2016

NOAA CHIEF SCIENTIST'S ANNUAL REPORT

Table of Contents

Table of Contents

Foreword

Why should you read this report?

This is the first Chief Scientist's Annual Report produced by the National Oceanic and Atmospheric Administration (NOAA). NOAA is a science-based service agency. Our mission of science, service, and stewardship depends critically on a sustained and impactful investment in research and development.

As the nation's environmental intelligence agency, with a legacy reaching back more than 200 years, our portfolio of research is a rich blend of disciplines, methods, and objectives. NOAA provides the weather forecasts, marine fisheries management, nautical charts, sea ice predictions and solar storm warnings for the nation, among many other daily products and services ... and all for less than 5 cents per day for each American citizen.

More than simply documenting the diversity and quality of our research, this report focuses first on the impact that our scientific investments have on the lives, livelihoods, and lifestyles of all American citizens. The links are clear between our research outputs and resulting outcomes, in terms of economic, environmental, and societal resilience.

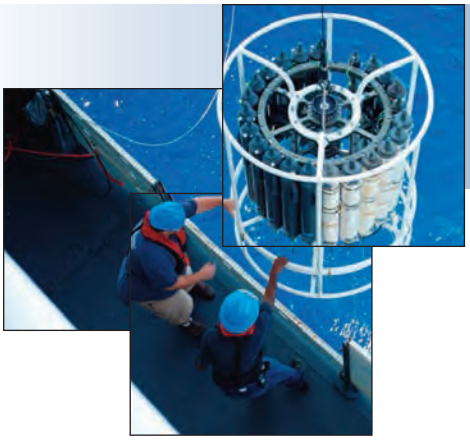
The quality of the research conducted and sponsored by NOAA is high, and in many cases, represents the gold standard for scientific investigation. Our researchers (federal employees and contractors), and our partners in academia, industry, and the non-profit sectors, are some of the most highly recognized and top-achieving scientists in the world.

In short, this report provides a singular cross-section of the research investments that are impacting our lives and our planet. The report provides an excellent representation of how taxpayer investments are paying off in both immediate and long-term benefits. That's why I hope even the casual reader will take the time to look at the many examples of impactful research presented in this *Chief Scientist's Annual Report for 2016*.

Rick Spinrad, PhD, CMarSci

Chief Scientist

December 2016



Introduction

NOAA's Research Portfolio

Enriching Life Through Science

Reaching from the surface of the sun to the depths of the ocean floor, the mission of the National Oceanic and Atmospheric Administration (NOAA) depends on a strong research foundation for understanding the complex systems that define our planet.

This understanding ultimately provides a range of users with the information and intelligence needed to protect lives, support livelihoods, and enhance lifestyles. From providing the daily weather forecasts that help safeguard communities, to informing fisheries management that keeps our nation fed and fishermen's jobs secured, NOAA's products and services affect more than one-third of America's gross domestic product and help protect people and property.

The Portfolio Logic Model

Like an investor administering financial holdings, NOAA manages its Research and Development (R&D) portfolio to ensure that we are serving the American public effectively while appropriately balancing investments across the agency's diverse mission responsibilities. The strategy for doing so is defined by NOAA's portfolio logic model: the *why*, *what, where* and *how* of NOAA's R&D investment.

NOAA's Mission: Science, Service and Stewardship

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

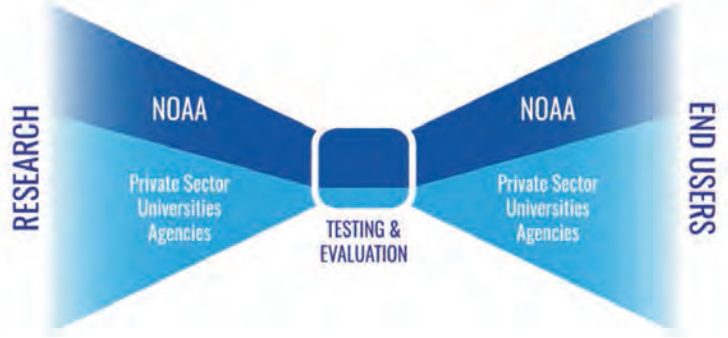
Why NOAA Invests in Research

NOAA's investment in research is critical to continually improving the quality, reliability, and cost-effectiveness of the products and services it provides to end users.

These products and services are developed through a dynamic engagement between the agency and its users: stakeholders communicate their needs to NOAA, sparking new research initiatives or improvements to current services, while NOAA continues to improve research and services to meet the needs of the people who depend on them.

By integrating research conducted internally with work from our partners, including cooperative institutes, universities, other government agencies, and the private sector, NOAA can transform basic conceptual research into the data, tools, and information our stakeholders rely on.

In short, we view the concept for this investment as a focusing effort in which we balance a *broad base of research investments to serve a wide diversity of end users.*



"Bow-tie" concept borrowed from UK Met Office.

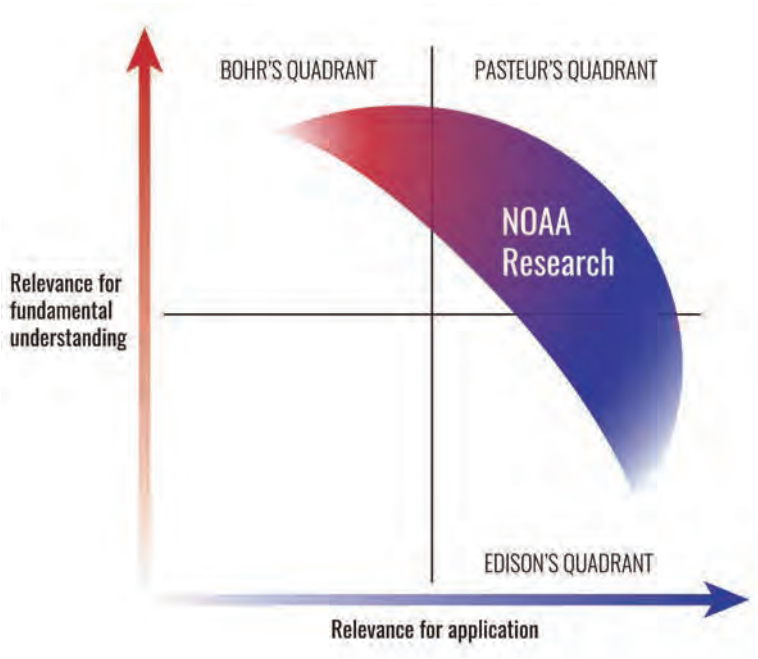
What Kind of Research NOAA Supports

NOAA's R&D addresses the needs of the user community while advancing fundamental scientific understanding. Our R&D portfolio must allow the flexibility to consider contributions to the scientific knowledge base separately from (albeit related to) enhancing applicability.

In the context of the classical treatment by Donald Stokes [*Stokes, 1997*], we strive to position our investment primarily in "Pasteur's Quadrant," while including critical investments aimed primarily at either advancing fundamental understanding or enhancing applications.

NOAA strategically invests in a mix of research projects across the risk-reward spectrum. We pursue a range of projects, from low-risk projects that result in incremental gains (e.g., periodic improvements to our already-existing storm prediction models) to high-risk projects with high potential gains but less certainty of success (e.g., exploratory research).

This sets NOAA on the cutting edge of R&D while still ensuring that we meet the needs and expectations of our users.



Donald Stokes proposed the above chart in his 1997 book Pasteur's Quadrant: Basic Science and Technological Innovation. *This chart portrays that, while some research largely focuses on fundamental understanding (Bohr's quadrant, upper left) or application (Edison's quadrant, lower right), it is possible for research to be highly relevant for both fundamental understanding and real-life applications (Pasteur's quadrant, upper right). The majority of NOAA research strives for this dual relevance as reflected in Pasteur's quadrant.*

VORTEX2 field command vehicle with tornado in sight. LaGrange, Wyoming.

Scientific staff on the NOAA Ship OSCAR ELTON SETTE sorting a mid-water trawl catch.

All Six NOAA Line Offices Provide a Unique Contribution to NOAA R&D

The National Marine Fisheries Service (NMFS), also known as NOAA Fisheries, is responsible for the stewardship of the nation's ocean resources and their habitat. Their main goals are to ensure productive and sustainable fisheries, safe sources of seafood, the recovery and conservation of protected resources, and healthy ecosystems — all backed by sound science and an ecosystem-based approach to management. The sound science behind these goals is largely carried out by NMFS's regional science centers and laboratories.

The National Ocean Service (NOS) works to provide science-based solutions through collaborative partnerships to address evolving economic, environmental, and social pressures on our ocean and coasts. NOS program offices address the science of ocean and coastal resources, tides, the complexity of Earth's surface, coastal resilience, nautical chartmaking, marine sanctuaries, responses to oil and chemical spills, and ocean observation and monitoring.

The National Environmental Satellite, Data, and Information Service (NESDIS) aims to provide timely access to global environmental data from satellites and other sources to promote, protect, and enhance the nation's economy, security, environment, and quality of life. Their research activities involve operating the NOAA National Data Centers, providing data and information services including Earth system monitoring, performing official assessments of the environment, and conducting related research.

The Office of Oceanic and Atmospheric Research (OAR) seeks to use rigorous research to better understand the complex systems that support our planet. OAR runs several NOAA research laboratories and the National Sea Grant College Program, as well as heading offices focused in ocean exploration, climate, weather and air quality, unmanned aircraft systems (UAS), and ocean acidification.

The National Weather Service (NWS) works to provide weather, water, and climate data, as well as forecasts and warnings for the protection of life and property and enhancement of the national economy. NWS carries out developmental activities to transition research advancements from NOAA and external research community into enhancements to NWS operational warning and forecast services to build a Weather-Ready Nation.

The Office of Marine and Aviation Operations (OMAO) does not have an internal R&D agenda but instead supports the research of other line offices by providing, managing, and operating the aircraft and marine vessels necessary to carry out this research.






Where NOAA Invests in Research

NOAA maintains both intramural and extramural research investments. There is not a singular formula nor operational concept for distributing research support inside and outside of the agency.

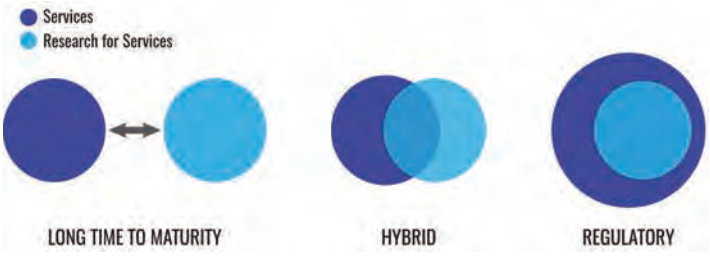
Some programs invest the majority of their R&D funding internally, at labs and science centers with federal employees. Other programs invest the majority of their funding to external R&D partners, at universities, industry, and other research institutions.

Moreover, in many cases, programs invest with a distribution of R&D funds intramurally and extramurally.

In the past, NOAA analyzed the balance of investment [Fluharty et al., 2006; MacDonald et al., 2006]. Most recently, NOAA issued Strategic Research Guidance in 2015 [NOAA, 2015] and 2016 [NOAA, 2016a], and NOAA Administrative Order (NAO) 216-115A [NOAA, 2016c].

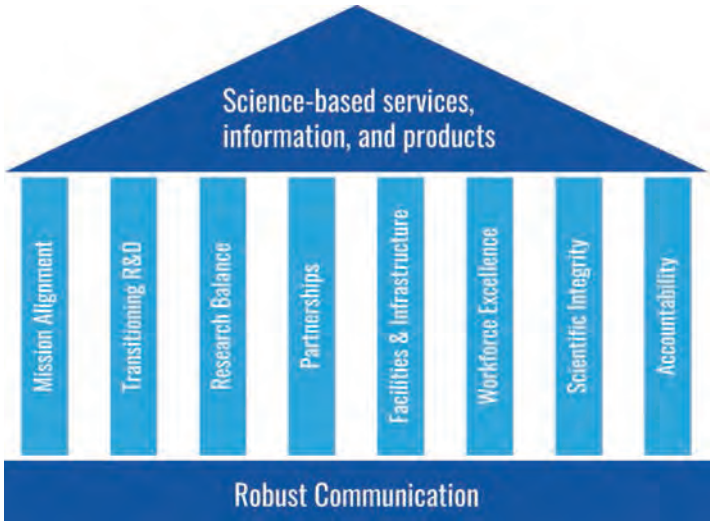
This guidance indicates that the principles around which the determination should be made about where to invest research funding are based on the expected time to maturity of research (for which external investments allow flexibility and 'course-corrections' through grants and contracts), and applicability to regulatory functions (for which direct engagement between the users and researchers might be most easily accommodated through internal investments).

Conceptually, this means that a balance of considerations for mission relevance, time to maturity, and need for flexibility indicate the balance of intramural and extramural investment as shown below.



NOAA partnerships are vital to the agency's R&D efforts, allowing for collaboration with leading universities, federal agencies, private companies, NGOs, and other science innovators, as well as the mutually beneficial sharing of facilities, equipment, and staff expertise.

Key mechanisms for partnerships include Cooperative Institute (Prospectus for Cooperative Institutes in the 21st Century -CI21 [NOAA, 2016d]) and Cooperative Science Center agreements with universities; the Sea Grant network; extramural grant programs; contracts; Cooperative Research and Development Agreements with the private sector; and more.



What Principles Guide NOAA Research

NOAA strives to direct, formulate, and evaluate all agency research in light of the following eight principles through the NOAA Administrative Order (NAO) 216-115A: mission alignment, transition readiness (NAO 216-105B [NOAA, 2016b]), research balance, optimized partnerships, sustained facilities and infrastructure, workforce excellence, scientific integrity, and accountability.

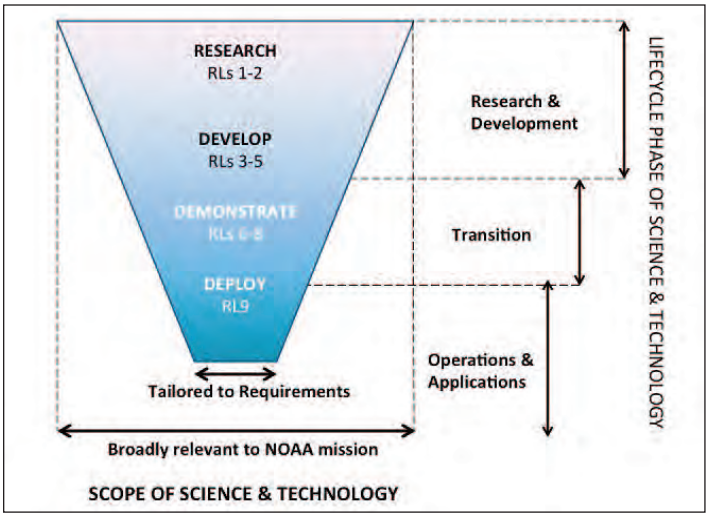
These principles, grounded in communication within the agency and between our partners, work together to uphold NOAA's high-quality research, development, services, and products.

How NOAA Research Transitions into Operations, Applications, Commercialization, and Utilization (R2X)

It is essential to ensure there is transition of research and development to maintain our capability of meeting mission requirements across all NOAA missions.

In the Fiscal Year (FY) 2017 President's Budget, NOAA proposed the creation of the Research Transition Acceleration Program (RTAP). RTAP is designed to support the acceleration of mature R&D activities to the "mission-qualified" level (Readiness Level 8, RL 8) in one to three years. This pace is significantly reduced from historically longer transition times, which have taken decades in some cases.

NOAA's RTAP will improve the process and provide the needed resources to accelerate the transition of NOAA's R&D outputs into operations, applications, commercialization, and other uses for societal benefits, which we call R2X. The full description of NOAA's re-engineered transition process is defined in NAO 216-105B. In the end, these process and resource improvements will continue to strengthen the culture of transitioning R&D at NOAA.



Currently, NOAA line offices are conducting a limited range of highly successful transition activities. The activities listed below highlight just a few of the R&D projects that have been selected to move from research to operations, applications, and policy.

Establishing an Operations-to-Research Infrastructure (S4) to Facilitate Research-to-Operations Transitions of Multiple Scientific Projects Aimed at Improving NOAA Modeling Systems

- NOAA and academia established an infrastructure called S4 to engage the broader research community in the use of NOAA numerical modeling systems. This infrastructure was composed of a supercomputer, a user support mechanism, and a software configuration management system, models porting.

  These scientists are working on improving satellite data utilization in NOAA numerical modeling systems in order to facilitate their Research to Operations (R2O) transitions. Through S4, researchers from government, private sector, and academia have access to a variety of NOAA numerical models including ocean, weather, air quality and land, which allow them to perform their research in an operational-like environment and therefore greatly facilitate their R2O transition effort and mature their technical readiness level.

- A multitude of NOAA systems benefited from the S4, including the Global Forecast System/ Gridpoint Statistical Interpolation (GFS/GSI) system for global weather forecasting, the Hurricane Weather Research and Forecast (HWRF) for hurricane prediction, the Hybrid Coordinate Ocean Model (HYCOM) system for ocean prediction, North American Land Data Assimilation System (NLDAS) for land assimilation, and prediction and Weather Research and Forecasting model coupled to Chemistry (WRF-Chem) system for air quality.

Transitioning Optical Technologies to Improve Surveys for Red Snapper and Other Reef Fishes

- Current fish surveys conducted in the Gulf of Mexico provide measures of observations per unit effort that can be compared over space and time, enabling the generation of relative abundance indices. While relative abundance indices are considered good indicators of biomass trends, these indices do not give an accurate estimate of the overallstock size.

  This research 1) develops a capability for estimating true local density for red snapper and other fish species from video surveys, 2) classifies the seabed and other habitat parameters to estimate stock conditions, and 3) generates absolute abundance estimates aimed at reducing uncertainty in the stock assessment and improve NOAA Fisheries ability to monitor the status of red snapper and other reef fish.

- Operationalizing these optical technologies will provide total abundance estimates of red snapper and other reef fishes, reducing scientific uncertainty, improving the stock assessment and providing for more sustainable fishery yield.

Operationalizing a Forecast System for Lake Erie Harmful Algal Blooms

- The goal of transitioning the Lake Erie forecast system from demonstration at the National Centers for Coastal Ocean Science (NCCOS) to operations at the Center for Operational Oceanographic Products and Services (CO-OPS) is to establish an operating capability for twice-weekly bulletin forecasts that provide information on the current size, density, and location of the Harmful Algal Bloom (HAB) along with a 72 hour forecast of transport projection.

  The transition plan documents the steps necessary to achieve that objective without additional resources to base budgets and articulates the observations/data streams required to support the sustainment of operational requirements of the forecast system.

- By providing sustained operational semi-weekly bulletin forecasts of potential threats to public water supplies, stakeholders are better able to make effective and timely water treatment decisions so as to avoid major impacts such as the Toledo water crisis of 2014.

North American Multi-Model Ensemble (NMME)

- A multi-model ensemble prediction system comprised of operational and research climate models developed and demonstrated via NOAA Climate Test Bed (CTB) was transitioned to NWS Climate Prediction Center (CPC) as an operational seasonal prediction tool. Uniquely, the product makes operational use of research climate models to form the ensemble forecast.

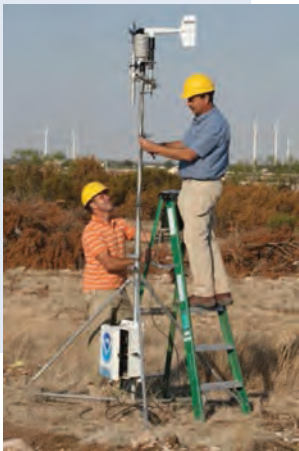
- As part of the Weather Ready Nation vision, such forecasts and applications stemming from NMME hold the promise of providing early warning of and mitigation to high-impact weather events.

Automated High-resolution Ensemble-based Hazard Detection Guidance Tool

- The overarching goal of this work is to transition a well-tested system for generation of ensemble post-processing hazard guidance products to operational status in the National Weather Service.

  A direct outcome of the project improves the ensemble hazard guidance tool for operational forecasters, thereby reducing the ensemble information overload problem and enabling a more efficient and accurate characterization of forecast uncertainty. Ultimately, the National Weather Service's weather guidances will become more useful and higher quality.

- This tool will improve forecast accuracy of high-impact weather features such as rainbands, snow bands, low ceilings etc.; and will enhance forecasters' ability to communicate forecast uncertainty.

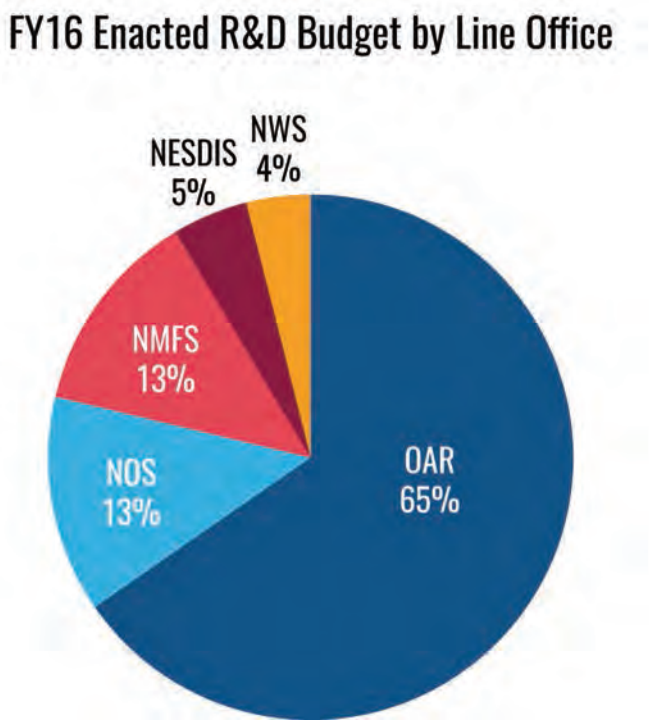


What is the Budget for NOAA Research?

NOAA's Fiscal Year 2016 (FY16) Enacted budget included approximately $560 million, or 10% of the agency's total budget, to support R&D — where R&D is defined as all research and development activities not including facilities and equipment.

This continues a five-year trend of increased support for R&D, highlighting NOAA's efforts to keep up with increased stakeholder demand for environmental intelligence and services in the face of a changing planet.

Note: Budget figures exclude equipment and facilities spending but include both intramural and extramural investments, unless otherwise specified. All numbers were acquired from the NOAA Budget Office.

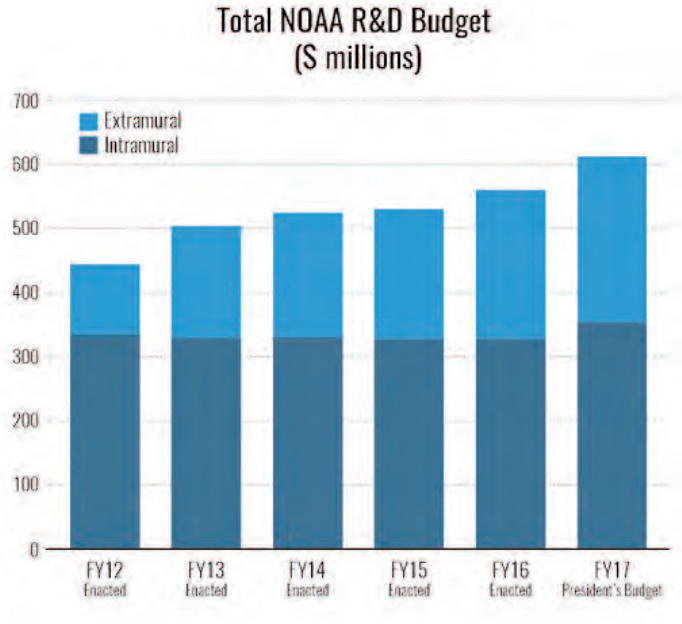


NOTE: OMAO supports the research of other line offices through providing, managing, and operating the aircraft and marine vessels necessary to carry out this research.

Where Does it Go?

NOAA's R&D activities are supported by all line offices and numerous programs. Almost 60 percent of NOAA's FY16 R&D budget supported internal R&D efforts, including those at NOAA labs and science centers. The remaining 40 percent was set aside for extramural research, enabling partnerships and collaborations with non-NOAA entities.

Over the past five years, NOAA has been dedicating an increasing percentage of our resources to extramural research, which shows the importance NOAA places on external partnerships in fulfilling our R&D mission.



Note: All graphs exclude facilities and equipment from R&D budget calculations.

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NOAA (2016b), NOAA Administrative Order 216-105B - Policy of Research and Development Transitions, National Oceanic and Atmospheric Administration, Washington, D.C.

NOAA (2016c), NOAA Administrative Order 216-115A - Research and Development in NOAA, National Oceanic and Atmospheric Administration, Washington, D.C.

NOAA (2016d), Prospectus for Cooperative Institutes in the 21st Century (CI21), p. 24, Washington, D.C.

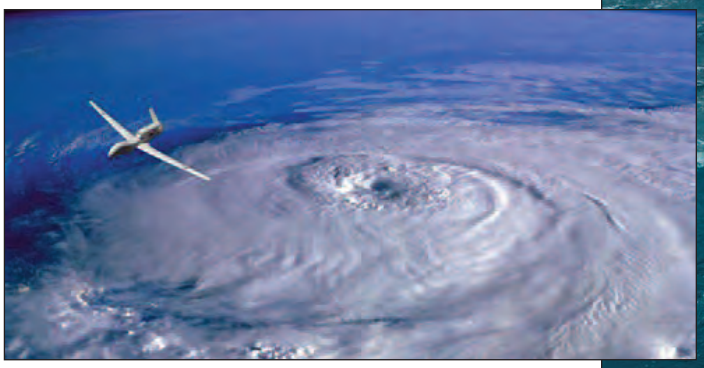
Stokes, D. E. (1997), Pasteur's quadrant: Basic science and technological innovation, Brookings Institution Press.

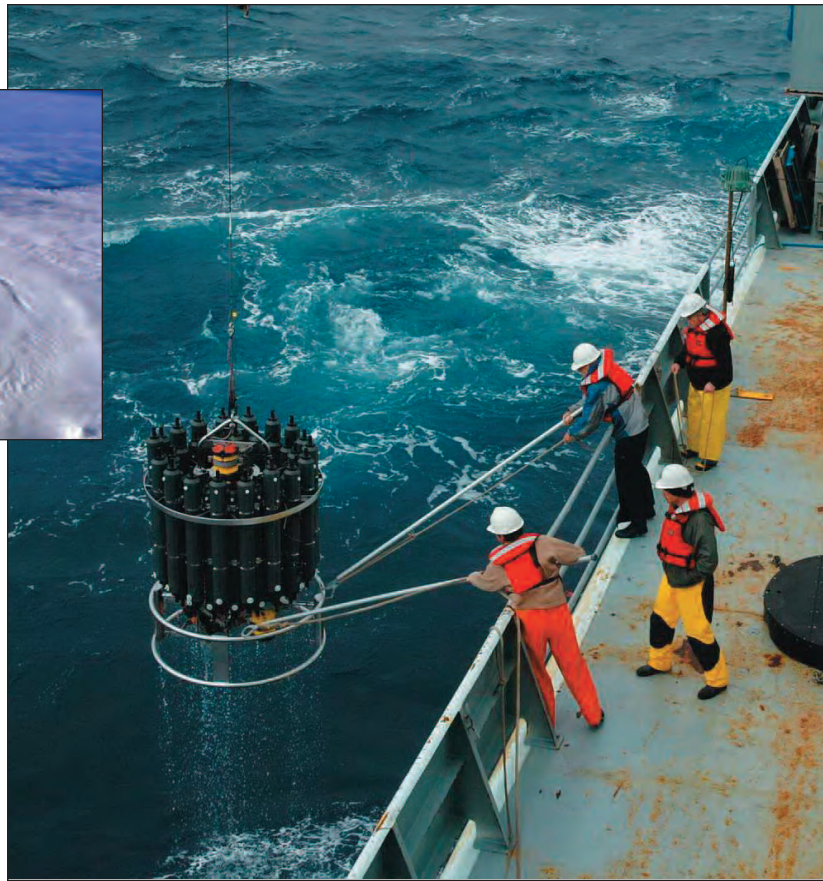
NOAA has a broad set of predictive responsibilities, reflected in its large and highly diverse modeling enterprise. Models are essential tools for enhancing scientific understanding, making predictions and projections, and ensuring informed decision-making to meet NOAA's mission needs. For example, NOAA uses models for the following:

- *Developing and improving weather, air quality, and ocean forecasting*
- *Providing predictions and projections of atmospheric, hydrologic, cryospheric, and oceanic dynamics and composition over a range of temporal and spatial scales*
- *Developing hazard mitigation such as tsunami and oil spill trajectory models, and ecological forecasting models for harmful algal blooms, hypoxia and ocean acidification*
- *Supporting ecosystem-based management of marine resources including understanding and predicting associated socio-economic impacts*

Model development and improvements depend on a continued understanding of earth system processes, developed through targeted field and laboratory studies as well as the exploitation of new types and sources of data.

