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FORECASTING SUCCESS: ACHIEVING U.S. WEATHER READINESS FOR THE LONG TERM

SUBCOMMITTEE ON OCEANS, ATMOSPHERE, FISHERIES, AND COAST GUARD
COMMITTEE ON COMMERCE, SCIENCE, AND TRANSPORTATION
U.S. SENATE

December 12, 2013

Good morning Chairman Begich, Ranking Member Rubio, and Members of the Subcommittee. It is my honor to testify before you today on the state of United States (U.S.) weather forecasting capabilities and opportunities that now enable us to take weather predictions to the next level, especially for extreme events. We at the National Oceanic and Atmospheric Administration (NOAA) welcome your interest and the opportunity to discuss this important topic. As a mission-driven, operational agency, NOAA is responsible for global satellite observations, in-house research, research collaborations with our valued external partners, operational forecast excellence, and the delivery of critical products and services. The NWS works with NOAA's other Line Offices to realize our mission.

NWS has the sole federal responsibility for issuing weather and water warnings to communities across the country and in U.S. territories to protect lives and property. NOAA, as an agency, is trusted with the responsibility to provide environmental information and forecasts 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 safeguard lives. To do so, we work closely with the larger community of federal, state, and local emergency officials, other federal agencies, and the commercial weather enterprise to deliver the best possible information that science and technology can provide. Put simply, NOAA provides critical information that saves lives and enhances our national economy. We also work with the academic and research community to continually conduct weather research to improve our forecasts and warnings.

Driving Change – Society's Changing Needs

Our Nation is experiencing an increase in extreme weather events. Over the past two years, our country has endured devastation from fires in the South and West; drought over the plains and western states; Hurricane/Post-tropical Cyclone Sandy; destructive tornadoes and severe storms in Oklahoma, Washington, Illinois, and the Midwest; and the massive floods in Colorado and Utah. The NWS has the best forecasters in the world providing critical life-saving forecasts and

warnings. However, to take weather prediction to the next level we must evolve to ensure that the U.S. becomes a Weather-Ready Nation in the face of increasing threats related to extreme events. To ensure that forecasts are better used by a diverse group of decision makers, we need to provide accurate and consistent forecasts through a fully integrated field office structure comprised of all field and headquarters units working together to create fully consistent and seamless products and services. And we must organize ourselves internally to ensure our forecasters are linked to, and trained to communicate with, decision makers at the federal, state and local levels. This evolution will help create a Weather-Ready Nation. In addition, we need to bring additional capabilities in environmental prediction to the forefront as we work toward integrating land, sea, and air predictions into an environmental prediction capability.

Congress recognized the need for NWS to change and directed that two studies be conducted. The first, done by the National Academy of Sciences (NAS): "Weather Services for the Nation: Becoming Second to None" (August 2012),[1] examined the NWS Modernization and Restructuring of the 1990s as a background for moving forward. The follow-on study was conducted by the National Academy of Public Administration (NAPA): "Forecast for the Future: Assuring the Capacity of the National Weather Service" (2013).[2] Both studies reaffirmed NOAA's Weather-Ready Nation concept and supported the strategic goals outlined in the NWS Strategic Plan[3] for impact based decision support services for a wide variety of extreme events. Furthermore, the reports emphasized that NWS must change in order to keep pace with stakeholder and societal needs and emphasized that any changes need to be transparent, orderly, deliberate, and continuous and must involve our stakeholders. We know we cannot do it alone. We also know we must not fear change.

We need more than just the best forecasters. We need improved numerical weather prediction models to meet increasing demands for more accurate and reliable forecasts and warnings. We need a NWS workforce trained and structured to meet growing needs for decision support services for our core partners in the emergency management community. We need a fully integrated field structure to produce a consistent set of forecasts for a wide range of extreme events. We need to streamline multiple ways of disseminating our forecasts, watches, and warnings. We need well-resourced observing platforms including NOAA's next generation geostationary and polar orbiting satellites. We need an integrated weather-water approach to advance environmental predictions, especially along our coasts. We need active and engaged collaboration across the entire weather, water and climate enterprise to enhance what the NAS called the "secondary value chain" to build out enhanced services for the whole U.S. economy. In short, to meet the country's expanding needs, we need to institute a challenging set of changes in NWS science and technology, services, workforce, partnership relations, and to a significant degree, culture. And we need to do all this during this period of budget uncertainty.

