WRITTEN STATEMENT OF
KATHRYN SULLIVAN, PH.D.
ACTING UNDER SECRETARY OF
COMMERCE FOR OCEANS AND ATMOSPHERE
AND ACTING NOAA ADMINISTRATOR
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
U.S. DEPARTMENT OF COMMERCE

ON
"RESTORING U.S. LEADERSHIP IN WEATHER FORECASTING, PART 2"

BEFORE THE
SUBCOMMITTEE ON ENVIRONMENT
HOUSE COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY
U.S. HOUSE OF REPRESENTATIVES

June 26, 2013

Introduction

Chairman Stewart, Ranking Member Bonamici, and Members of the Committee, it is my honor to testify before you today on the state of United States (U.S.) weather forecasting capabilities and opportunities to improve forecasting of high impact events such as hurricanes, tornadoes, and winter storms. We at the National Oceanic and Atmospheric Administration (NOAA) welcome your interest in something we care strongly about. NOAA is trusted with the responsibility to provide environmental intelligence to American citizens, businesses, and governments to enable informed decisions on a range of issues and scales local to global and short-term to long-term. NOAA provides a suite of products and services to the American people, including the reliable and timely delivery of public weather warnings which help to safeguard lives. To do so, we work closely with the larger community of emergency officials, other federal agencies, and the commercial weather enterprise to deliver the best possible information that science and technology can provide. Put simply, this is information that saves lives and enhances our national economy.

NOAA continually strives to provide the most accurate and timely forecasts that the best advances in science and technology can deliver. Much of our success in providing these services and products comes from scientific and technological breakthroughs produced by research across disciplines, time and space scales. Therefore, we caution against actions that would insert rigid boundaries between advancing our mission and the research that helps achieve that goal. The dynamic systems of this planet are interconnected in rich and complex ways, and the past successes we have achieved in forecast improvement have come by looking broadly across those linkages. Furthermore, the NOAA National Weather Service (NWS), driven by demand from our customers, has evolved to provide more than just short-term weather forecasts. NOAA's prediction capabilities are becoming a fusion point that emergency managers, broadcasters, and the public increasingly turn to as a trusted one-stop shop that distills scientific information into "impacts coming my way." This is done by embracing a number of interrelated fields of science, and not just physical science, examining the atmosphere, oceans, land, ice, and space, but also the social and economic sciences.

While we do have concerns with the legislation, it does set a clear goal of delivering substantial improvements to our weather forecast capabilities for high impact events. Improved weather forecast capabilities are a goal of NOAA's. It is a significant and worthwhile endeavor, and it is an ambitious, yet achievable goal. In fact, it harkens to a similar goal set forth by President Kennedy to put a man on the moon. That goal led to a concerted national effort, with government and industry partnered together. It also forced us to pursue advances across a wide range of scientific fields. To get to the moon and back, we didn't just need powerful rockets. We needed advances in metallurgy, chemistry, physics, computing, instrumentation, human physiology and countless other fields. In other words, if we had focused solely on building better rockets, we never would have achieved our goal. I believe there are similar analogies to be made here. In order to advance weather forecasting we must realize advances across all of the interdisciplinary fields of earth science and research. We must leverage partnerships within government, academia, and the commercial sector, and we must actively pursue a balanced program to advance all of the factors critical to success in concert.

NOAA's weather prediction capabilities are supported by four fundamental pillars: observations; scientific research; computer modeling; and our people – who provide the forecasts, warnings, and decision support services to key decision makers. In order to advance forecasting capabilities, we must strengthen all four of these components together. In my testimony, I will highlight the importance of each of these pillars by elaborating upon:

- The interconnectedness of our earth systems and the need for making sustained observations across a range of temporal and spatial scales;
- The robust and vital national foundation that these pillars represent, and the importance of continuity and synergy between observations, research, and forecast operations;
- The products and services that NOAA provides to the Nation that help save lives, protect property, make communities more resilient and safe, and foster private sector growth; and
- How NOAA has gotten to where it is today, what we have learned, and where NOAA must go in the future.

Today's priorities may require surges in resources for immediate action, but we cannot ignore the investments in observations and foundational research that set the stage for long-term environmental sustainability and future service advancements. We must maintain equilibrium between the push-pull of research and operations, and between responding today and preparing for tomorrow, in order to increase our effectiveness and value to the American public.

Research Flexibility

As a former astronaut, I can tell you that one view out the shuttle window vividly illustrates what every textbook, research project, and phase of human history also teaches: that the Earth's systems are interconnected in complex ways, and we must seek to understand these linkages if we wish to improve any application of earth science to our everyday life. For example, historically, weather and climate models only incorporated atmospheric inputs and outputs. Only recently have these been integrated with ocean models to provide a more robust picture of our earth system. The Earth system models of the future will increasingly involve coupling atmospheric data with ocean, land, ice, ecological, and space-based data. A better understanding of how these dynamic Earth systems are interconnected is vital to advancing weather forecasting. This is what our researchers and forecasters strive for every day.