While a single report outlining the scientific work and achievements of NOAA researchers throughout the past year would fill many volumes, this NOAA Chief Scientist's Annual Report highlights a small but representative fraction of the critical work NOAA does every day. The research depicted in this chapter highlights some of the data, tools, products, and services that NOAA's research activities provide, giving us critical insights into the complex and diverse integrated earth systems that impact our country and our planet.





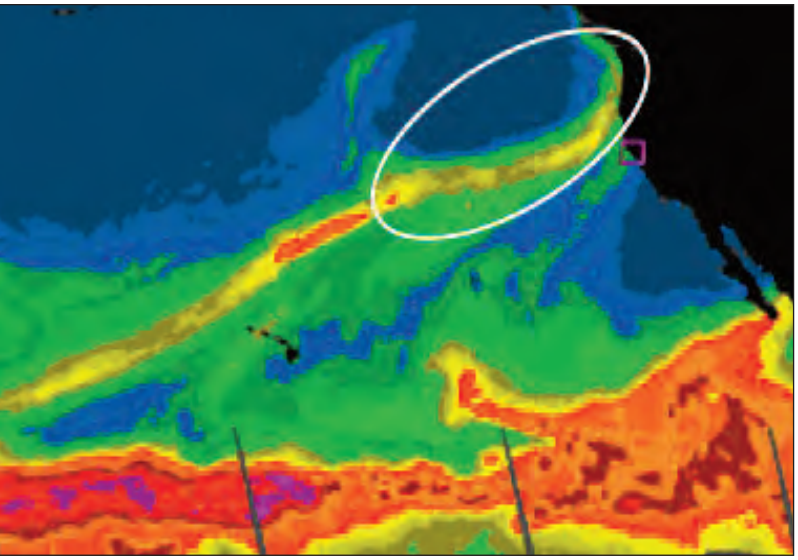
Leading-Edge Research for Improved Forecasts

El Niño Rapid Response Campaign Yields New Discoveries on Weather Phenomena

From January-March 2016, NOAA scientists and partners led by the Earth System Research Laboratory (ESRL), pulled together a major field effort that analyzed the mechanics of an El Niño event in unprecedented detail in order to gather data to improve weather forecasts thousands of miles away.

NOAA's team, along with NASA, the U.S. Air Force, and the Scripps Institution of Oceanography, studied a major wind-driven precipitation event to give forecasters a detailed look at an "atmospheric river" as it reached the U.S. West Coast. This resulted in the discovery of new, complex distributions of moisture in the tropics and subtropics that were not well-represented in operational model analyses or satellite measurements.

This research had never been done with a major El Niño and will ultimately help NOAA researchers understand the first link in the chain that produces, among many other weather impacts, extreme precipitation events on the West Coast.



> "NOAA/ESRL's Physical Sciences Division has managed to pull together a major field effort that will analyze the mechanics of this El Niño in truly unprecedented detail."
>
> *- Bob Henson, Weather Underground*

During the campaign, the NASA Global Hawk UAS (Unmanned Aircraft System) and NOAA Gulfstream jets flew 100,000+ miles, the *NOAA Ship Ronald H. Brown* logged 3,000 miles, and 725 meteorological sensors (sondes) were launched from Christmas Island for comprehensive data collection. Overall, the campaign discovered new, complex distributions of moisture in the tropics and subtropics that were not well-represented in operational model analyses or satellite measurements. Preliminary observed data for the 2016 event show a much different impact on California rains than those that happened in 1983 and 1988.

Perhaps most surprising is that Southern California has become even drier despite high expectations for rain this time around. Initial studies suggest the addition of data collected by the campaign could improve model characterization of the atmospheric river and downstream weather forecasts for Alaska and the western and central United States.

Unmanned Aircraft Systems Utilized to Improve Hurricane Forecasts

After Hurricane Sandy, Congress provided funding to NOAA and NASA through the Disaster Relief Appropriations Act of 2013, to study the effectiveness of high altitude, long endurance unmanned aircraft system in maintaining weather forecast skill for dangerous oceanic storms, in the event data are missing from our polar-orbiting weather satellites.

Photo credit: NASA

Flying at 60,000 feet, the Global Hawk UAS passes over most storms at sea and provides a full three-dimensional picture of an oceanic storm. In 2015 and 2016, the project team flew the Global Hawk over tropical storms Erika and Fred, and three Pacific storm systems.

These 24-hour Global Hawk flights carried NASA remote sensors and successfully demonstrated first-use of an automatic UAS dispensing system for sondes (sensors) dropped into the hurricane. NOAA and NASA are now evaluating the impact of real-time weather data gathered by the Global Hawk UAS on weather prediction models used by the National Weather Service.

While data gathered by Global Hawk is still being analyzed, it appears that when satellite atmospheric moisture and temperature data are missing, similar Global Hawk data may improve two-day storm predictions of Atlantic Ocean tropical cyclone track and intensity, and predictions for storms impacting Alaska and the central U.S.

Additionally, another small unmanned aircraft, the Coyote (launched from NOAA's Hurricane Hunter P-3 aircraft), collects data in the hurricane boundary layer where manned aircraft cannot fly. A 2016 upgrade to the P-3 antennae now allows the Coyote to fly ten times further than before, up to 50 miles, from the P-3 aircraft while collecting and transmitting continuous observations.

NOAA also has the ability to transmit real-time data collected from its instrument package to NOAA's National Hurricane Center (NHC) for the first time, including data from a new infrared sensor to measure sea surface temperature, which is a vital parameter for understanding the lifecycle and intensity of hurricanes.

NOAA's Atlantic Oceanographic and Meteorological Laboratory (AOML) is currently working with a Coyote to evaluate the temperature, relative humidity, and pressure instrumentation, as well as improve measurements of heat fluxes near the eyewalls of hurricanes, an under-sampled aspect of hurricanes that could improve NOAA's ability to predict changes in hurricane intensity.

Model Enhancements Improve Timeliness and Resolution of Weather Forecasts

On August 23, 2016, NOAA's High-Resolution Rapid Refresh (HRRR) and Rapid Refresh (RAP) models received significant updates. The HRRR is an hourly updated model that covers the lower 48 United States at 3km resolution and uses radar assimilation to provide the short-range precipitation forecast component for the National Water Model. The RAP is an hourly updated model covering all of North America at 13-km resolution.

> "The FAA has long supported [NOAA's] numerical modeling research and the most recent operational transition of the HRRR to NWS operations improves aviation forecasts at air terminals and aloft, reducing air traffic delays, which cost the airline [industry] billions of dollars annually."
>
> *- Steve Abelman, Federal Aviation Administration*

These upgrades enable more effective assimilation of surface, radar reflectivity and lightning, and cloud observations — resulting in significant improvement in timing and location of thunderstorm forecasting. These models show improved boundary-layer physics that can be applied to energy applications and aerosol-aware cloud microphysics that remove significant biases in the current operational models.

The upgrades significantly increase use of polar-orbiting and GOES (geostationary) satellite data, adds National Centers for Environmental Prediction's (NCEP) first assimilation of lightning data, and pushes hourly forecasts out an additional 3 hours (from 15 to 18 hours for HRRR and from 18 to 21 hours for RAP) to help the National Weather Service (NWS) extend lead-times for high-impact events such as thunderstorms.

The HRRR is the first model to produce 15-minute snap-shots that are updated every hour with resolution sharp enough to predict individual thunderstorms. Using grid points about two miles apart, the HRRR can aid forecasters to pinpoint neighborhood-sized threats such as potentially tornado-producing storms, heavy precipitation that can lead to flash flooding, and abundant snowfall. The HRRR was developed by NOAA's Earth System Research Laboratory and version 1.0 was put into NWS operations in the fall of 2014.

Wind Forecast Research Optimizes Renewable Energy Efforts

As part of the Atmospheric Science for Renewable Energy (ASRE) effort with the Department of Energy (DOE), NOAA's Earth System Research Lab is seeking to improve forecasts of wind turbine-height winds. More accurate short-term forecasts of atmospheric conditions help the industry make these power sources more reliable, efficient, and easier to integrate onto the power grid.

To support this effort, the second Wind Forecast Improvement Project (WFIP2) is taking place in Oregon's rugged Columbia River Gorge through the spring of 2017. WFIP2 builds on the first WFIP, conducted in the Great Plains and Texas in 2011 and 2012. In both projects, new public- and private-sector weather observations were fed into NOAA's RAP and HRRR hourly weather prediction models.

The first WFIP showed that integrating new observations into the RAP and HRRR models and improving model physics made wind forecasts up to 15% more accurate in areas with flat terrain. WFIP-2 is now extending this project to rugged terrain to see if it can accurately predict winds between the ground and the tips of the wind turbine blades and then integrate this data into an even higher-resolution 750-meter HRRR "forecast grid." These high-resolution weather data will enable ASRE scientists to develop a model that can support optimized energy systems that use large amounts of wind and solar power.

> "NOAA's continual advancement of forecast skill improves the stability of our electric grid, and directly reduces the cost of integrating more renewable energy into our resource mix."
>
> *- Dr. Jim McCaa, Manager, Vaisala Energy Advanced Applications*

Storm surge from Hurricane Carol lashes Rhode Island Yacht Club - 1954

Hurricane Surge Forecasting to Better Predict Flooding in Coastal Communities

The Hurricane Surge On-demand Forecast System (HSOFS) is a hurricane storm surge forecast system that predicts flooding in coastal communities using data from an advanced high-resolution storm surge model.

HSOFS simulates water levels as hurricanes track across the Western Atlantic Ocean and Gulf of Mexico and cover the coast from Texas to Maine, including Puerto Rico and the U.S. Virgin Islands.

The model was successfully implemented for operational use on NCEP Central Operations' high performance computing system. The model grid and testing were originally developed in a project with Architecture, Engineering, Consulting, Operations, and Maintenance (AECOM) and Riverside Technology, Inc., and further testing and transition to operations was performed in partnership with NOAA.

HSOFS will be used near the time prior to hurricane landfall in order to provide additional guidance to the National Hurricane Center on flood risks, thereby protecting coastal communities with advance flood warnings.

Last Place on Earth Where CO_2 Exceeds More Than 400 ppm

On May 23, carbon dioxide (CO_2) levels in the Earth's atmosphere exceeded 400 parts per million (ppm) at the South Pole, locking in levels of heat-trapping gas not seen for millions of years. Since before the Ice Age, measurements taken at NOAA's atmospheric observatories on Mauna Loa and at the South Pole both indicate that CO_2 will not fall below 400 ppm. NOAA researchers now estimate it will not dip below this level during our lifetime and probably much longer.

Over the course of the year, CO_2 levels rise during fall and winter and decline during the Northern Hemisphere's summer as terrestrial plants consume CO_2 during photosynthesis. However, plants capture only a fraction of annual CO_2 emissions, so for every year since observations began in 1958, there has been more CO_2 in the atmosphere than the year before. Passing the 400 ppm milestone is thus a symbolic but nonetheless important reminder that human activities continue to reshape our planet in profound ways.

The annual growth rate of atmospheric CO_2 measured at NOAA's Mauna Loa Observatory in Hawaii jumped 3.05 ppm during 2015, the largest year-to-year increase in 56 years of monitoring. Part of last year's jump was attributable to El Niño, the cyclical Pacific Ocean warming that produces extreme weather across the globe, causing terrestrial ecosystems to lose stored CO_2 through wildfire, drought and heat waves. Last year was the fourth consecutive year that CO_2 grew more than 2 ppm — which set another record.

The last time CO_2 hit 400 ppm in Antarctica was several million years ago during the early Pliocene epoch, during which the Earth underwent "significant change in climate that had major global and regional implications," and was then preceded by small changes in atmospheric CO_2 concentration.

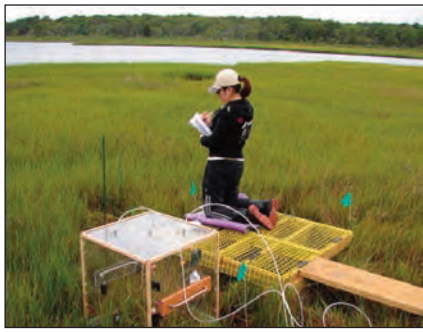
Better Forecasts for Harmful Algal Blooms

NOAA's National Centers for Coastal Ocean Science (NCCOS) continues to improve the nation's ability to forecast, detect, and mitigate the impacts of harmful algal blooms (HABs). HABs occur when colonies of algae — simple plants that live in the sea and freshwater — grow out of control while producing toxic or harmful effects on people, fish, shellfish, marine mammals, and birds.

NCCOS and its partners predict when and where HABs will occur through delivering HAB forecasts for Lake Erie, the Gulf of Maine, and the Gulf of Mexico. In 2016, the early season projections for Lake Erie were improved by adding a Maumee River flow forecast model from the National Weather Service, substantially reducing the uncertainty of those projections.

NCCOS also established an initial operating capability at NOAA's Center for Operational Oceanographic Products and Services (CO-OPS) for the production of the twice-weekly Lake Erie HAB bulletin, a capacity that will be finalized in 2017.

Advancing Research on Blue Carbon



Blue carbon, or the carbon captured and stored in coastal and ocean ecosystems, has been gaining attention internationally and domestically in recent years, advancing NOAA's involvement in understanding this form of carbon capture.

In 2015, NOAA and Restore America's Estuaries established the Coastal Wetland Carbon Working Group. This group is working towards conducting a baseline assessment of U.S. blue carbon stocks and incorporating coastal wetlands into the U.S. greenhouse gas inventory 2017 submission, as blue carbon has historically been left out of greenhouse gas inventories.

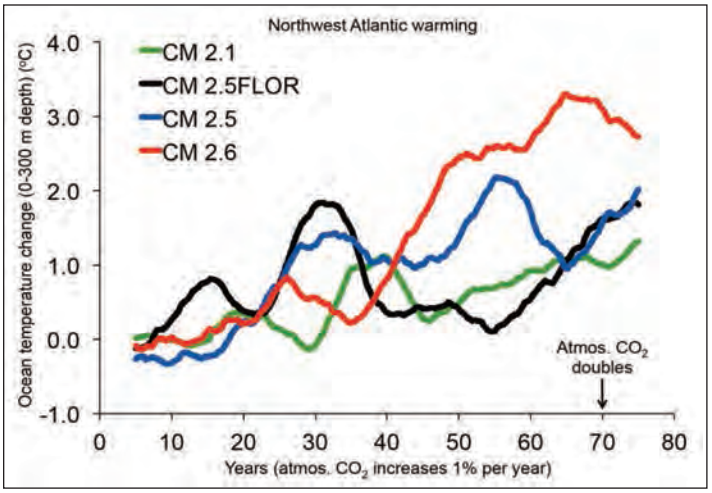
NOAA is working towards an approval of the Verified Carbon Standard (VCS) methodology for coastal wetland restoration, which enables global coastal wetland restoration projects to generate carbon offset credits to be bought and sold on the voluntary carbon market.

These projects all work towards a higher degree of incorporation of the important role of blue carbon into our understanding of the planet's carbon balance in the face of a changing climate.

Global Climate Model Revealing Changing Ocean Conditions

Historically, global climate models have been too coarse to represent accurately the Gulf Stream position in the Northwest Atlantic. Thus, temperature projections in this region were based on unrealistic regional ocean circulation data. NOAA's Geophysical Fluid Dynamics Lab (GFDL) high-resolution global climate model is now capable of accurately resolving water mass circulation in this area, increasing confidence in warming projections of the Northwest Atlantic Ocean.

Scientists from GFDL and their colleagues examined the effect of increasing atmospheric CO_2 on ocean temperature in the Northwest Atlantic using four models with varying resolutions. Their findings, based on output from four global climate models of varying ocean and atmospheric resolution, indicate that ocean temperature in the U.S. Northeast Shelf is projected to warm twice as fast as previously projected and almost three times faster than the global average.



Furthermore, the highest-resolution model also shows a northerly shift of the Gulf Stream and a retreat of the fresh polar current, contributing to the increase in temperature over the region. The highest resolution GFDL model, CM2.6 , matched the Northwest Atlantic circulation and water mass distribution most accurately. These findings illustrate that prior climate change projections for the region may be far too conservative.

Fish Species Response to Climate Change Off the Atlantic Coast

NOAA researchers recently studied a variety of marine fishery species grouped by similar depth and temperature distribution and evaluated the pace and magnitude of climate change effects for these bottom-dwelling fish found on the U.S. Northeast Shelf.

Nearly 70 species were classified into four distinct "assemblages," a group of species sharing a common environmental niche — in this case temperature, depth, and seasonal movement. It was found that those groups have similar responses to the effects of climate change.

Additionally, interactions between individual species in those groups may be affected by the amount of available habitat, predator-prey relationships, and competition for food resulting from shifts in range and distribution. This study represented an important advancement in the understanding of changes in fish assemblages in recent decades.

Along the Mid-Atlantic Bight, economic impacts will be felt as shifting distributions of traditionally harvested species alter patterns of their availability to local fishing communities. Ultimately, the results are lost access to stocks managed with species-specific quotas and rising fuel and travel costs as vessels seek out species in more distant areas.

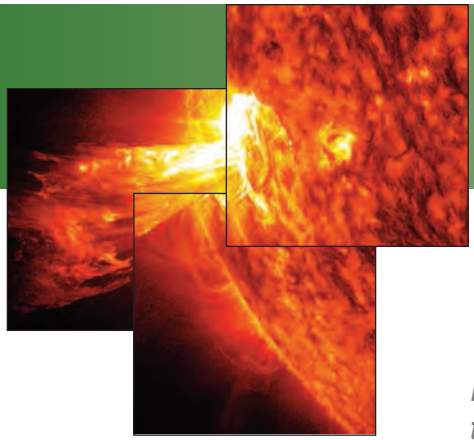
Warm Blood Makes Opah an Agile Predator

Research by NOAA Fisheries has revealed the opah (*Lampris guttatus*), or moonfish, as the first fully warm-blooded fish that circulates heated blood throughout its body, similar to mammals and birds, giving it a competitive advantage in the cold ocean depths.

Fish that typically inhabit such cold depths tend to be slow and sluggish, conserving energy by ambushing prey instead of chasing it. But the opah's constant flapping of its fins heats its body, speeding its metabolism, movement, and reaction times, scientists reported this year in the journal Science.

Satellite tracking showed opah spend most of their time at depths of 150 to 1,300 feet, without regularly surfacing. Their higher body temperature should increase their muscle output and capacity, boost their eye and brain function, and help them resist the effects of cold on the heart and other organs.

While mammals and birds typically maintain much warmer body temperatures, the opah is the first fish found to keep its whole body warmer than the environment. That warm-blooded advantage turns the opah into a high-performance predator that swims faster, reacts more quickly, and sees more sharply.



NOAA uses a wide range of sensors and platforms to conduct sustained and experimental observations of phenomena ranging from solar flares to undersea earthquakes that are essential to NOAA's environmental intelligence mission. As the only federal agency with the operational responsibility to provide weather, water, ocean, climate, and ecosystem forecasts, NOAA is charged with collecting accurate, timely, and comprehensive observations of the Earth and its surrounding space.

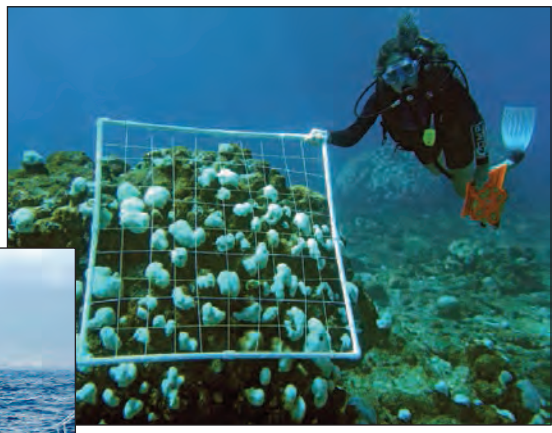
These activities generate greater than 20 terabytes of data each day (more than twice the data of the entire printed collection of the United States Library of Congress), which, in turn, NOAA utilizes to produce useful environmental intelligence for society. These data, and the intelligence derived from these data, are critical tools that support government decisions and policies, scientific research, and the economic, environmental, and public health of the United States.

Data science efforts within NOAA span the entire data exploitation spectrum including acquisition, quality control, metadata cataloging, validation, reprocessing, storage, retrieval, dissemination, and production of useful intelligence and products for society. To support NOAA's data management efforts, advances in signal processing (e.g., compression, sampling, thinning) are needed in order to keep pace with the scale at which NOAA is generating and collecting environmental data. Furthermore, NOAA is also investigating and leveraging emerging developments in high-performance data access, storage and computing, data mining, natural language processing, and machine learning.

Innovative processing techniques and R&D are being investigated to extend sensor capabilities to extract new products from measurements and find ways to increase the signal-to-noise ratio of measurements. To support improved data applications, NOAA continues to make advances in the current capabilities to couple 'traditional' datasets (e.g., physical, chemical, and biological) and fuse those data with 'non-traditional' data (e.g., social, behavioral, and economic) and 'unconventional' sources (e.g., citizen science).

Lastly, in light of exponentially increasing computational demands and the goals of the White House National Strategic Computing Initiative, NOAA seeks to connect its high-performance computing capabilities with this expanded data analytics capability as well as augment its petascale computing systems and capabilities toward the exascale.

Listed within this chapter are a few representative examples of the many ways NOAA has leveraged and improved its observational assets and data to make groundbreaking discoveries and provide improved environmental intelligence for its stakeholders and the American people.



Providing More Accurate, Timely, and Comprehensive Observations

Next Generation Satellite Provides Enhanced Observational Capabilities

The Geostationary Operational Environmental Satellite-R Series (GOES-R) is the nation's next generation of geostationary weather satellites in support of NOAA's R&D Enterprise. These satellites, beginning with the successful launch of the first of the GOES-R satellites, GOES-16, on November 19, 2016, will provide continuous imagery and atmospheric measurements of Earth's Western Hemisphere, total lightning data, and space weather monitoring to provide critical atmospheric, hydrologic, oceanic, climatic, solar and space data.

The GOES-R series will significantly improve the detection and observation of environmental phenomena that directly affect public safety, protection of property, and our nation's economic health and prosperity.

The satellites will provide advanced imaging with increased spatial resolution and faster coverage for more accurate forecasts, real-time mapping of lightning activity, and improved monitoring of solar activity. In six months, this new satellite will send back more weather data than all U.S. weather satellites combined over the last 41 years.

> "[GOES-R] puts [the U.S] on top of the food chain when it comes to weather satellites around the world. Nobody has anything like this." – *Al Roker, Today Show 8/25/16*

The Advanced Baseline Imager (ABI) will collect three times more data and provide four times better resolution and more than five times faster coverage than the current GOES.

The Geostationary Lightning Mapper, or GLM, will map total lightning (in-cloud and cloud-to-ground) continuously over the Americas and adjacent ocean regions.

The GOES-R Advanced Baseline Imager (ABI) is installed onto the GOES-R spacecraft at Lockheed Martin in Littleton, Colorado, on October 13, 2014.

Research has shown that lightning flash rate increases can be a predictor of impending severe weather and total lightning data from GLM has great potential to increase lead-time for severe thunderstorm storm warnings.

Additionally, scientists will explore how new and improved sensors on GOES-R will enhance NOAA products to inform aviators of developing severe weather and flight icing conditions to help enhance aviation weather forecasts.

The satellites will also host a suite of instruments that will provide significantly improved detection of space weather for more accurate monitoring of energetic particles responsible for radiation hazards, improved power blackout forecasts, increased warning of communications and navigation disruptions, and more.

New Frontier of Using DNA to Study Marine Life

'Omics is a simple term to describe advanced biological tools, including, for example, genomics, metabolomics, and proteomics.

A new program at NOAA's Atlantic Oceanographic and Meteorological Laboratory (AOML) is using 'omics to study genes and proteins to better understand how marine organisms and ecosystems remain healthy.

AOML is constructing an experimental aquarium to finely manipulate ecosystem stress for identification of genes that allow some corals to resist bleaching.

In 2016, routine field sampling began in the Florida Keys to better understand the microbiome — microbial communities critical to coral health.

Moreover, over 19 million DNA sequences have been incorporated into characterization of plankton communities in the California Current to understand the capacity of food webs to support fish stocks.

In 2016, three California Cooperative Oceanic Fisheries Investigations (CalCOFI) cruises collected samples for 'omic analysis, and upcoming research will test whether an automated underwater vehicle (AUV) can deliver such samples to reduce costs and increase sample coverage, which is needed for NOAA model and forecast missions.

Coral Reef Outlook to Predict Future Bleaching Events

NOAA Coral Reef Watch has developed a forecast that significantly enhances NOAA's capability for predicting coral bleaching events.

The newest version of the Four-Month Bleaching Outlook provides more than fourfold increase in resolution (now 0.5° x 0.5°, formerly 1.0° x 1.0°) and more accurate predictions of environmental conditions.

Since the start of this current and longest, most widespread global coral bleaching event, Coral Reef Watch's Four-Month Bleaching Outlook has successfully predicted mass bleaching events all over the globe.

In conjunction with Coral Reef Watch's daily 5km satellite global coral bleaching thermal stress products, marine resource managers and scientists are using this outlook to help them prepare for, communicate about, monitor, and respond to bleaching on their local coral reefs. For example, in 2010, Thailand and Malaysia closed numerous dive sites in response to the severe bleaching they had observed.

In 2016, Thailand closed ten sites in May, well before the peak of the bleaching season, in part due to NOAA's Four-Month Outlook of severe bleaching.

(Photo credit: R. Vevers, XL Catlin Seaview Survey)

Ocean Exploration Activities Reveals New Discoveries

The Campaign to Address Pacific monument Science, Technology, and Ocean NEeds (CAPSTONE) is a strategic ocean exploration initiative to gather baseline information about U.S. marine protected areas in the Central and Western Pacific.

These marine national monuments and national marine sanctuaries encompass over 100 million square miles of emergent land, coral reef, ocean, benthic communities, and maritime heritage resources, all within the U.S. Exclusive Economic Zone.

While NOAA and other federal agencies are charged with their management, little is known about these protected areas. NOAA's Office of Ocean Exploration and Research (OER) worked closely with counterparts across the agency and with the external science community to identify CAPSTONE priorities and to plan expeditions to document the geologic history, natural resources, deep sea biogeography, and vulnerable marine habitats of this vast undersea wilderness.

During the 2015 and 2016 CAPSTONE expeditions, OER and its partners in NMFS, NOS, NESDIS, and OMAO mapped 154,440 square miles of seafloor, discovered hundreds of potentially new species of flora and fauna, and collected hundreds of biological and geological samples.