In order to advance weather forecasting as a whole, NOAA must realize advances across all of the interdisciplinary fields of earth science, research, technology and observations. We must leverage partnerships within government, academia, and the commercial sector, and we must actively pursue, in concert, a balanced program to advance all of the factors critical to success.

[1] http://www.nap.edu/catalog.php?record_id=13429
[2] http://www.napawash.org/2013/1455-forecast-for-the-future-national-weather-service.html
[3] http://www.nws.noaa.gov/com/weatherreadynation/files/strategic_plan.pdf

NWS agrees with the NAPA recommendations and embrace them fully. We are moving forward to address the main challenges set forth in the NAPA study:

- Pace of Change: Working toward an orderly and deliberate process
- Budget: Aligning budget to function and linking to performance, transparency
- Managing Innovation: Engaging all stakeholders and avoiding hidden costs
- Consistent Services: Timely, accurate, reliable services consistent across the Nation
- Labor/Management Relations: Building a strategic partnership

There is an ever increasing demand for additional lead time ahead of severe weather events. Emergency management officials and Federal partners have indicated that at ideal capabilities, NWS 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. Similarly, an hour of warning before a powerful tornado, versus the minutes of warning we provide today, might allow hospitals to move patients, people to seek secure shelter and avoid being caught in vehicles, homes, or schools not robust enough to withstand a powerful storm.

NWS strives to integrate the best advances in science and technology in order to provide the most accurate and timely forecasts possible. Much of our success comes from scientific and technological breakthroughs made by research that spans across disciplines, time, and space scales. The dynamic systems of this planet are interconnected in rich and complex ways, and success in forecast improvement comes by looking broadly across those linkages.

Furthermore, NWS, driven by demand from our customers, has evolved to provide more than just short-term weather forecasts. Our prediction capabilities are becoming a fusion point that emergency managers, broadcasters, federal agencies, and the public increasingly turn to as a trusted source that distills scientific information into "impacts coming my way." This is done by embracing a number of interrelated fields of physical and social sciences, examining the atmosphere, oceans, land, ice, and space, and determining the best ways to communicate forecasts and warnings to ensure preparedness and response that can save lives and protect property.

While our computer predictions have improved, it is the dedication of our skilled workforce that makes it all possible. Recent tornado outbreaks throughout the south and Midwest, land falling hurricanes, and snowstorms in the Midwest all attest to the forecasting skill and dedication of the NWS workforce. NWS employees stayed on the job issuing life-saving warnings to the public at large even though their own families were living in the direct path of the devastating hurricanes and tornadoes. The South Dakota snowstorm occurred during the October furlough and dumped 3-4 feet of snow. The staff at the Rapid City, SD forecast office stayed at the office for 2-3 days, despite the personal impact on them and their families. It is this dedication to the NWS protect life and property mission that I find most admirable.

State of Predictions

Hurricane/Post-tropical Cyclone Sandy (Sandy) is an excellent example of how far we have come and yet how far we have to go to become a Weather-Ready Nation. Sandy devastated the eastern U.S. from North Carolina northward to Maine, with impacts reaching west as far as Wisconsin. Days prior to Sandy, NWS forecasters used models, integrating satellite, aircraft, and other weather observations to predict the path of the storm. Our forecasters gave emergency personnel and the public an accurate track forecast a full five days before the October 29 U.S. landfall which bought local communities the time they needed to issue evacuations and move or secure valuable infrastructure. We deployed fourteen forecasters to emergency operations centers in the northeast including Federal Emergency Management Agency (FEMA) regions, and state and local emergency operations centers, including New York City. 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 FEMA to preposition response assets and emergency managers to more precisely evacuate coastal areas in the path of this unprecedented storm, saving countless resources and lives. Our forecasts also allowed New York City Metropolitan Transportation Authority officials to move valuable resources supporting the mass transit system out of harm's way enabling a rather quick return to relatively normal system operations. It is these types of Decision Support Services to our critical partners in the emergency management community that we believe we must expand and orient ourselves to deliver.