In the scientific world, “weather” is classified at shorter time scales, which technically extends to two weeks. Any forecast timescales beyond two weeks are classified as “climate.” But the “climate” forecast timescales we are talking about here are weeks, months, seasons, and years - not centuries. For example, one takes into account the weather prediction when deciding what clothing to wear tomorrow, while climate information will determine the composition of your winter wardrobe and aid in scheduling a winter getaway at a ski resort. The American public and vital industries rely not only on our weather products but also on our climate outlooks. Furthermore, our weather products and services are strengthened by our understanding of the weekly, monthly, seasonal, annual, and inter-annual earth system phenomena. If the goal is to achieve actionable seasonal hurricane outlooks, or accurate drought forecasts six months to two years in advance, one needs to conduct our research beyond two weeks. In other words, we often need to work on climate timescales in order to improve weather forecasts and services.

There is an ever increasing demand for additional lead time ahead of severe weather events. Emergency management officials have indicated that at ideal capabilities NOAA would provide highly consistent and accurate hurricane landfall predictions at days five and six, allowing for pre-positioning of crews, enhanced mitigation and evacuation efforts, and improved recovery planning – all of which can result in many more lives saved and significantly less money spent. Similarly, an hour of warning before a powerful tornado, versus the minutes of warning we can give today, might allow people to seek secure shelter and avoid being caught in vehicles, homes, or schools not robust enough to withstand a powerful storm. Many economic sectors such as agriculture, energy, and water management would see significant cost savings with highly accurate drought predictions from six months, to several years in advance. Imagine the benefit for a farmer in the Midwest of knowing before spring planting that a severe drought is expected throughout the entire growing season. If NOAA is to achieve these goals, we must research both shorter time scales and longer time scales.

The links among weather, climate variability, and climate change are pervasive and important to understand in order to improve weather prediction. We caution against actions to increase one important mission area to the detriment of the NOAA research programs in climate or ocean science. In the long term, this would weaken and undermine NOAA's weather forecasting enterprise in that weather is closely linked to the state of the ocean and variations in climate. As weather forecasting seeks to extend forecasts beyond ten days, and climate modeling seeks to shrink the resolution and time scale to less than a year, we are refining the intersection between where weather ends and climate begins.

We share the Committee’s goal of enhancing weather research and improving forecasts. However, as NOAA’s integrated response to Hurricane/Post-Tropical Cyclone Sandy (Sandy) demonstrated, protecting society today from “weather hazards” requires the ability to fuse information about all the impacts a hazard will have, such as flooding, storm surge, and navigation impacts. While NWS remains dedicated to the operational forecast mission, their success is not just measured in their ability to predict atmospheric pressure and temperature, but in the ability of the rest of the agency, such as that of the Office of Oceanic and Atmospheric Research (OAR), to conduct cutting edge research, and in NOAA’s ability to translate and integrate information into useful guidance for the surrounding community.

This past October, NOAA mobilized programs and efforts from across the agency to help the public prepare for, respond to, and recover from Sandy. In the weeks prior to Sandy, NOAA used models informed by satellite, aircraft, and other weather observations to predict the path of the storm. NOAA gave emergency personnel and the public an accurate track forecast a full four days before the October 29 U.S. landfall. We also provided forecasts of total rainfall, storm surge, wave height, and other phenomena that would impact the mid-Atlantic and northeastern states. Our accurate predictions enabled emergency managers to more precisely evacuate coastal areas in the path of this unprecedented storm, saving countless resources and lives.

Once the storm passed through the Northeast, NOAA coordinated with Federal, State, and local agencies to aid on-the-ground responders to help communities get back on their feet. For example, NOAA vessels were instrumental in identifying and clearing marine hazards blocking New York and New Jersey ports, enabling ships to provide critical fuel resupply just days after the storm. Maritime traffic resumed more quickly, thanks in good part to NOAA regional navigation managers embedded within command centers and survey assets we mobilized rapidly after the storm passed. In addition, NOAA planes and scientists conducted aerial surveys of the affected coastlines and immediately published the photos online, allowing emergency managers and residents to examine the damage even before ground inspections were permitted. More than 3,000 miles of coastline were surveyed, and more than 10,000 images processed to document coastal damage and impacts to navigation.

NOAA is now working to help affected communities recover. The Disaster Relief Appropriations Act of 2013 (P.L. 1132) appropriated $326 million to NOAA that will enhance our ability to help coastal States recover from the impacts of Sandy. The technical tools and information that NOAA’s coastal programs provide—such as coastal inundation products, maps, and storm surge modeling capabilities—are helping communities rebuild in a manner that is smarter and safer, and improvements in our forecasting capabilities will ensure that we are better prepared for similar events in the future. NOAA’s integrated response to Sandy demonstrates how our agency leverages its diverse capabilities to support the nation from preparedness to response to recovery: **data** collected from a spectrum of platforms enables the development of **environmental intelligence** from science-based models to support a suite of **products** to provide decision support to individuals, communities, and governments.

