the United States.² Improved forecasts and warnings are essential for protecting public health, especially for individuals who are at high risk of complications due to poor air quality.

² Kaiser, J., "Evidence Mounts That Tiny Particles Can Kill" *Science* 289, 22-23. 2000



The Office of Management and Budget (OMB) defines the conduct of Research and Development (R&D) as "...creative work undertaken on a systematic basis in order to increase the stock of knowledge, including knowledge of man, culture and society, and the use of this stock of knowledge to devise new applications." NOAA tracks the conduct of R&D as well as assets which support R&D, including equipment and facilities. Those assets include vessels that support research missions and high performance computing infrastructure.

The following charts display the scope and nature of R&D at NOAA:

- NOAA requests a total of \$737 million for R&D in FY 2012.
- R&D represents 13.4 percent of total NOAA funding for FY 2012. Of that, R&D equipment accounts for 2.9 percent of NOAA's total FY 2012 request.
- 72 percent of NOAA's R&D, excluding equipment, is intramural and 28 percent is extramural
- NOAA's R&D budget, excluding equipment, is 85 percent research and 15 percent development
- NOAA's Office of Oceanic & Atmospheric Research (OAR) manages 24 percent of NOAA's R&D. The remainder of R&D is distributed among the operational Line Offices. The proposed Climate Service will manage 35 percent of NOAA's R&D budget, much of which was transferred from OAR.
- NOAA's FY 2012 request includes \$162 million for Research and Development Equipment.

DEFINITIONS

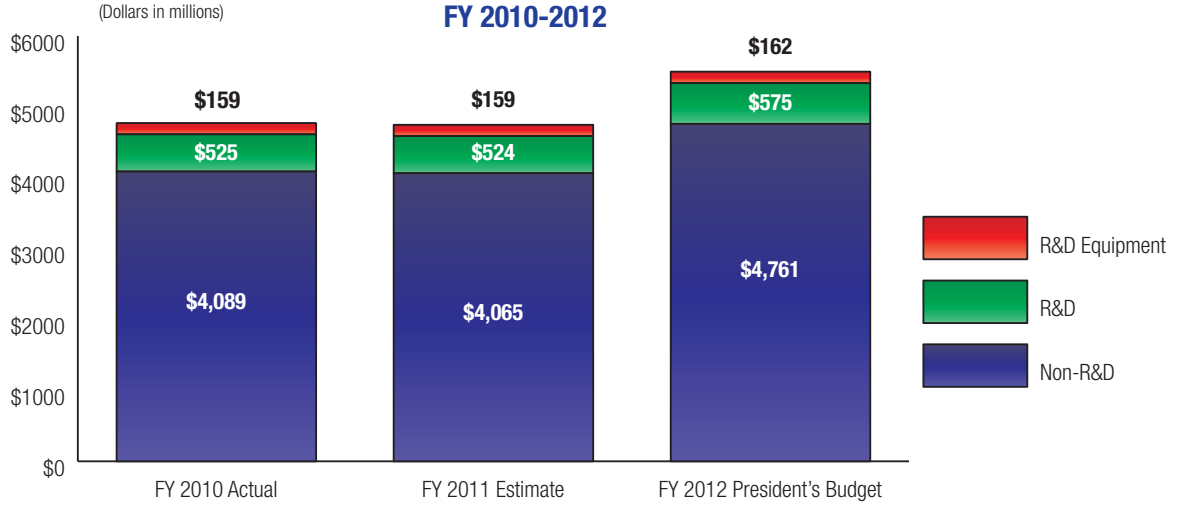
- Research and Development includes those activities aimed at broadening general knowledge about scientific topics, applied investigations on specific topics, and development of new technologies.
- Research is defined as systematic study to gain knowledge or understanding about a topic.
- Development is defined as systematic application of knowledge or understanding, directed toward the production of useful materials, devices, and systems or methods, including design, development, and improvement of prototypes and new processes to meet specific requirements.
- Equipment includes infrastructure to support Research & Development such as OMAO's research vessels, High Performance Computers, and laboratory equipment.