I am proud of the work NOAA did during Sandy and especially proud of the work NWS forecasters did. Our people rose to meet the challenge this unprecedented storm presented. Last spring we released our Sandy assessment. This assessment found that our forecasts saved lives and property. It also highlighted areas we can improve. Most significantly, the report 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. NWS is working across NOAA, and especially with the National Ocean Service (NOS), to work with the coastal and water communities to improve storm surge and inundation products and determine how best to communicate that information. We could not advance in this area without the NOS. The synergies of having the NWS and NOS working together within NOAA to improve the storm surge products and services available to the Nation cannot be overstated. 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.

While we did well with our predictions for Sandy, some computing and communication shortfalls were apparent. Congress recognized these issues and provided "game changing" funding in the Disaster Relief Appropriations Act of 2013. In the summer of 2013, NWS completed a major upgrade to the operational weather supercomputers which brought operational forecast computing a threefold hardware capability increase. This base-budget-funded upgrade included major resolution enhancements and an advanced global model that runs more economically on the new hardware. Funds from the Disaster Relief Appropriations Act of 2013 will be used in FY 2014 and FY 2015 to improve operational and weather research computing capability. With these funds, NOAA's operational computing capability will increase tenfold by late 2015. The FY 2014 President's Budget requests additional funds for NOAA to upgrade

operational computing, which when implemented will provide a 27-fold increase in operational computing capability by 2015. That advancement will give the NWS unmatched operational computing capability and the ability to run the latest long-range forecast models with improved resolution and physics, and the ability to more accurately assimilate the data from new NOAA polar orbiting satellites and geostationary satellites.

This increase in capacity will allow NWS to bring proven research and forecast model development into operation as it is completed, rather than wait simply because the computing resources are not available. The Disaster Relief Appropriations Act of 2013 not only provided 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. In addition to computing capacity, the President's FY 2014 budget request continues this trend of pulling proven research improvements into operations. Transitioning science developed in NOAA's Office of Oceanic and Atmospheric Research (OAR) into operational use at the NWS and NOS is a high priority for NOAA as a whole.

Increasing Focus on Decision Support and Outcome Measures

Over the past three years it has become apparent that we cannot measure the success of our mission only by the accuracy of information, but we must also measure success by how effectively we apply our information, predictions, outlooks and forecasts to societal needs. As such, we are pursuing a number of innovative approaches not only to provide significantly more lead time for forecasts, but also to ensure that people truly understand 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. Our emphasis on 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.

There is much more to be done if we are to achieve new life-saving advancements in the future, and we are committed to working with our Federal, academic, private sector, and international partners in the broader enterprise to continue this record of success.

NWS' 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 and the public. 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 investments in high quality global observational data, the accuracy of our operational forecast models would suffer. Only by evolving in concert across each of these realms can we realize significant, sustained improvement in forecast capabilities.

Of the data actually assimilated into NWS numerical weather prediction models that are used to produce the longer term weather forecasts three days and beyond, over 93 percent comes from satellites, of which over 80 percent are from polar-orbiting satellites. These polar-orbiting satellites include NOAA's Polar-orbiting Operational Environmental Satellite (POES), Suomi

National Polar-orbiting Partnership (Suomi NPP) satellite, and the National Aeronautics and Space Administration (NASA) Earth Observing Satellites (EOS) in the afternoon orbit, and the European Metop satellites which fly in the mid-morning orbit. GOES satellites, along with Doppler Radar, assist operational weather forecasters to monitor existing conditions and provide essential information over data-sparse areas, including the oceans and the Gulf of Mexico. Maintaining continued development of the JPSS and GOES-R Series satellites is critical for not only maintaining current capabilities, but supporting advancements in forecasting capabilities.