Scientists from around the world participated in CAPSTONE from shore in real-time through telepresence. Similar results are expected for the final CAPSTONE expedition in 2017. Ocean exploration partners (such as the Schmidt Ocean Institute) are expected to contribute to CAPSTONE in 2018 and beyond.

As a result, U.S. marine protected area managers, and the scientists that support them, have rich new "environmental intelligence" for decision-making.

Assessment of Whale Health Using Unmanned Aircraft Systems

The Marine Mammal and Turtle Division at NOAA's Southwest Fisheries Science Center has successfully integrated an unmanned aircraft system (UAS) component into whale status assessments. A small, unmanned hexacopter is now being used to provide diagnostic information on whale health and condition.

Over the past year, more than 300 flights have been successfully conducted for the collection of overhead photogrammetry images from a number of protected whale populations.

Notable projects include a photogrammetric assessment of the body condition of all 81 individuals in the population of endangered Southern Resident killer whales and the collection of whale blow samples to study respiratory diseases in endangered North Atlantic right whales.

Hexacopters have also been deployed from the NOAA Ship *Oscar Elton Sette* to calibrate counts of dolphin schools made by visual observers around the Hawaiian Islands. Together, these applications demonstrate how this new technology can both refine traditional abundance-based assessments and provide new data on whale health to better understand and manage population changes to meet recovery goals and prevent depletion.

Sampling whale's breath using an unmanned hexacopter.

Utilizing Electronic Monitoring and Reporting to Improve Commercial Fisheries

To monitor annual fish catch limits and improve bycatch accounting, the National Marine Fisheries Service designed and implemented innovative electronic monitoring (EM) systems for fishing boats. EM systems typically consist of one or more cameras positioned to monitor fishing activities on a vessel, along with several sensors receiving fishing effort information.

In 2016, NOAA's EM research and development focused on building an EM system using stereo cameras with machine vision learning algorithms to automate the identification and measurement of individual fish, representing a major breakthrough in EM technology.

Another example is a camera chute system, which is being tested to report the number and weight of halibut discarded in an Alaska trawl fishery in real time.

Eight new EM video programs for monitoring bycatch compliance using single-camera technologies will be fully implemented by 2018 in the Northeast, the West Coast, and Alaska. These innovations will help improve the timeliness, quality, integration, and accessibility of the data.

Utilizing Ocean Sensors on Marine Mammal Satellite Tags

This joint effort between NOAA and Wildlife Computers, funded by the National Cooperative Research Program and the North Pacific Research Board, developed a satellite-linked fluorometer, a device used to measure parameters of fluorescence, for pinnipeds (seals and sea lions).

A miniature fluorometer was interfaced with a data-archiving tag and a satellite transmitter. Pinnipeds carrying this instrument serve as ocean-sensing platforms to record chlorophyll-a and sea temperatures in the water column in order to index primary production.

Understanding the foraging ecology of pinnipeds relative to the spatial and temporal variability of these variables is also advantageous for their management and conservation. Understanding these factors is important as changes in primary production, associated with changes in sea ice due to climate change, are expected to have cascading effects on food web dynamics in Arctic waters.

Evaluation of Sea Lion and Seal Response to Unoccupied Aircraft Systems

In 2016, Alaska Fisheries Science Center biologists worked with the NMFS Office of Protected Resources to begin an evaluation of the behavioral response of Steller sea lions and northern fur seals to a small-unmanned aircraft system (UAS).

The UAS, a small six-motor rotor-craft (i.e., hexacopter), was used to fly vertical transect lines at varying decreasing altitudes, and pinniped response was recorded by ground observers.

Understanding these disturbance thresholds is important, as harassment of marine mammals is prohibited by the Marine Mammal Protection Act without an exemption or exception. For the research community, these thresholds can inform permitted UAS activities.

The need for responsible UAS operation around marine mammals is also important as UAS ownership becomes more popular with the general public and within the commercial industry.

Autonomous and Piloted Aircraft Support Search and Rescue

NOAA's Unmanned Aircraft Systems (UAS) Program Office, working together with representatives of AeroVironment Inc., conducted a Search and Rescue Exercise, called Arctic Shield, in the waters north of Alaska in order to test the utility of integrating unmanned aircraft into a simulated response incident.

Working from the deck of the U.S. Coast Guard Cutter HEALY, the research team launched a small unmanned aircraft, the AeroVironment Puma, to search for a simulated missing person stranded in the icy waters.

Following the launch, the Puma used both its electro-optical and infrared cameras to locate the simulated victim, affectionately named Thermal Oscar, floating in a survival raft on the water approximately one nautical mile away from the ship.

The Puma was able to relay the coordinates to the test control center on board the HEALY, which then directed a Coast Guard H-60 and ERA Helicopter to the scene. Both helos deployed rescue swimmers to simulate recovery and then returned safely to shore. The exercise concluded with a successful net capture of the Puma UAS and a recovery of the survival raft by the HEALY.

Much of this mission was conducted under the auspices of a Cooperative Research and Development Agreement (CRADA) between NOAA and AeroVironment, which, in this case, allows NOAA and AeroVironment to jointly test UAS capabilities in a series of real-life mission-based scenarios.

The results from these tests will be analyzed by both NOAA and AeroVironment to improve NOAA's operational capabilities and AeroVironment's products.

Advancement of Shoreline Mapping Techniques

The NOAA National Geodetic Survey (NGS) is responsible for mapping the national shoreline. For the past several years, NGS has been working to advance the use of topographic-bathymetric (topo-bathy) LIDAR for coastal mapping.

In 2016, NOAA conducted the first surveys of the Florida Keys using this new technology, which provides improved elevation data both above and below the water allowing for improved accuracy shoreline data products that make life easier for those living or working on the coast.

The improved elevation information will be used by a multitude of federal and state agencies for applications including nautical charting, coastal inundation modeling, floodplain mapping, and habitat mapping and wetland restoration.

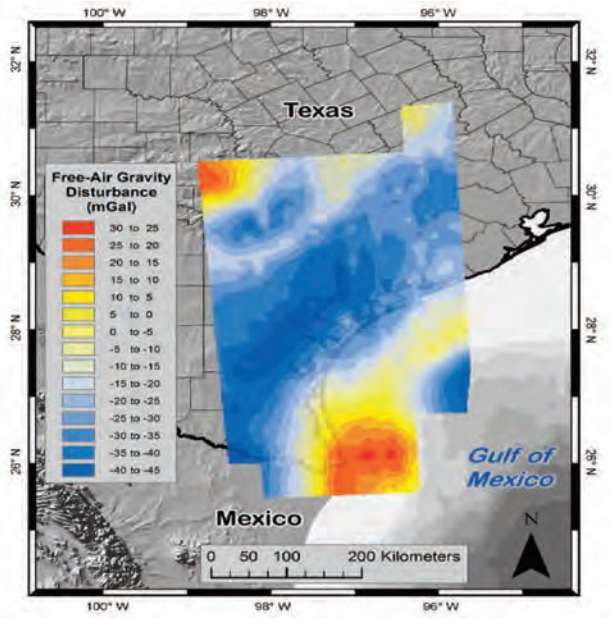
Gravity Data from Unmanned Aircraft to Improve Floodplain Management

NOAA's Gravity for the Redefinition of the American Vertical Datum (GRAV-D) project is a nationwide effort to collect gravity data from airborne instruments.

These measurements are used to create precise estimates of elevation (up to 2 cm in many places) which are used to provide more accurate models of water flow on land. Through a Small Business Innovation Research grant, NOAA conducted one of the first tests of a gravity-measurement device on an optionally piloted aircraft in April 2016; test flights were operated in "unmanned mode" with a safety pilot aboard.

An unmanned plane can more easily obtain GRAV-D data in remote locations and has the potential to greatly reduce the costs and safety hazards associated with data collection in key remote areas such as Alaska.

Improved accuracy of gravity measurements will provide an estimated $240 million in annual savings from improved floodplain management and an additional $282 million in savings from activities that benefit from more precise elevations, including coastal resource management, construction, agriculture, and emergency planning.



Map of Free-Air Gravity Disturbance Grav- D data using Equal Interval in Texas.

Expansion of Oblique Aerial Imagery Collections to Provide Insight Before and After Extreme Weather Events

Over the past five years, NOAA has advanced its methods of collecting aerial imagery through the use of oblique aerial imagery, which allows for the assessment of damage to vertical structures such as homes and office buildings, a capacity that previous imagery methods lacked.

In 2015, NOAA collected oblique imagery in various regions across the U.S. to provide a "before" picture of these areas prior to any natural disasters. The value of this imagery was showcased during historic flooding events in 2016 in the Midwest and Gulf Coast where post-flooding "after" imagery was collected and could be compared to NOAA's "before" imagery of the area pre-flooding.

> "[FEMA] would like to extend [our] gratitude for [NOAA's] unflinching and admirable actions during the Hurricane Matthew response and recovery. [NOAA's] tireless efforts and scores of flight hours resulted in the collection of over 15,000 high resolution images of flood and surge damage from Florida to Virginia and continue to serve FEMA Headquarters and FEMA Region IV Individual Assistance, Public Assistance, and Recovery programs. The images document the storm's impacts and the suffering of thousands of disaster survivors and will help FEMA analyze conditions and damages over the coming weeks as we seek to extend federal assistance to these affected citizens." – *Glen Russell (FEMA), following Hurricane Matthew*

This imagery assisted Federal Emergency Management Agency's (FEMA) response to these disasters by allowing the agency to assess where flood waters may impact population centers and critical infrastructure. The imagery also provides a valuable tool for insurers and homeowners to assess property damage.

Aerial photo of Tar River east of Rocky Mount, N.C. Archive photo was captured on May 19, 2015 and present-day photo was captured on Oct. 11.

Development of Low Cost Sea Temperature Sensor

In 2016, NOAA developed a low cost sea temperature sensor to be used at coral reefs around the world and provide high accuracy measurements (0.05-0.1 C). For approximately $10 in parts, it is estimated that the sensors will run more than 240 days using two AA batteries when they are deployed operationally.

In comparison, similar off-the-shelf sensors run over $100 each. The decrease in cost will allow substantially more sensors to be deployed at coral reefs worldwide and increase our spatial resolution of sea temperature in critical locations.

These sensors will provide micro-habitat sea temperature fluctuations at coral reef areas, offer environmental intelligence on coral bleaching, and a comparison/validation with satellite sea surface temperature data. This is crucial to better understand and monitor the daily fluctuations at coral reefs.

In early November 2016, the sensors were tested by measuring temperature every 10 minutes at depths up to 110 feet for about two months, then retrieved to evaluate performance.

As development of the sensors continues, they will have the capability to transfer data from underwater via infrared communication, and other sensors (e.g., pressure, light, conductivity) will be added to the unit.

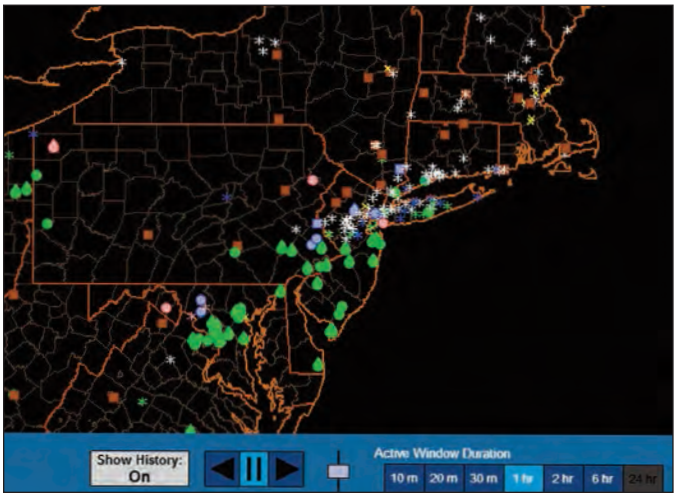
Once the sensors are operational, initial deployments are planned for coral research locations such as the Florida Keys and Sri Lanka, and elsewhere under a broad program in collaboration with the global coral reef monitoring organization, ReefCheck.

These new sensors will provide significantly more information and data about ocean temperature and coral reefs at a mere fraction of the cost.

Engaging Citizen Science to Improve Weather Forecasts Worldwide

An exemplary application of citizen science, the Meteorological Phenomena Identification Near the Ground (mPING) project is a crowd-sourcing, mobile phone app that allows anyone to submit precipitation observations to NOAA's National Severe Storms Laboratory (NSSL).

These observations are used to validate and improve radar-based precipitation type (e.g., rain, sleet, snow, freezing rain, etc.) methodologies developed by NSSL in support of NWS forecasters.



A database has been developed for efficient and secure ingest and distribution of mPING observations via an open application program interface (API), which allows other app developers to access and distribute the data.

Since January 2016, over 137,000 reports have been submitted to the database. During this same time, the database has been queried 886,000 times, of which 506,000 queries (57%) are from NOAA/NWS entities. mPING data are flowing into the NWS and may now be displayed within their operational display system via a "plug-in."

Finally, mPING was featured in the 10th NOAA Science Days presentations, where speakers shared results about new statistical techniques that improve the skill of winter precipitation type forecasts (out to 18 hours) by a factor of 4-6, for ice pellets and freezing rain over older techniques.

NOAA Instrumental in Creating Citizen Science Website

Citizen Science is a rapidly growing field that offers opportunities for government to partner with the public to address real-world challenges. Dr. John Holdren, Assistant to the President for Science and Technology, issued a memo entitled Addressing Societal and Scientific Challenges through Citizen Science and Crowdsourcing to detail a plan for taking advantage of these opportunities.

Released on September 30, 2015, the document highlights how citizen science projects can enhance scientific research and STEM learning as well as address societal needs.

To address this call, NOAA worked through the Federal Community of Practice for Crowdsourcing and Citizen Science in partnership with the White House Office of Science and Technology Policy to contribute to the creation of CitizenScience.Gov. NOAA has submitted 40 of the 306 projects currently in the catalog and ten posts telling the stories of NOAA projects were included on the site's blog.

This work resulted in increased awareness of and interest in NOAA and Federal citizen science initiatives. CitizenScience.Gov has had over 25,000 visits to date. Following the launch of the site, the recruitment rate for the Federal Community of Practice for Crowdsourcing and Citizen Science more than doubled, with the community growing to 322 members representing 60 federal organizations.

Increased Satellite Capability to Monitor Global Sea Levels

Jason-3, the fourth in a series of US-European satellite altimeter missions designed to measure the sea surface height variability of the global ocean, was successfully launched on January 17, 2016, from Vandenberg Air Force Base, California, in support of NOAA's R&D Enterprise.

Jason-3 is a four-partner endeavor jointly led by NOAA, the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT), the National Aeronautics and Space Administration (NASA), and the French space agency, Centre National D'Etudes Spatiales (CNES).

Jason-3 observations are used to monitor the changing circulation patterns of the ocean, forecast hurricanes and El Niño events, and, most importantly, to track the rate of global sea level rise which has accelerated over the past half century due to climate change.

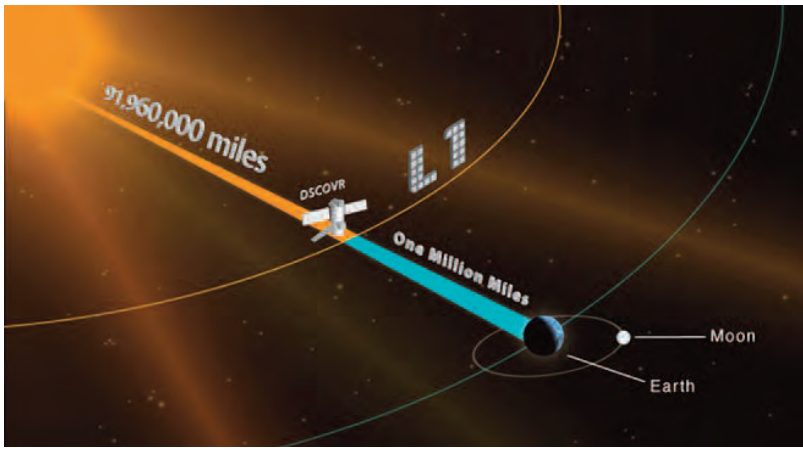
Just six months after launch, in July 2016, Jason-3 was declared operational and near real-time data products were made publicly available. Together with its predecessor Jason-2, the Jason-3 mission will double global data coverage of the world's oceans.

Key for Revolutionizing Space Weather Forecasts

Deep Space Climate Observatory (DSCOVR) satellite was successfully launched from Cape Canaveral, Florida on February 11, 2015, in support of NOAA's R&D Enterprise. DSCOVR will maintain the nation's real-time solar wind monitoring capabilities, which are critical to the accuracy and lead time of NOAA's space weather alerts and forecasts.

Space weather, and the resulting geomagnetic storms, has demonstrated the potential to disrupt virtually every major public infrastructure system, including transportation systems, power grids, telecommunications and GPS. With timely and accurate alerts produced from DSCOVR data, infrastructure managers can take action to avert the greatest damage.

DSCOVR will typically be able to provide a 15 to 60 minute warning time before the surge of particles and magnetic field, known as a coronal mass ejection (or CME), associated with a geomagnetic storm reaches Earth. DSCOVR data will also be used to improve predictions of geomagnetic storm impact locations. DSCOVR became the primary space weather mission from the L1 orbit on July 27, 2016.



Future Satellite for Global Weather Forecasts

JPSS-1, or NOAA-20 as it will be known once operational, is the second spacecraft within NOAA's new generation of polar-orbiting satellites that will launch in 2017 in support of NOAA's R&D Enterprise.

Polar-orbiting weather satellites provide approximately 85% of the inputs for numerical weather prediction models. These key observations increase the accuracy of weather forecasts three-to-seven days in advance of severe weather events, enabling emergency managers to make timely decisions that protect American lives and property, including ordering effective evacuations.

In Fiscal Year 2016, all of the instruments on JPSS-1 were integrated to the spacecraft and underwent environmental testing. Together, JPSS and Polar Follow-on will provide continuity of critical, global Earth observations through 2038.

JPSS-1 spacecraft and United Launch Alliance Delta II payload attach fitting finish fit check.

Leveraging Next-Generation Resolution

The Visible Infrared Imaging Radiometer Suite (VIIRS) aboard Suomi NPP and JPSS satellites continues to provide improved insights for established data users.

VIIRS is a critical new observational capability for NOAA users because of its sub-kilometer spatial resolution and global coverage. For example, the new platform has expanded NOAA's toolkit for vegetation and drought monitoring, providing agricultural users significant value in crop planning and risk mitigation.

VIIRS is also now being demonstrated routinely by the National Weather Service for improved fire smoke forecasting as well as flood and river ice assessments.

The VIIRS flood product, coupled with a high spatial resolution digital elevation map, provides an enhanced flood map at 30 meters and has provided critical information to the National Weather Service River Forecast Centers and the Federal Emergency Management Agency (FEMA) for emergency response and damage assessment.

Translating New Capabilities to New Science and Operational Applications

VIIRS's Day/Night band has unique capabilities to deliver new and unprecedented applications for satellite data, expanding the consumer base that can benefit from earth observations data.

In particular, this instrument has fostered several new products in development, such as a boat detection algorithm to identify potential illegal fishing in marine sanctuaries. This will help enable stakeholders to have actionable data to direct resources towards illegal fishing enforcement.

Other ongoing projects in development are detection products for gas flares, in order to track and reduce routine flaring; volcanic activity, to provide warning to communities and aviators; and coastal sea ice in the Alaskan regions, to provide tailored maritime safety information where other sources of data are limited or lacking.

SNPP D/NB-captured East Coast snows

Driving the State-of-the-Art of Severe Storm Prediction

The Suomi NPP and JPSS satellites also carry the Cross-Track Infrared Sounder (CrIS) and the Advanced Technology Microwave Sounder (ATMS).

Leveraging both of these data sources, the NOAA-Unique Combined Atmospheric Processing System (NUCAPS) covers the globe to exploit their full information content and provide three dimensional information about atmospheric temperature, humidity, and composition of trace gases.

National Weather Service (NWS) forecasters gained some hands-on experiences with NUCAPS in Fiscal Year 2016 during the Hazardous Weather Testbed Spring Experiment. During a proving grounds activity over Idaho, the NUCAPS soundings revealed instability and moisture near the surface and lower atmosphere. An hour later, an intense hail storm rolled over the area, demonstrating a clear direction for how novel capabilities can improve prediction products.

Accessibility of All NOAA Data through Partners

NOAA's Big Data Partnership (BDP) was established in April 2015 through three-year cooperative research and development agreements (CRADAs) between NOAA and Amazon Web Services, Google, IBM, Microsoft and the Open Commons Consortium.

The BDP is investigating how the value inherent in NOAA's data may be leveraged to broaden their utilization and dissemination through the use of modern cloud platforms and associated technologies. The CRADA Collaborators work with NOAA experts to identify and deliver those datasets of interest, around which they can build business cases to justify their investments.

NOAA's Next Generation Weather Radar (NEXRAD) weather radar data were among the first data to be delivered. The National Centers for Environmental Information (NCEI) transferred the complete NEXRAD Level II historical archive to four interested BDP collaborators.

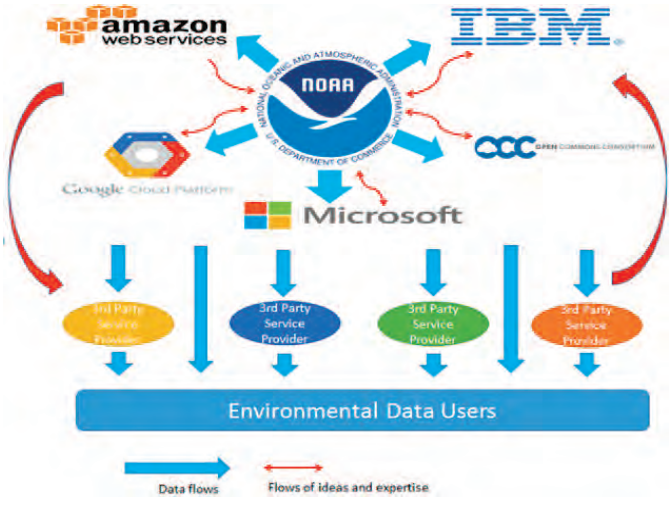
Amazon Web Services (AWS) was the first to make freely available the complete archived Level-II data through its AWS platform, with The Climate Corporation as a business partner and data consumer.

AWS also collaborated with Unidata/University Corporation for Atmospheric Research (UCAR) to establish a real-time NEXRAD data feed, thereby providing on-demand dissemination of both archived and current data seamlessly through the same access mechanism by October 2015.

Through this cloud platform alone, the utilization of the NEXRAD data by volume has increased by 130% over the past usage patterns observed at NCEI, while the load on NCEI systems has decreased by 50%.

Additional NOAA datasets including fisheries catch data, numerical weather prediction model output, advanced weather radar products, and geostationary satellite data are at various stages of discussion and development.

NOAA and its collaborators are beginning to realize the potential of this collective effort among federal government, private industry, and academia, including stimulating new business opportunities and novel applications — all at no net cost to the U.S. taxpayer.



NOAA regularly monitors and assesses risk from environmental hazards. However, that investment has no value unless NOAA also communicates risk effectively. NOAA remains steadfast in its focus to transition research conducted within and across a variety of social science disciplines (e.g., psychology, economics, political science, sociology, and anthropology) into user friendly applications and policy, giving individuals and groups the decision aids they need.

NOAA leverages established relationships with other federal agencies, most notably the National Science Foundation (see NOAA-National Science Foundation Memorandum of Agreement), who invest considerable resources in social, behavioral, and economic sciences research.

The summaries found within this chapter provide some representative examples of the research and development underway at NOAA in the realms of decision science, risk assessment, and risk communication.

Photo credit: White House

Assessing and Communicating Risk for More Informed Decision Making

Sustainable Management and Resilience of U.S. Fisheries in a Changing Climate

Warming oceans, rising seas, ocean acidification, and hypoxia threaten the resilience of fisheries that are an important source of jobs, food, recreation, and economic activity for the nation.

In 2014, the Office of Oceanic and Atmospheric Research and the National Marine Fisheries Service established a new competitive research program to advance understanding of current and future climate-related impacts on living marine resources and the communities that depend on them.

The goal is to increase the production, delivery, and use of climate-related information to inform sustainable management and resilience of the nation's fisheries in a changing climate, as called for in the NOAA Fisheries Climate Science Strategy.

In FY15, the Climate Program Office's Coastal and Ocean Climate Applications (COCA) program partnered with the NMFS Office of Science and Technology to award seven multi-year research grants projects to study the impacts of a changing climate on fish and fisheries.

Six of the projects are supporting research to understand and respond to climate impacts on fish and fisheries in the Northeast Shelf Large Marine Ecosystem and the seventh supported a workshop in FY16 to identify science priorities for better understanding ecosystem tipping points in the North Pacific.

The six multi-year research projects are already providing critical advances in the understanding and projecting of climate-related impacts on fish stocks and fisheries in the Northeast marine ecosystem.

Assessing the Vulnerability of the California Current Ecosystem to Ocean Acidification

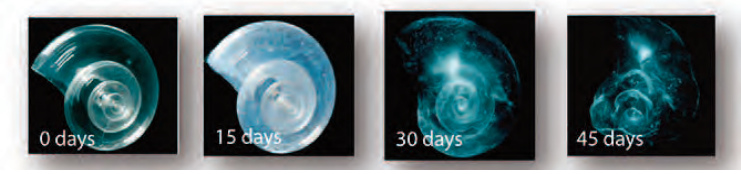
Assessing the vulnerability of U.S. coastal large marine ecosystems to the effects of ocean acidification (OA) is a primary goal of the NOAA Ocean Acidification Program (OAP).

To achieve this, the OAP works to coordinate efforts across the agency to determine how ocean chemistry is changing in response to OA, evaluate the sensitivities of marine resources to these changes, and provide tools and information to impacted dependent human communities.

In 2016, the OAP advanced efforts along each of these fronts, including support for the fifth West Coast Ocean Acidification (WECOA) cruise executed by the Pacific Marine Environmental Laboratory (PMEL) in May – June, 2016. WECOA documented multiple ecosystems stressors (OA, temperature, and hypoxia) throughout the California Current.

Data from these surveys are important inputs for the development and validation of the Joint Institute for the Study of the Atmosphere and Ocean (JISAO) Seasonal Coastal Ocean Prediction of the Ecosystem (J-SCOPE). J-SCOPE provides seasonal outlooks for the Pacific Northwest waters, including forecast of corrosive conditions harmful to valuable living marine resources.

Documenting and predicting changes in ocean chemistry are most useful to stakeholders and industries when there is a robust understanding of the sensitivity of the marine resources to ocean chemistry.



The pteropod, or "sea butterfly", is a tiny sea creature about the size of a small pea. Pteropods are eaten by organisms ranging in size from tiny krill to whales and are a major food source for North Pacific juvenile salmon. The photos above show what happens to a pteropod's shell when placed in sea water with pH and carbonate levels projected for the year 2100. The shell slowly dissolves after 45 days. Photo credit: David Liittschwager/National Geographic Stock.

OAP has supported critical research at the Northwest Fisheries Science Center (NWFSC) to examine the potential effects of OA on a broad range of marine resources. In 2016, OAP-funded researchers at NWFSC reported the effects of OA on the survival rate of a broad range of species in the California Current Ecosystem.

The researchers were able to ascribe uncertainty bounds to the response of a range of species and functional groups. This advance supports the incorporation of OA into future ecosystem forecast models that can inform private and public-decision makers at the local, state, and regional level.

Tools and Expertise Help U.S. Aquaculture Industry Expand

Offshore aquaculture is a promising new frontier for U.S seafood production. However, the growth of this industry has been constrained by concerns regarding negative environmental effects of improperly sited farms.

In response to these concerns, NOAA's National Centers for Coastal Ocean Science (NCCOS) and NOAA's Office of Coastal Management partnered to develop a new offshore aquaculture planning tool, CanVis Aquaculture.

