

IMPROVEMENTS IN HURRICANE FORECASTING AND THE PATH FORWARD

HEARING

BEFORE THE

SUBCOMMITTEE ON OCEANS, ATMOSPHERE,
FISHERIES, AND COAST GUARD

OF THE

COMMITTEE ON COMMERCE,
SCIENCE, AND TRANSPORTATION
UNITED STATES SENATE

ONE HUNDRED FOURTEENTH CONGRESS

SECOND SESSION

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ONE HUNDRED FOURTEENTH CONGRESS

SECOND SESSION

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IMPROVEMENTS IN HURRICANE FORECASTING AND THE PATH FORWARD

WEDNESDAY, MAY 25, 2016

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

The Subcommittee met, pursuant to notice, at 2:20 p.m. in room SR-253, Russell Senate Office Building, Hon. Marco Rubio, Chairman of the Subcommittee, presiding.

Present: Senators Rubio [presiding], Ayotte, Booker, Nelson, Blumenthal, Schatz, and Markey.

OPENING STATEMENT OF HON. MARCO RUBIO, U.S. SENATOR FROM FLORIDA

Senator RUBIO. We'll call this hearing to order.

I want to thank all of you for being here. I apologize for the delay. We had another meeting that ran over a few minutes.

I wanted to convene this hearing one week before the official start of the 2016 hurricane season. As the hearing title suggests, we will be focusing on improvements in forecasting, and we will discuss how track and intensity forecasts can be further enhanced.

Ninety years ago, Florida was hit by a Category 4 storm that was later named the Great Miami Hurricane, but it not only devastated Miami but crossed the Gulf of Mexico, inflicting damage to Pensacola Bay. This was a time of little meteorological data or capabilities, and, thus, alerts to Floridians came too late.

The National Hurricane Center reports that Coconut Grove experienced a 15-foot storm surge, and people mistakenly left their homes as the storm's calm eye centered overhead. It is unclear how many people perished, as the Red Cross estimates 373 souls lost their lives, but the count cannot be certain as more than 800 people were missing.

Although my home state of Florida has not seen a hurricane make landfall in almost 11 years, we must never sit idle and succumb to hurricane amnesia.

Innovation is the key to ensuring lives and property are spared by accurate forecasting. This hurricane season, there are two new tools that will be at the disposal of our researchers and forecasters.

The first is called the Coyote. It is a small unmanned aerial system deployed directly from the P-3 hurricane hunters. This drone is able to fly into weather conditions that are otherwise impossible

for manned aircraft, while capturing atmospheric observations and relaying that data in real time to the Hurricane Center.

While this technology has been in testing since 2014, I hope it will be fully utilized in upcoming storms.

The second involves tools for storm surge, which is critically important as water is responsible for 90 percent of the deaths associated with storms. The storm surge watch and warning graphic, while still in the experimental phase, will provide watches and warnings to coastal residents similar to those issued for tropical storms or hurricanes, but will focus solely on the risks associated with high water. In response to these risks, it will issue guidance for evacuations in the areas impacted.

The potential storm surge flooding map, which began testing during 2014, will finally become operational this season. This map will highlight areas where storm surge could inundate areas and estimate the height at which waters could reach.

One only needs to look at Hurricane Katrina to realize how devastating storm surge can be. Not heeding storm surge warnings could be the difference between life and death.

I applaud the National Hurricane Center for its work on this new tool, and I stress the importance of educating people on the dangers of storm surge. The need for timely and accurate forecasts cannot be overstated. Indeed, advancements in forecasting have made great strides as technology and research have intersected.

As our witness notes in his written testimony, the National Hurricane Center's five-day track forecast is about as accurate as the three-day forecast was just 20 years ago.

This improvement in modeling not only allows more notice for evacuations, which will help especially in the Florida Keys, but appropriately provides for proper planning and damage mitigation to be conducted prior to a storm.

Also, increased confidence in the center's track and intensity forecasts will lead to the public's trust in heeding those warnings.

Last year, along with my colleague Senator Nelson, I introduced the Hurricane Forecast Improvement Act. This bill would require NOAA to improve guidance for hurricane track, intensity, and storm surge forecasts. It is modeled after NOAA's Hurricane Forecast Improvement Project, which has laid the groundwork for coordinating and improving research.

This program has a worthy goal of reducing errors in storm tracking. And with continued research, it is my hope a reduction in the loss of life, injury, and economic harm will result.

Now is the time to continue the momentum for research and technology to drive our forecasters to better track storms, not cut millions of dollars from the project, as the administration's Fiscal Year 2017 budget suggests.