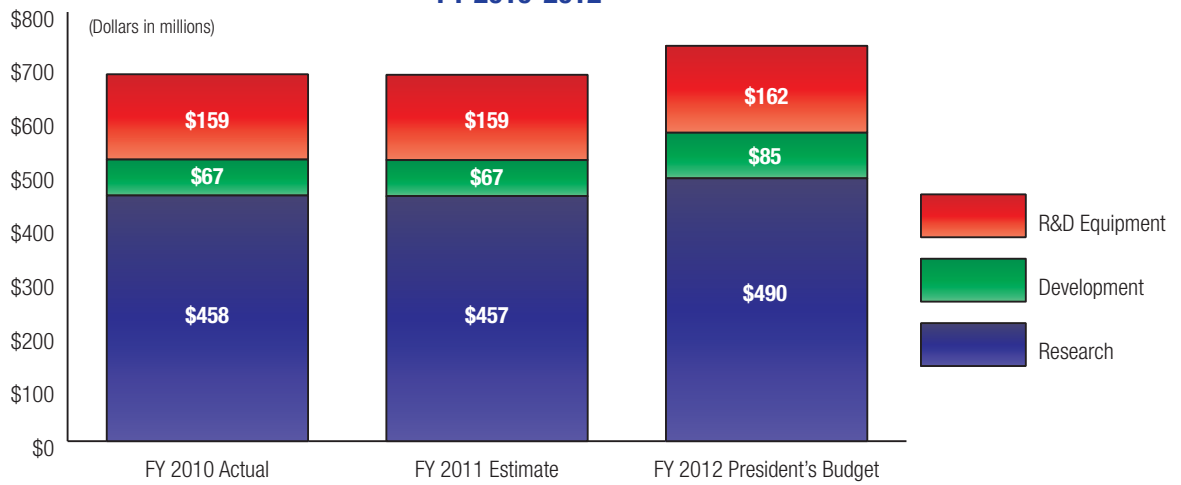
- Extramural research is that which is ultimately performed by non-Federal entities and may include private companies, academia, non-profits, state and local governments, etc.
- Intramural research is that which is performed by Federal Agencies



NOAA R & D APPROPRIATION FUNDING FY 2010-2012

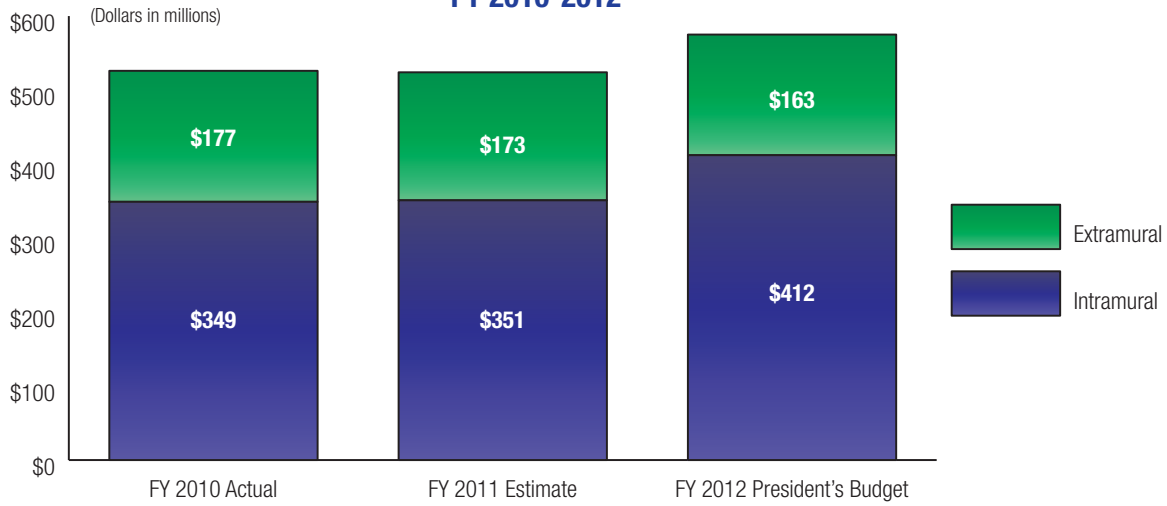


RESEARCH & DEVELOPMENT APPROPRIATION FUNDING FY 2010-2012





EXTRAMURAL & INTRAMURAL APPROPRIATION FUNDING FY 2010-2012



FY 2012 R & D APPROPRIATION BUDGET BY LINE OFFICE