This seascape visualization tool contains an image library of aquaculture gear, vessels, buoys, and other infrastructure that can be used to simulate the changes that result from aquaculture development. Coastal managers and developers in Hawaii, California, and Washington are currently using this tool to visualize and plan offshore aquaculture projects.

Tools to Meet Challenges of a Changing Climate

The U.S. Climate Resilience Toolkit (CRT) — a website designed to help people find and use science-based tools, information, and subject matter expertise to build climate resilience — received significant updates in FY16, driven by requests from users.

In March 2016, as part of World Water Day, NOAA launched a new section of the Toolkit, called the Water Resources Dashboard, to provide access to maps and data that can help water resource managers and urban planners monitor the potential for extreme precipitation, flooding, and drought in their regions.

In June, the Toolkit's interface was enhanced with a responsive, mobile device-friendly design. In July, a rebuilt version of the Toolkit's Climate Explorer, an interactive mapping & graphing tool, was published. Residents, communities, and businesses now have easy access to down-scaled climate projections for every county in the contiguous United States.

In FY16, the Toolkit's visit rates increased by 59% over the FY15 rate and hundreds of public stakeholders have been served in interactive working sessions. Furthermore, the CRT has directly supported several municipalities and three federal departments (Departments of Commerce, Interior, and Justice).

Decision Science, Risk Assessment & Risk Communication

Hurricane Katrina at peak intensity in the Gulf of Mexico on August 28, 2005.

Weather-Ready Nation Helps to Build Ready, Responsive, and Resilient Communities

The Weather-Ready Nation (WRN) initiative is about helping our Nation become more resilient to increasingly extreme weather, water, and climate events through greater accuracy in forecasts and warnings, evolving services to community decision makers, and better ways to communicate risk to stakeholders and the public.

Following the two WRN national dialogue events in Norman, OK (2011) and in Birmingham, AL (2012), NOAA began in earnest to better integrate the social and the physical sciences to more clearly articulate risk and uncertainty as it relates to environmental hazards.

NOAA's Office of Oceanic and Atmospheric Research and the National Weather Service jointly awarded four two-year projects to stimulate research and develop collaborations between social and physical scientists towards building a WRN. The results of this research will improve communication within the weather community and to the public in order to invoke a response that will help protect life and property during dangerous weather events.

In addition to these WRN projects and other social science research efforts, NOAA developed a report, Risk Communication and Behavior: Best Practices and Research Findings, that summarizes risk communication and behavior literature within the context of key episodic hazards relevant to NOAA's mission, products and services, and provides recommendations for implementation as well as future research.

This report is intended to be used as a practitioner's guide to improve the way NOAA communicates watches, warnings, and other products that can be used more effectively by decision makers at the federal, state and local levels and by the general public in the face of extreme weather, water, and climate events.

> "We have had several very successful Weather-Ready Nation events in conjunction with the NWS Peachtree City office during recent years. Each one of these events has had lasting effects on the Atlanta community — leaving neighborhoods much better prepared to handle severe weather challenges." – *Garry A. Harris, Center for Sustainable Communities*

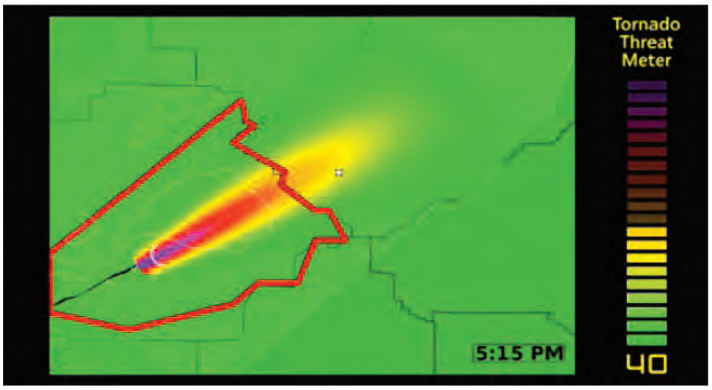
Forecasting a Continuum of Environmental Threats

The current NOAA National Weather Service watch and warning process has not fundamentally changed in more than 50 years. Society, technology, and science, however, have made great advances.

The Forecasting a Continuum of Environmental Threats (FACETs) paradigm proposes to modernize the high-impact weather forecasting and communication process by adapting it to evolving technology. At the core of this paradigm shift is a change to the current deterministic approach for hazardous weather warnings to one based upon Probabilistic Hazard Information (PHI).

This would enable decision-makers who require more advanced notice, such as hospitals, schools, and large venues, to set their own threat thresholds based on their specific needs. It would also enable new science advances, such as Warn-on-Forecast and Phased Array Radar, to be fully leveraged into better warnings and forecasts for society.

FACETs will find ways to fine-tune threat output in a way that people will choose to implement their safety plan. This is where social and behavioral sciences integration will have the greatest impact, although contributions of these disciplines are essential in all facets of the threat forecasting process. Collaborative research projects between OAR, NWS, and academic partners are beginning to move us toward the FACETs paradigm.



In the spring of 2016, several experiments were conducted in the NOAA Hazardous Weather Testbed bringing together NWS forecasters, researchers, and partners such as emergency managers and broadcasters to evaluate early prototypes of forecast and warning technology based on the FACETs approach.

Tracking Previous Events and Forecasting Potential Floods

As sea levels rise, the number of nuisance flooding events at certain coastal locations will increase, even in the absence of a storm event. It is becoming increasingly likely that certain areas will begin to flood regularly, simply during high tide. This spotlights the need for an inundation tool that is always available, not just during significant weather events.

The Coastal Inundation Dashboard tracks past events and forecasts times when flood thresholds may be exceeded. This information can educate communities on what has led to flooding events in the past and provide advanced notice (including alerts) when minor, moderate, or major flooding events may occur, even on fair-weather days.

A prototype Coastal Inundation Dashboard product has been developed for Hampton Roads, VA; New York City/Long Island, NY; and Morehead City, NC. Additional dashboard regions will follow, with a long-term goal for coverage across the entire U.S. coast. And, since all dashboards utilize the same infrastructure, these new dashboard will require fewer resources to develop.

Mapping Living Marine Resources Supports Development of Offshore Renewable Energy

Scientists at the National Centers for Coastal Ocean Science (NCCOS) recently completed and published an environmental assessment of the distribution of marine animals and ocean floor habitats around the main Hawaiian Islands, with special consideration given to species likely to interact with renewable energy infrastructure.

These data will serve as foundational material for Bureau of Ocean Energy Management's (BOEM) renewable energy leasing process and will help identify potential issues for future National Environmental Policy Act (NEPA) analysis as Hawaii strives to generate 100% of its electricity from renewable energy sources by 2045.

In a similar study also published in 2016, NCCOS and BOEM looked at the ecological features of the seafloor in a proposed offshore wind energy area off the coast of North Carolina. BOEM used these findings to modify the size and boundaries of the original area of interest to minimize possible impacts to sensitive reef and fishery habitats.

Promoting Nature-based Shorelines to Protect the Coast

Scientists at the National Centers for Coastal Ocean Science (NCCOS) worked with other offices within NOAA to co-author NOAA's Guidance for Considering the Use of Living Shorelines in October 2015.

NCCOS scientists found that living shorelines, or shorelines made up of mostly natural material, can reduce damage and erosion while simultaneously providing ecosystem services to society, including food production, carbon dioxide reduction, nutrient and sediment removal, and water quality improvement.

This guidance document encourages nature-based shoreline stabilization techniques and highlights NOAA science, tools, and training that support such techniques. The publication has been shared with local, state, and federal coastal managers in hopes that these living shorelines can be incorporated into coastal community resilience efforts.

Climate Vulnerability Assessment of Northeast Fish and Shellfish

The Northeast Fish and Shellfish Climate Vulnerability Assessment (NEVA) used knowledge from scientific studies and expert opinion to identify the relative vulnerability of 82 fish and invertebrate species (e.g., cod, herring, lobster, scallops) to potential changes in climate. Results from the research, indicate that over 50% of the species have high potential for a change in their distribution due to climate change.

> "This kind of assessment will be a key component for making management plans to ensure U.S. fisheries remain sustainable and resilient in the face of future climate change."
> – *Dr. Christopher Gobler, School of Marine and Atmospheric Sciences at Stony Brook University*

Negative impacts, such as reduced abundance or productivity, are expected for 42 of the species, including some of the Northeast's most important fish resources including Atlantic cod, sea scallop, and mackerel.

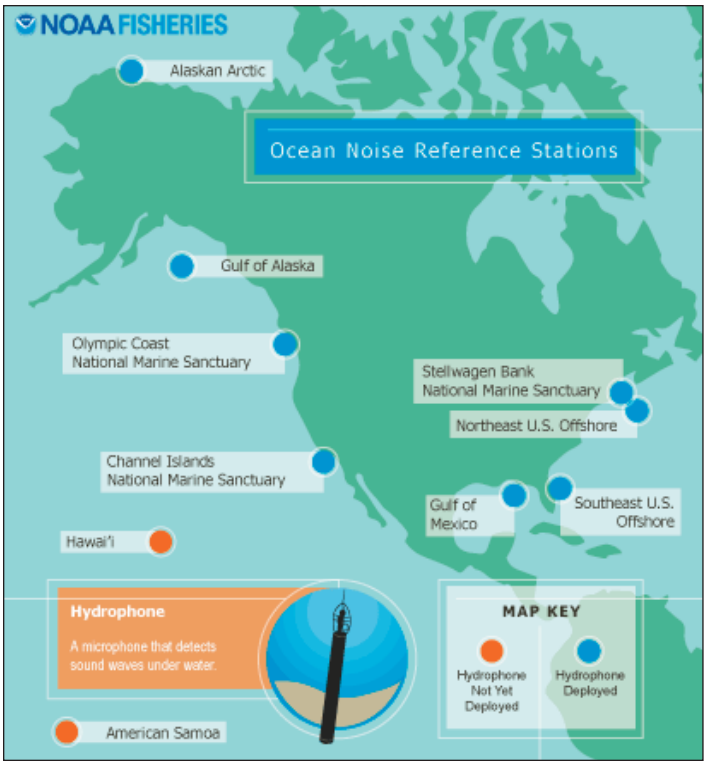
Positive effects are anticipated for 14 of the species, including longfin squid, butterfish, and Atlantic Croaker, indicating that there will be both 'winners' and 'losers' from the effects of climate change.

Results from this work have been used in Endangered Species Listing decisions as well as to examine the vulnerability of coastal communities to climate change impacts. This is the first in a series of regional assessments, with similar projects currently underway for the Bering Sea and California Current Ecosystems.

Impact of Ocean Noise on Marine Life

Over the last two decades, research has increasingly shown that anthropogenic ocean noise could potentially cause not only acute behavioral and physiological problems in marine life (e.g., avoidance, hearing impairment), but also long-term chronic impacts (e.g., stress, loss of communication range).

This research is increasingly showing the need for marine management frameworks that can better account for chronic and cumulative noise effects mediated through ecosystems.



On June 1, 2016, NOAA released a Draft Ocean Noise Strategy Roadmap, NOAA's first-ever holistic approach to address this issue, for public comment. The Roadmap is a cross line-office framework intended to guide NOAA to improved understanding and management of ocean noise impacts over the next decade.

The public response, including over 13,000 emails and a petition with over 72,000 signatures supporting the effort, was incorporated and the Roadmap was finalized in September 2016.

Research-based efforts directly addressing key Roadmap recommendations are also currently being implemented, including: a cross-NOAA collaboration establishing the Ocean Noise Reference Station Network, an 11 site passive acoustic monitoring network deployed throughout U.S. waters to monitor long-term trends and changes in underwater soundscapes; and a long-term passive acoustic data archive that has been developed with the National Centers for Environmental Information to provide a repository and public access point for acoustic datasets.

Technical Guidance on Anthropogenic Sound in the Ocean

Marine mammals rely on keen hearing for navigation, predation avoidance, foraging, and communication in complex, three-dimensional marine environments, yet human-introduced ocean noise can interfere with these activities.

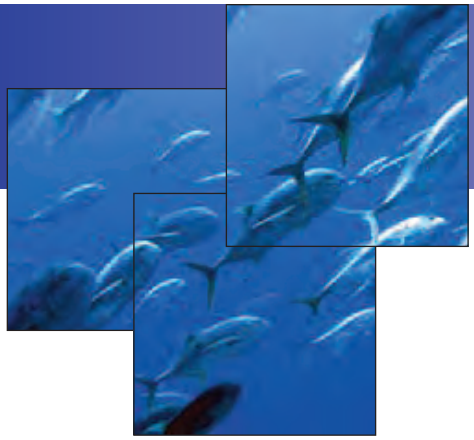
In August 2016, NOAA published the Technical Guidance on Anthropogenic Sound to provide acoustic threshold levels for assessing the effects of anthropogenic sound on marine mammal species under NOAA Fisheries' jurisdiction.

It leverages data from marine mammal hearing loss laboratory studies to identify the thresholds at which individual marine mammals are predicted to experience changes in their hearing sensitivity (either temporary or permanent) for all underwater anthropogenic sound sources.

NOAA intends for its analysts and managers, other federal agencies, and other relevant stakeholders to use this guidance to better predict how a marine mammal's hearing will respond to sound exposure.

This is the first time NOAA Fisheries has presented acoustic threshold levels for marine mammals in a single, comprehensive technical document in order to improve consistent implementation across the array of relevant laws that protect marine mammals.

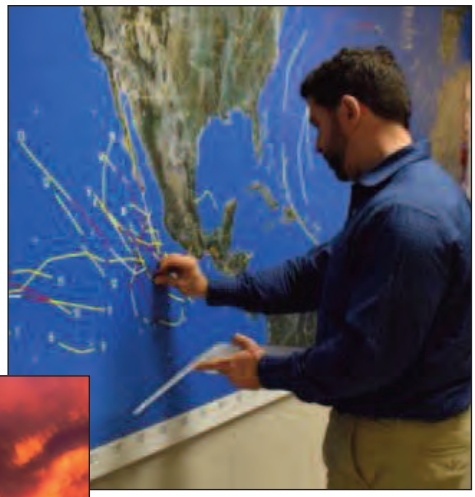
Photo credit: White House



Leveraging capabilities and expertise from across NOAA to better understand and predict all aspects of the water cycle remains a critical national priority.

NOAA is uniquely positioned to provide the tools, data, and information needed to strengthen the nation's water security, reduce vulnerability to climate variability and change, and catalyze more effective management and use of our nation's valuable water resources. In short, NOAA's water research focuses on predictability of water quantity and water quality.

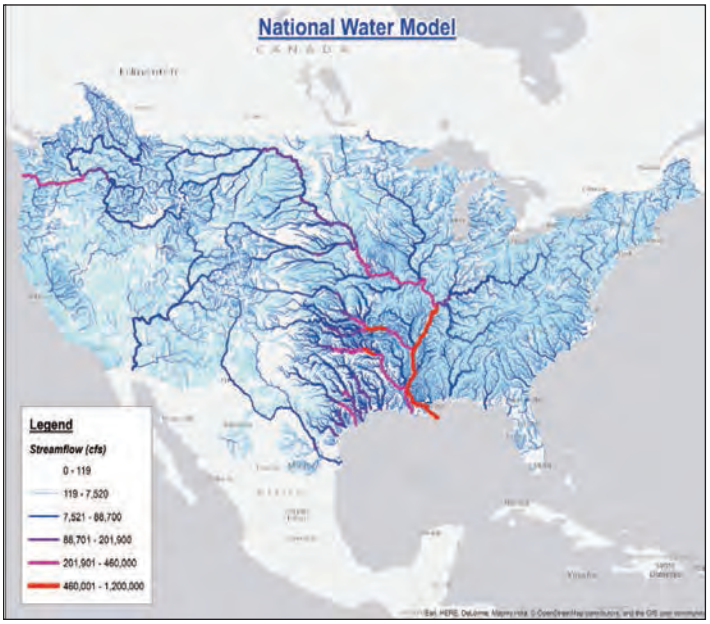
The research examples depicted in this chapter represent a portion of the research happening at NOAA concerning water and the critical role the agency has in enhancing water-related products and decision-support services across the country.



Strengthening our Nation's Water Security and Reducing Vulnerability to Climate Change & Variability

Increased Capability in Water Prediction Nationwide

On August 16, 2016, NOAA's efforts to build a "Weather-Ready Nation" took a major step forward with the National Weather Service's launch of a new, highly sophisticated National Water Model (NWM).



This new system is a continental-scale water resources model based on the Weather Research and Forecasting Hydrology (WRF-Hydro) architecture developed by the National Center for Atmospheric Research (NCAR) and represents NOAA's first foray into high performance computing for water prediction.

Unprecedented in its reach, this new National Water Model leverages NOAA's investment in atmospheric prediction and data from over 8,000 U.S. Geological Survey (USGS) stream gauges to produce flow simulations for 2.7 million stream reaches, extending water resources information to the homes and businesses of 100 million Americans who live in coastal communities.

Using this model, NWS forecasters now have access to data for 700 times more locations than previously available. For the first time, communities will receive hourly, weekly, and monthly water forecasts based on output from the National Water Model.

This information will help businesses, community leaders, first responders, emergency managers, and state and local governments make more informed decisions to protect lives and livelihoods.

Tracking Precipitation to Provide Flash Flooding Forecasts at the Neighborhood Level

The Flooded Locations and Simulated Hydrographs (FLASH) project advances the state of flash flood prediction through newly developed rainfall estimation tools and hydrologic models.

FLASH begins with rainfall rates measured by radar and uses a sophisticated modeling system to track what every raindrop is doing on the ground: whether it infiltrates into the soil or flows across impervious roads, parking lots, and waterways. The system models where water will go and when and where it will become a flood, with updates as frequent as every two minutes — a key attribute for cities that can flood quickly.

In FY16, research indicated that the FLASH system doubles accuracy of the current operational system and improves the spatial resolution by 500%, which can indicate specific locations of flash flood impacts down-stream, saving lives and mitigating damage to property.

These new high-resolution tools will provide reliable flash flood forecasts at the neighborhood level as well as provide up to six hours of forecast lead time, affording critical time for community response. FLASH improves National Weather Service forecasters' abilities to identify rare, severe flash floods from minor ones, enabling them to communicate this information to local emergency managers and the public.

The FLASH forecasts are particularly useful over small, fast-reacting headwater basins and in urban catchments, complementing the new National Water Model for flash flood modeling and prediction.

Better Toxin Detection for Harmful Algal Blooms

Toxins produced by harmful algal blooms (HABs) accumulate in marine resources and are a major cause of human seafood poisoning, which impacts subsistence harvests, economic development, and international trade.

Overabundance of harmful algae can result in phenomon known as red tide.

Tests, known as receptor binding assays, developed by NOAA scientists to measure levels of HAB toxins have recently been accepted by the Interstate Shellfish Sanitation Conference.

This standardized test for regulatory users helps secure the food supply against these potent algal-based toxins and is in various phases of implementation in testing laboratories worldwide.

In Alaska, NOAA scientists trained staff at the Sitka Tribe of Alaska Environmental Regulatory Laboratory on the extraction and detection of HAB-related paralytic shellfish toxins. Implementation of this NCCOS-developed technology by the Sitka tribe will mitigate the threat of toxic shellfish consumption from traditional subsistence shellfish harvesting to members of the Southeast Alaska Tribal Toxins partnership.

The development of HAB toxin detection methods, specifically receptor binding assays, also has a domestic and international component for their implementation.

Domestically, the use of this method is currently being evaluated by relevant public health agencies in Washington and California. Internationally, NOAA has an agreement with the International Atomic Energy Agency to support the use of this method worldwide.

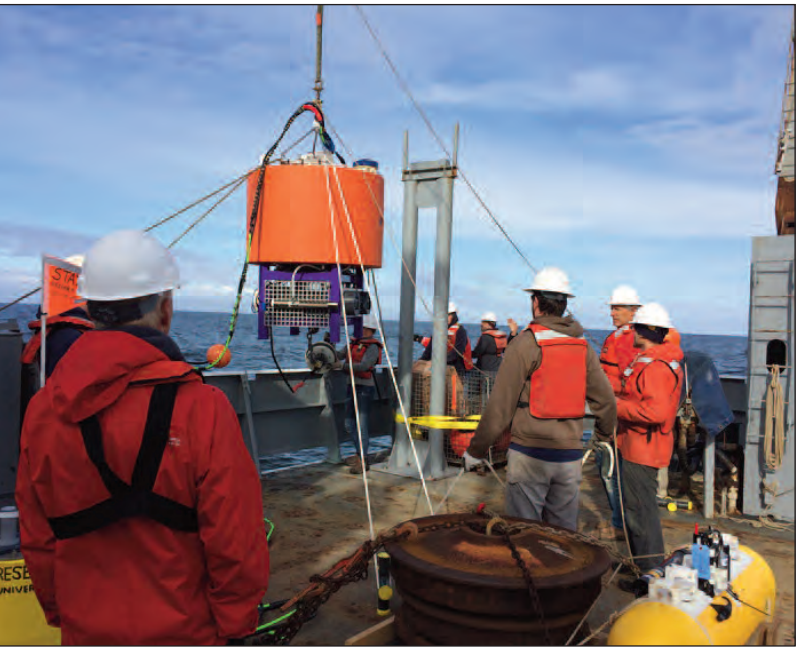
In-situ Water Collection Instrument Sequences Samples in Near Real Time

In September 2016, for the first time, an Environmental Sample Processor (ESP) was deployed in a freshwater system. The ESP—a "lab in a can" designed by Monterey Bay Aquarium Research Institute (MBARI) — autonomously collects water samples, then extracts and analyzes them for harmful algae abundance and their related toxins in near real-time.

In collaboration with NOAA's National Centers for Coastal Ocean Science (NCCOS) and the Cooperative Institute for Limnology and Ecosystems Research (CILER), NOAA's Great Lakes Environmental Research Laboratory is developing the capability to monitor for microcystins, the dominant toxins in western Lake Erie harmful algal bloom (HAB) events, in real-time.

The goal is to combine the ESP toxin data with NOAA's other Lake Erie HAB forecasting products to act as an early warning system for drinking water managers.

Water Prediction



Environmental Sample Processor (ESP) deployment.

In 2014, over 400,000 residents of Ohio were deprived of municipal drinking water after HAB contamination was detected in drinking water drawn from Lake Erie.

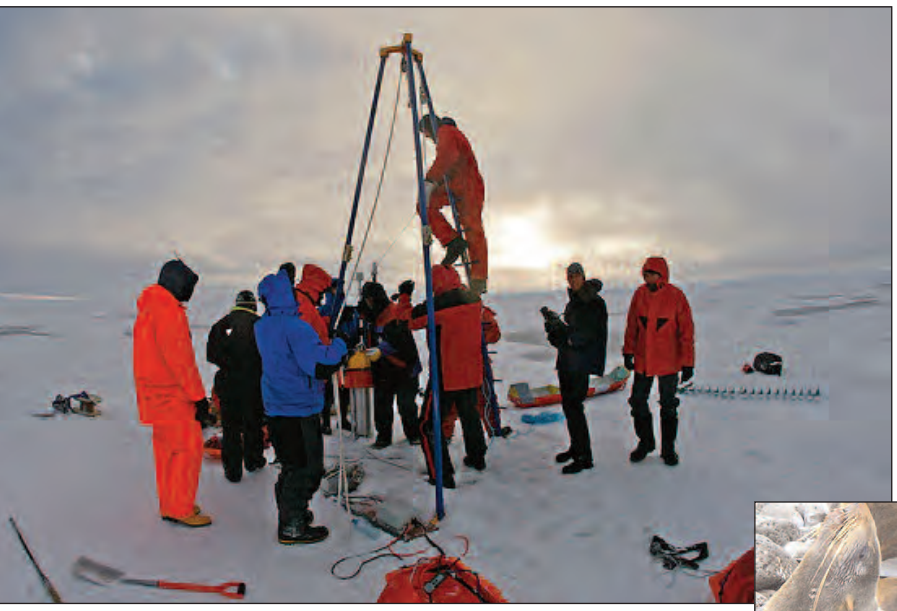
This suite of tools will provide critical data on bloom location, toxicity, and predicted movement before the water reaches municipal water intakes.

NOAA provides Arctic information and a set of indicators that describe the present state of the Arctic ecosystem and climate. Climate change is making the Arctic a greener, warmer, and increasingly accessible place for economic opportunity. However, climate impacts such as sea ice loss and rising ocean acidification are straining coastal community resilience and sound resource stewardship. In addition, advancing U.S. security interests in the Arctic requires improved maritime domain awareness, for which NOAA's weather and sea ice forecasts are critically important.

In order to understand, mitigate, and adapt to the impacts that anthropogenic and climatic stressors are having on the Arctic, NOAA is engaging in innovative research to fill critical gaps in the understanding of the Arctic environment. The priorities of NOAA's Arctic Program align with the White House National Strategy for the Arctic Region as well as the research drivers of the Interagency Arctic Research Policy Committee.

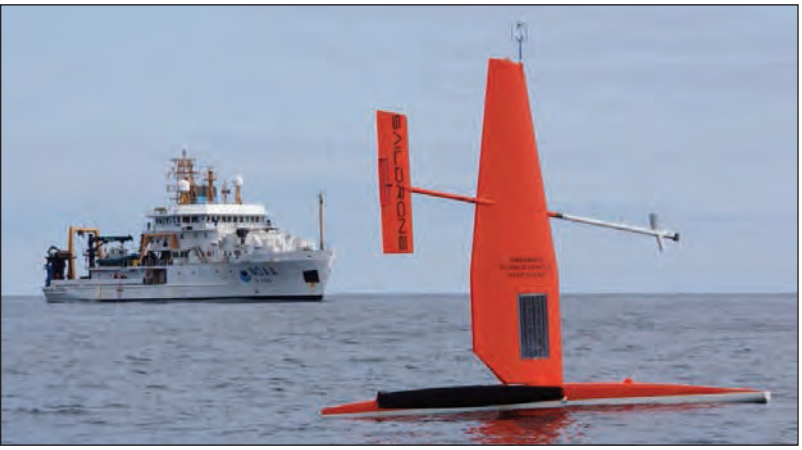
As a leader of Arctic research, NOAA is working to develop more accurate and timely predictions of changing sea-ice cover with the help of sustained observational efforts as well as the development of improved sea-ice models. In Arctic coastal zones, NOAA is undertaking research and monitoring of water levels, erosion, and changes in coastal bathymetry to strengthen resiliency efforts in coastal communities and improve coastal navigation services.

NOAA's research to advance scientific understanding of key Arctic species and how climate-related changes and biophysical interactions impact those species, other marine resources, and the communities that rely on them is critical. This research will assist in the development of responsible High Arctic fisheries management plans.



This chapter provides a representative sampling of the research that NOAA scientists are conducting to best understand how the Arctic region and its living resources are being impacted and influenced by global weather, ocean, and climate patterns.

Understanding the Changing Arctic Environment



Innovative Technology for Arctic Exploration

The Saildrone is a solar and wind powered ocean unmanned surface vessel (USV) developed by Saildrone, Inc., in partnership with the NOAA Pacific Marine Environmental Laboratory.

The novel design of this platform allows speeds approximately twice as fast as similar USVs, significantly expands payload capacity (~200 lbs.; ~10x similar USVs), and equips the drone with four high-throughput solar panels, allowing the operation of a diverse sensor array.

For example, this new technology allows the Saildrone to track a pod of whales for over three months, rather than only a week as was previously possible. This provides researchers with a more accurate picture of habitat utilization for whale species.