I had hoped my legislation, which was adopted in Chairman Thune's larger weather bill, would have made it to the President's desk by now. But, unfortunately, it has been tied up due to unrelated issues.

Nonetheless, I will continue to push for its passage and support the center's work for better forecasting.

I must note that Senator Nelson has been a good partner in these efforts. I know he will be here in a few moments to speak

to us as well, and I look forward to continuing that partnership so that this does, indeed, get signed into law.

In closing, Floridians will always remember the year 1992 as the year Hurricane Andrew changed the landscape of our state forever. Known as the third largest hurricane to hit the United States, Andrew produced a 17-foot storm surge, was responsible for 23 deaths, and caused \$26.5 billion in damage. For the terrible destruction the storm inflicted on Florida, it also shed light on the need to be prepared.

Last week, our Nation recognized Hurricane Preparedness Week. Our witness, Dr. Knabb, took part in many activities throughout the gulf coast to increase awareness. Education coupled with strong support from State and local partnerships is the key to ensuring families and have a hurricane plan in place.

At the end of the day, the most important function of storm forecasting is, indeed, to protect the lives of those we love.

Floridians are incredibly resilient, but as we enter this year's hurricane season, which I hope will not be active, I urge everyone to assess the risk and develop a plan and be prepared.

On a side note, two weeks ago, I visited the National Hurricane Center in Miami, and I saw firsthand the good work that is being done on this front.

Again, I thank Dr. Knabb for appearing before us today.

Now I recognize Ranking Member Booker for his opening statement.

**STATEMENT OF HON. CORY BOOKER,
U.S. SENATOR FROM NEW JERSEY**

Senator BOOKER. I want to thank Chairman Rubio for having this very important hearing. It is an honor to sit between two Florida Senators. It is also very appropriate, given how many people from New Jersey are retiring in Florida.

[Laughter.]

Senator BOOKER. This really reflects the demographics of his state.

This is a very important hearing, but it is also a very timely hearing, as the National Hurricane Center prepares for the upcoming hurricane season, which starts just next week.

I would like to thank our witness, Dr. Richard Knabb, the Director of the National Hurricane Center. I really thank him for his testimony and his dedicated service to our Nation.

On October 29, 2012, Hurricane Sandy made landfall in southern New Jersey. It, too, as was discussed earlier by the Chairman about Andrew, changed our state forever.

By the time it had dissipated, it had claimed 159 lives and left more than \$70 billion in damage along its path. Sandy affected the entire eastern seaboard from Florida to Maine with its gale force wind gusts as far west as the western Great Lakes.

Hurricanes wreak havoc, bring devastation, and bring pain and agony to families. They also bring devastation and pain to our economy.

There are 30 coastal states that border the Atlantic, the Pacific, the Gulf of Mexico, and the Great Lakes. Nearly 40 percent of

Americans live and work in coastal regions, contributing to over half of our Nation's economic productivity.

Rising ocean and atmospheric temperatures are causing more extreme weather events. Scientists are telling us that we can expect the frequency of the most intense storms to increase substantially in some areas, including the Atlantic basin.

Manmade climate change, I believe, is real. Manmade impacts on our climate system are real.

According to the Intergovernmental Panel on Climate Change, manmade global warming by the end of the 21st century will cause hurricanes globally to be more intense, on average of up to 11 percent stronger. Those sound like abstract percentages, but that equates to significantly more damage to our communities.

Just last year, we had a record-setting storm with Hurricane Patricia. It reached sustained winds of 215 miles per hour, the strongest recorded hurricane in history.

Accurate hurricane prediction is absolutely vital for all levels of government when we are making emergency management decisions and keeping the public out of harm's way. Those at the National Hurricane Center, under the leadership of Dr. Knabb, are making exceptional progress in their efforts to increase observation and develop products that improve the forecasting accuracy.

This coming hurricane season, NOAA will deploy up to eight Coyote unmanned aircraft, which will fly above and through future hurricanes to better measure critical data within storms. In addition, the center's new potential storm surge flooding map will become fully operational this hurricane season and will provide critical evacuation and emergency management information, potentially saving many lives.

In New Jersey, the Geophysical Fluid Dynamics Lab (GFDL) is conducting research on the gaps in data linking extreme weather events and climate change. Scientists at the GFDL use high-performance computing to develop models and simulations to improve understanding and prediction of the behavior of the atmosphere, the oceans, and climate.