I am proud of the work NOAA did during Sandy. Our people rose to meet the challenge that great storm presented. Last month we released our Sandy assessment and while it found that NOAA’s forecasts saved lives and property it also highlighted areas we can improve. Most significantly it recommended that NOAA accelerate improving our storm surge products. Consistent and accurate storm surge forecasts further in advance will help affected states in their response to tropical cyclone hazards. We are committed to improved storm surge products and how best to communicate that information – because we are committed to serving our users. To make good on that commitment we must continue to direct resources to ocean and coastal research, observing, and mapping, not away from them.

The success of NOAA's mission should be measured by the strength of its research, the accuracy of its information, and by the effectiveness of its application to societal needs. As such, NOAA is pursuing a number of innovative approaches not only to provide significantly more lead time for forecasts, but also to ensure that people hear these warnings and take informed and appropriate actions to protect their own safety. Our Nation needs to be ready for weather impacts, respond to them, and be resilient to recover from them. This mixture of technological and social science advancements is a new approach to building a "Weather-Ready Nation" and one that we expect to provide large returns – measured in avoided economic losses and saving of lives and property.

Observations, Research, and Prediction

NOAA's Weather Mission

Since it was established, NOAA has relied on mission-focused research and innovation to improve our services to the Nation. NOAA has the sole federal responsibility of issuing severe weather warnings to communities across the country. NOAA-led weather innovations spanning decades - such as the national Doppler Radar network, dual-polarization radar, weather modeling improvements, and next generation geostationary and polar-orbiting satellites - continue to provide our Nation with increases in advanced warnings that help save lives and property from severe weather events that can devastate communities. The weather and climate disasters for 2012 exceeded $110 billion in damages, making that the second costliest year since 1980. Eleven events each had losses exceeding $1 billion in damages, including seven severe weather and tornado events, two tropical cyclones, and the yearlong drought and its associated wildfires.[1] NOAA was able to provide advanced and accurate forecasts to the states and communities facing these challenges, thanks to its continued investment in the long-term research and development that fuel innovation. There is much more to be done if we are to achieve new life-saving advancements in the future, and NOAA is committed to working with its federal, academic, private sector, and international partners in the broader enterprise to continue this record of success.

As I stated above, NOAA's environmental predictive capabilities are supported by four foundational pillars: observations, scientific research, computer modeling (including High Performance Computing), and our people – who provide forecasts, warnings, and decision support services to key decision makers. In order to advance forecasting capabilities, we must strengthen all four of these pillars in concert. For example, our forecast models are only as good as the data we put in them. Without sustained investments and continuity in high quality observational data, the accuracy of our operational forecast models would suffer. Only by evolving in concert across each of these realms can we revolutionize forecast capabilities.

Similarly, while near-term advances in observing, computing, and forecast model development are important, long term research and the effective transfer of research into operations are equally important. NOAA must have a continued investment in longer term research (looking five to fifteen years ahead) aimed at developing the next-generation radars, prediction models and services that will make, and keep, the U.S. and our NWS "second to none." In the wake of severe storm events, there is often a tendency to focus on the operational mission above all else. We see time and time again that the best way to ensure future advances and innovation is to maintain a robust research program independent of, but tied richly to, the operational mission.

Similarly, innovation is necessary in order to meet the Nation's weather and water needs. Specifically, investing in shoring up aging infrastructure, improving scientific understanding, and implementing enhanced services are necessary to reduce risk to the Nation. Perfect forecasts

---

[1] http://www.ncdc.noaa.gov/news/preliminary-info-2012-us-billion-dollar-extreme-weatherclimate-events

don't save lives without the infrastructure to disseminate them and an understanding of how best to communicate to spur individuals to take action. In addition, NOAA must increase its capacity to collect and assimilate ever-growing quantities of data to improve model performance, and hence weather predictions and forecasts. This, too, can only be achieved through advancements in scientific research and technological advancements. Future technology improvements and computing assets are crucial pieces of our national infrastructure.

The State of NOAA's Weather Forecasting

The tornadoes that caused so much devastation last month in Oklahoma, as well as those of Alabama and Missouri in 2011, and the huge toll from hurricanes such as Sandy and Katrina, underscore the importance of delivering the best possible weather information with as much lead time as possible. For example, NOAA's four-day predictions for hurricane track have become as reliable as our two-day predictions were prior to 1995. Today's 5-day temperature forecasts have the same level of accuracy that 3-day forecasts had 20 years ago. Our tornado warning lead times have more than doubled over the past two decades, to an average of 13 minutes. This is possible because NOAA's weather and climate research and development efforts are integrated into operations as a mainstay of NOAA's forecast and warning operations and capabilities. However, there are still significant areas for improvement.

