

**WRITTEN STATEMENT BY
DR. RICHARD KNABB
DIRECTOR, NATIONAL HURRICANE CENTER
NATIONAL WEATHER SERVICE
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
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**COMMITTEE ON COMMERCE, SCIENCE, AND TRANSPORTATION
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Good morning Chairman Rubio, Ranking Member Booker, and Members of the Subcommittee. It is my honor to testify before you today on the state of United States hurricane forecasting capabilities, the partnerships between the National Oceanic and Atmospheric Administration (NOAA) and other government agencies that make effective use of those forecasts, and our public outreach and education efforts to prepare our citizens well in advance of the next hurricane. We at NOAA welcome your interest and the opportunity to discuss these important topics. NOAA's mission is to understand and predict changes in the Earth's environment, from the depths of the ocean to the surface of the sun, and to conserve and manage our coastal and marine resources. As a mission-driven, operational agency, NOAA is responsible for global satellite observations, atmospheric and oceanic research (both in-house and collaborative research with our valued external partners), operational weather and water forecasts, and the delivery of critical products and services.

The National Weather Service (NWS) -- a line office within NOAA -- is a science-based service organization that works closely with NOAA's other line offices in carrying out its mission. NWS has the sole federal responsibility for issuing weather and water warnings to protect lives and property in communities across the country and in U.S. territories. NOAA provides 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 that help safeguard lives. To do so, we work closely with the larger community of state, local, and tribal emergency management officials, other federal agencies, and the commercial weather industry 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 external community to continually conduct weather and water research to improve our forecasts and warnings.

The NWS has the best forecasters in the world providing critical, life-saving products and services. However, to take weather prediction to the next level and ensure that the U. S. becomes a Weather-Ready Nation in the face of increasing weather and water threats, the NWS must evolve. To ensure that forecasts are better used by a diverse group of decision-makers, we

are striving to provide more accurate and consistent forecasts through a fully integrated field office structure. We are organizing ourselves internally to ensure our forecasters have strong and effective relationships with decision-makers at the federal, state, local and tribal levels. The success of NOAA's mission in this area depends on four integrated pillars: observations; supercomputing; research; and our forecasters.

The NWS National Hurricane Center (NHC) is one of nine NWS National Centers for Environmental Prediction (NCEP). NHC's mission is to: save lives; mitigate property loss; and improve economic efficiency by issuing the best watches, warnings, forecasts and analyses of tropical weather, and by increasing understanding of related hazards. NHC has a vision to be America's calm, clear and trusted voice in the eye of the storm and, with our partners, to enable communities to be safe from tropical weather threats. NHC maintains a continuous weather watch, and issues analyses, forecasts and warnings of weather and ocean conditions over millions of square miles of the North Atlantic, including the Gulf of Mexico and Caribbean Sea, and the eastern North Pacific. It communicates its products through multiple methods, including the media. NHC also conducts an extensive outreach and education program as a very visible component of building a Weather-Ready Nation. NHC's operational, outreach, and other supporting activities are conducted by extensively collaborating with the local NWS Weather Forecast Offices, other NCEP centers, other line offices within NOAA, the emergency management community and other agencies at the federal, state, local and tribal levels, the media, other private sector entities, academia, like-minded nonprofit organizations, and numerous international meteorological services and other organizations.

Over the past few years, NOAA has made noteworthy progress supporting the hurricane program. Funding provided in the Disaster Relief Appropriations Act, 2013, referred to as the "Sandy Supplemental," has provided NOAA significant funding for ocean observing, hurricane related research, coastal monitoring, upgrades to the two NOAA Hurricane Hunter aircraft, accelerating our hurricane related storm surge prediction capabilities, and providing a critical historic enhancement in operational high-speed computing leading to higher resolution computer models.

The Hurricane Challenge

The United States has not experienced landfall of a major hurricane (defined as category 3 or stronger on the Saffir-Simpson Hurricane Wind Scale) since Wilma in October 2005. Wilma was also the last hurricane of any strength to strike the state of Florida. Nevertheless, several other hurricanes and tropical storms have come ashore and resulted in major impacts and loss of life in this country. Many of those impacts and losses have been due to water, with storm surge causing extensive damage in coastal areas and freshwater floods extending well inland. Storm surge from tropical storms and hurricanes poses a great threat for large loss of life in a single day, and has always been a factor even prior to more recent notable storm surge events including Ike (2008) and post-tropical storm Sandy (2012). NOAA is developing new tropical storm surge products and warnings that are scheduled to be implemented operationally during the next couple of years. Work also is underway to develop the capability to issue tropical warnings even prior to the formation of a tropical cyclone, with potential debut of this experimental capability in

2017, which will enable even more timely watches and warnings to be issued for storms that form close to the U.S. coast.