This research can be used to understand the causes of unusual and destructive events such as Sandy and Andrew, and lead to improved hurricane predictions.

We must do more. We must do more to connect our global climate models with our regional hurricane models. What is ultimately needed is a unified prediction system that pushes the boundaries of forecasting from hours to years so that we can save more lives.

We cannot prevent future hurricanes from happening, but we can certainly prevent future lives from being lost. It is imperative that we increase our funding for R&D in this area.

Again, I want to thank the Chairman for his leadership on this issue and for holding this hearing. I look forward to hearing from our witnesses. Now, I imagine I would like to hear from the other Senator from Florida.

Senator RUBIO. The senior Senator from Florida and the Ranking Member on the Commerce Committee, Senator Nelson.

**STATEMENT OF HON. BILL NELSON,
U.S. SENATOR FROM FLORIDA**

Senator NELSON. Thank you, Mr. Chairman.

Dr. Knabb, I hope you have a very boring job all the way up through the end of November.

We have been lucky for 10 years, but we weren't so lucky in 1992 with Hurricane Andrew. Then there was Katrina and Rita and Wilma in 2005, which covered Florida. So I hope you have a boring job.

As Senator Rubio and I know as native Floridians, hurricanes are a way of life. It used to be that way. It hasn't been that way for the last 10 years.

When I was a kid, a hurricane was an excuse to get out of school. When I was a bachelor, a hurricane was an excuse to have a party. But now these things are deadly. We know what Andrew did to Florida's homeowners' insurance marketplace. We know the 26 people who were killed by Andrew. And you can go on and on.

What Senator Booker was talking about, this UAV called a Coyote. We had it here yesterday. It is about that long. You eject it from the P-3 through a hole in the underside of the airplane, and it is like a canister instrumented like a normal sonde, like the sondes that are about that long, that big around that we eject out of the G-IV that flies at 45,000 feet over the hurricane. But the P-3 goes right in.

Then this thing comes out of the airplane. It opens up the wings. It opens up the tail. It opens up the propeller. It can go out there, get into the eyewall and loiter where the fiercest winds are, taking all of these measurements to help folks like Dr. Knabb more accurately predict the hurricane's track, its intensity, and its winds. That means saving a lot of lives and a lot of property.

Senator Rubio and I have been looking at this and filing legislation to codify the Hurricane Forecast Improvement Project. We simply have too much at risk.

So I am looking forward to the head of the Hurricane Center's testimony.

Senator RUBIO. Thank you. I am going to defer my questions. Actually, let's begin with our distinguished witness today, Dr. Knabb, who is the Director of the National Hurricane Center. He received his Bachelor's Degree in Atmospheric Science from Purdue, and his Master's of Science and Doctorate of Meteorology from Florida State University.

I was going to make a joke because I'm from Florida, but Florida State is great. We talked about it when I went to visit you.

Dr. KNABB. You can make a Rutgers reference, if you like.

Senator RUBIO. He didn't go to Rutgers.

But I was just commenting, when I was visited there, a lot of the forecasters, Florida State was well-represented in the Hurricane Center.

He completed his postdoctoral work at the University of Hawaii, and he has served as Director at the National Hurricane Center since 2012.

We appreciate you appearing before us today, and we look forward to your testimony.

**STATEMENT OF DR. RICHARD KNABB, DIRECTOR, NATIONAL
HURRICANE CENTER, NATIONAL WEATHER SERVICE,
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION,
U.S. DEPARTMENT OF COMMERCE**

Dr. KNABB. Good afternoon, Chairman Rubio and Ranking Members Booker and Nelson, and members of the Subcommittee. It truly is my honor to testify before you today on the state of the United States hurricane forecasting capabilities.

I will also focus on the partnerships between NOAA and other Federal, State, and local government agencies that make effective use of these forecasts and to whom we provide decision-support services, and our public outreach and education efforts in collaboration with numerous public and private partners to prepare our citizens well in advance of the next hurricane.

We at NOAA welcome your interest, support, and the opportunity to discuss these important topics.

NOAA's National Weather Service has the best forecasters and technical experts in the world that enable us to provide critical life-saving forecasts, warnings, products, and services. The National Hurricane Center is one of nine centers of expertise in the National Centers for Environmental Prediction, known as NCEP. That is part of the National Weather Service as well.

The Hurricane Center 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, importantly, by increasing the understanding of these related hazards.

The Hurricane Center also conducts an extensive outreach and education program, and it is a very visible component of building a weather-ready Nation.