Environmental Observations

Our current forecast process uses observations gathered by NOAA-operated systems such as *in situ* weather stations, balloons, buoys, radars, and satellites, as well as data collected by other federal agencies, international partners, and the commercial and academic sectors. These observations provide the critical foundation for the continuum of research models, operational models, and accurate forecasts and warnings.

NOAA's current satellites, both the polar-orbiting satellites and the geostationary satellites, provide critical data to support daily weather forecasting, including detection and monitoring of severe weather and space weather, and measuring the state of the atmosphere to incorporate in weather models. NOAA augments the data it requires by leveraging relevant data from foreign satellites and by purchasing data from the commercial sector to meet the agency's needs. We are in continual dialogue with the commercial sector and our international partners, and we recognize the value and importance of these public-private and international partnerships.

Weather Research Partnerships

NOAA's research endeavors include strong connections to academia, the federal government, international agencies, and the commercial sector. NOAA works hand-in-hand with the academic sector. More than half of NOAA's 18 Cooperative Institutes, several Sea Grant Colleges, and two Cooperative Science Centers are advancing various aspects of weather research. Other federal contributors include, but are not limited to, the National Aeronautics and Space Administration (NASA), the Department of Defense (DoD), U.S. Geological Survey (USGS), and investigators supported by the National Science Foundation (NSF), with notable contributions from the NASA/NOAA/DoD Joint Center for Satellite Data Assimilation.

Interagency Collaboration

NOAA and NASA have partnered for more than 40 years in the area of Earth Observations. As outlined in the 2010 National Space Policy,[2] NOAA and NASA collaborate to provide research-to-operations transition of capabilities and measurements that NASA has developed into ongoing and long-term observations aboard NOAA operational platforms. This arrangement has resulted in the successful transition of the satellite altimetry (sea surface height) capability (known as Jason) to operations, due in large part to the utility of the data for many of NOAA's programs, especially hurricane forecasting. Data and imagery from NOAA's polar-orbiting and geostationary satellites, in conjunction with sea surface height measurements, have proven extremely useful to predicting hurricane intensification. Future satellite systems, including those currently being procured, will continue to provide enhanced observations to support more accurate weather forecasts and more timely warnings.

NOAA has two critical partners, USGS and the U.S. Army Corps of Engineers (USACE), in flood-fighting, forecasting, and prediction. USGS funds and operates the vast majority of the nearly 6,000 river and stream gauges that NWS uses to monitor and forecast river flooding. Without these real-time gauges, and without their historical data, NOAA would be severely hampered, and in many cases unable, to issue its lifesaving flood warnings. Similarly, as USACE manages river and reservoir projects, the two-way communication of data and information about the timing and amount of discharge is critical to our river modeling and flood forecasting. Through the tri-agency Integrated Water Resources Science and Services partnership, the three agencies are joined in a common mission to provide critical data and information to each other, and to the public.

A program this Committee has long supported, the National Integrated Drought Information System (NIDIS) program, is built on longstanding efforts among the agencies and institutions that have historically focused on drought risk assessment and response. The NIDIS Act prescribes an interagency approach, led by NOAA, to "enable the Nation to move from a reactive to a more proactive approach to managing drought risks and impacts." The goals of the program are to (a) improve public awareness of drought and attendant impacts and (b) improve the coordination and capacity of counties, states, and watersheds to reduce drought risks proactively. NIDIS partners include the National Drought Mitigation Center (NDMC) at the University of Nebraska-Lincoln, U.S. Department of Agriculture, Department of Energy, Department of Homeland Security, Department of the Interior, Department of Transportation, USACE, NASA, and NSF, just to name a few. The number of watershed, state, and local drought and water plans using NOAA-based information has increased significantly since NIDIS was initiated in 2007. The support that NIDIS has generated and the ability of the program to meet the needs of the Nation are a result of the strong partnerships that the program has with other agencies, outreach organizations, and an enabling set of programs and observational capabilities. In December 2012, the Secretary of Agriculture and the Acting Secretary of Commerce signed an updated DOC-USDA Memorandum of Understanding (MOU) that is aimed at improving cross-agency collaboration on drought risk reduction, the development and delivery of drought information services at local and regional scales for relevant economic sectors, and the fostering of improved understanding by end-users. Necessary advancements in drought prediction, forecast products, and services require the integration of multiple scientific disciplines across

[2] http://www.whitehouse.gov/sites/default/files/national_space_policy_62810.pdf

multiple time scales. Such advancements cannot be achieved if efforts are limited to short timescales and isolated in single scientific disciplines.