The benefits and planned advancements of our predictive capabilities are realized only if people receive the information and take appropriate actions. Taking responsibility not only for advancing prediction but also for understanding how to communicate our predictions as effectively as possible is a major part of our Weather-Ready Nation initiative and a major piece of my vision for the future of the NWS. NWS uses many different ways to disseminate warning information ranging from conventional methods including our own NOAA Weather Radio All-Hazards network and the broadcast media, to social media including Facebook and Twitter. Cell phones are rapidly becoming a major way for the public to receive emergency information. Wireless Emergency Alerts (WEA) are credited with saving lives during the November tornado outbreak in Illinois. News media reported WEA simultaneously activating many cell phones during church services in Washington, Illinois. People received the warning then went to shelters in the churches as the tornado roared through the neighborhood. This is exactly what was envisioned when Congress appropriated the funds for the wireless alert program, managed by FEMA, Federal Communications Commission, and NOAA, and implemented by the cellular phone industry. Contrast this with the 1994 Palm Sunday Tornado Outbreak in Alabama, when a tornado warning was issued, but 20 people were killed in a a Cherokee County Alabama church because they did not receive the tornado warning prompting them to take shelter. We have come a long way, but there is more we need to do to become a Weather-Ready Nation – to be ready for the event, to be responsive, and to be resilient. Our work with social science is allowing us to provide our information in ways and words that people can understand and take action.

While advances in observing, computing, and forecast model development are important, innovation is necessary in order to meet the Nation's weather and water needs. NWS is conducting six pilot projects at local Weather Forecast Offices (WFOs) to test the evolution of decision support services to meet society's needs. One such innovative effort is in the Tampa Bay, Florida, WFO. This effort is integrating weather forecasts into ecological forecasting for Tampa Bay and the local estuaries. This and other Pilot Project innovations aim to test and demonstrate new products and services that can have broader use elsewhere to address changing and evolving customer needs.

While these advances and innovative efforts are important, addressing aging infrastructure, improving scientific understanding, and implementing enhanced services are also necessary to reduce risk to the Nation. Perfect forecasts don't save lives without the infrastructure to disseminate them and an understanding of how best to communicate to spur individuals to take action. I plan to evolve the NWS to devote more time and attention into working with partners in the social sciences to understand how to communicate better and then in training our workforce to implement the best practices learned.

In addition, NWS must increase its capacity to collect and assimilate ever-growing quantities of data to improve forecast model performance, and hence weather predictions and forecasts. This, too, can only be achieved through scientific research and technological advancement. Future technology improvements and computing assets are crucial pieces of our National infrastructure.

Weather Enterprise Collaboration

To provide the best possible weather services to the Nation, NOAA has developed a close working relationship with the U.S. commercial weather sector. This has been growing since the 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 continuously to enhance its efforts across the weather enterprise, allowing more participation of the commercial and academic sectors in the development of advanced prediction capabilities that have potential for transition into products and services. NWS work also fosters development in the commercial sector that leads to significantly better products for specific audiences and needs. NWS could not meet its mission without the private sector, nor could the private sector be thriving without NWS.

Weather Research and Computing Partnerships

Improvements in weather forecasts and warnings all begin with an idea. Research is essential to determine the viability of the concept and then key to transition those proven ideas and concepts into operations, whether they are improvements in computer models and data, or forecast and warning techniques. Our closest partner in weather research is the Office of Oceanic and Atmospheric Research (OAR) within NOAA. The work at OAR's National Severe Storm Laboratory, its Earth Systems Research Laboratory, and at the Atlantic Oceanographic and Meteorological Laboratory has been integral to the advancements the NWS has made in prediction and forecasting over the past decade. In addition, many Federal agencies work with NOAA and conduct weather research including, but not limited to, the 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. Integrated and focused weather research efforts are needed, particularly in this challenging budget climate in which we find ourselves.

We are fortunate that the science and technology of weather prediction is in a period where new advances are becoming available, thanks in large part to federal researchers working in close partnership with external partners. For example, OAR is developing concepts that apply high-resolution computer models in shorter-range forecasts to increase tornado warning lead times. An estimated 15 minutes of warning lead time was provided for the recent Washington, Illinois, tornado. With advances in observing and forecast modeling, under the Warn-On Forecast Program, NOAA is working to extend warning lead times from the current average of less than

15 minutes to a period of up to an hour, to help save lives and property. The extended lead times for severe local storms would be realized by applying an ensemble of weather forecast models to provide a measure of uncertainty with such warnings to the public, since no single model can capture the natural variability of the atmosphere, nor the sensitivity of such models to the number and quality of the observations and complexities of the model physics.