An important strategy in our operational communications, development of new products and warnings, and outreach and education efforts is to lessen the focus on the category of the hurricane and increase attention on the individual impacts from wind and water hazards that could occur in each community – namely winds, tornadoes, storm surge, inland flooding, and ocean waves and rip currents. We continue to emphasize that hurricanes and tropical storms are *not* just coastal events or just a problem for people with beachfront property, as evidenced from post-tropical storm Sandy.

Since the establishment of the NHC in the 1950s, NOAA has built collaborations with emergency managers, the media, and the research community – collaborations that have helped reduce U.S. hurricane-related deaths by two-thirds. We have recently published statistics that reveal how much work remains to be done to further reduce the loss of life from tropical cyclones in this country. During the past half century, we have lost almost as many people to “indirect fatalities” as we have to “direct fatalities.” Indirect fatalities are casualties that, while not directly attributable to one of the physical forces of a tropical cyclone, would have been unlikely to occur in the absence of the storm. These indirect fatalities include, among others, deaths attributable to carbon monoxide poisoning, cardiovascular failure, vehicle accidents, electrocution, falls, and fires in residences caused by open flames.

Direct deaths are defined as fatalities attributable to the forces of the storms and their remnants. The most common examples of direct deaths from tropical systems are drowning as a result of storm surge, storm-driven waves, rip currents, or freshwater floods from rain. They also include physical trauma incurred from wind-borne debris or structural failure induced by wind (including hurricane-spawned tornadoes). Almost 90 percent of deaths from land falling tropical cyclones are attributable to water. Storm surge incidents accounted for about half of the deaths, while inland flood events caused by excessive rainfall took close to one quarter of the lives. After adding the many people who also lost their lives at the beach due to rip currents or waves, or while boating, that leaves only about 10 percent of direct fatalities being due to wind.

Storm surge from tropical cyclones remains a great threat for a large loss of life event from a single-day natural disaster. Recognizing this situation, our product development during the past several years has placed a heavy focus on storm surge from tropical systems, and that work is showing good results. In 2014, NHC began experimental production of a Potential Storm Surge Flooding Map, which will be operational beginning this hurricane season. In 2017, the NWS plans to issue tropical system-related Storm Surge Watches and Warnings for the East and Gulf Coast states, actions designed reduce the number of storm surge fatalities. We have also significantly increased our outreach and education efforts on tropical storm surge and on water hazards overall, since the public generally tends to misunderstand and underestimate their risk due to water. The hurricane challenge is exacerbated by an increasing vulnerability as coastal populations and infrastructure grow. NOAA’s public outreach messaging is not only about the hurricane hazards themselves, but also about what people should be doing to get ready, starting well in advance of the next hurricane, and about resiliency in the face of the hazards that could occur where they live.

We battle mightily against public complacency as certain parts of the country have gone for years to decades since their last significant hurricane impact. That fact motivates us to be innovative and leverage partnerships to increase the reach and effectiveness of our outreach and education efforts. The introduction of new tropical storm surge products and warnings during the next couple of years will also serve to increase public and partner focus on preparing in advance for that hazard. We work hard to explain that overall hurricane activity has almost no relationship to hurricane impacts in any one community. Many people have the perception that our hurricane risk has declined in recent years, especially in comparison to the very active and destructive seasons in the U.S. in 2004 and 2005. We remind everyone, however, that there is a significant difference between how busy a given year or a particular decade might be overall, versus how bad it might be where you live. The year 1992 is one of the best examples of this, since it was overall a below-average year for hurricanes in the Atlantic basin, with only one major hurricane forming, but that one was Andrew that struck South Florida as a category 5 hurricane.

Improvements in Hurricane Forecasts and Observations

In recent years, NOAA has extended tropical cyclone forecasts from three to five days, watches out to two days and warnings to 36 hours, and tropical cyclone formation forecasts from two days to five days. NOAA has reduced track (storm location) forecast errors by 50 percent over about the past 15 years. We are taking advantage of several opportunities that now enable us to take predictions to the next level.