International Collaboration

NOAA also partners with international satellite agencies to share the responsibilities of acquiring specific data or capabilities beneficial to both parties. Perhaps the best-known example is the collaboration with Europe's operational weather satellite agency, the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT). Through this partnership, NOAA has provided 11 instruments to fly aboard three MetOp satellites, which provide data in the mid-morning orbit that are used by NWS in its numerical weather prediction models. By providing the instruments to EUMETSAT, NOAA avoided the hundreds of millions of dollars it would have cost to procure a spacecraft bus and pay for launch services to get the data NWS needs for reliable forecasts.

Commercial Sector Collaboration

To provide the best possible weather services to the Nation, NOAA has also developed a close working relationship with the U.S. commercial weather sector. This has been growing since the 2003 National Academy of Sciences report, *Fair Weather: Effective Partnerships in Weather and Climate Services,* and has gained momentum in recent years with NOAA's "Weather Ready Nation" initiative. The NOAA Science Advisory Board established, and has recently re-chartered, the Environmental Information Services Working Group to strengthen connections between public and commercial sector activities in weather and climate. The American Meteorological Society also responded to the report and sponsored a productive set of meetings and interactions among the full weather enterprise, including Federal, academic, and commercial sectors. NOAA works to encourage more participation from the commercial and academic sectors in the development of advanced prediction capabilities that have operational potential. NOAA's work also fosters development of the commercial sector to significantly tailor products for increasingly specific audiences and needs.

Over the past decade, NOAA has purchased data from the commercial sector to fulfill a number of specific requirements. For example, NOAA purchased synthetic aperture radar data from the MDA Corporation to support operational sea ice and oil spill detection and monitoring programs. NOAA plans to continue this practice with commercial entities that have data that NOAA needs, as long as it is supplied within NOAA's operational construct. Looking to the future, NOAA is assessing the possibility of expanding data purchases from commercial sources and is closely monitoring ongoing international demonstration projects in this area. The President's FY 2014 Budget Request for NOAA also proposes to formally establish the National Mesonet Program, with a request of $5.5 million to promote the use of mesonet data. This request enables NOAA to procure and use surface and near-surface, localized weather data from commercial and academic sources, to improve forecasts and warnings of small-scale, high impact weather events that can quickly threaten lives and property.

Evaluating New Data Sources and NOAA's Data Policy

The NOAA Observing System Council (NOSC) studies existing and emerging observing systems to determine the best technologies that should be incorporated into operations. The NOSC compares the capabilities of these systems to NOAA requirements, and determines optimal solutions for the evolution of its entire system. NOAA and the NOSC use many tools, including Observing System Simulation Experiments (OSSEs) and Observing System Experiments (OSEs), in their ongoing development of the integrated system. Even though these quantitative analyses require a significant investment of manpower, High Performance Computing, and funding, NOAA believes that the increased rigor available from these quantitative tests will allow us to be more effective as the acquisition of observing systems becomes more complex. They are useful tools and have the potential to give NOAA better capability to weigh options before procurement of assets. We recognize their role in helping to prioritize and determine the potential use of commercial sources for major satellite and ground-based observing systems in the NOAA observing suite. However, NOAA cautions against requiring OSSEs to quantitatively assess the relative value and benefits of *all* observing system capabilities. In some cases, for example, evaluating systems that already exist, simpler OSE's (e.g. data denial studies) can be used. If the legislative language is too prescriptive, NOAA could consume its observation programs in OSSEs for years before being able to actually use the data. This would be entirely counter to the stated constructive intent of the legislation.

NOAA's data activities are governed by a "full and open" data policy consistent with the Office of Management and Budget's (OMB's) Circular No. A-130, the May 9th, 2013 Executive Order titled "Making Open and Machine Readable the New Default for Government Information", and the aforementioned 2010 National Space Policy. These policies provide the framework that allows NOAA to widely distribute its products and services to support its public safety and global environmental monitoring mission. There are significant benefits to providing publicly-funded data for free such as promoting advances in predictive capabilities and supporting a robust private weather industry. The U.S. weather services model recognizes the role played by the private sector weather enterprise, including the media, in developing tailored, value-added products and services and in communicating important weather information to citizens. By ensuring weather data are easily accessible and freely available, NOAA seeks to foster the growth of the environmental information enterprise to best serve the public interests in both public safety and commercial opportunity. In contrast, European service models for weather services are fundamentally different than in the U.S., in that they seek to recoup costs through fee-for-services. The U.K. Meteorological Office, for example, is self-sustaining via fee-for-services - in effect a government consulting service. If these European business models were applied in the U.S., it would most likely be seen as government competition that impedes private sector growth.

U.S. weather services are provided through an "environmental information enterprise" composed of government, private, and academic sectors. As noted by the National Academy of Sciences, "this three-sector system has led to an extensive and flourishing set of weather services that are of great benefit to the U.S. public and to major sectors of the U.S. economy."