The topics of weather research and the implementation of the best research into operations are particularly timely. The NAPA study also emphasized the importance of transitioning research efforts to operations, as well as the communication of operational needs to the researchers. I can report that Acting Administrator Sullivan is making this effort a high priority of hers. NAPA 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 NAS study 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. While NOAA research endeavors in both NWS and OAR include connections to academia, the federal government, international agencies and the commercial sector, more can be done. The U.S. Weather Research Program (USWRP) was introduced as an interagency program led by NOAA and the NSF in 1991. NOAA, NSF, NASA, and to a lesser degree DOE, were all part of the USWRP. The main purpose of the USWRP was to define outstanding weather research topics and fund these efforts both within the Federal community and, importantly, the academic community research efforts on these topics. The USWRP commissioned a series of collaborations among federal and academic scientists that formed prospectus development teams (PDTs) in the 1990s to define outstanding weather research topics. There were 11 PDTs that published papers in the Bulletin of the American Meteorological Society throughout the 1990s and early 2000s that described important research problems that could advance the state of atmospheric science and, if addressed, would lead to improvements in weather observations, predictions, and warnings that would ultimately benefit society. Since 1999, USWRP has been a program within NOAA, and now, since FY 2009, resides NOAA's OAR. Within funds provided, efforts have focused on hurricanes, heavy precipitation, severe convection, forecast model improvements and the communication of weather predictions and warnings. All of this research aims to improve high-impact weather and air quality forecasts. NOAA is proud of its record of accurate storm forecasts and warnings.

Advanced Data Assimilation and Forecast Modeling Innovations

Forecast quality depends critically on the ability to add and retain, 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 each an important factor for improving operational forecasts. Recently, an advanced assimilation system originally developed by OAR and other research partners was implemented by NWS, resulting in significant improvements in our medium range predictions. While substantial data assimilation and forecast 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. Regional-scale forecast model ensembles will have the capability to explicitly represent convection (individual thunderstorms), which is critically important to be able to use these models to extend the tornado warning lead time to one hour.

Global weather forecast models are the basis of predictions from one day to two weeks in advance. With broader geographic coverage, global models are the key to forecasting major storms with oceanic origins, such as hurricanes and nor'easters, as well as key to predicting the precursors to longer term seasonal drought and heat waves. Global models are also critical to NWS' success in preparing the public three to eight days in advance for conditions that could lead to major tornado outbreaks, floods and fire weather conditions. 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 is required to understand how to formulate and incorporate new physical processes into the models. Inevitably, when these steps have been accomplished, the forecast skill will take a big step forward. These advances can only come about through a robust research and tech transfer effort. Sustaining such an effort into the future is the surest way to continue advancing U.S. weather forecasting capability and NOAA – through OAR and NWS together - is the lynchpin to drive this work.

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. OAR is developing new radar capabilities such as Multifunction Phased Array Radar (MPAR), which may increase our lead times and abilities to predict storms hours in advance. Additionally, a new approach, referred to as the "Warn on Forecast" paradigm in the NWS *Weather-Ready Roadmap* plan, is needed to extend warning lead time. This approach is being developed by NOAA scientists at OAR's National Severe Storms Laboratory. National scale high-resolution forecast models are needed to predict particularly the details of severe weather events such as widespread tornado outbreaks, such as the one that devastated Alabama and adjoining states in April 2011, and landfalling hurricanes undergoing rapid changes in intensity. The NSF National Center for Atmospheric Research led the initial development over the last 15 years with the creation of the regional Weather Research and Forecast (WRF) model. Based on this model, NOAA researchers working at OAR's Earth Systems Research Laboratory and partners have developed the High Resolution Rapid Refresh (HRRR) model, a key to the "Warn on Forecast" paradigm. Running in an offline experimental model, the HRRR model 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, the result of major research efforts and investments, is the new hurricane prediction model that came on line for the 2013 hurricane season. The operational HWRF model represents a significant step forward in our understanding of hurricane structure and intensity forecasting. The research has been a joint effort across NOAA, notably NWS, OAR, and academic partners as part of the Hurricane Forecast Improvement Project. This advancement highlights the importance of the research (OAR) and operational (NWS) entities working hand-in-hand: as research improves, so do the forecasts. We have 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