We take very seriously our annual efforts to verify our forecasts. Verification enables us to assess our progress in making forecast accuracy improvements and provides statistical information that drives our suite of probabilistic products that responsibly convey forecast uncertainties in real-time. NHC issues an official forecast of the cyclone's center location and intensity (the maximum surface wind speed) for all operationally designated tropical or subtropical cyclones in the Atlantic and eastern North Pacific basins. Forecasts are issued every six hours and contain projections valid 12, 24, 36, 48, 72, 96, and 120 hours (five days) after the forecast's initial time. At the conclusion of the season, forecasts are evaluated by comparing the projected positions and intensities to the corresponding post-storm derived "best track" positions and intensities for each cyclone.

We have made tremendous progress in hurricane prediction. Our five-day track forecast today is about as accurate as the three-day forecast was 20 years ago. This forecast improvement has resulted in a reduction in the coastal area that needs to evacuate, if all other factors, such as storm size, are considered equal. The new supercomputers for which Congress appropriated funds have allowed us to run more complex and sophisticated forecast models, including the new Hurricane Weather Research and Forecast (HWRF) model. The HWRF model represents a significant step forward in our prediction of hurricane structure and intensity. The research and development has been a joint effort between NOAA (primarily NWS and NOAA's Office of Oceanic and Atmospheric Research (OAR)) and academic partners as part of the Hurricane Forecast Improvement Project (HFIP). This advancement highlights the importance of the research and operational entities working hand-in-hand to transfer promising research techniques into operations. Another joint effort between NWS and OAR, the Joint Hurricane Testbed (JHT)

is a virtual environment for cutting-edge technology testing and demonstration funded by the U.S. Weather Research Program (USWRP). The JHT connects the tropical cyclone research community with forecast operations. This year, eight JHT research and development projects focused on improving the transition of new applied research from universities and federal laboratories directly into NOAA operations in the areas of improved tropical cyclone and hurricane analysis, modeling, and forecasting techniques. A new tool available to the forecasters helps identify the probability of tropical cyclone genesis as far as five days in advance. This method was initially developed for the North Atlantic basin, but work is underway to expand the tool to other hurricane-prone ocean basins. Since its inception 15 years ago, the JHT has supported nearly 100 projects and demonstrated great success by transitioning about 70 percent of them into NWS operations, resulting in improved NOAA services for the public.

HFIP is intended to improve track and intensity forecast accuracy by 50 percent in 10 years. HFIP continues with a multi-year, multi-million dollar effort to improve hurricane forecasts. We are meeting the five-year HFIP goal to reduce hurricane forecast track and intensity errors by 20 percent, and to extend the useful range of forecasts to seven days. Recent enhancements that have been made to the operational HWRF have made it our best-performing intensity model over the 2013-15 period. HFIP is also supporting promising work to help identify and adjust for biases in the primary track and intensity models. In addition, HFIP continues to support some new product development and evaluation. We remain on schedule with our progress toward implementation of the new tropical storm surge products and warnings.

Operations continue to benefit from, and rely on, aircraft reconnaissance. Ten WC-130J aircraft are specially configured and operated by the U.S. Air Force Reserve from the 53rd Weather Reconnaissance Squadron, 403rd Wing, located at Keesler Air Force Base in Biloxi, Mississippi. When flying a hurricane mission, military air crews fly directly through the eye of the storm several times each flight. They collect data and transmit it in near real time by satellite directly to NHC so forecasters can analyze and predict changes to the hurricane's path and strength. This refining of storm track models saves U.S. taxpayers millions of dollars. The NOAA Gulfstream-IV and Lockheed WP-3D Orion are part of NOAA's fleet of highly specialized research and operational aircraft. These aircraft are operated, managed and maintained by the NOAA Office of Marine and Aviation Operations, based at MacDill Air Force Base in Tampa, Florida. The G-IV flies at high altitudes around and ahead of a tropical cyclone, gathering critical data that depict the atmospheric steering flow, and that data feed into and result in improved accuracy from hurricane forecast models. The P-3's are NOAA's hurricane research and reconnaissance aircraft. These versatile turboprop aircraft are equipped with an unprecedented variety of scientific instrumentation, radars and recording systems for both in-situ and remote sensing measurements of the atmosphere, the earth and its environment. These two aircraft have led NOAA's continuing effort to monitor and study hurricanes and other severe storms, and other non-hurricane-related missions in their "off season."

In 2014, NOAA successfully deployed a small unmanned aircraft-- the Coyote --from a hurricane hunter aircraft into the eye of Hurricane Edouard. NOAA plans to expand the use of this unmanned aircraft in 2016. Planned flights will measure the strongest winds and collect critical continuous observations at altitudes in the lower part of a hurricane, an area that would otherwise be impossible to reach with manned aircraft. Data will be sent in real-time to

forecasters at the NHC. We anticipate data from new technologies such as this will contribute significantly to improved understanding of tropical cyclone processes and ultimately to improvements in track and intensity predictions.