Looking to the Future: Opportunities for Weather Research and Technology Development

NOAA is proud of its record of accurate storm forecasts and warnings. We are fortunate that the science and technology of weather prediction is in a period where new advances are rapidly becoming available, thanks in large part to Federal researchers working in close partnership with external partners. For example, NOAA is developing concepts that apply high-resolution models in shorter-range forecasts to increase tornado warning lead times. An estimated 16 minutes of warning lead time was provided for the recent Moore, Oklahoma tornado. With advances in observing and modeling, we will continue to extend warning lead times to help save lives and property, but we need to maintain strong observations and research portfolios, as identified in the FY 2014 President's Budget request, in order to realize these potential improvements in weather forecasting.

The topics of weather research and the implementation of the best research into operations are particularly timely. A recent study by the National Academy of Public Administration (NAPA), called *Forecast for the Future: Assuring the Capacity of the National Weather Service* emphasized the importance of transitioning research efforts to operations, as well as the communication of operational needs to the researchers. It summarized the need for ongoing change in NWS, such as:

> *The Panel found enormous support for the weather, water, and climate products and services provided by the NWS. However, both internal and external stakeholders see additional and ongoing change as necessary to continue to enhance NWS performance. To continue to provide the range and caliber of current products and services, the NWS, like any technologically dependent organization, will need to refresh or replace aging technology, infrastructure, and systems.*

The National Academy of Sciences Report, *Weather Services for the Nation*: *Becoming Second to None,* also makes a number of recommendations regarding weather research. This report emphasized the community enterprise that is needed to improve weather forecasts, from academic and government research, through technology transition, and with special emphasis on the connection between NOAA's weather enterprise and the U.S. commercial weather sector.

Observing Systems Technology Innovation

In addition to ongoing research and partnerships, NOAA is working on numerous innovations for future weather operations and research in the observing arena. To continue the march of progress represented by the recent deployment of the NOAA-developed dual-polarization radar system, NOAA is supporting emerging next-generation radar technology via the Multifunction Phased Array Radar (MPAR) program. A joint development effort of NOAA, the Federal Aviation Administration, the DoD, and other agencies, MPAR, if implemented, would reduce the number of U.S. surveillance radars by nearly 40%, with associated cost savings of nearly $4.8 billion over the lifecycle of the system. MPAR can serve weather surveillance and other purposes simultaneously. Nationwide deployment would provide much greater protection to the people of the U.S. as it's solid-state, stationary construction allows for sampling the atmosphere much more frequently and with higher resolution than is presently the case with NEXRAD radars.

The follow on to the current NOAA polar and geostationary satellites (JPSS and GOES-R respectively) are in development, and when launched later in the decade, will yield significant increases in timeliness, resolution and accuracy over the existing satellites they will replace. New satellite-based observing technologies and applications, such as the Global Positioning System Radio Occultation-based systems, are also showing significant positive impact in both global and regional data assimilation and forecasting. Finally, initial tests suggest that new technologies such as Unmanned Aircraft Systems have potential to improve hurricane and other storm predictions.

Advanced Data Assimilation and Forecast Modeling Innovations

Forecast quality depends critically on the ability to add, or assimilate, observed information on the initial state of the atmosphere, ocean, land surface, and ice regions to forecast models. Advanced data assimilation techniques, increased forecast accuracy through higher resolution and improved representation of the atmospheric, oceanic and land physical processes are important factors for improving operational forecasts. While substantial data assimilation and model improvements have occurred over the past five years, considerable progress is yet to be made. Over the next decade, global and regional data assimilation and model capabilities and techniques will become more integrated into a single system capable of providing forecast data from less than one hour to more than two weeks.

Global models are the basis of predictions from one day to two weeks in advance. With broader geographic coverage, global models are the key to the forecasting of major storms with oceanic origins, such as hurricanes and nor'easters. Global models are also critical to NOAA's success in preparing the public three to eight days in advance for conditions that could lead to major tornado outbreaks. By the end of the decade, the next generation of global models will run at horizontal resolutions of a few miles, with more accurate representation of physical processes. As model resolution increases, research will be required to understand how to formulate and incorporate new physical processes into the models. When these steps are accomplished, the ability to forecast both large and small storms will take a big step forward. The best way to ensure these advances take place is through a sustained research and technology transfer effort.

Trends in yearly-averaged tornado warning lead time suggest that the present weather warning process, largely based upon a warn-on-detection approach using Doppler radars, is reaching a plateau and further increases in lead time will be difficult to obtain through this method. A new approach, referred to as the "Warn on Forecast" paradigm in NWS *Weather Ready Roadmap* plan, is needed to extend warning lead time. National scale high-resolution models are particularly promising and critical for predicting the details of severe weather events such as tornadoes and hurricanes. The NSF National Center for Atmospheric Research led the initial development over the last 15 years, of the regional Weather Research and Forecast (WRF) model. Based on this model, NOAA researchers and partners have developed the High Resolution Rapid Refresh (HRRR) model, a key to the "Warn on Forecast" paradigm. This model has exhibited very promising results. Running in an offline experimental model, it forecast the derecho that affected the eastern U.S. on June 29, 2012 twelve hours before the storm hit the Washington DC area. This same model forecasted nine hours in advance the dangerous conditions and general characterization of the thunderstorms that formed the destructive tornadoes that affected Alabama on April 27, 2011.