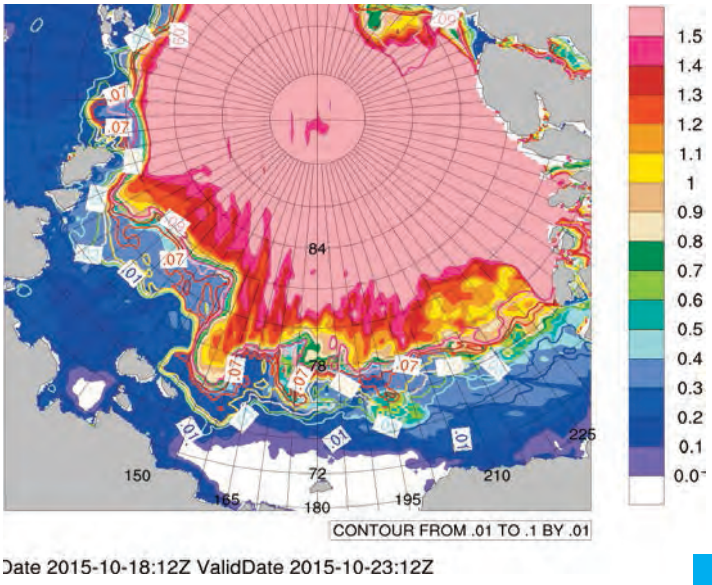
During 2016, OAR researchers at PMEL and Saildrone, Inc. have partnered with researchers at the National Marine Fisheries Service and the National Marine Mammal Laboratory to utilize the Saildrone as a joint reconnaissance tool for fisheries and ecological population surveys.

Using the Saildrone to track populations of pollock, fur seals, and critically endangered whales will direct ship-board surveys to key areas to improve survey efficiency and enhance accuracy and coverage of stock assessments. This will aid sustainable fisheries management and conservation efforts in an area already undergoing significant environmental change.

Forecasting Sea Ice

The Arctic region has some of the most extreme and challenging environmental conditions on Earth. Safely traveling, fishing, transporting goods, and managing resources in the Arctic critically depends on accurate weather, marine, and sea ice forecasts. Improving predictions in this complex, evolving, and interconnected world of ice, ocean, and atmosphere requires an innovative research approach.

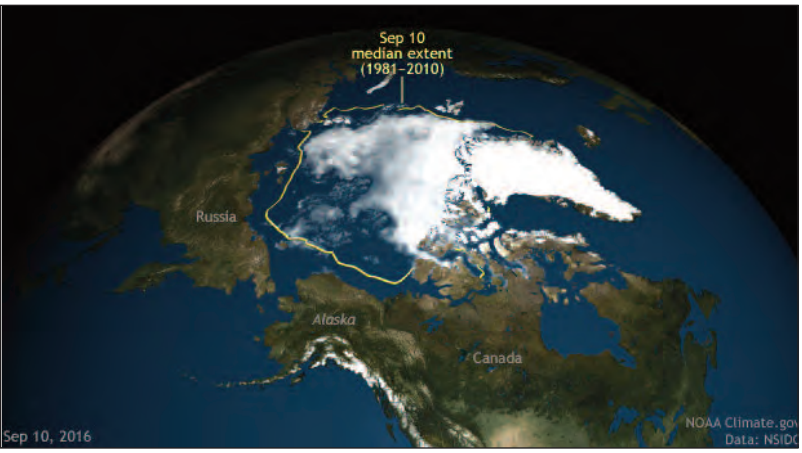
Towards this goal, NOAA is enhancing and testing a fully-coupled model — where the sea ice, ocean, and atmosphere conditions evolve together — to provide experimental 0-10 day forecasts of sea ice during the 2015 and 2016 fall freeze-up seasons. Working with operational partners at the National Weather Service, the National Ice Center (NIC) has provided the NOAA team with unparalleled opportunities to assess the model's skill compared to observations made by buoys, ships, aircrafts, and satellites.



Five day forecast of total sea ice thickness (m).

Due to longer seasons and more extensive areas of open water, there is increased interest and need for more, and better, weather forecasts. These same factors, however, make forecasting and the models on which the forecasts are base increasingly more challenging.

Along with research at a regional scale, research is being conducted as part of the Next Generation Global Prediction System of the National Weather Service. This effort will establish a baseline skill of incorporating the coupled air-sea-ice dynamics into modeling and forecasts; additional complexity factors including waves and land hydrology will then be added to better understand severe wave conditions and the strong influence of freshwater river runoff.



2016 Arctic sea ice summer minimum.

Distributed Biological Observatory

In response to dramatic loss of sea ice and warming in the Pacific Arctic, NOAA initiated the development of a Distributed Biological Observatory (DBO) to track concomitant shifts in the marine ecosystem.

The DBO provides a framework to coordinate sampling of biodiversity 'hotspots' across a latitudinal gradient extending from the northern Bering to the Beaufort Sea. Repeated sampling of these hotspots is essential to understanding how the marine ecosystem is responding to warming in the Arctic, which is proceeding at twice the pace of the rest of the planet.

The DBO is executed with international partners from Korea, Canada, Russia, Japan, and China, coordinated via the Pacific Arctic Group, with 2016 marking the seventh consecutive year of successful collaborative science.

Using Infrared and Color Instruments to Monitor Marine Mammals in the Chukchi Sea

A joint U.S.-Russia aerial survey for bearded seals, ringed seals, and polar bears (in collaboration with U.S. Fish and Wildlife Service) was completed for the entire Chukchi Sea in April - May 2016.

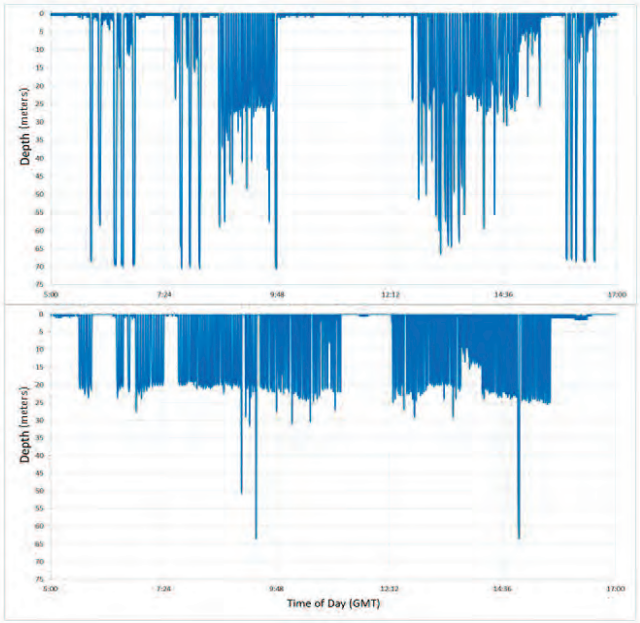
This survey was the first comprehensive survey of the Chukchi Sea for these species, the first time that polar bear and seal surveys have been combined, and the first survey of polar bears by instruments (as opposed to traditional, visual survey methods).

Infrared cameras were used to detect the warm bodies of mammals against the cold background of sea ice, while high-resolution color photos enabled species identification. These aerial surveys require the collection and processing of millions of thermal and color images, along with extensive data on sea ice conditions and track line coordinates.

The final population estimates and species distribution maps will be produced over the next two years, although several publications on the methods and results from similar surveys of the Bering and Okhotsk Seas (2012-2013) are already available. Population estimates and distribution maps are critical for assessment and management of these protected species — important subsistence resources for coastal communities in Arctic Alaska — that are vulnerable to loss of sea ice in a warming Arctic climate.

Monitoring of Northern Fur Seal Foraging Behavior

NOAA worked with Advanced Telemetry Systems to produce a long-life (>4 years), light-weight (12 g) VHF radio transmitter for attachment as a flipper tag on northern fur seals in the Bering Sea. The VHF transmissions are pulse-coded and decoded by a data-logging receiver that can isolate as many as 100 transmitters on a single frequency.



Dive plots for two female northern fur seals.

The tags provide exceptionally "clean" data on presence-absence activity patterns of adult female northern fur seals while they are provisioning their pups. Preliminary results with very limited numbers of tags at a single rookery demonstrated high precision and significant inter-annual variability in fur seal foraging success (an index of prey availability) from a single rookery on St. Paul Island.

In collaboration with the NMFS Alaska Regional Office and University of Alaska Anchorage, this study is expanding to estimate 1) variation in fur seal foraging success across rookeries representing a broader oceanographic region, 2) the disturbance effects of subsistence harvest of fur seal pups on St. George Island, and 3) rates of emigration that currently complicate our study of fur seal demographics. These are all important areas for the conservation and management of northern fur seals in the Bering Sea.

Insights into the Prince William Sound Fisheries Following the Exxon Valdez Oil Spill

In September 2015, scientists at the Northwest and Alaska Fisheries Science Centers published a landmark paper in *Scientific Reports* describing the delayed impacts of transient embryonic crude oil exposures on pink salmon and Pacific herring.

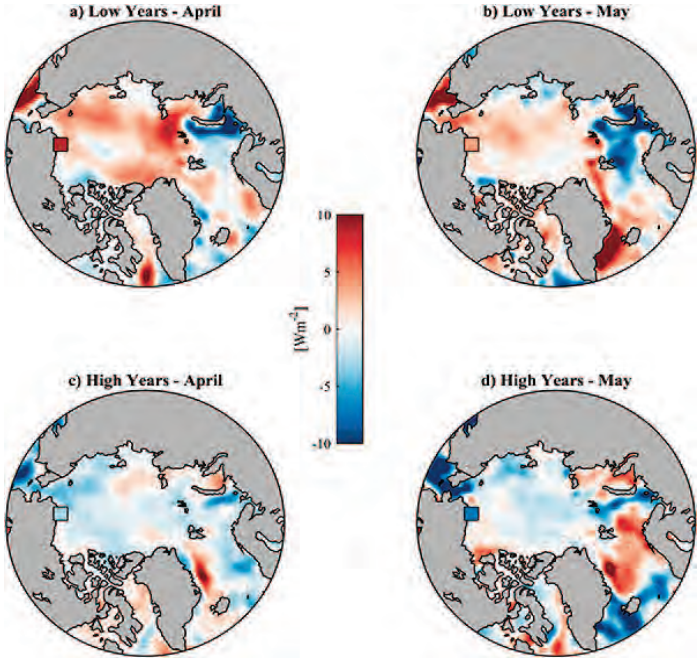
The 1989 Exxon Valdez spill extensively oiled shoreline-spawning habitats for species in Prince William Sound. The commercial herring fishery collapsed three to four years later, at a time when herring spawning in or near the spill zone would have recruited into the adult population.

Similarly, pink salmon populations declined in impacted regions of the Sound. Though a casual connection between the oil spill and fisheries declines was never established, this remains one of the most controversial unanswered questions in modern exotoxicology.

Role of Springtime Arctic Clouds in Determining Autumn Sea Ice Extent

Recent studies suggest that radiative forcing from clouds and the atmosphere during spring affects the progress of the entire sea ice melt season and the eventual minimum extent of sea ice in September, although with controversial results regarding the relative importance of different processes.

NOAA is focusing on observations of cloud radiative forcing (CRF), which quantify the perturbation to the surface radiation budget caused by cloud cover. CRF in spring at Barrow, Alaska, is found to be correlated with the minimum sea ice extent in September. And, though Barrow is only a single point over land, reanalysis of data suggests that Barrow is situated in a gateway location that likely samples atmospheric signals that relate to processes responsible for the springtime conditioning of sea ice.



Increased cloud cover enhancing warming (red) in April and May coincides with low sea ice years. The opposite effect (blue) is prevalent in high sea ice years. In all panels the small square is the location of Barrow, AK, and its color shows that the observations from Barrow are consistent with model data.

The observations are well suited for capturing the time-evolution of seasonal changes in CRF, showing that low sea ice years are characterized by increased cloud cover in April, followed by decreased cloud cover in May.

The opposite is true for years with higher than average September sea ice. Researchers found that the evolution of exchanges in the dominant processes through which clouds modulate the surface energy budget is critical for interpreting their relationship to sea ice.

Climate Prediction Center Experimental Seasonal Sea Ice Prediction

Accurate prediction of sea ice is essential for stakeholders in the Arctic region, yet the current NOAA operational Climate Forecast System (CFS) produces erroneous Arctic sea ice predictions, which are characterized by too much sea ice during the melt season and too little sea ice during the early freeze season.

To determine the causes for the prediction errors, the Climate Prediction Center (CPC) carried out a series of diagnostic experiments that identified errors in the sea ice initialization and physical parameterizations as the root cause of the erroneous prediction.

CPC developed an Experimental Forecast System with fixes for these errors, which resulted in a dramatic skill improvement for sea ice forecasts. Experimental predictions from March to October of 2015 and 2016 were produced, and the comparison with available observations showed that the CPC Experimental Forecast System produced significantly more accurate seasonal sea ice forecasts than the operational CFS.

Predictions from the CPC Experimental Forecast System have become a routine contribution to the NWS Alaska Region's Sea Ice Outlook. This project was carried out in close collaboration with the University of Washington Polar Science Center.

Bibliometrics

This chapter represents one of the most rigorous performance assessments of NOAA's scholarly research conducted to date. Using data from 2011 to 2015, we set out to determine NOAA's core research areas (i.e., those in which NOAA publishes the most), and then used established and robust scholarly performance metrics to demonstrate NOAA's level of productivity and impact within these core research areas. In a benchmarking exercise, these findings were then compared with those of other federal agencies conducting research in these same disciplines.

In summary, between 2011 and 2015, NOAA scientists authored or co-authored 10,663 articles spanning 144 research areas. Nearly 81% (8,676) of these articles fell within seven research areas (found below), all of which are strongly aligned with the agency's mission objectives.

1) *Meteorology and Atmospheric Sciences*
2) *Marine and Freshwater Biology*
3) *Oceanography*
4) *Environmental Sciences*
5) *Fisheries*
6) *Ecology*
7) *Geosciences (Multidisciplinary)*

Given this clear demarcation in productivity, we defined these seven research areas as NOAA's core research areas. We then compared NOAA's level of productivity and impact to the four other federal agencies that were most productive in each respective research area (not always the same four agencies). In short, NOAA is at the leading edge in both productivity and impact across all seven research areas.

Hundreds of NOAA employees and partners participated in the 5th annual NOAA Restoration Day in two separate events — one in Maryland and the other in Virginia.

Researchers and forecasters collaborate in the NOAA Hazardous Weather Testbed. The National Severe Storms Laboratory and National Weather Service host this event each year to test and evaluate emerging technologies and science for NWS operations

Methodology

All approaches and analyses employed herein are consistent with the National Academies' Best Practices in Assessment of Research and Development Organizations (NAS, 2012) and the principles set forth in the Leiden Manifesto (Hicks et al., 2015).

Scholarly data and metrics for this report were obtained by using InCitesTM (Thomson Reuters), which is a web-based platform that allows for the assessment and comparison of the productivity and citation impact of research organizations.

For the purposes of this report, a "NOAA article" or "article" is defined as any peer-reviewed publication cataloged in the Web of Science (WoS) core collection that lists "National Oceanic and Atmospheric Administration" or "NOAA" in the institutional affiliation tag of the article.

Importantly, this does not include articles that only acknowledge receiving financial, logistical, or other support from NOAA. The scope of this report is constrained to only articles published between 2011 and 2015, and that were cataloged in the InCites Dataset, as of September 23, 2016.

As a caveat, the use of WoS for article collection means that book chapters, technical reports, and some journal articles are not included. Consequently, the publication counts presented in this report are undercounts of the actual number of publications produced by NOAA. However, despite these limitations, the collection of articles analyzed herein constitute a representative sample of the articles published by NOAA between 2011 and 2015.

NOAA's core research areas were determined by using the WoS research schema, which, in total, is comprised of 252 research areas. Within each research area, productivity was assessed based on the total number of published articles, and citation impact was assessed using the following metrics (each metric is hyperlinked to a webpage that provides a definition):

i) Hirsch-Index or H-index ; ii) percent of documents cited; iii) Category Normalized Citation Impact or CNCI; iv) percent of documents in the top 10% of cited articles.

For benchmarking purposes, productivity and citation impact data were also collected for the four most productive federal agencies (i.e., those with the most published articles) aside from NOAA, within each of the respective core research areas.

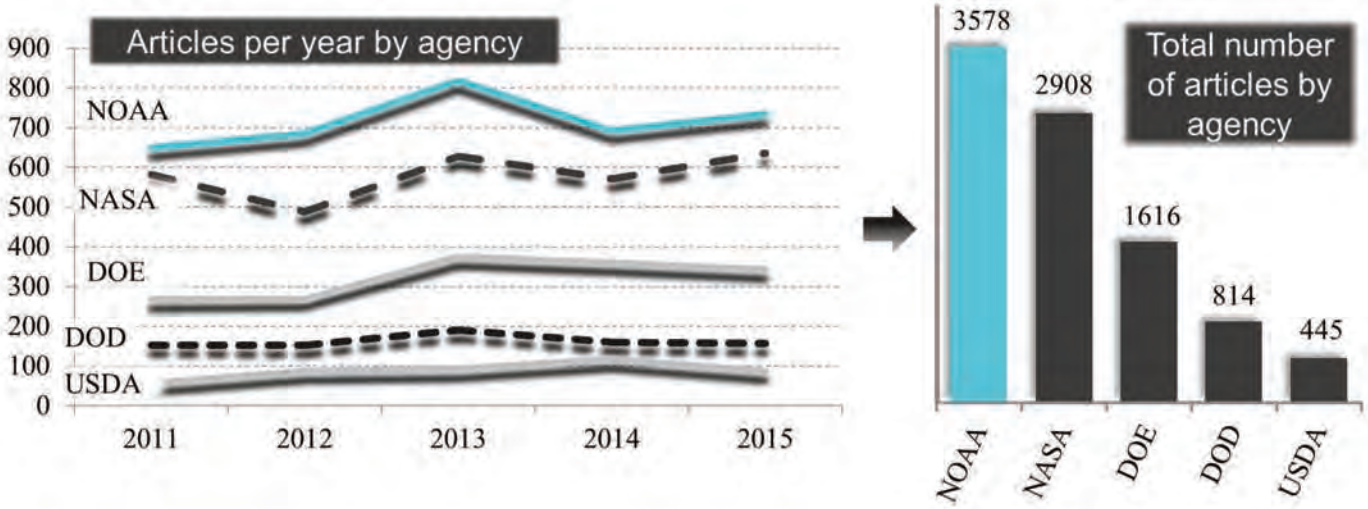
References:

NAS (2012). *Best Practices in Assessment of Research and Development Organizations,* The National Academies Press.

D. Hicks, P. Wouters, L. Waltman, S. de Rijke, I. Rafols. 2015. The Leiden Manifesto for Research Metrics, *Nature* (520) 429-431.

Productivity Meteorology and Atmospheric Sciences

- Between 2011 and 2015, NOAA published an average 716 articles per year in the field of meteorology and atmospheric sciences, resulting in a total of 3578 articles.
- NOAA has consistently published more articles in the field of meteorology and atmospheric sciences than any other federal agency.



Top Journals

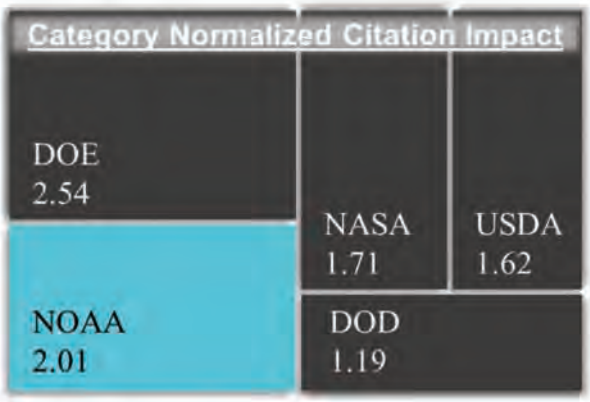
- Journal of Geophysical Research-Atmospheres
- Journal of Climate
- Atmospheric Chemistry and Physics
- Bulletin of the American Meteorological Society
- Monthly Weather Review

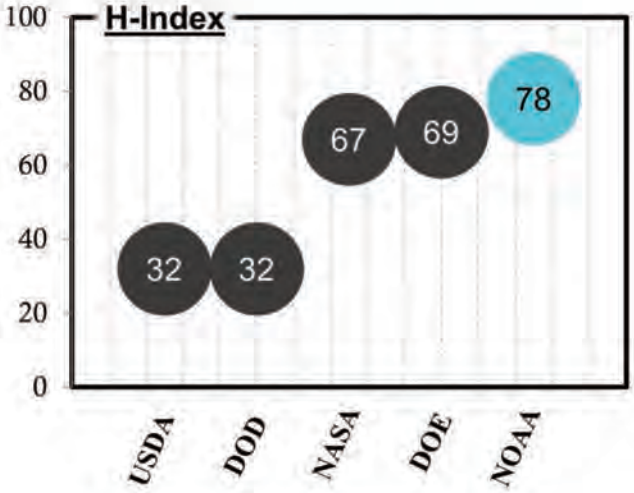
Highly Cited Papers

- Taylor, et al. 2012. An Overview of the CMIP5 and the experiment design. BAMS.
- Rienecker, et al. 2011. MERRA: NASA's Modern-Era Retrospective Analysis for Research and Applications. J. Climate
- Compo, et al. 2011. The Twentieth Century Reanalysis Project. Q. J. R. Meteorol. Soc.

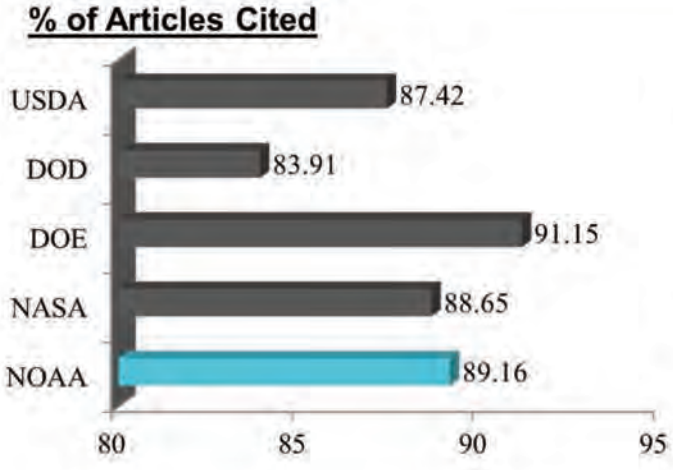
Impact Meteorology and Atmospheric Sciences

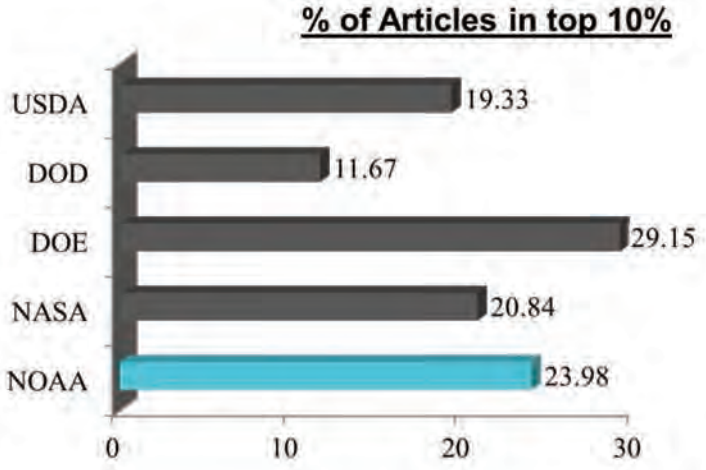
- This collection of articles has a Category Normalized Citation Impact of 2.01, or twice that of the average within the field of meteorology and atmospheric sciences.
- Within the field of meteorology and atmospheric sciences, NOAA has an H-index of 78 -- meaning that 78 of these articles have been cited in the peer reviewed literature at least 78 times.





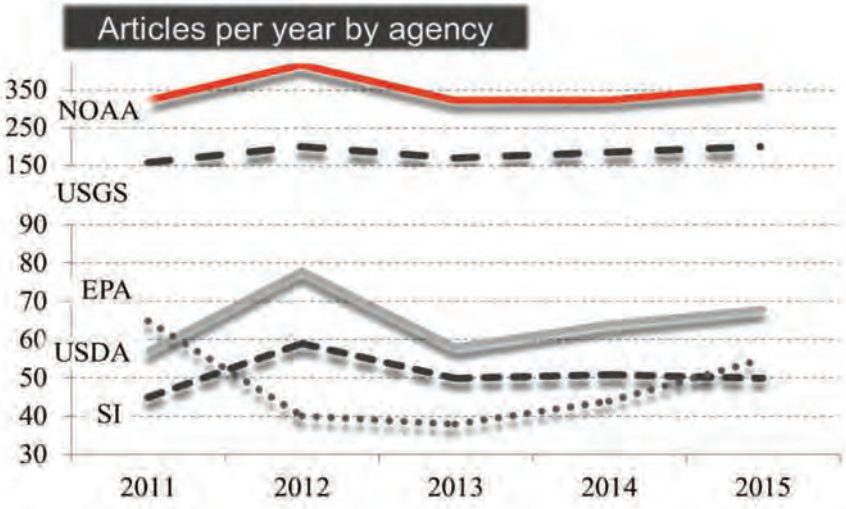
- In total, 89% of the 3578 articles have been cited within the peer reviewed literature.
- 24% of the 3578 articles fall within the top 10% of the most cited articles in meteorology and atmospheric sciences.

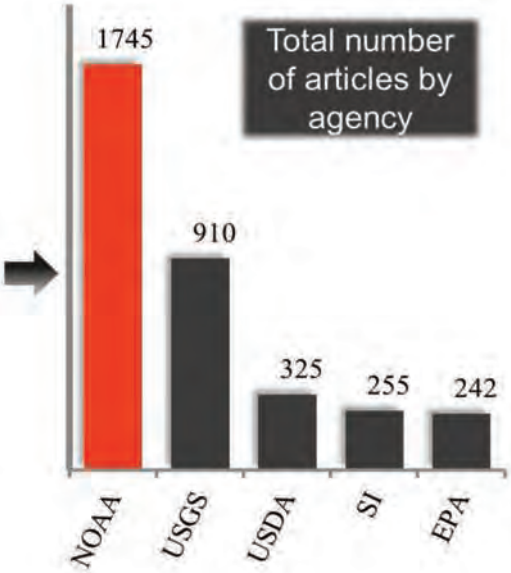




Productivity Marine and Freshwater Biology

- Between 2011 and 2015, NOAA published an average 349 articles per year in the field of marine and freshwater biology, resulting in a total of 1745 articles.
- NOAA has consistently published more articles in the field of marine and freshwater biology than any other federal agency.