The United States has not experienced a landfall of a major hurricane defined as Category 3 on our Saffir-Simpson hurricane wind scale since Wilma in October 2005. Wilma was also the last hurricane of any intensity to strike the state of Florida.

Nevertheless, several other hurricanes and tropical storms have come ashore in the United States and resulted in major impacts and loss of life in this country. Many of those impacts and losses, including Sandy in New Jersey, have been due to water, with storm surge causing fatalities and extensive damage in coastal areas, and deadly and damaging freshwater floods caused by heavy rain extending well inland.

We continue that hurricanes and tropical storms are not just coastal events or just a problem for people with beachfront property.

Our recent studies have documented that during the past half century, nearly nine out of 10 fatalities, as Senator Rubio mentioned, in the United States from the direct forces of tropical cyclones have been due to water. Wind can be dangerous and destructive, of course, but people often do not realize just how heavy, powerful, damaging, and deadly water can be.

In addition to the lives we lost at the beach and on boats, 25 percent of these fatalities have been caused by rain-induced flooding that is the most frequent cause of death, meaning that it has taken lives in more tropical cyclones than any other hazard.

But the deadliest hazard overall, however, taking the largest number of lives overall in far fewer events, has been storm surge. Storm surge causes about half of the direct tropical cyclone fatalities in the United States.

So motivated by the desire to reduce storm surge fatalities, we have placed a heavy focus on storm surge in our tropical cyclone product development during the past several years. That work is coming to fruition.

A potential storm surge flooding map is operational beginning this hurricane season. Developed over several years in consultation with social scientists, emergency managers, broadcast meteorologists, and others, this map shows in a game-changing way, I believe, where the storm surge flooding could occur; how far inland from the immediate coastline the flooding could go that could be miles in some locations, in some scenarios; and how high above normally dry ground storm surge floodwaters could reach in a given community.

So emergency managers will be able to more clearly identify areas that they must decide to evacuate. And our media partners will be much more on the same page, conveying a consistent message on storm surge.

And the map will first be disseminated when we issue a hurricane watch or tropical storm watch, and when storm surge poses a threat for any portion of the Gulf or East Coast of the United States.

Then, in 2017, we plan to issue a new National Weather Service storm surge watch and warning for tropical cyclones. While it is not an actual watch and warning for 2016, we will this year experimentally issue a prototype storm surge watch/warning graphic for tropical cyclones for the gulf and east coast of the United States. This graphic, like the actual warning will be in 2017, will depict those areas that have a significant chance of a life-threatening storm surge.

The goal of both, the potential storm surge flooding map and the storm surge watch and warning, it is to increase the chances that when people are instructed by their emergency managers to evacuate, they go.

The effectiveness of our partnerships with the emergency management community at the Federal, State, local, and tribal levels are as high as ever. NOAA, FEMA, the U.S. Army Corps of Engineers, and the Federal partners in the National Hurricane Program provide evacuation decisionmaking training and tools to State and local emergency managers. The jointly run Hurricane Liaison Team at the Hurricane Center then supports real-time decision-making by facilitating the rapid exchange of critical information regarding tropical cyclone hazards and their potential impacts between NHC and emergency managers at all levels.

Our advances in communicating these individual wind and water hazards are taking advantage of the tremendous progress NOAA has made in tropical cyclone predictions. We have reduced tracked forecast errors by about half during the past 15 years in our 5-day track forecast today, about as accurate as the 3-day forecast was about 20 years ago.

In addition, tropical cyclone forecasts were recently extended from 2 to 5 days, the tropical cyclone formation forecasts.

Work is also well underway to develop the capability to issue Hurricane Center forecasts and Weather Service tropical storm and hurricane watches and warnings even prior to the formation of a tropical cyclone, with a potential debut of the capability experimentally in 2017.

This change would enable us to issue even more timely watches and warnings for storms that form close to the U.S. coast, including storm surge watches and warnings starting in 2017.

The new supercomputers that Congress appropriated have allowed us to run more complex and sophisticated forecast models, including the new Hurricane Weather Research and Forecast, or HWRF, model. The HWRF represents a significant step forward in our operational prediction of hurricane structure and intensity. This research and development has been a joint effort between NOAA, primarily involving the Weather Service and NOAA's research division, OAR, and our academic partners as part of the Hurricane Forecast Improvement Project, HFIP.

HFIP continues with a multiyear, multimillion dollar effort to improve hurricane forecasts intending to improve tracking and intensity forecasting accuracy by 50 percent in 10 years. We are already meeting the 5-year HFIP goal to reduce hurricane forecast track and intensity errors by 20 percent.