High-performance computing capacity and computer forecast 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 in New Jersey almost precisely at a full eight days out. Meanwhile, the NOAA 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 greater 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 NWS forecasters used all available information, including the ECMWF, as they made their official forecasts for Sandy's track and eventual landfall in New Jersey. A version of the GFS running at higher resolution similar to the ECMWF model had Sandy tracking into New Jersey at the same time frame as the ECMWF. To address the capability gap, NOAA and its partners in the Navy and academia are working on a directed research program, called the High Impact Weather Prediction Project, to enhance our global weather prediction models during the next few years. This is another example of how the Disaster Relief Appropriations Act of 2013 funds are being rapidly applied to our mission.

As mentioned earlier, a major upgrade to NWS operational computers was completed last summer, bringing NWS operational computing a threefold hardware capability increase today. With the Disaster Relief funding, NOAA's weather computing capability will increase tenfold by 2015. We thank Congress for these investments in NWS' computing capability, which will surely save lives and property in the future. Further investments requested in the FY 2014 President's will provide a 27-fold increase in operational computing capability by 2015 - an advancement that will give the NWS unmatched operational computing capability and the ability to run the latest long-range forecast models with improved resolution.

Research to Operations

NOAA is continually working to enhance the transfer of research advances into NWS operational and information services. OAR has developed the capability to provide improved

longer range computer forecasts as well as short-range severe weather forecasts, but the 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. In order to improve forecast and warnings across the country, the focus is to accelerate the transition of research and technology from the broad research/technology communities into operations at the NWS.

Achieving a Weather-Ready Nation

With the destruction we have already seen this year from extreme weather and flood 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. NWS is not alone at NOAA in this work. The National Ocean Service is also squarely focused on improving the Nation's resilience to extreme events along the coasts as well as OAR's Sea Grant program through their diverse network of extension agents on the ground in every coastal state. In addition, other programs within OAR, like the National Integrated Drought Information System (NIDIS), are focused on increasing resilience in the Nation's drought prone regions. For all of NOAA realizing a Weather-Ready Nation, where society is prepared for and responds to high impact weather events, is vital and the NWS is proud to lead the way.

In December two years ago, NOAA and our partners[4] initiated an ongoing 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 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 GIS enabled storm surge inundation maps. It includes the analysis of the promise and pitfalls of using Twitter in severe weather forecast operations, the assessment

[4] "Weather Ready Nation: A Vital Conversation on Tornadoes and Severe Weather." This activity was co-supported by NOAA/NWS and the National Science Foundation. A follow-up meeting in April 2012 in Birmingham, AL – "Weather Ready Nation: Imperatives for Severe Weather Research" was also jointly supported by NOAA/NWS and NSF. http://www.nws.noaa.gov/com/weatherreadynation/workshops.html

of how the public uses our 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 for highlighting information about ongoing or upcoming weather events. Additionally, the offices use 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 (WEA), putting real-time alerts in the palm of your hand. Importantly this year we are running tests to evaluate different language to include in blizzard and severe storm warnings that may more effectively communicate the severity of the warnings. NWS 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.

Our work during the Illinois tornado outbreak, which I described earlier, is an indication of how we are beginning to address these concerns.

Evolving the NWS Service Delivery Model

Population growth, growing infrastructure threats, and an increasingly interdependent economy are creating new challenges for the Nation. At the same time, science, technology, and communications are rapidly advancing and providing potential solutions that will enable the NWS to better meet our country's needs. As the world has changed, so too has the NWS in many aspects. We have advanced our scientific and technical capabilities to better meet the needs of Americans. The result is an organization with a greater capacity to provide timely information to protect lives and property. However, more needs to be done to ensure we can change as quickly as society demands to meet its ever changing needs.

Adjusting the NWS service delivery model to reflect current demands and to meet society's evolving and future needs is essential to ensuring safety of life and property, and enhancing the economy. Recent studies by the National Academy of Sciences validated the need for improvements in numerical weather prediction, increases in decision support services, better partnerships with the private weather enterprise to advance a Weather-Ready Nation initiative and meet society's needs. NWS needs to be flexible to meet evolving needs and become second to none.