Data from satellites are the most critical component of NOAA's observation network. NOAA has managed the operation of polar-orbiting operational environmental satellites (POES) since 1966 and geostationary operational environmental satellites (GOES) since 1974. Over the decades, these systems have supported weather and environmental monitoring programs that are relied upon by users in the U.S. and around the world. Satellites provide more than 95 percent of the data assimilated into NOAA's operational numerical weather prediction (NWP) models. These NWP models are used to forecast the weather seven or more days ahead, and, in particular, the NWP models are essential to forecasting the development of extreme weather events, including hurricanes.

Data from GOES satellites are vital for observing and tracking tropical cyclones, and their precursor disturbances when a few hours, or even minutes, matter. We are excited about the launch of the new GOES-R satellite, scheduled for later this year. Technological advances of GOES-R include improvements upon existing data, such as increased spatial, temporal, and spectral resolutions for Earth monitoring, and new observations, such as lightning data. Many of the GOES-R products are aimed at monitoring hurricanes and their environment and are expected to lead to, more timely, accurate, and actionable warnings. The resolution of visible satellite images will be down to ½ km, and we will be able to receive images (pictures) every minute. The one-minute images will allow us to see the hurricane "breathe." We will see things and learn on a scale that we have not ever before had available to us. The Japanese Himawari satellite, which has the same imager as will be on GOES-R, has produced amazing data.

New and Planned Operational Public Products and Warnings

Our strategy for developing new public products and warnings in recent years has been to focus more on the individual hazards posed by tropical cyclones and less on categorization of the cyclones themselves based on the strength of the sustained wind speeds generated at the (i.e. Saffir-Simpson scale using wind strength to describe hurricane intensity "CAT" 1-5). This year we will be issuing a Potential Storm Surge Flooding Map that will clearly and concisely depict the risk associated with the storm surge hazard from a tropical cyclone. Developed over the course of several years in consultation with social scientists, emergency managers, broadcast meteorologists, and others, this map shows:

- Geographical areas where inundation from storm surge could occur
- How high above ground the water could reach in those areas

Areas of possible storm surge flooding for a given tropical cyclone are represented in different colors on the map based on water level, as shown in this example:

We are also developing a tropical cyclone surge watch and warning product to compliment the flooding graphic depicted above. We believe this new watch/warning product will increase awareness of the potential life and property impacts from storm surge and flooding. Work is also

underway to be able to issue tropical storm warnings even *prior to the formation* of a tropical cyclone, with potential debut of this experimental capability in 2017.

Federal Support of Hurricane Evacuation Decision-Making

The effectiveness of our partnerships with the emergency management community at federal, state, local and tribal levels is as high as ever.

The NWS, along with the U.S. Army Corps of Engineers, directly support the Federal Emergency Management Agency's (FEMA's) National Hurricane Program (NHP), which provides state and local governments with resources to inform their hurricane planning and response actions. This NHP support is accomplished by conducting hurricane evacuation studies, providing access to the HURREVAC (www.hurrevac.com) software program as a common platform to view hurricane forecast information and evacuation timing guidance, and providing real-time technical assistance to state and local emergency managers to support their hurricane evacuation and response decisions. In addition, the NHP partners provide comprehensive hurricane preparedness training to emergency managers each year. In the past 25 years, more than 1,500 emergency managers have participated in the week-long hurricane workshops at the NHC, co-hosted by FEMA.

NWS has also partnered with FEMA to provide another venue of federal support for state and local governments through the Hurricane Liaison Team (HLT). The HLT concept was piloted during the active 1995 hurricane season and formalized the next year following a request from the Governor of Florida. The HLT supports response operations by allowing rapid exchange of critical information regarding tropical cyclone hazards and potential impact between the NHC and Federal, state, local and tribal emergency managers. The HLT facilitates daily video briefings with NHC, FEMA leadership, and other senior federal officials. The HLT includes NWS meteorologists, emergency managers, and FEMA Regional Hurricane Program Managers that have technical knowledge of local and state hurricane evacuation plans and trusted relationships with state, local and tribal emergency managers in the affected area.

These trusted relationships begin long before hurricane threats develop each year. The combined efforts of the HLT and NHP ensure that the nation works together to build, sustain, and improve our capability to prepare for, mitigate, protect against, and respond to hurricanes.

Public Outreach and Education

Our outreach efforts serve to get the public and our partners ready far in advance of the next hurricane, so they know what they will do when we issue our forecasts and warnings for the hazards they might face in a real-time tropical cyclone event.