Recent enhancements that have been made to the operational HWRF have made it our best performing intensity forecasting model during the 2013 to 2015 period.

Operations continue to benefit from and rely on aircraft reconnaissance, both the WC-130J aircraft of the U.S. Air Force Reserve from the 53rd Weather Reconnaissance Squadron, 403rd Wing, in Biloxi, Mississippi, and the NOAA G-IV jet, and NOAA P-3 stationed at MacDill Air Force Base in Tampa, Florida.

We are also excited about the launch of the new GOES-R satellite scheduled for later this year. Its technological advances include improvements upon existing data, such as dramatically increased spatial, temporal, and spectral resolutions for Earth monitoring, and new observations such as lightening data.

I am convinced that all of the data forecast technology, products, warnings, evacuation decisions and plans will not achieve their full potential if individuals, families, and businesses do not prepare now, well in advance for the next hurricane. People need to know ahead of time what they will do during an actual hurricane event, so that they can survive the event and recover quickly in the aftermath.

Many things that we all desperately need to do, including myself and my family, to prepare are far more difficult, expensive, or even impossible to do if we wait until a hurricane is on our doorstep.

We battle mightily against public complacency and a lack of preparedness as certain parts of the country have gone for years, or even decades in some places, since their last significant hurricane impact. We work hard to explain that overall hurricane activity has almost no relationship to hurricane impacts in any one community.

We remind everyone that it only takes one. In 1992, that hurricane season was below average, overall, and Andrew was the one

that struck South Florida as a Category 5 hurricane. There was a tremendous difference between how busy the season might be overall and how bad it could be where you live. We all must prepare for hurricane season the same way every year.

Thank you for the opportunity to testify today. I'm happy to take any questions you might have.

[The prepared statement of Dr. Knabb follows:]

PREPARED STATEMENT OF DR. RICHARD KNABB, DIRECTOR, NATIONAL HURRICANE CENTER, NATIONAL WEATHER SERVICE, NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION, U.S. DEPARTMENT OF COMMERCE

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 decisionmakers, 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 decisionmakers 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-3s 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 $\frac{1}{2}$ 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.

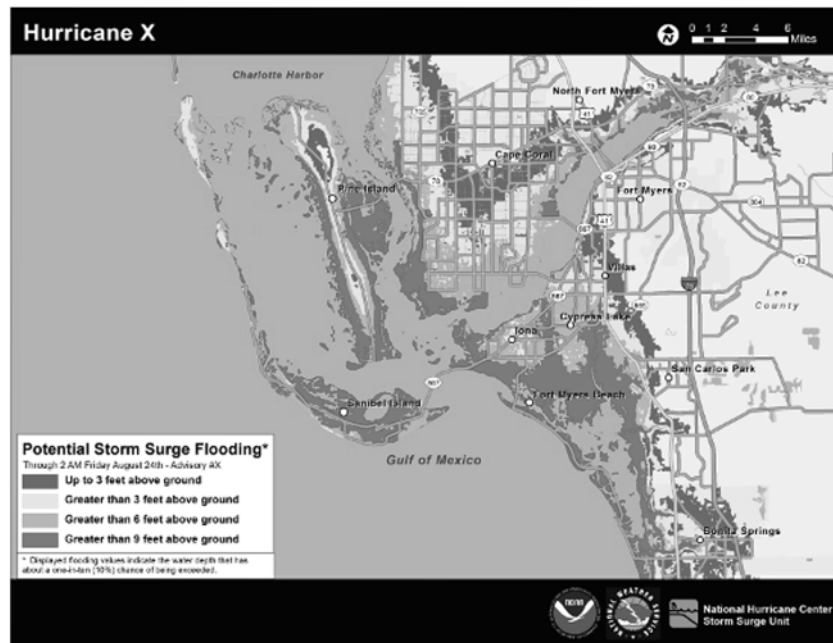
New and Planned Operational Public Products and Warnings

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 to-

gether 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.

Senator RUBIO. Thank you.

I'm going to defer the beginning of the questions to the Ranking Member, Senator Booker.

Senator BOOKER. Thank you very much.

I really appreciate both your written testimony as well as the words you spoke. You're right. I was Mayor when Hurricane Sandy hit, and we lost people because of the water, that storm surge that came in so suddenly; in one case I will never forget, a person drowned in their car.

We had waves as high as 32 feet. We had storm surges at about 10 feet. Sea levels are continuing to rise now just because of climate change.