Top Journals

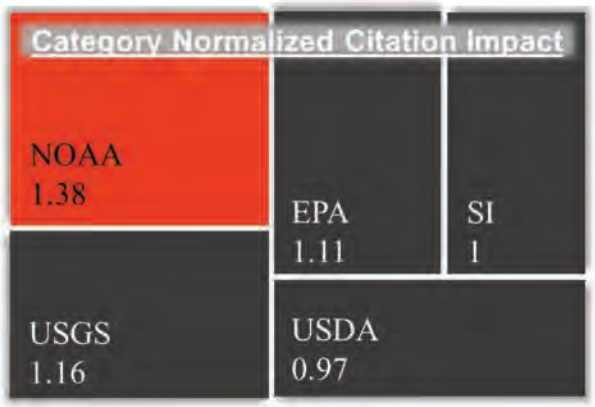
- Marine Ecology Progress Series
- ICES Journal of Marine Science
- Canadian Journal of Fisheries and Aquatic Sciences
- Journal of Shellfish Research
- Marine Mammal Science

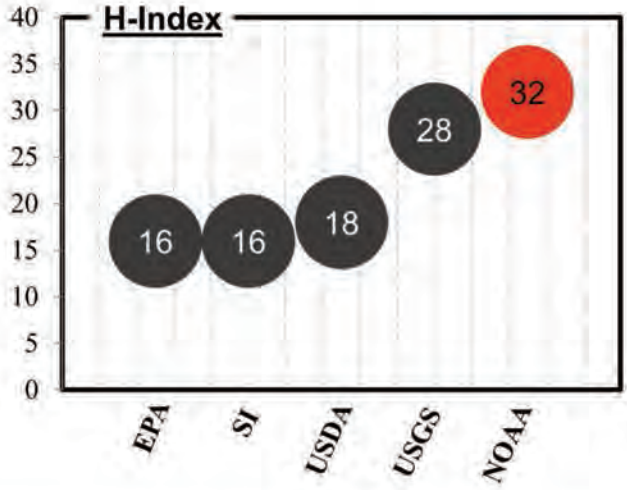
Highly Cited Papers

- Doney, et al. 2012. Climate Change Impacts on Marine Ecosystems. Ann Rev Mar Sci.
- Sugihara et al. 2012. Detecting Causality in Complex Ecosystems. Science.
- Ferreira et al. 2011. Overview of Eutrophication indicators to assess environmental status within the European Marine Strategy Framework Directive. Estuar. Coast. Shelf. Sci

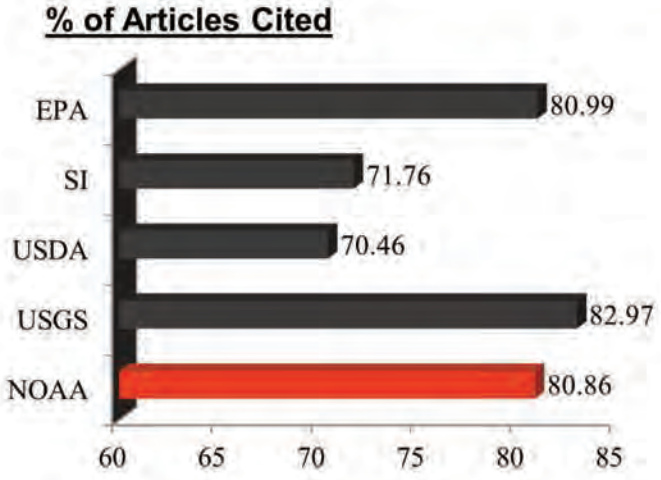
Impact Marine and Freshwater Biology

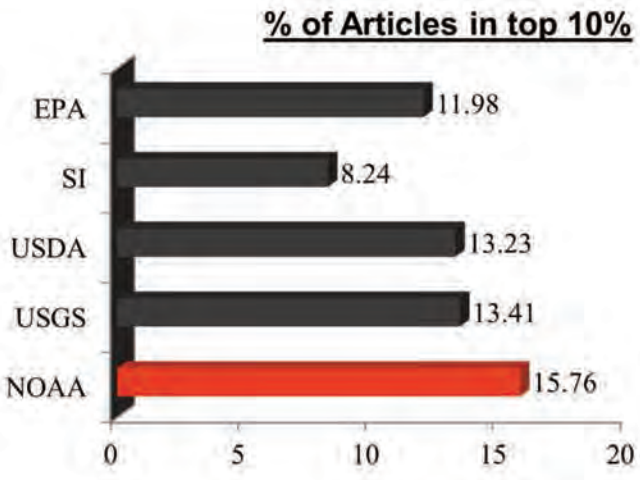
- This collection of articles has an above average Category Normalized Citation Impact of 1.38.
- Within the field of marine and freshwater biology, NOAA has an H-index of 32 -- meaning that 32 of these articles have been cited in the peer reviewed literature at least 32 times.



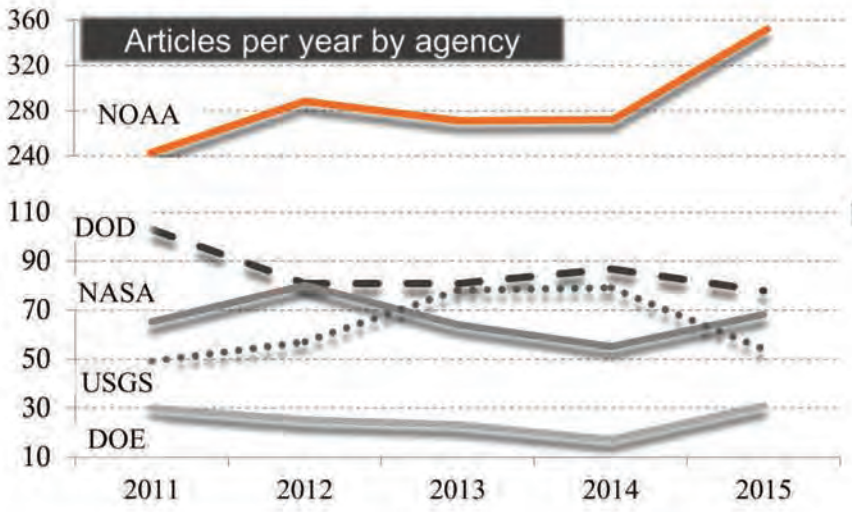


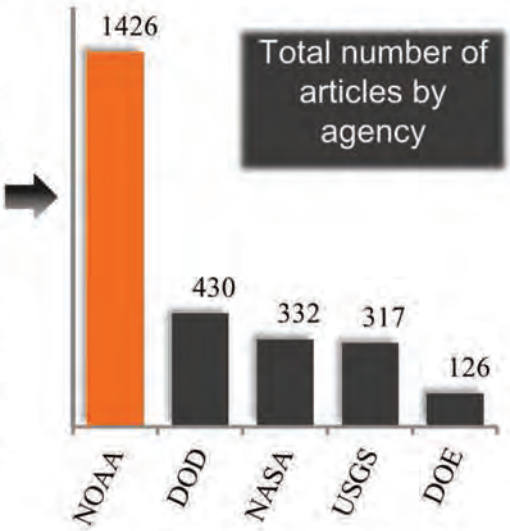
- In total, 81% of the 1745 articles have been cited within the peer reviewed literature
- 16% of the 1745 articles fall within the top 10% of the most cited articles in the field of marine and freshwater biology.





- Between 2011 and 2015, NOAA published an average 285 articles per year in the field of oceanography, resulting in a total of 1426 articles.
- NOAA has consistently published more articles in the field of oceanography than any other federal agency.





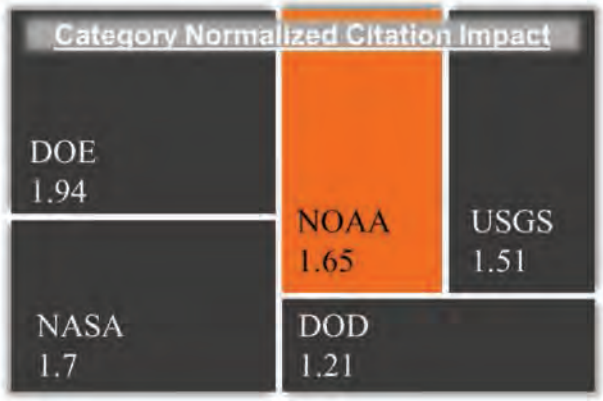
Top Journals

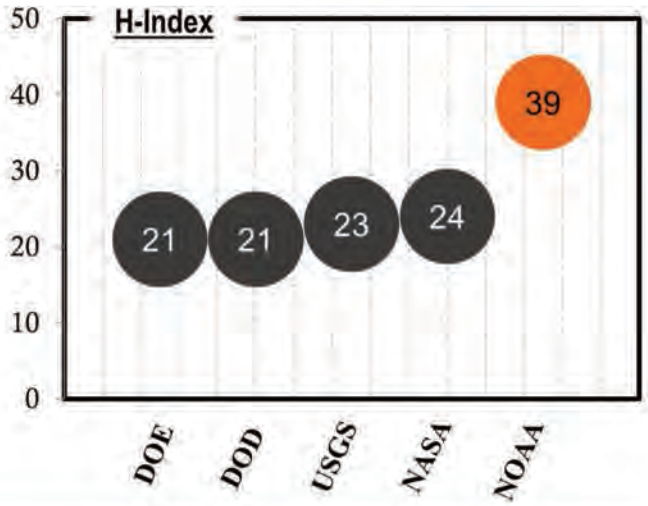
- Marine Ecology Progress Series
- Journal of Geophysical Research-Oceans
- ICES Journal of Marine Science
- Deep-Sea Research Part II- Oceanography
- Oceanography

Highly Cited Papers

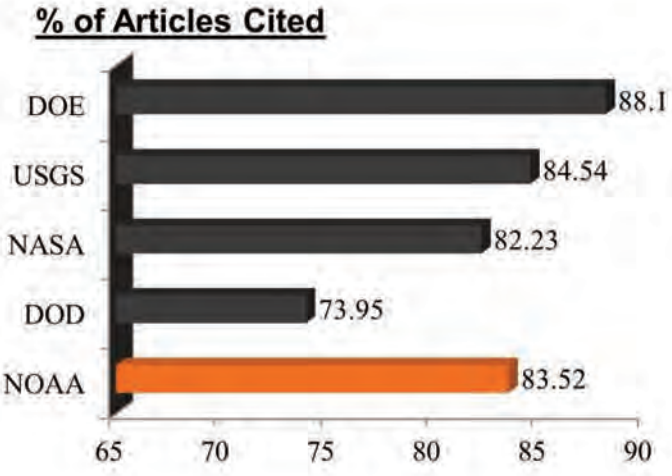
- Smith, et al. 2011. Impacts of Fishing Low-Trophic Level Species on Marine Ecosystems. Science.
- Hunt et al. 2011. Climate Impacts on Eastern Bering Sea Foodwebs: a synthesis of new data and an assessment of the Oscillating Control Hypothesis. IJMS.
- Barton et al. 2012. the Pacific Oyster, *Crassostrea gigas*, shows negative correlation to naturally elevated CO2 levels: Implications for near-term ocean acidification effects. Limnol Oceanogr.

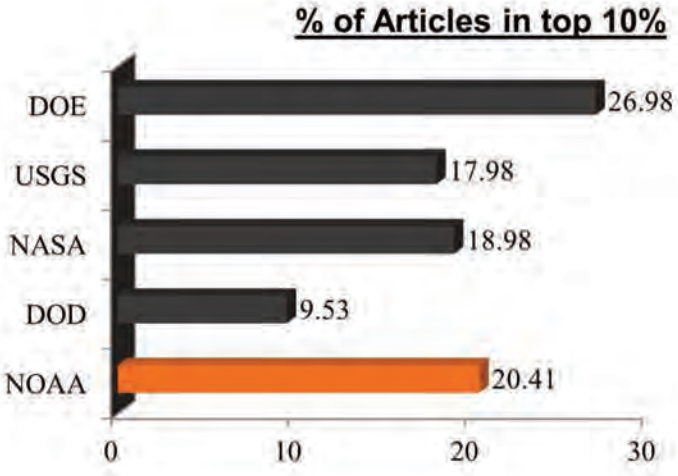
- This collection of articles has an above average Category Normalized Citation Impact of 1.65.
- Within the field of oceanography, NOAA has an H-index of 39 -- meaning that 39 of these articles have been cited in the peer reviewed literature at least 39 times.





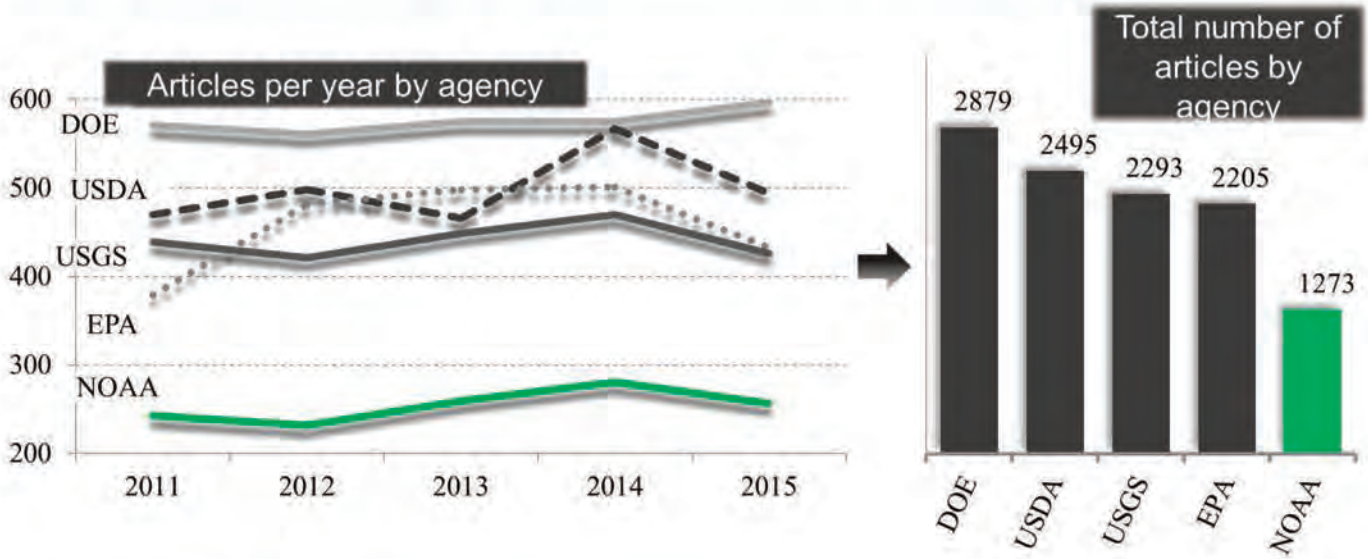
- In total, 84% of the 1426 articles have been cited within the peer reviewed literature
- 20% of the 1426 articles fall within the top 10% of the most cited articles in the field of oceanography.





Productivity **Environmental Sciences**

- Between 2011 and 2015, NOAA published an average 255 articles per year in the field of environmental sciences, resulting in a total of 1273 articles.
- NOAA consistently ranks 5th among federal agencies in the number of articles published in the field of environmental sciences.



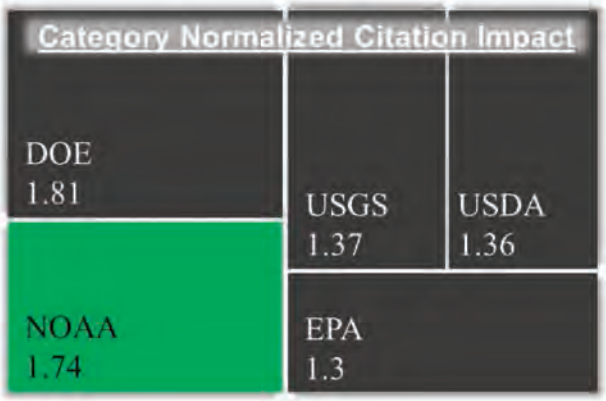
Top Journals

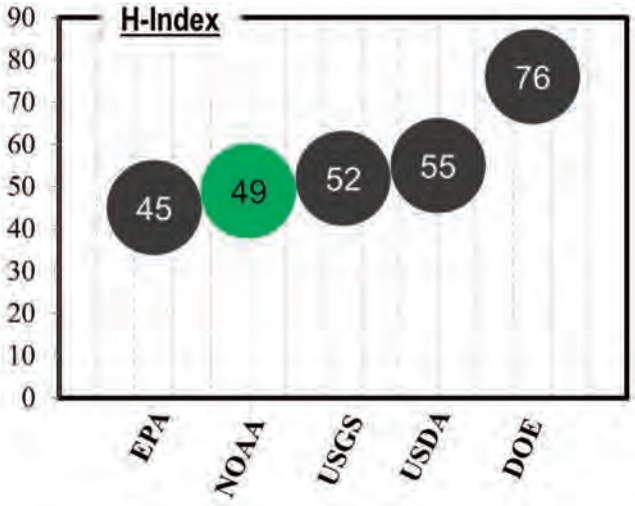
- Atmospheric Environment
- Environmental Science and Technology
- Marine Pollution Bulletin
- Journal of Great Lakes Research
- Remote Sensing of Environment

Highly Cited Papers

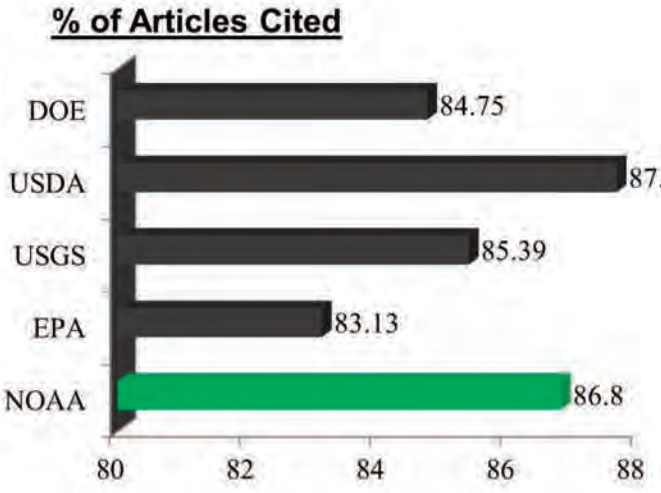
- Meinhausen, et al. 2011. The RCP greenhouse gas concentrations and the extensions from 1765 to 2300. Clim. Change.
- Aufdenkampe, et al.. 2011. Riverine coupling of biogeochemical cycles between land, oceans, and atmosphere. Front Ecol Environ.
- England et al. 2011. Recent intensification of wind-drive circulation in the Pacific and the ongoing warming hiatus. Nat. Clim. Change.

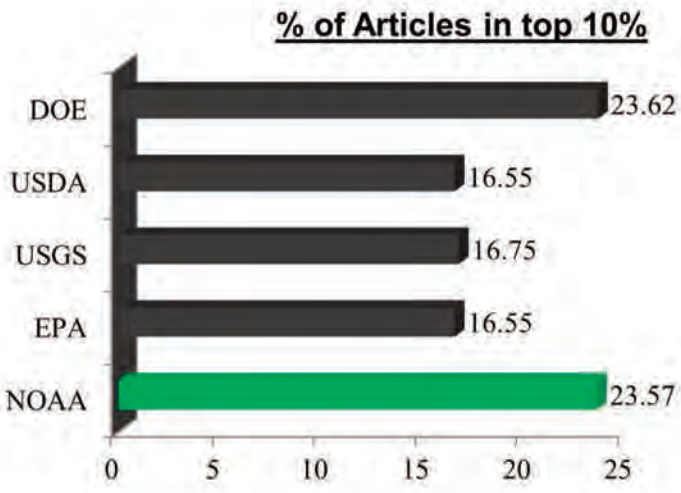
- This collection of articles has an above average Category Normalized Citation Impact of 1.74.
- Within the field of environmental sciences, NOAA has an H-index of 49 -- meaning that 49 of these articles have been cited in the peer reviewed literature at least 49 times.



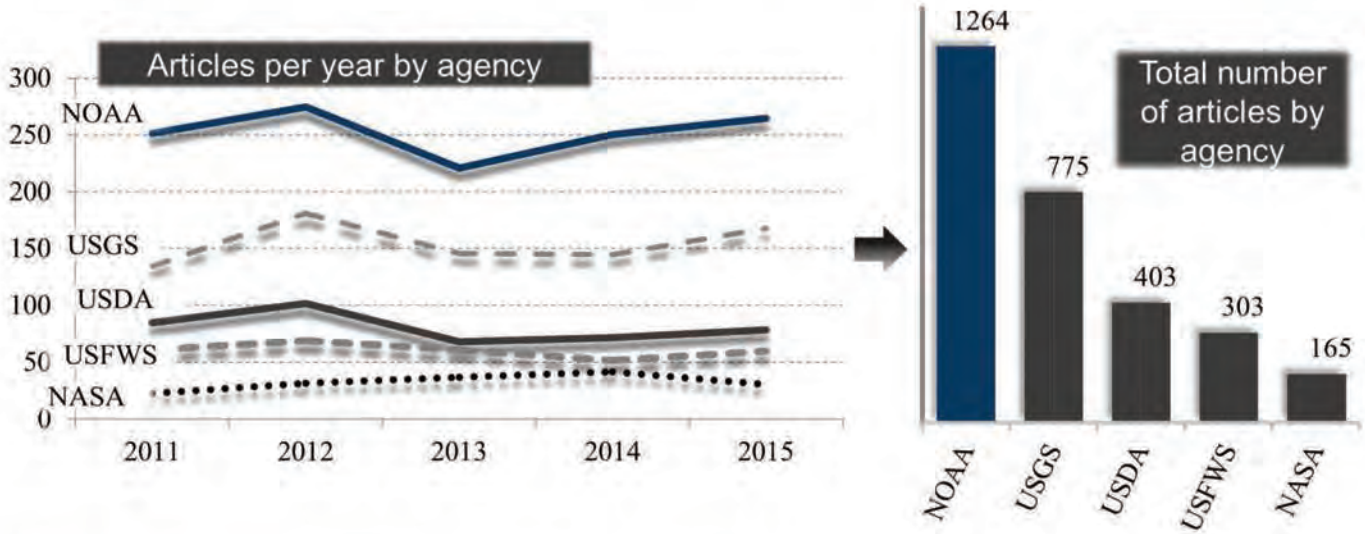


- In total, 87% of the 1273 articles have been cited within the peer reviewed literature
- 24% of the 1273 articles fall within the top 10% of the most cited articles in the field of environmental sciences.





- Between 2011 and 2015, NOAA published an average 253 articles per year in the field of fisheries, resulting in a total of 1264 articles.
- NOAA has consistently published more articles in the field of fisheries than any other Federal Agency.



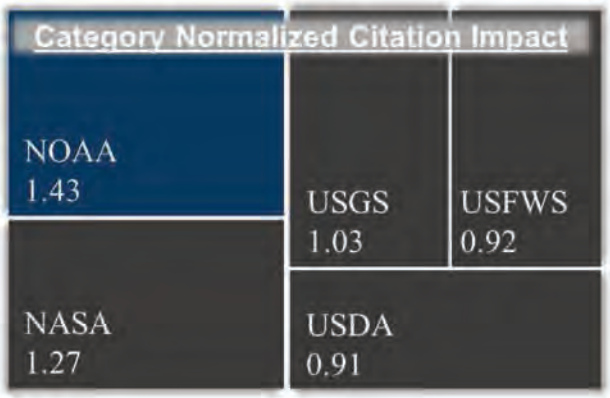
Top Journals

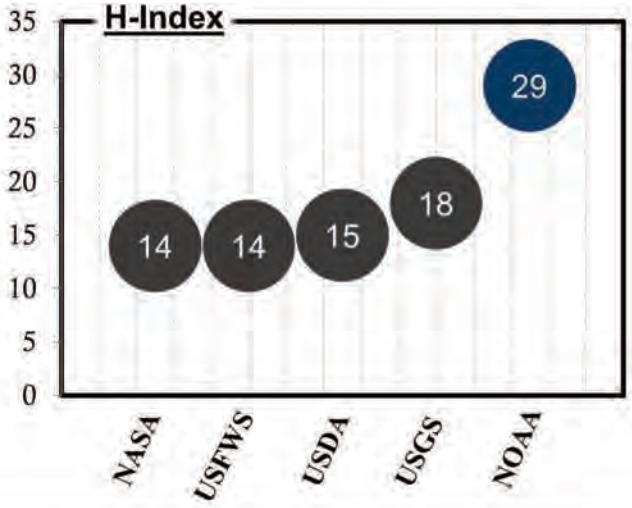
- ICES Journal of Marine Science
- Canadian Journal of Fisheries and Aquatic Sciences
- Fisheries Research
- Journal of Shellfish Research
- Transactions of the American Fisheries Society

Highly Cited Papers

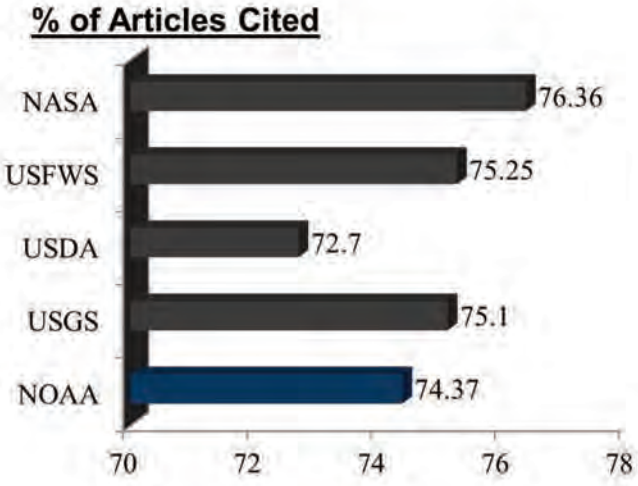
- Brown-Peterson, et al. 2011. A Standardized Terminology for Describing Reproductive Development in fishes. Mar. Coast. Fish.
- Fulton, et al. 2011. Lessons in modeling and management of marine ecosystems: the Atlantis experience. Fish Fish.
- Methot et al. 2011. Stock Synthesis: A biological and statistical framework for fish stock assessment and fishery. Fish Res.

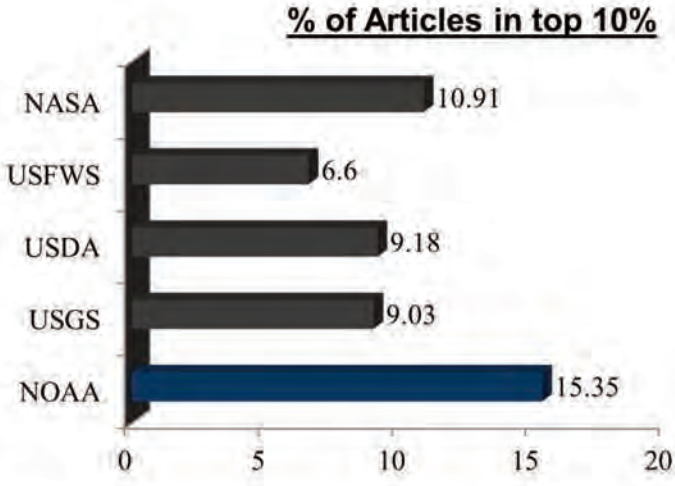
- This collection of articles has an above average Category Normalized Citation Impact of 1.43.
- Within the field of fisheries, NOAA has an H-index of 29 -- meaning that 29 of these articles have been cited in the peer reviewed literature at least 29 times.



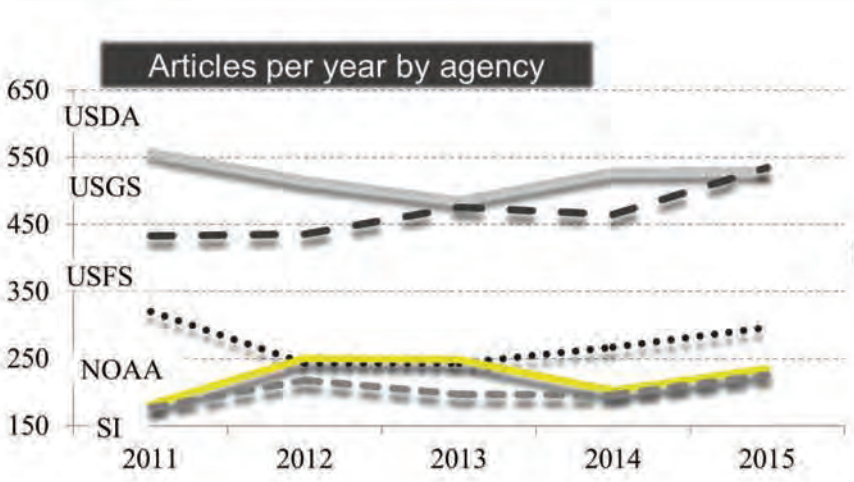


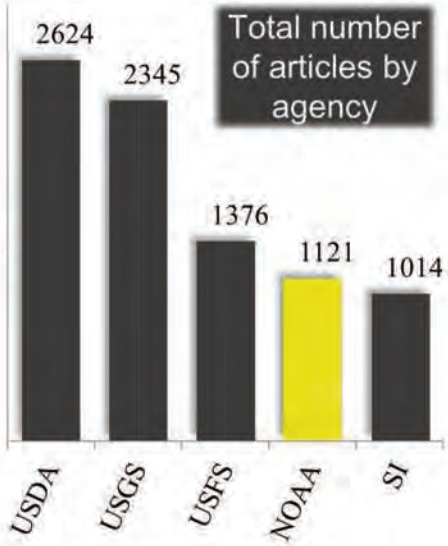
- In total, 74% of the 1264 articles have been cited within the peer reviewed literature
- 15% of the 1264 articles fall within the top 10% of the most cited articles in the field of fisheries.