Another notable advancement in forecasting resulting from investment in research is the new hurricane prediction model that will come on line for the 2013 hurricane season. The operational Hurricane Weather and Research Forecast model represents a significant step forward in our understanding of hurricane structure and intensity forecasting. The research has been a joint effort across NOAA as part of the Hurricane Forecast Improvement Project. This advancement highlights the importance of the research and operational entities working hand-in-hand: as research improves, so do the forecasts. NOAA has achieved much higher skill in recent years through improved computing capability, the ability to zoom in observationally for a "deeper look" at specific areas of storms as they form, and the ability to assimilate critical observation data from a variety of platforms.

Advances in Computing Capability

Computing capacity and computer modeling are indispensable requirements for extending weather warning lead times to save lives. While many nations run their own numerical weather prediction computer models, the European Centre for Medium-Range Weather Forecasts (ECMWF) model is repeatedly singled out as the "best in the world." For example, the ECMWF model was able to predict Sandy's landfall almost precisely a full eight days in advance. Meanwhile, the NOAA's Global Forecast System (GFS) eight day forecast predicted Sandy to move further offshore instead of making landfall. It was not until the five day forecast that the NOAA GFS model track became equivalent to the ECMWF track. Running at a higher resolution on nearly ten times the computing power of the GFS, the dominance of the ECMWF model highlights the need for the very best computing capability. It is important to note that NOAA forecasters used all available information, including the ECMWF, as they made their official forecasts for Sandy's track and eventual landfall in New Jersey.

Major advances in weather research depend critically on increases in computing capability. Top-end supercomputing has maintained a growth rate of doubling every three years for the past five decades. In recent years, as computer processing unit speeds have met physical limits, further increases in computational power have been achieved by increasing parallelism – or carrying out many computations simultaneously. NOAA will continue to pursue new technologies to ensure computing capacity continues to increase and meet the demand for increased accuracy, resolution, and extended forecasts and warnings.

A major upgrade to NOAA operational computers is scheduled to be completed next month, July 2013, in which NOAA operational computing will undergo a threefold hardware capability increase. This upgrade will include major resolution enhancements and an advanced global model that runs more economically on the new hardware. The Disaster Relief Appropriations Act of 2013 is providing additional funds to improve operational and weather research computing in both FY 2014 and FY 2015. With these funds, NOAA's operational computing capability will increase tenfold by 2015. The FY 2014 President's Budget requests additional funds for NOAA to upgrade operational computing, which will provide a 27-fold increase in operational computing capability by 2018. That advancement will give NOAA unmatched operational computing capability and the ability to run the latest long-range forecast models with improved resolution.

While we appreciate the Committee's interest in upgrading our operational computing capabilities, we would like to point out that this work is already well on its way. We would caution against directing funding away from research and to High Performance Computing because it would have a serious negative impact on NOAA's ability to develop the next generation of ocean, weather, and climate models. In addition to operational supercomputing, cutting-edge high performance computing for ocean and climate research is also essential to the development of next-generation weather services and products. For example, seasonal to inter-annual "earth system" climate models are essential to advancing long-term weather forecasts for extreme events such as drought and floods. We recommend that the balance between research and operation requirements be driven by the needs of the user community, which is why we encourage the subcommittee to further consider the balance between weather operations and ocean and climate research supercomputing reflected in this bill.

Since researchers are often working on models that will not become operational for three to five years or more, and with computer speed doubling every two to three years, a good rule of thumb is that researchers should have computing capabilities that are two to four times the current operational needs in order to ensure continued advancement of operational products and services. Therefore, with the significant investment in NOAA's operational computing through the Disaster Relief Appropriations Act of 2013, the next challenge is how to ensure NOAA's research computing continuously keeps pace with NOAA's growing operational computing capabilities.

Research to Operations

NOAA is continually working to enhance the transfer of research advances into NOAA's operational and information services. NOAA research has developed the capability to provide improved longer range computer forecasts, but NWS has lacked the operational computing capacity to transition these research developments to operations. The Disaster Relief Appropriations Act of 2013 not only brings funds to improve our computing capabilities, but also to implement scientific research activities into operational weather, storm surge and coastal forecast models, to accelerate weather research, and to enhance observations. The President's FY 2014 budget submission continues this trend of increasing computing capacity and pulling proven research improvements into operations.