After hearing what you just said about this incredible new technology that is really looking at some of these storm surge products and warnings, can you give us an idea about what we can do to try to expedite these tools coming online?

Dr. KNABB. I am very excited to report to everyone about the potential storm surge flooding map going operational this year. That is many years in the making with a lot of social scientists and partners involved in the development of that product.

It has been thoroughly tested. We have gone through exercises with the emergency managers. We really think that is going to be a game-changing tool for their evacuation decisionmaking and communicating the hazard to the public this year.

We just sent out the service change notice today that that product is going operational today, so that is very exciting. It really is going to get everybody on the same page.

The storm surge watch/warning also is more than a decade in the making. Even though it is going to be 2017, next year, when that warning goes operational, the public, everybody, will see a prototype storm surge watch/warning graphic this year that will, in no less of an important way, convey where we, as National Weather Service forecasters, think there is a significant chance of life-threatening storm surge.

So in many ways, we are already there in terms of dramatically enhancing how we communicate the storm surge hazard in real time.

We do want to continue to enhance these products. The purpose of another experimental year with this prototype storm surge watch/warning graphic is to get a little more feedback from our partners and factor that into what goes operational with the storm surge warning in 2017.

Senator BOOKER. Dr. Knabb, if I may, and if I can correctly interpret the Chairman's thoughts on this as well, I have some concerns that we are not investing enough in R&D, and there is this urgent need to significantly increase our research and development in this area.

Could you give me an idea of how increased R&D funding would help, in terms of expediting our forecasting capabilities?

Dr. KNABB. Sure. So, again, just to reiterate, the Hurricane Forecast Improvement Project is ongoing, and it is leading to changes that are being implemented every year. The new HWRF model enhanced through HFIP over 2013 to 2015 is our leading intensity model during that period.

If we want to continue to improve our track and intensity forecast, it has involved and will continue to involve having the correct, most useful data from inside the hurricane and in the environment; advanced computer models that leverage research data and other knowledge to increase our understanding of hurricanes and incorporate that knowledge into the models; assimilation schemes that allow the models to take advantage of all those data; and faster computers in order to run these more advanced models, along with the staff to do the technical work to get us to the next stage.

Senator BOOKER. So, yes or no? Do you believe that if Congress and the administration were to invest more in R&D in this area, that it would significantly help in our preparedness, could potentially save many, many lives and help us avert significant economic damage?

Dr. KNABB. Yes, I think that the last several years of HFIP show us that investing in research and development, and computer modeling, and data simulation capabilities, that allows us to utilize things like various types of aircraft data that we collect.

Senator BOOKER. So really quick, my last question.

NOAA's Geophysical Fluid Dynamics Laboratory, GFDL, based in Princeton, New Jersey, has developed cutting-edge climate modeling that for the first time has successfully reproduced the observation year-by-year variations in Category 4 and Category 5 hurricanes. We are very proud of that in our state. These results high-

light the potential use of climate change modeling for long-term, season-by-season hurricane prediction, which could really help the U.S. prepare for storms.

How could increased funding, specifically for the research and development of high-performance computing, improve NOAA's ability to provide long-term forecasting of extreme weather?

Dr. KNABB. Yes. More computing power has already allowed us to run more advanced models for our 5-day forecasting. It is part of how we are, through Sandy supplemental funding, helping out with the supercomputing capabilities, allowing us to run the storm surge model in real time fast enough to generate that new potential storm surge flooding map and guidance for the storm surge warning.

Likewise, if anyone is going to make progress in forecasting future hurricane activity over the long haul, more advanced models, faster computers, are part of that equation.

But, of course, at the Hurricane Center, our focus is on the supercomputer power and the modeling capabilities that allow us to improve the accuracy of our track and intensity forecast in the 5-day period. Again, HFIP has shown that investing in that capability can lead to improvements, as it has, and that project is ongoing. We are going to hopefully continue to see some benefits from that.

Senator BOOKER. Dr. Knabb, thank you for that. I may have to step away, but please understand that, on behalf of my whole entire state, we really do appreciate the important work that you are doing. The growing sophistication and capabilities is really making a difference.

And my hope is that we as a Congress will recognize how much investments here can produce overall returns for this country as a whole.

So I am grateful for your leadership, grateful for your work. I hope that we can continue to support you in more robust ways.

Thank you, Mr. Chairman.

Senator RUBIO. Thank you, Senator Booker.

Senator Nelson?

Senator NELSON. Did you really get 32 feet of sea level rise surge in Hurricane Sandy?

Senator BOOKER. Waves as high as 32 feet in the storm surge.