- Between 2011 and 2015, NOAA published an average 224 articles per year in the field of ecology, resulting in a total of 1121 articles.
- NOAA consistently ranks 4th among federal agencies in the number of articles published in ecology.





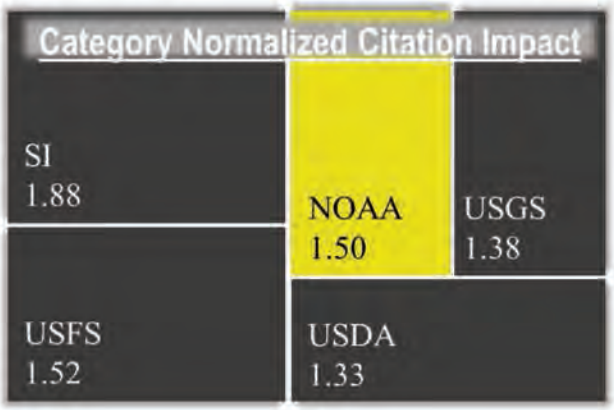
Top Journals

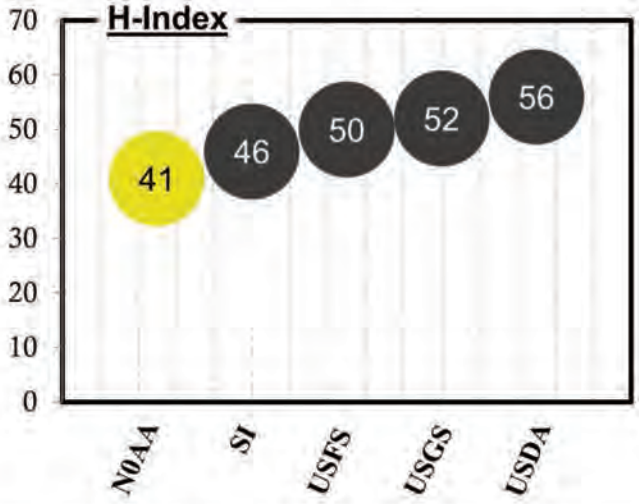
- Marine Ecology Progress Series
- Plos One
- Biogeosciences
- Journal of Experimental Marine Biology and Ecology
- Environmental Biology of Fishes

Highly Cited Papers

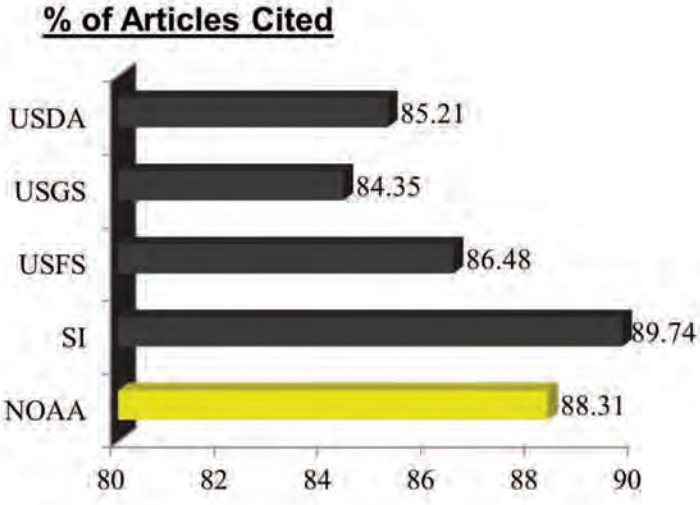
- Burrows, et al. 2011. The pace of Shifting Climate in Marine and Terrestrial Ecosystem. Science.
- Block et al. 2011. Tracking Apex marine predator movements in a dynamic ocean. Nature.
- Aufdenkampe et al. 2011. Riverine Coupling of biogeochemical cycles between land, oceans, and atmosphere. Front Ecol Environ.

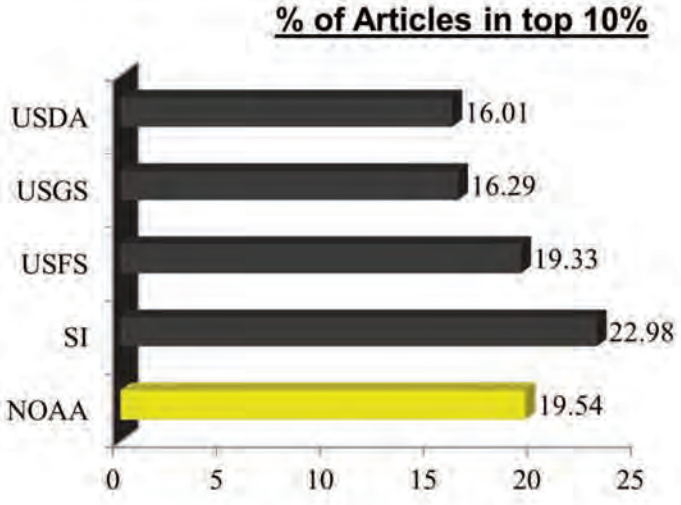
- This collection of articles has an above average Category Normalized Citation Impact of 1.50.
- Within the field of ecology, NOAA has an H-index of 41 -- meaning that 41 of these articles have been cited in the peer reviewed literature at least 41 times.





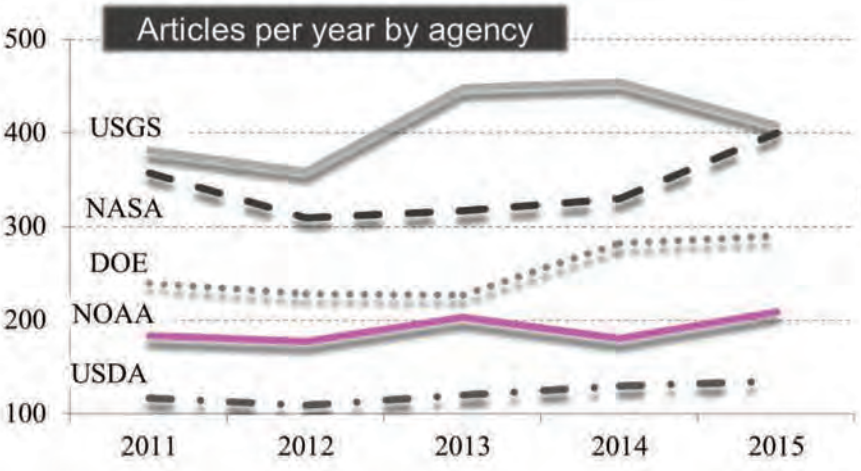
- In total, 88% of the 1121 articles have been cited within the peer reviewed literature
- 20% of the 1121 articles fall within the top 10% of the most cited articles in the field of ecology.

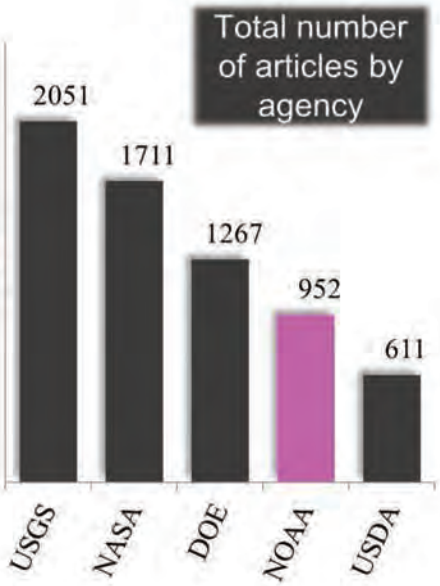




Productivity Geo-Sciences

- Between 2011 and 2015, NOAA published an average 190 articles per year in the field of geo-sciences, resulting in a total of 952 articles.
- NOAA consistently ranks 4th among federal agencies in the number of articles published in the field of geo-sciences.





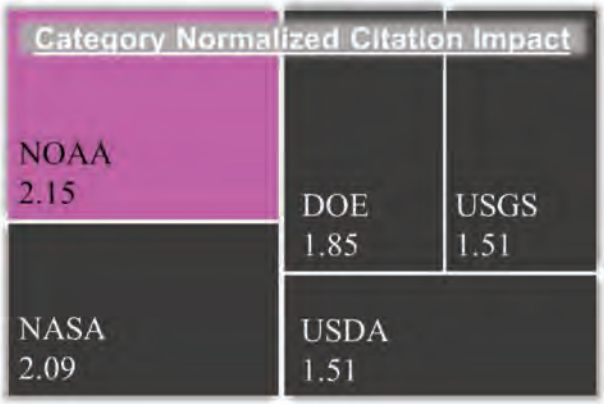
Top Journals

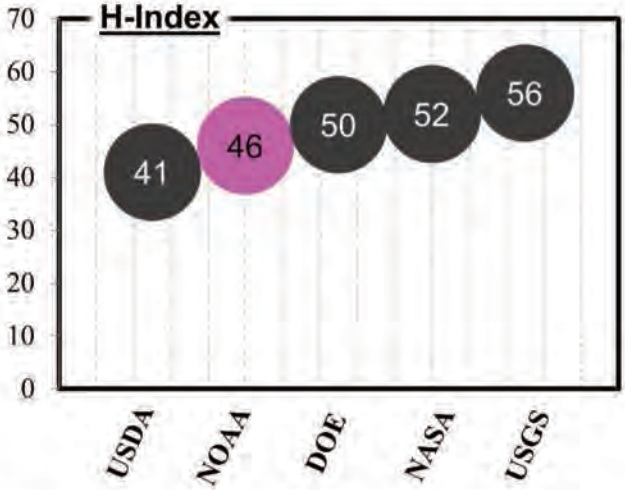
- Geophysical Research Letters
- Biogeosciences
- Nature Geoscience
- Journal of Hydrology
- Global Biogeochemical Cycles

Highly Cited Papers

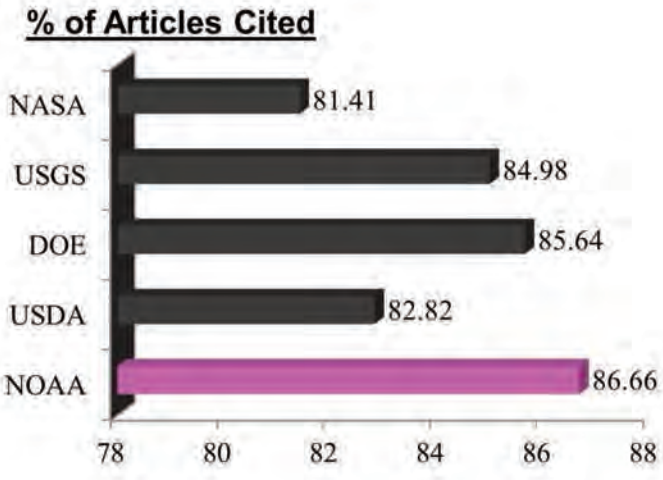
- Kirschke, et al. 2013. Three decades of global methane sources and sinks. Nature Geoscience.
- Seton et al. 2012. Global continental and ocean basin reconstructions since 200 MA. Earth Science Reviews.
- Thompson et al. 2011. Signatures of the Antarctic ozone hole in Southern Hemisphere climate change. Nature Geoscience

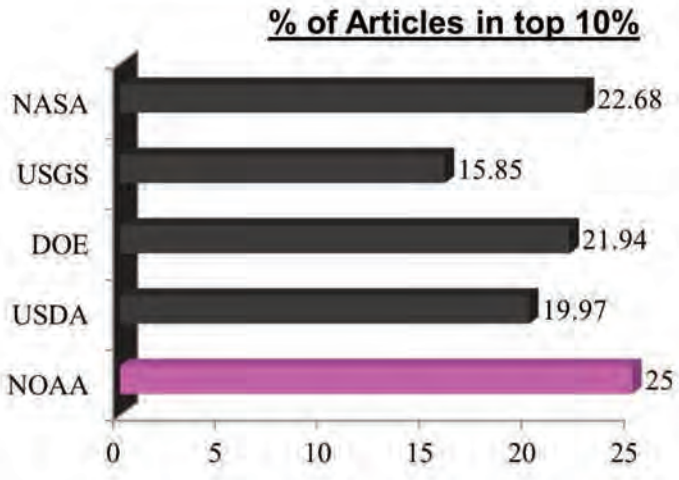
- This collection of articles has a Category Normalized Citation Impact of 2.15, or more than twice that of the average within the field of geo-sciences.
- Within the field of geo-sciences, NOAA has an H-index of 46 -- meaning that 46 of these articles have been cited in the peer reviewed literature at least 46 times.





- In total, 87% of the 952 articles have been cited within the peer reviewed literature
- 25% of the 952 articles fall within the top 10% of the most cited articles in the field of geo-sciences.





NOAA's Scientific Workforce

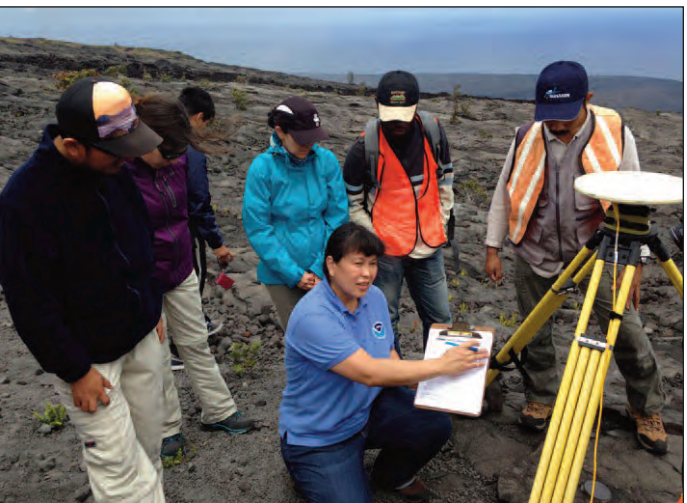
A creative and vibrant scientific workforce is at the core of NOAA's R&D and mission services enterprise. Each day, NOAA works to improve lives and support livelihoods through the support of a highly skilled, passionate, and diverse workforce, which includes federal employees, contractors, grantees, as well as dedicated volunteers.

Today with over 11,300 federal employees and thousands of NOAA team members, NOAA represents leading experts from a diversity of academic disciplines, from researchers studying space weather impacts on electricity here on Earth's surface, to mechanical engineers working on deep sea ocean exploration, to social scientists who investigate how to best communicate storm warnings to the public to prevent casualties.

Scientific Awards and Achievements

Our incredible employees are recognized time and time again through appointments to leadership positions in professional societies, external awards, invitations to speak at prestigious events, and more. Collectively, these employees drive high-quality labs and programs to achieve meaningful work, establishing NOAA as a leader amongst federal agencies in the majority of its main R&D focus areas.

One notable way that outstanding achievements are recognized is through a variety of awards. Within this chapter, you will find the NOAA employee and team member winners for **Scientific** or **Engineering** Achievements. The winners of these awards demonstrate the far-reaching impact that R&D at NOAA can have on the nation.



In addition to scientific achievement, many folks within NOAA receive additional awards for leadership, professional excellence, heroism, and more. While we are unable to list all of the NOAA staff who have been honored this year, you can find the additional award winners within the linked websites (e.g., Department of Commerce Gold and Silver Medals and NOAA Administrator's Award).

Department of Commerce and National Oceanic and Atmospheric Administration Research-Based Awards

(104 awards presented to 384 individuals and 12 offices)

Award	Recipient (s)	Award Organization
2015 Department of Commerce Gold Medal	Barbara French, John Incardona, Jana Labenia Cathy Laetz, Tiffany Linbo, Nathaniel Scholz, Catherine Sloan	Department of Commerce
2015 Department of Commerce Gold Medal	Assimilation and Modeling Branch, NCEP Central Operations, Environmental Modeling Center	Department of Commerce
2015 Department of Commerce Gold Medal	Global Climate and Weather Modeling Branch, Production Management Branch, Statistical Modeling Branch	Department of Commerce
2015 Department of Commerce Gold Medal	NMFS Bering Sea Research Team, OAR Bering Sea Research Team	Department of Commerce
2015 Department of Commerce Silver Medal	Zdenka Willis, Jessica Snowden, John Murphy, Kevin Schrab, Pamela Taylor, Martin Yapur, David Helms, Mark Vincent, Felipe Arzayus	Department of Commerce
2015 Department of Commerce Silver Medal	Ritchie Graves, Scott Carlon, Dale Bambrick, Bryan Nordlund	Department of Commerce
2015 Department of Commerce Silver Medal	Annarita Mariotti, Gabriel Vecchi, Rich Gudgel, William Stern, Jin Huang, Huug vanDendool, Qin Zhang, Suranjana Saha	Department of Commerce
2015 Department of Commerce Silver Medal	Joseph Cione, Erica Rule, CDR Nancy Hann, CDR Kristie Twining, CDR Justin Kibbey, James Roles, Jeff Smith, Steven Paul, Andrew Hornbeck, Joseph Bosko	Department of Commerce
2015 Department of Commerce Silver Medal	Kenneth Howard, Jian Zhang, Jonathan Gourley, Luis Cano, Mark Miller, Scott Jacobs, Rebecca Cosgrove, Michelle Mainelli, Cameron Shelton	Department of Commerce
2015 Department of Commerce Silver Medal	Jeremy Mathis, Christian Meinig, Noah Lawrence-Slavas, Scott Stalin, Nicholas Delich, Stacy Maenner-Jones	Department of Commerce

Award	Recipient (s)	Award Organization
2015 NOAA Employee of the Month	Maria Torres, Tom Carey, William Sweet, Kristin Rusello, Jay Harris, Jeannine Montgomery, James (JJ) Johnson, Shelia Deiotte, Boyin Huang, Monica Youngman, Todd Smith, Linda McGuckin	NOAA
2015 NOAA Team Member of the Month	Jeremiah Blondeau, Ricardo Domingues, Will Tyburczy, Joselyd Garcia, Don Horvat, Heidi Samuelson, Karen Kavanaugh, Emma Htun, Ryan Spackman, Lola Stith, Rick Rives, Alan Free	NOAA
2015 NOAA Administrator's Award	Yong Han	NOAA
2015 NOAA Administrator's Award	Kristin Rusello, Elizabethann English, David Pearl, Cheryl Sexton McCarty, Stacey Nathanson, LTJG Alexander Johnston	NOAA
2015 NOAA Administrator's Award	Gary Shigenaka, Bradford Benggio	NOAA
2015 NOAA Administrator's Award	Christopher Clement, Alison Hammer Weingast, David Morris ("Moe") Nelson, Jill Petersen, Jason Rolfe, Nancy Wallace, Aneesah Whaley	NOAA
2015 NOAA Administrator's Award	Rebecca Allee, Todd Davison, Laura Golden, Alan Lewitus, Rob Magnien, Scott Cross, Marjorie Elizabeth Clarke, Steve Giordano, Kristen Laursen, Doug Lipton, Susan Baker, Shannon McArthur, Paula Davidson, Nicole Kurkowski, Shelby Walker, Tracy Rouleau	NOAA
2015 NOAA Administrator's Award	LCDR Michael Gonsalves, Christina Fandel, Patrick Keown	NOAA
2015 NOAA Administrator's Award	Drew Saunders, David Helms, Kevin Kelleher, John Schneider, Greg Pratt	NOAA
2015 NOAA Administrator's Award	Ko Barrett, Cynthia Decker, Adam Parris, Kathelene Williamson, Dave Easterling, Kandis Wyatt, Stephanie Herring, Thomas Karl, Roger Griffis, Margaret Davidson, David Diamond, Brady Phillips, MacKenzie Tepel	NOAA
2015 NOAA Bronze Medal	Wanda Harding	NOAA
2015 NOAA Bronze Medal	James Kossin	NOAA
2015 NOAA Bronze Medal	Monica Todirita	NOAA

Award	Recipient (s)	Award Organization
2015 NOAA Bronze Medal	Russell S. Vose, Scott Applequist, Michael Squires, Imke Durre, Matthew J. Menne, Claude N. Williams, Jr., Christopher Fenimore, Karin Gleason, Derek Arndt, Jesse Enloe	NOAA
2015 NOAA Bronze Medal	Peter L. Boveng, Michael F. Cameron, Paul B. Conn, Shawn P. Dahle, John K. Jansen, Benjamin Hou, Brett T. McClintock, Erin E. Moreland, Jay M. Ver Hoef	NOAA
2015 NOAA Bronze Medal	Michael Schirripa, Mandy Karnauskas, Christopher Kelble, J. Kevin Craig	NOAA
2015 NOAA Bronze Medal	Roy Anderson, Mark Armstrong, Don Breidenbach, Steve Breidenbach, Eric Duvall, Mark Eckl, Kendall Fancher, Philippe Hensel, Ajit Singh, Dru Smith	NOAA
2015 NOAA Bronze Medal	Gregory Dusek, Christopher Paternostro, Paul Fanelli, Zhong Li, Patrick Burke, Jack Harlan	NOAA
2015 NOAA Bronze Medal	Amy Merten, Kari Sheets, Michele Jacobi	NOAA
2015 NOAA Bronze Medal	Joe N. Chrisman, Steven D. Smith	NOAA
2015 NOAA Bronze Medal	Huug van den Dool, Jin Huang, Qin Zhang	NOAA
2015 NOAA Distinguished Career Award	Felix Kogan	NOAA
2015 NOAA Distinguished Career Award	William G. Pichel	NOAA
2015 NOAA Distinguished Career Award	Thomas Wrublewski	NOAA
2015 NOAA Distinguished Career Award	Robert (Rob) Bistodeau	NOAA
2015 NOAA Distinguished Career Award	Linda Despres	NOAA
2015 NOAA Distinguished Career Award	Alec D. MacCall	NOAA
2015 NOAA Distinguished Career Award	Glen Watabayashi	NOAA
2015 NOAA Distinguished Career Award	David W. Behringer	NOAA

Award	Recipient (s)	Award Organization
2015 NOAA Distinguished Career Award	James E. Lee	NOAA
2015 NOAA Distinguished Career Award	Peter Pickard	NOAA
2015 NOAA Distinguished Career Award	Patricia Wnek	NOAA
2015 NOAA Distinguished Career Award	Richard J. Doviak	NOAA
2015 NOAA Distinguished Career Award	Ngar Cheung Lau	NOAA
2015 NOAA Distinguished Career Award	Akkihebbal R. Ravishankara	NOAA
2015 NOAA Distinguished Career Award	David J. Stensrud	NOAA
2015 Technology Transfer Award	Elaine Harrell, Shawn Puyear	NOAA
2015 Technology Transfer Award	Ian Taylor	NOAA
2015 Technology Transfer Award	John A. Ogren, Patrick J. Sheridan, James W. Wendell	NOAA
2016 Department of Commerce Gold Medal Award	N. Michael Simpson, Douglas Biesecker, Ronald Mahmot, Nancy DeFrancesco, Kevin Berberich, Richard Ullman, Jeffrey Clegg, H. Douglas Whiteley, Irene Parker, Suzanne Hilding	Department of Commerce
2016 Department of Commerce Gold Medal Award	Kenneth L. Pryor	Department of Commerce
2016 Department of Commerce Gold Medal Award	Jeffrey S. Whitaker	Department of Commerce

Award	Recipient (s)	Award Organization
2016 Department of Commerce Gold Medal Award	Jay Lawrimore, Anthony Arguez, Boyin Huang, Matthew Menne, Russell Vose, Huai-Min Zhang, Patricia Viva Banzon, Byron Gleason, Thomas Smith, Claude Williams	Department of Commerce
2016 Department of Commerce Gold Medal Award	Greg Bast, Devin Brakob, Ken Heystek, Terry Lynch, Bill Olney, James Price, Scott Price, Damon Sans Souci, Michael Silah, Mark Sweeney	Department of Commerce
2016 Department of Commerce Gold Medal Award	Diane Kapareiko, Dorothy Jeffress, Gary Wikfors	Department of Commerce
2016 Department of Commerce Gold Medal Award	Southern Region – National Weather Service	Department of Commerce
2016 Department of Commerce Gold Medal Award	James M. Roberts	Department of Commerce
2016 Department of Commerce Silver Medal Award	Mark Tew, Pablo Santos, David Sharp, Shannon White, Michael Dion, John Kuhn, Frank Alsheimer, Matthew Belk	Department of Commerce
2016 NOAA Employee of the Month	Ashfaq Dawood, Scott Jones, Jennier Saari, Bonnie Morgan, Tia Brown, Dan Kircheis, Shallin Busch, Genevieve Contey, Mariel Hughes, Mary Fairbanks, Imke Durre, Kyle Ward	NOAA
2016 NOAA Team Member of the Month	Susan Osborne, Carly Weil, Nicole Bonnie, Caridad Ibis Gonzalez, Patrick Condemi, Stephanie Stabile, Randall Silver, Brendan Reser, Chris Haith, L. Hokulani (hoku) Ka'aekuahiwi-Pousima, Elizabth (Meme) Lobecker, Rhonda Graves	NOAA
2016 Distinguished Career Award	David M. Anderson	NOAA
2016 Distinguished Career Award	Joan Arrington Browder	NOAA
2016 Distinguished Career Award	Roland R. Draxler	NOAA
2016 Distinguished Career Award	William T. (Bill) Peterson	NOAA
2016 Distinguished Career Award	Gary Shigenaka	NOAA
2016 Distinguished Career Award	Sam Pooley	NOAA

Award	Recipient (s)	Award Organization
2016 Distinguished Career Award	Michael K. Trainer	NOAA
2016 Distinguished Career Award	Qin Xu	NOAA
2016 NOAA Administrator's Award	Suzanne Hilding	NOAA
2016 NOAA Administrator's Award	R. Bradley Pierce	NOAA
2016 NOAA Administrator's Award	Jessica Kondel	NOAA
2016 NOAA Administrator's Award	Scott McEntire	NOAA
2016 NOAA Administrator's Award	Peyton Robertson, Bruce Vogt, John Lazar, Jr., David Bruce, Stephanie Westby	NOAA
2016 NOAA Administrator's Award	Andrea Bleistein, Steven Cooper, Douglas Hilderbrand, Michael Hudson, Marie Lovern, David Manning, Kevin Scharfenberg, Jennifer Sprague, Christopher Strager, Jason Tuell	NOAA
2016 NOAA Administrator's Award	Dustin C. Goering, Brian A. Connelly, Steven D. Buan, Wendy L. Pearson	NOAA
2016 NOAA Bronze Medal Award	Boyin Huang, Viva Banzon, Jay Lawrimore, Thomas Peterson, Thomas Smith, Huai-min Zhang	NOAA
2016 NOAA Bronze Medal Award	Shobha Kondragunta, Istvan Laszlo	NOAA
2016 NOAA Bronze Medal Award	Glenn Tallia, Tahara Dawkins, Eve Douglas	NOAA
2016 NOAA Bronze Medal Award	Steve Branstetter, Ken Brennan, Kelly Fitzpatrick, Elaine Harrell, Catherine Hayslip, Janet Miller, Pat O'Shaughnessy, Shawn Puyear, Jessica Stephen, Andrew Strelcheck	NOAA
2016 NOAA Bronze Medal Award	James M. Nance, Rick A. Hart, James A. Primrose, Rebecca C. Smith, Jo Anne Williams, Timothy J. Baumer, Susan D. Gerhart	NOAA
2016 NOAA Bronze Medal Award	Rhonda Reed, Elif Fehm-Sullivan, Chris Keifer, Shelby Mendez, Jeffrey McLain, Erin Strange, Juan Carlos Garza, Sierra Franks	NOAA
2016 NOAA Bronze Medal Award	Alan Mearns, Gary Shigenaka	NOAA