Recent Research to Operations Examples

The weather warning improvements in recent years are the result of intensive research by NOAA and its academic, international, and commercial partners. Without our current operating model of drawing on resources from within and outside of NOAA, and our policy of open and free access to our data, we would not be where we are today. Here are just a few examples of some of the recent advances we have achieved:

- **Dual-Polarization Radar** is the next generation of Doppler radar, which NOAA recently finished upgrading. It provides real-time measurements that improve forecasts of rainfall and snowfall amounts, tornado and hail detection, and other meteorological elements.
- **Advanced Weather Interactive Processing System (AWIPS)** has been developed, operationalized, and deployed by NOAA and is used at every weather forecast office nationwide.
- **HYSPLIT** is a model developed by NOAA and utilized by NOAA and other customers for emergency response operation for smoke, dust, volcanic ash, and nuclear events.

Improvements continue in forecast operations, but significant strides are needed at all spatial and temporal scales – from small scale prediction of tornadoes and severe thunderstorms, to the medium scale eastern U.S. derecho that ravaged the mid-Atlantic States last year, and to the larger scale prediction of the track and intensity of hurricanes, winter storms, and drought. These modeling advances are possible only through validated, robust observations taken from multiple platforms.

Achieving a Weather-Ready Nation

With the destruction we have already seen this year from weather events, we take little solace in knowing that outcomes could have been worse without the work of NOAA and our federal, state, local, academic, and commercial partners. There is much more that needs to be done to improve the Nation's resilience. In addition to improved forecast and warning accuracy and lead times, integrated research, education, and outreach are essential ingredients to improving preparedness. Realizing a Weather-Ready Nation, where society is prepared for and responds to high impact weather events, is vital.

NOAA is continuing a dialog with the Nation's top experts to examine what can be done in the short- and long-term to improve how NOAA communicates severe weather forecasts and warnings. We've engaged leaders in broadcast meteorology, social sciences, and emergency management, as well as outreach specialists such as Sea Grant extension agents and Warning Coordination Meteorologists, and the weather industry to focus on the community response to and preparedness for severe weather. Included in this effort are innovative technologies and social media to improve our effectiveness in reaching those in harm's way and provoking appropriate response, whether to the urgency of a tornado or tsunami warning, or to the longer-term likelihoods of flooding or drought. Social science research includes the development of new or reconfigured graphics, such as evolving the hurricane forecast cone of uncertainty, and visualization techniques to better communicate tropical cyclone risk, such as storm surge inundation maps. It includes analysis of the promise and possible pitfalls of using Twitter in severe weather forecast operations, the assessment of how the public uses NOAA's online tools to understand and prepare for flood risk, and the identification of factors relevant to an individual's response to a tornado warning. Most NWS offices have established Facebook pages, providing an additional medium for conducting outreach and education, as well as highlighting information about ongoing or upcoming weather events. Additionally, NOAA uses NWSChat to give core external partners an invaluable opportunity to interact with NWS experts and to refine and enrich their communications to the public, and more private companies are carrying weather warnings on wireless networks, providing real-time alerts to your cell phone or email. And this year NOAA is running tests to evaluate different language to include in blizzard and severe storm warnings that may more effectively communicate the severity of the warnings. NOAA is exploring ways to make its information easier to find, easier to understand, and easier to apply in operations by the public and the Emergency Management community, which will result in improved decision making for risk management of life and property.

Conclusion

NOAA forecasts, warnings, and community-based preparedness programs are vital in enhancing the economy and saving lives and property. It all starts with a commitment to environmental observations, to research and improved forecasting and warnings, and ends with a Weather-Ready Nation in which businesses, governments, and people are prepared to use those forecasts to mitigate impacts. In spite of our best efforts, severe weather events still cause loss of life and significant damage. We recognize that there is always room for improvement and more of these impacts could be mitigated with more timely, accurate, and focused forecasts, watches, and warnings. The impacts and lives lost from the disasters experienced over the past year alone would have been far worse without NOAA's observations, research, forecasts, people and the extensive work of NOAA and our federal, non-federal, state, and local partners to improve the Nation's preparedness for these events through education and outreach.

While NOAA supports the ambitious goals of improving the Nation's weather forecasting capabilities, we are concerned about the bill's funding impact to other mission critical activities identified the FY 2014 President's Budget, including climate and oceans research, observations, and research supercomputing. It is critical that NOAA support its observations and research portfolios if advancements in weather forecasting are to be realized. We look forward to working with the subcommittee to identify the appropriate balance between operations, research, and observations to best support NOAA's missions.

NOAA regards protection of the people of the U.S. from the devastation that weather can bring as a sacred trust and duty. Despite our concerns, NOAA appreciates the evident thought and foresight that the Committee has shown in development of "The Weather Forecasting Improvement Act of 2013." We look forward to working with Committee on this bill, and thank you for allowing me to testify today.