The FY 2014 President's Budget request builds on the Disaster Relief Appropriations Act of 2013: to increase our operational high performance computing capacity for improved numerical weather prediction; increase consistency in our forecasts and messaging; solidify our technical and communications dissemination infrastructure; increase research in Decision Support Services; accelerate the transition of proven research into operations; and work with our employees through the National Weather Service Employees Organization (NWSEO) to make all this happen. We believe these aims are all supported by the best advice we have from the NAS, and are consistent with the advice we received from NAPA. We are also sure there is much more that needs to be done and we are committed to working with Congress, the weather

enterprise, and ultimately the entirety of U.S. society, to create the agile and effective NWS required to build a Weather-Ready Nation.

Given the rapid rate of change, NWS needs to be quick, flexible and agile to meet society's rapidly changing needs. NWS is looking ahead to a broader, end-to-end and comprehensive strategy that creates an organization capable of change. This is essential as we move toward a more fully integrated field office structure issuing improved and consistent forecasts and warnings, especially for extreme events. The discussion will focus on what services the U.S. needs from NWS and how best to provide these. Streamlining and refocusing of the NWS budget structure by aligning the budget to function and linking to performance and transparency may be another element of change.

This strategy will enable us to transform the NWS into an agile, responsive organization that can adapt quickly to new missions and integrate new science and technology without a large federal investment. NWS must have orderly, deliberate, continuous and transparent mechanisms to explore new operating concepts, tools to inform decision on changes, and safeguards to ensure no degradation of services while implementing changes to operations. Both headquarters and field operations cannot be realigned simultaneously. NWS is analyzing current headquarters functions to ensure capabilities will be in place to support and lead field operations. This must include the capacity to redesign and implement service delivery model improvements for the NWS that prioritizes our ability to meet the evolving demands for our products, services and forecaster expertise. We are planning to have a NWS headquarters designed for the new, more agile NWS. The National Weather Service plans to begin its transformation in FY 2015 by engineering NWS Headquarters functions to align with current operations and meet the evolving needs of the future. This includes such functions as implementing a fully integrated field structure with consistent national products, resourcing dissemination properly and sharing the best practices of our forecasters and field structure to speed innovation; all the while running a transparent and accountable budget formulation and execution process.

For the Modernization and Associated Restructuring (MAR), the NWS used extensive test and evaluation of new technology and service delivery concepts. It was strictly internal to NWS with limited stakeholder input and participation. For the future NWS, all programs and office types are included – WFOs, RFCs, national centers – and we expect full stakeholder participation in the development, testing and evaluation stages with a strong focus on evaluation to determine the viability of implementing the "tested" technology or services into operations.

NWS will follow the recommendations from both NAS and NAPA and develop a deliberate process that engages all stakeholders, users and partners, including NWSEO. What we know is that the status quo will not do and for the future, with whatever service delivery model is developed, NWS needs to operate in a new paradigm. NWS will choose what to develop and test, with no presupposition of a larger or smaller agency. We will employ a stringent evaluation that informs investment choices – with the appropriate level of investment determined by Congress and the Administration. The outcome is: NWS tests and demonstrates possible changes in services and operations, and that testing and demonstration is fully open to stakeholders, encouraging and soliciting their participation. The results, rather than unfounded assertions, drive change toward a Weather-Ready Nation.

Conclusion

NWS 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, to our people – forecasters, modelers, technicians and managers and it 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. I am proud of the NWS especially our people who are on the front lines delivering critical products and services every day to help keep our citizens safe. We are government at its best. But I need each of you to know that we can do better. Even 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 our Federal, non-federal, state, local, academic and commercial partners to improve the Nation's preparedness for these events through education and outreach.

The protection of the people of the U.S. from the devastation that weather can bring is a sacred trust and duty given to the NOAA. Together, we must ensure NWS services and operations lives up to this trust and duty. We have come a long way, but there is more we need to do to become a Weather-Ready Nation – to be ready for the event, to be responsive, and to be resilient.