Senator NELSON. Did that cover up a good part of the coastal New Jersey?

Senator BOOKER. Oh my gosh, the devastation, I'm sure you remember, looking at our state, it was catastrophic. Even in a city like Newark, when I was Mayor, the surge came in so dramatically that it swept away homes, moved them off their foundations, swept away businesses, and, unfortunately, resulted in the loss of life.

Senator NELSON. In the monster Hurricane Andrew in 1992, we had a 17-foot storm surge. It was a hurricane that now they think was well into a Category 5 with winds in excess of 160 miles per hour. That is why it tore up so much of Homestead, Florida.

I will never forget flying over in a National Guard helicopter; there were only two buildings left in downtown Homestead. One was the bank, which was very well constructed. The other one, Senator Rubio, was an old Florida cracker house that had been

built back in the old days that withstood the winds and everything else.

Of course, that caused a revolution in Miami-Dade County in building codes, much for the better, because under the old codes, places were just wiped out completely.

Senator BOOKER. You will have to tell me one day what a cracker house is.

[Laughter.]

Senator NELSON. The old-line Floridians, like Senator Rubio and me, used to be referred to as crackers because they would drive the cattle to Punta Rassa, which is now near Fort Myers. And they would put those cattle on the cattle drive on a boat going for Havana. The way they drove them was through cow whips, crackers. So that is why we are Florida crackers.

Senator RUBIO. Then my ancestors would receive them as they came to Cuba. It is all kind of intertwined.

[Laughter.]

Senator NELSON. There you go.

All right, I have just a couple quick questions. I'm going to make it very quick.

Senator BOOKER. By the way, that is a term I will never use, cracker house. We don't have those in New Jersey.

Senator NELSON. Oh, you might have a different kind house in New Jersey.

Senator BOOKER. No, sir. No, sir.

[Laughter.]

Senator NELSON. OK, you have two P-3s, and you have one G-IV. Now if they were down, you would be in a world of hurt, would you not, on estimating the track and intensity, and so forth?

Dr. KNABB. Yes, Senator. Then NOAA G-IV jet is an operational resource that we utilize when the gulf or east coast of the U.S., or Puerto Rico or the Virgin Islands, are threatened by hurricane. The G-IV jet flies in the environment of the hurricane in a pattern that we designate to drop the sondes, provide vertical profile data over the data-sparse oceans, go into the computer forecast models, and in so many past cases have shown to enhance the accuracy of the model track forecast and, therefore, operational track forecast.

The NOAA P-3s are research laboratories that we also receive the data from in real time. They have also been ideal platforms for many years for developing new technologies that have made their way onto the Air Force WC-130J aircraft.

So, yes, the NOAA G-IV and P-3s are extremely important to our operations and our future developments based on that research.

Senator NELSON. So if you had an accident or a maintenance problem, and you were down with the P-3s, you do have backup with the Air Force?

Dr. KNABB. Yes, it's important to emphasize that the Air Force WC-130J aircraft, there are 10 of those stationed at Biloxi, Mississippi, at Keesler Air Force Base. They are the operational workhorse. We task them routinely into everything from a developing tropical disturbance trying to become a depression or storm up to Category 5 hurricanes.

Senator NELSON. Can they drop the sondes?

Dr. KNABB. They could.

Senator NELSON. They drop the bigger sondes that we are talking about, the Coyote?

Dr. KNABB. Right. The benefit of the NOAA G-IV jet, it flies at higher altitude and much faster speed than either of the P-3s or the C-130. So we really need the G-IV to do the environmental surveillance missions to get the data into the models, track forecasting, and the P-3s are obviously vital to what the hurricane research division and others are doing to conduct their field program to advance the science, which is what instrumentation like the Coyote is promising to do.

Again, we see some of these data in real time. Occasionally, we see the data from the Coyote in real time. It is not a core part of our operations yet, but it has the potential to augment the heavy manned aircraft from the P-3s and the C-130s. So the C-130 is operational workhorse.

Senator NELSON. What I am getting at is that you have a backup with the P-3s. It is single point failure with the G-IV, right?

Dr. KNABB. An equivalent capability aircraft, correct. There is not a backup for it. But we could use the P-3s and/or the C-130s to do the surveillance missions, but the vertical profiles wouldn't be from as high of an altitude.

Senator NELSON. And your accuracy is increased by 15 percent by the G-IV in the vertical profile?

Dr. KNABB. On average, it is in that neighborhood that we have made the improvements in past forecasting. Yes, the G-IV is very important.