NOAA has conducted an annual Hurricane Awareness Tour (HAT) for more than 30 years, alternating between the U.S. Gulf and Atlantic coasts. The tour now coincides with the presidentially-declared National Hurricane Preparedness Week. As part of its efforts to build a Weather-Ready Nation, each year NOAA's hurricane experts typically tour five U.S. coastal cities to raise awareness about the importance of preparing for the upcoming hurricane season. The tour typically includes a U.S. Air Force Reserve WC-130J or NOAA P-3 hurricane hunter

aircraft and the NOAA G-IV aircraft. This year the tour partnered with the nonprofit Federal Alliance for Safe Homes (FLASH) with the “#HurricaneStrong” campaign to re-energize and inspire hurricane resilience by increasing public awareness and action before the next storm strikes. The tour visited San Antonio, Galveston, New Orleans, Mobile, and Naples. The public and media toured the aircraft and met forecasters and aircraft crews. Staff from local emergency management offices, FEMA, non-profit organizations, such as the American Red Cross and FLASH, and several local NWS Weather Forecast Offices joined various stops on the tour.

The Weather-Ready Nation (WRN) Ambassador initiative is NOAA’s effort to formally recognize its partners who are improving the nation’s readiness, responsiveness, and overall resilience against extreme weather, water, and climate events.

To be officially recognized as a WRN Ambassador, an organization must commit to:

- Promoting Weather-Ready Nation messages and themes to their stakeholders;
- Engaging with NOAA personnel on potential collaboration opportunities;
- Sharing their success stories of preparedness and resiliency;
- Serving as an example by educating employees on workplace preparedness

Building a Weather-Ready Nation requires more than government alone. It requires the private and academic members of “America’s Weather Enterprise” to provide information for better community, business, and personal decision making, and innovative partnerships across all segments of society. We must involve everyone in an effort to move people – and society – toward heeding warnings, taking action, and influencing their circles of family, friends, and social network to act appropriately. The WRN Ambassador initiative is the connecting hub of a vast network of federal, state, local and tribal agencies, academic researchers, the media, the insurance industry, nonprofit organizations, the private sector, and many others who are working together to address the impacts of extreme weather on daily life. Together we will inform and empower communities, businesses, and people to make pre-event decisions that can be life-saving and prevent or limit devastating economic losses. We are a nation of many communities, and it is only through connected communities that we will achieve this goal.

International Collaborations

The hydrometeorological services of the Caribbean, Central America and North America have a long history of effective collaboration, strong relationships, and a shared focus on learning from one another and improving our collective service to the citizens of our respective nations. As NHC Director, I chair the World Meteorological Organization’s Regional Association IV Hurricane Committee, which was established in 1978 and includes nations with meteorological interests in North and Central America and the Caribbean. This committee seeks to improve tropical cyclone prediction and coordination in the region by bringing member countries together on an annual basis to address issues such as data collection requirements, operational and technical coordination, research priorities and transition to operations, forecast practices and procedures, outreach, and training. The committee meeting is a tremendous opportunity for us to gain a greater understanding of how our evolving meteorological and hydrological services will operate each year, to enhance the benefits of our shared data, forecast information, and training efforts, to learn key lessons from the impacts in the previous year, and to update our regional

procedures and plans so we can perform together during the upcoming hurricane season to the best of our combined abilities.

Conclusion

Expectations from those NOAA serves are high, and we strive to exceed those expectations. All of the technologies we apply to issuing the best possible forecasts will live up to their full potential only if communities, families, and individuals also prepare far in advance. We all must dedicate ourselves to taking steps now to be ready, long before the next hurricane strikes. NWS forecasts, warnings, and community-based preparedness programs are vital to enhancing the economy and saving lives and property. It all starts with a commitment to environmental observations, research and improved forecasts and warnings, and our people (forecasters, modelers, technicians and managers). It culminates with striving to become 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, hurricanes and tropical storms will still cause loss of life and significant damage. We recognize that there is always room for improvement. I believe NOAA and the NWS 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 recent tropical disasters experienced over the past few years would have been far worse without NOAA's observations, research, forecasts, people and the extensive work of our federal, non-federal, academic and commercial partners to improve the nation's preparedness for these events through education and outreach.

The protection of the American people from the devastation that weather and water can bring is a sacred trust and duty given to the NOAA and NWS by Congress. Together, we must ensure our services and operations live 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. Remember, as Hurricane Andrew proved in 1992, it only takes one.