Award	Recipient (s)	Award Organization
2016 NOAA Bronze Medal Award	Richard Stumpf, Michelle Tomlinson, Tim Wynne, Marc Suddleson, Quay Dortch, Timothy Davis, Duane Gossiaux, Eric Anderson, Steven Ruberg, Margaret Lansing, Tom Joyce, Steve Constant	NOAA
2016 NOAA Bronze Medal Award	Aijun Zhang, Degui Cao, Eugene Wei, Zizang Yang, John Kelley, Hocheng Lin	NOAA
2016 NOAA Bronze Medal Award	Russell Treadon	NOAA
2016 NOAA Bronze Medal Award	Weather Forecast Office Seattle, WA, Northwest River Forecast Center	NOAA
2016 NOAA Bronze Medal Award	CDR Kristie Twining	NOAA
2016 NOAA Bronze Medal Award	Gustavo Goni, Francis Bringas, George Halliwell, Richard Bouchard	NOAA
2016 Silver Sherman Award	Kate Becker	NOAA
2016 Silver Sherman Award	Otto Bruegman	NOAA
2016 Silver Sherman Award	Hayden Frank	NOAA
2016 Silver Sherman Award	George Graettinger	NOAA
2016 Silver Sherman Award	Stephanie Herring	NOAA
2016 Silver Sherman Award	Justin Hospital	NOAA
2016 Silver Sherman Award	Michael Husler	NOAA
2016 Silver Sherman Award	Jason Kroll	NOAA
2016 Silver Sherman Award	Fred Samplasky	NOAA
2016 Silver Sherman Award	Thomas B. Schott	NOAA
2016 Silver Sherman Award	Fredrick Toepfer	NOAA
2016 Silver Sherman Award	Marian Westley	NOAA
2016 Silver Sherman Award	James (Marty) Williams	NOAA

Award	Recipient (s)	Award Organization
2016 Technology Transfer Award	Edward Meyer	NOAA
2016 Technology Transfer Award	Steven Breidenbach, John Ellingson, Kendall Fancher, Charles Geoghehan, Timothy Hanson, David Zenk, Brian Ward	NOAA
2016 Technology Transfer Award	Rodney Riley	NOAA

External Scientific Awards

(54 awards presented to 75 individuals and 7 offices)

Award	Recipient (s)	Award Organization
2016 AAAS Fellow	Carol Stepien	American Association for the Advancement of Science
2016 AAAS Fellow	Venkatachalam (Ram) Ramaswamy	American Association for the Advancement of Science
2016 Remote Sensing Prize	Richard J. Doviak	American Meteorological Society
2016 Yoshi Sasaki Award	Katie Bowden	Univ. of Oklahoma
Alan Berman Research Publication Award	Sean Helfrich	Naval Research Laboratory
Aviation Meteorology Award	Center Weather Service Unit - Memphis and Weather Forecast Office - Memphis	National Weather Association
Award for an Exceptional Specific Prediction	National Weather Service Forecast Office, Taunton, Massachusetts	American Meteorological Society
Award for Exceptional Specific Prediction	Buffalo Weather Forecast Office	American Meteorological Society
Banner I. Miller Award	David Nolan, Robert Atlas, Kieran T. Bhatia, Lisa Bucci	American Meteorological Society

Award	Recipient (s)	Award Organization
Bjerknes Lecturer	Isaac Held	American Geophysical Union
CIRA Research and Service Initiative Award	Steve Albers	Cooperative Institute for Research in the Atmosphere
CIRES Bronze Medal for Superior Performance	Shilpi Gupta, Hilary Peddicord, Beth Russell	Cooperative Institute for Research in the Environmental Sciences
CIRES Outstanding Performance Award	Chris Golden	Cooperative Institute for Research in the Environmental Sciences
CIRES Technology Award	Betsy Andrews and Anne Jefferson	Cooperative Institute for Research in the Environmental Sciences
Cleveland Abbe Award for Distinguished Service to Atmospheric Sciences by an Individual	Louis W. Uccellini	American Meteorological Society
Colorado Governor's Award for High Impact Research	Environmental Modeling Branch	CO-LABS
Dissertation Award	Barb Mayes Boustead	American Association of State Climatologists
Distinguished Service Award	Kevin Friedland	Gulf of Maine Council on the Marine Environment
Dobson Award	Birgit Hassler	International Ozone Commission
Dr. T. Theodore Fujita Research Achievement Award	Jonathan Blaes	National Weather Association
Early Career Fellows	Ariana Sutton-Grier	Ecological Society of America
Editor's Award	Mark Govett	American Meteorological Society
Edward T. LaRoe Memorial Award	Barb Taylor	Society for Conservation Biology North America
Gilbert F. White Lecturer	Roger Pulwarty	American Geophysical Union

Award	Recipient (s)	Award Organization
Haagen-Smit Prize	Georg Grell, Stuart McKeen, Gregory Frost	Elsevier
Innovation in Science Sustainability Award	Ariana Sutton-Grier, Katya Wowk, Holly Bamford	Ecological Society of America
Interagency Partnership Award	James Verdin, Michael Ek, Christopher Jackson, Xiwu Zhan, Frank Monaldo, Pedro Restrepo	Federal Laboratory Consortium
Larry R. Johnson Special Award	Storm Prediction Center and Weather Forecast Office	National Weather Association
National Academy of Engineering Member Inductee	Honorable Kathryn Sullivan	National Academy of Engineering
Operational Achievement Award	Lance Wood	National Weather Association
Operational Achievement Award	Thomas Hultquist	National Weather Association
Outstanding Performance Award for Science and Engineering	Brian Lerner	Cooperative Institute for Research in Environmental Sciences
Outstanding Performance Award for Science and Engineering	Andrew Rollins, Troy Thornberry Laurel Watts, Richard McLaughlin	Cooperative Institute for Research in Environmental Sciences
Outstanding Performance Award for Service	Rick Tisinai, Gabrielle Accatino, Catherine Burgdorf-Rasco	Cooperative Institute for Research in Environmental Sciences
Outstanding Student Presentation Award	Erin McDuffie	American Geophysical Union
Pew Marine Conservation Fellow	Jennifer O'Leary	PEW Charitable Trusts
Presidential Early Career Award for Scientists and Engineers	Nate Bacheler	White House Office of Science and Technology Policy
Presidential Early Career Award for Scientists and Engineers (PECASE)	James Thorson	White House Office of Science and Technology Policy
Presidential Early Career Award for Scientists and Engineers (PECASE)	Gijs de Boer	White House Office of Science and Technology Policy

Award	Recipient (s)	Award Organization
Professor Dr Vilho Väisälä Award for an Outstanding Research Pape	Dale Hurst	World Meteorological Organization
Public Education Award	Maria Torres	National Weather Association
Publication of Enduring Significance Award	Dan Holland	Marine Resource Economics
Regional Emmy Award	Kurt Mann and Todd Shortridge	National Capital Chesapeake Bay Chapter of the National Academy of Television Arts and Sciences
Roger Jones Award	Louis W. Uccellini	American University
Rutgers Challenger and Distinguised Alumni Award	Craig McLean	Rutgers University
Salish Sea Science Prize	Nathaniel Scholz, Jennifer McIntyre, David Baldwin	SeaDoc Society
Samuel J. Heyman Service to America Medal	James Mcfadden	Partnership for Public Service
Samuel J. Heyman Service to America Medal	Richard Alan Feely	Partnership for Public Service
Special Achievement Award	Eleanor Vallier-Talbot and Jeffrey S. Tongue	National Weather Association
Sverdrup Gold Medal Award	Michael McPhaden	American Meteorological Society
The Walter Orr Roberts Lecturer in Interdisciplinary Sciences	Venkatachalam "Ram" Ramaswamy	American Meteorological Society
U.S. THORPEX Certificate of Recognition	Zoltan Toth	THORPEX
UVIG Achievement Award	Melinda Marquis, Stan Benjamin, Joseph Olson	Utility Variable-Generation Integration Group
Yoram J. Kaufman Unselfish Cooperation in Research Award	Karen H. Rosenlof	American Geophysical Union

Scientific Integrity

At the direction of President Obama, NOAA and its sister agencies have put Scientific Integrity at the forefront, addressing two aspects of the issue: 1) raising the stature of our research scientists in the Federal government; and 2) addressing scientific misconduct.

For the former, NOAA has developed procedures and policies to ensure that employees are encouraged to serve in elected positions in professional societies. These prestigious positions give our scientists the opportunities to help frame and direct research agendas and priorities within the relevant technical communities. As a result, NOAA now has 36 people, in 22 organizations, serving in these capacities, and many of those serving have done so at the highest levels. The impact this will have on our ability to recruit and retain top scientific talent into the federal government is quite powerful.

This list reflects only those NOAA personnel who were actually serving, effective October 1, 2016.

NOAA Scientist	Job Title	Professional Society	Position
John Bates	Meteorologist / Principal Scientist	American Geophysical Union (AGU)	Member, Board of Directors
Andrea Bleistein	Physical Scientist	American Meteorological Society	Councilor
Stephania K. Bolden	Supervisory Fisheries Biologist	North American Sturgeon and Paddlefish Society	Member at Large of the Governing Board
Michelle Crockett	National Program Manager EEO and Diversity	Federally Employed Women	Immediate Past President
Laura Furgione	Deputy Assistant Administrator for Weather Services	American Meteorological Society	Councilor on the Executive Board
John Gagan	Science and Operations Officer	National Weather Association	Council Member
Randy Graham	Meteorologist in Charge, Weather Forecast Office Salt Lake City, UT	National Weather Association	Secretary
Jeffrey Kelley	General Forecaster/ Meteorologist	The High Plains Chapter of the American Meteorological Society/ National Weather Association	Treasurer

NOAA Scientist	Job Title	Professional Society	Position
Gail Hartfield	Senior Forecaster at Weather Forecast Office Raleigh, NC	National Weather Association	President Elect
Fiona Horsfall	Chief, NWS Climate Services Division	American Association of State Climatologists	ex-Officio Executive Board
Tamara Houston	Regional Climate Services Program Manager	American Association of State Climatologists	ex-Officio Executive Board
Daniel Howard	Sanctuary Superintendent, ONMS	San Francisco International Ocean Film Festival (SFIOFF)	Member, Board of Directors
Dan Kowal	Chief, Standards & Evaluation Branch	Colorado State Science Fair	Treasurer
Jayme Layber	Hydrologist	California Geographic Information Association	Board Member
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Michael Vescio	Meteorologist in Charge	National Weather Association	Secretary
Christa von Hillebrandt-Andrade	Manager, Caribbean Tsunami Warning Program	International Association with Physical Science of the Oceans	Member of the Executive Committee

Laboratory and Program Science Reviews

Peer review and evaluation is critical in maintaining NOAA's world-class research enterprise. The NAO on Research and Development in NOAA (NAO 216 115A) requires an evaluation of NOAA's R&D activities, including regular independent peer review assessments at least every five years.

These reviews assess R&D activities for quality of the science as well as how well the activities meet NOAA's mission needs and/or requirements (i.e. relevance and performance). Consistent with the principles and guidance codified in the NAO, each line office conducts reviews of their laboratories and programs.

The following hyperlinks associated with the various NOAA laboratories and science programs offer more detail for reviews conduced to date.

External reviewers assessed the quality of the laboratories' research and development, and they reviewed the approaches that are in place to ensure that high quality work will be performed in the future. Furthermore, they assessed progress toward meeting OAR's goal to conduct preeminent research.

Reviewers assessed the degree to which the research and development is relevant to NOAA's mission and of value to the nation. Finally, reviewers assessed the overall effectiveness with which the laboratories plan and conduct their research and development, given the resources provided, to meet NOAA Strategic Plan objectives and the needs of the nation.

Office of Oceanic and Atmospheric Research Science Program and Laboratory Reviews

In 2016, OAR conducted lab reviews of the Great Lakes Environmental Research (GLERL) and Air Resources (ARL) Laboratories as part of the five-year cycle of laboratory reviews.

OAR Laboratories that Conduct Science Programs Covered by OAR Science Program Reviews

Laboratory/Office	Last Review Date
Atlantic Oceanographic and Meteorological Laboratory (AOML)	2014
Air Resources Laboratory (ARL)	2016
Earth System Research Laboratory (ESRL)	2015
Geophysical Fluid Dynamics Laboratory (GFDL)	2014
Great Lakes Environmental Research Laboratory (GLERL)	2016
National Severe Storms Laboratory (NSSL)	2015
Pacific Marine Environmental Laboratory (PMEL)	2014

National Marine Fisheries Service Science Program Reviews

In January 2013, as part of ongoing improvement efforts, NOAA Fisheries began a systematic peer review process at all six of our regional science centers and our headquarters Office of Science and Technology.

Experts from within and outside the agency carefully examine our fisheries science programs on a five-year cycle to evaluate the quality, relevance, and performance of research conducted in NMFS Science Centers and associated laboratories to strategically position the agency in planning future science and research.

Reviewers provide recommendations to each Science Center program and these are addressed by relevant leadership in a formal response that includes a timeline of action items.

At the end of each year, a national response to the full suite of review reports is developed that includes action items best addressed at the national level.

The schedule of annual reviews covers the core science program areas that directly support the NMFS mission.

FY 2013 – Data used for fishery stock assessments

FY 2014 – Fishery stock assessment process

FY 2015 – Protected species science

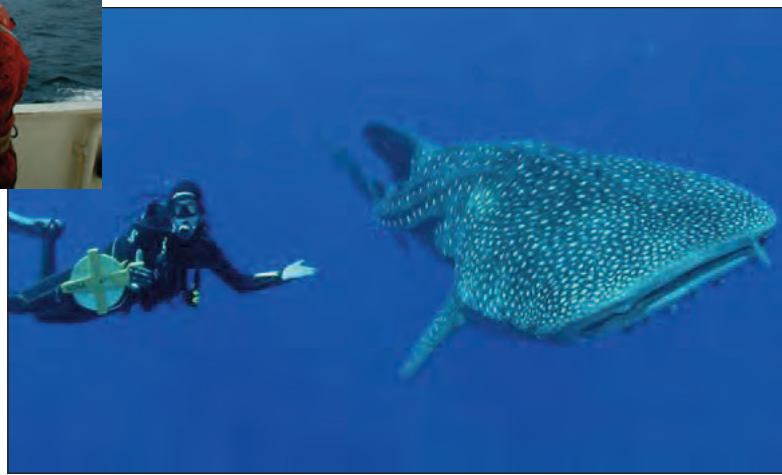
FY 2016 – Ecosystem, climate, and habitat science

FY 2017 – Economics and social science

NMFS plans to repeat the cycle of program reviews beginning in FY 2019, after strategic analysis of the program review results in FY 2018.

NMFS Regional Science Centers, Associated Laboratories, and Offices that Conduct Science Programs Covered by NMFS Science Program Reviews

NMFS Regional Science Center /Office	Associated Laboratories and Research Stations
Alaska Fisheries Science Center Seattle, WA	Auke Bay, AK
Northeast Fisheries Science center Woods Hole, MA	Milford, CT Narragansett, RI Orono, ME Sandy Hook, NJ
Northwest Fisheries Science Center Seattle WA	Manchester, WA Mukilteo, WA Newport, OR Pasco, WA Point Adams, OR
Pacific Islands Fisheries Science Center Honolulu, PI	
Southeast Fisheries Science Center Miami, FL	Beaufort, NC Galveston, TX Lafayette, LA Panama City, FL Pascagoula, MS Stennis, MS
Southwest Fisheries Science Center La Jolla, CA	
Office of Science and Technology, Headquarters, Silver Spring, MD	



National Ocean Service Science Program and Laboratory Reviews

Science from the National Ocean service delivers ecosystem science solutions to help sustain coastal communities and economies. Ultimately this research:

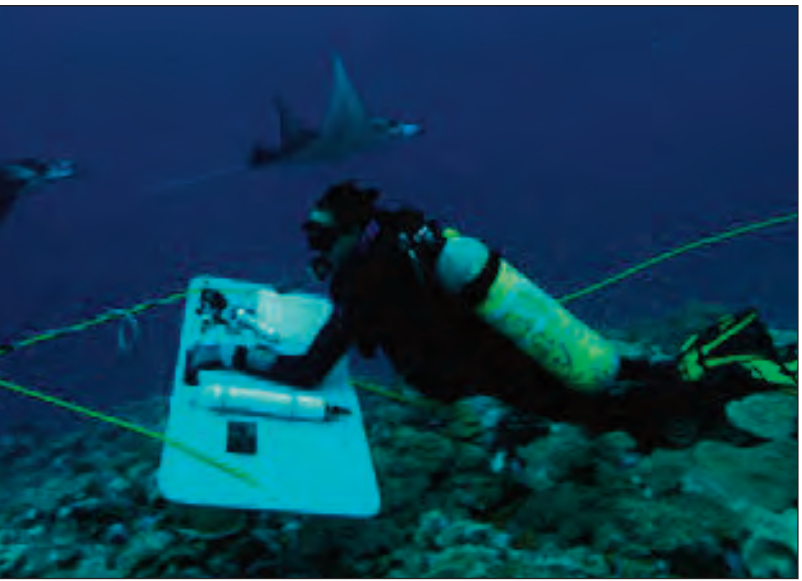
- Underpins NOAA's ability to predict and prepare for natural events and their impacts
- Enables faster and more accurate and efficient coastal mapping and monitoring
- Develops a multidisciplinary approach to understanding and conserving coral reef ecosystems
- Helps assess risk

National Center for Coastal Ocean Science (NCCOS)

Historically, NCCOS conducted periodic reviews of each of its Centers. These Centers were last reviewed between 2005 and 2012. An NOS-wide assessment between 2010 and 2012 provided extensive feedback and recommendations for coastal science, which initiated a realignment of NCCOS' science portfolio.

From 2014-2016 the office established a portfolio management system to oversee four key science priorities. Beginning in FY17, NCCOS will cycle through annual reviews on each of these priority areas:

Stressor Impacts and Mitigation – FY 2017
Marine Spatial Ecology – FY 2018
Social Science – FY 2019
Coastal Resilience and Climate Vulnerability – FY 2020



National Estuarine Research Reserve System

The National Estuarine Research Reserve System (NERRS) is a network of 28 coastal sites designated to protect and study estuarine systems. National estuarine research reserves are living laboratories, ideal sites for research and long-term monitoring.

Science Collaborative Program

The NERRS Science Collaborative, a competitive grant program, is the mechanism by which most of the NOAA-funded research undertaken at the nation's research reserves is accomplished.

An external review of the NERRS Science Collaborative program is currently underway. The University of Michigan is contracting with a third party to conduct the review. Results are expected in FY18.

System-Wide Monitoring Program (SWMP)

The monitoring program, known as the System-Wide Monitoring Program, provides long-term data on water quality, weather, biological communities, habitat, and land-use and land-cover characteristics.

Coral Reef Conservation Program Science Evaluation

The NOAA Coral Reef Conservation Program (CRCP) undertakes periodic evaluations of the information provided by NOAA scientific projects and programs that support coral reef conservation and management.

The purpose of the 2016 CRCP Ecosystem Science Review was to determine if the information provided by NOAA CRCP investments in ecosystem science is being used to support CRCP's mission and if CRCP ecosystem science is relevant, effective, and of high quality.

Information from this evaluation will be used to inform future allocation of CRCP resources to address strategic coral reef management needs in a targeted, cost-effective, and efficient manner.

NOS Associated Laboratories and Programs that Conduct Science Programs Covered by NOS Science Program Reviews

NOS Office	Lab/Program	Last Review Date
National Estuarine Research Reserve System (NERRS)	System-Wide Monitoring Program	2007
	Science Collaborative Program	Expected completion in FY18
Coral Reef Conservation Program (CRCP)	CRCP Science Evaluation	2016
Office of Coast Survey	Peer Review of the Coast Survey Development Lab's Spatially Varying Uncertainty Research program	2016
	Annual Peer review of the Joint Hydrographic Center	2016

National Weather Service Science Program and Laboratory Reviews

National Weather Service focuses on transitioning science advancements from research partners, such as OAR labs and the external research community, into the NWS by advancing their readiness levels and implementing them into operations based on prioritized operations and service requirements.

NWS developmental and transition organizations include the Environmental Modeling Center, Meteorological Development Laboratory, and National Water Center. In addition, the NWS field structure consists of science support and transition capability including Science Operations Officers (132), Development Operations Hydrologists (13), and seven (7) Service Centers in the National Centers for Environmental Prediction (NCEP).

NWS has regular processes to provide systematic science and management oversight and independent review for NWS developmental and transition organizations that ensure NWS development and transition priorities are consistent with operations service delivery requirements.

These processes include annual planning processes for operations and budget execution, quarterly program reviews conducted by NWS senior leadership, and annual reviews of NWS operational modeling and centralized product/service suites by stakeholders, partners, and users.

NWS also has a standing community advisory group of independent scientific experts under the auspice of University Corporation for Atmospheric Research (UCAR) to conduct annual reviews that ensure NWS models, tools, products, and services are based on sound science. The last UCAR review took place in August 2015 by the University Corporation for Atmospheric Research Community Advisory Committee (UCACN) Model Advisory Committee (UMAC).

Independent reviews, e.g., the UCAR group, provide findings and recommendations to NWS programs, and these are addressed by relevant leadership in a formal response that includes a timeline of action items. NWS development and transition organizations' response and action results are reported to the review group at the subsequent annual review meetings.

National Environmental Satellite, Data, and Information Service Science Program and Laboratory Reviews

NESDIS' Center for Satellite Applications and Readiness (STAR) promotes NOAA's investment in the acquisition and management of the nation's operational environmental satellites. STAR fulfills the critical role of advancing scientific-based research and development methods to transition satellite processing systems, environmental satellite measurements, and satellite observations to operations for stakeholder use.

An independent team of distinguished scientific administrators conducted an External Review of STAR research and development on March 19-21, 2010. It was STAR's first External Review since 2000.

Although such reviews had typically been conducted every five years, STAR's 2005 review was delayed while NOAA directed improvements to the oversight of NOAA science based on a) the quality of research, b) the relevance to NOAA's mission, and c) the performance of the research organization.

The new guidelines went into effect in 2009. STAR was the first organizations to be reviewed under those guidelines.

NESDIS Associated Laboratories and Programs that Conduct Science Programs Covered by NESDIS Science Program Reviews

Laboratory/Office	Last Review Date
Center for Satellite Applications and Research	2010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Conclusion

Scientific research and development are the foundation of advancing NOAA's mission. This report provides a wide, albeit shallow, rendition of the scope, complexity and relevance of our scientific portfolio.

In years to come, this series of *NOAA Chief Scientist's Annual Reports* will serve as a valuable compendium of the evolution of scientific knowledge and a reference for how far we have come in producing valuable environmental intelligence for humankind.

"Science can give mankind a better standard of living, better health and a better mental life, if mankind in turn gives science the sympathy and support so essential to its progress."
- *Vannevar Bush*

Glossary

ABI	Advanced Baseline Imager
AECOM	Architecture, Engineering, Consulting, Operations, and Maintenance
AOML	Atlantic Oceanographic and Meteorological Laboratory
API	Application Program Interface
ARL	Air Resource Laboratory
ASRE	Atmospheric Science for Renewable Energy
ATMS	Advanced Technology Microwave Sounder
AUV	Automated Underwater Vehicle
AWS	Amazon Web Services
BDP	Big Data Partnership
BOEM	Bureau of Ocean Energy Management
CAPSTONE	Campaign to Address Pacific monument Science, Technology, and Ocean NEeds
CFS	Climate Forecast System
CI	Cooperative Institute
CILER	Cooperative Institute for Limnology and Ecosystems Research
CME	Coronal Mass Ejection
CNCI	Category Normalized Citation Impact
CNES	Centre National D'Etudes Spatiales
CO-OPS	Center for Operational Oceanographic Products and Services
COCA	Coastal and Ocean Climate Applications
CPC	Climate Prediction Center
CRADA	Cooperative Research and Development Agreement
CRCP	Coral Reef Conservation Program
CRF	Cloud Radiative Forcing
CrIS	Cross-track Infrared Sounder
CRT	Climate Resilience Toolkit
CTB	Climate Test Bed
DBO	Distributed Biological Observatory
DOC	Department of Commerce
DOD	Department of Defense
DOE	Department of Energy
DSCVR	Deep Space Climate Observatory Satellite
EM	Electronic Monitoring
EPA	United States Environmental Protection Agency

ESP	Environmental Sample Processor
ESRL	Earth System Research Laboratory
EUMETSAT	European Organisation for the Exploitation of Meteorological Satellites
FACETS	Forecasting A Continuum of Environmental Threats
FEMA	Federal Emergency Management Agency
FLASH	Flooded Locations and Simulated Hydrographs
FY	Fiscal Year
GFDL	Geophysical Fluid Dynamics Lab
GFS	Global Forecast System
GLERL	Great Lakes Environmental Research Laboratory
GLM	Geostationary Lightning Mapper
GOES-R	Geostationary Operational Environmental Satellite R-Series
GPS	Global Positioning System
GRAV-D	Gravity for the Redefinition of the American Vertical Datum
GSI	Gridpoint Statistical Interpolation
HAB	Harmful Algal Bloom
HRRR	High-Resolution Rapid Refresh
HWRF	Hurricane Weather Research and Forecast
HYCOM	Hybrid Coordinate Ocean Model
J-SCOPE	JISAO Seasonal Coastal Ocean Prediction of the Ecosystem
JISAO	Joint Institute for the Study of the Atmosphere and Ocean
MBARI	Monterey Bay Aquarium Research Institute
mPing	Meteorological Phenomena Identification Near the Ground
NAO	NOAA Administrative Order
NASA	National Aeronautics and Space Administration
NCAR	National Center for Atmospheric Research
NCCOS	National Centers for Coastal Ocean Science
NCEI	National Centers for Environmental Information
NCEP	National Centers for Environmental Prediction
NEERS	National Estuarine Research Reserve System
NEPA	National Environmental Policy Act
NESDIS	National Environmental Satellite, Data, and Information Service
NEVA	Northeast Fish and Shellfish Climate Vulnerability Assessment
NEXRAD	Next Generation Weather Radar

NGS	National Geodetic Survey
NIC	National Ice Center
NLDAS	North American Land Data Assimilation System
NMFS	National Marine Fisheries Service
NWM	National Water Model
NOAA	National Oceanic and Atmospheric Administration
NOS	National Ocean Service
NPP	National Polar-orbiting Partnership
NSSL	National Severe Storms Laboratory
NUCAPS	NOAA-Unique Combined Atmospheric Processing System
NWFSC	Northwest Fisheries Science Center
NWS	National Weather Service
O2R	Operations to Research
OA	Ocean Acidification
OAP	Ocean Acidification Program
OAR	Office of Oceanic and Atmospheric Research
OER	Office of Exploration and Research
OMAO	Office of Marine and Aviation Operations
PMEL	Pacific Marine Environmental Laboratory
R&D	Research and Development
R2O	Research to Operations
R2X	Research Transitions to Operations, Applications, Commercialization, and Utilization
RAP	RApid refresh
RL	Readiness Level
RTAP	Research Transition Acceleration Program
S4	Supercomputer for Satellite Simulations and Data Assimilation Studies
SI	Smithsonian Institution
SWMP	System-Wide Monitoring Program
UAS	Unmanned Aircraft System
UCACN	University Corporation for Atmospheric Research Community Advisory Committee
UCAR	University Corporation for Atmospheric Research
UMAC	UCACN Model Advisory Committee
USDA	United States Department of Agriculture
USFS	United States Forest Service

USFWS	United States Fish and Wildlife Service
USGS	United States Geological Survey
USV	Unmanned Surface Vessel
VCS	Verified Carbon Standard
VHF	Very High Frequency
VIIRS	Visible Infrared Imaging Radiometer
WECOA	West Coast Ocean Acidification
WRF-CHEM	Weather Research and Forecasting model coupled to Chemistry
WRF-Hydro	Weather Research and Forecasting Hydrology
WRN	Weather-Ready Nation

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