Senator NELSON. All right. Now tell me this, the El Faro leaves port, headed for Puerto Rico, and he sails right into the middle of a hurricane. Now there are 33 lives, most of which were from Jacksonville, Florida, lost.

We are now in the investigation, finding out that they were getting 10-hour-old data on the storm.

What can we do about that?

Dr. KNABB. We at the Hurricane Center have been actively participating in the NTSB investigation that is ongoing.

This is also an opportunity to remind everyone that the National Hurricane Center is more than just about hurricanes. As you have seen when you visited the center, we have a Tropical Analysis and Forecast Branch, TAFB. It is our largest branch. Marine forecasters do offshore waters and high seas forecasts over the Atlantic, Gulf, and Caribbean.

We are very eager to find out all the outcomes of that investigation because we want to do everything possible to make sure that our marine users and partners are getting the data in a timely manner to prevent something like El Faro from ever happening again.

Now to head in that direction, we have already had some partners visit the Hurricane Center within the last month from the cruise ship industry, from the cargo ship industry, and from the Coast Guard, talking about how we enhance how they get our forecasts and warnings in real time. I'm learning that some of the decisionmakers in the various industries that make decisions on rout-

ing are often folks who are on land that are then communicating routing decisions to the ships at sea.

So we are going to make sure that we get training delivered to those decisionmakers. We are already planning an off-season training course next winter for these marine decisionmakers.

Senator NELSON. Good. Thank you.

Senator RUBIO. Thank you.

Senator Schatz?

**STATEMENT OF HON. BRIAN SCHATZ,
U.S. SENATOR FROM HAWAII**

Senator SCHATZ. Thank you, Mr. Chairman.

Dr. Knabb, thank you for your work. I just have two quick questions. Hopefully, they will be quick.

I have heard reports that NOAA is or was considering relocating the Central Pacific Hurricane Center to Florida in an effort to reduce staffing levels. Is this true?

Dr. KNABB. There are no plans within the National Weather Service to change the function of the Central Pacific Hurricane Center. In fact, we are continuing at the National Hurricane Center to partner with them, providing them training and working on ways to enhance the consistency of products and Web presence, and sharing of technology between NHC, the National Hurricane Center, and CPHC, the Central Pacific Hurricane Center.

Senator SCHATZ. Great. So I won't go into great detail about this, because I think we are now on the same page, but if you could continue to keep in touch with our staff regarding any possible plans. Obviously, from an expertise standpoint, from a time zone standpoint, and from the viewpoint of logistics and relationships with local civil defense officials, media partners, it makes a lot of sense to keep the Central Pacific Hurricane Center in the Pacific.

Dr. KNABB. Having worked in that office myself, I can tell you that the staff there are vital to providing decision support services to State and local emergency managers, and briefing the media.

Senator SCHATZ. Great. Thank you.

Forecasting hurricanes in the Pacific, as you know, is made more complicated by a lack of data. Over the course of the last 15 named storms in the Pacific last year, our civil defense community learned firsthand how much of a difference more data and adding hurricane hunters could make. What are your Pacific deployment plans for Coyote UAVs and APAR units when they are operational?

Dr. KNABB. The platforms that you just mentioned are research platforms that the research component of NOAA primarily schedules as part of their field program. We at the National Hurricane Center, and I am sure CPHC would be the same, we would be eager to see some of those data in real time and are even more eager to find out what the outcomes of those research efforts would be.

We do have at the National Hurricane Center in Miami permanently stationed Department of Defense employees that help us coordinate the taskings that we issue from Hurricane Center Miami and CPHC in Honolulu on where we want to send the Air Force C-130s and the NOAA G-IV and P-3 aircraft.

As you saw last year, those aircraft resources were forward-deployed to Honolulu to fly the many systems that were in the central Pacific. We and CPHC collaborate on that.

Senator SCHATZ. Thank you very much.

Thank you, Mr. Chairman.

Senator RUBIO. Thank you.

Senator Blumenthal?

**STATEMENT OF HON. RICHARD BLUMENTHAL,
U.S. SENATOR FROM CONNECTICUT**

Senator BLUMENTHAL. Thanks, Mr. Chairman.

Thank you for being here. I noted that you began your career in Hawaii and then moved to California and then to Florida, so you have seen a lot of different weather patterns around the country, and you have also seen differences, perhaps, in responses to hurricane warnings.

Superstorm Sandy, which was a hurricane before it hit Connecticut, did untold and tragic damage in part because people failed to respond to the warnings that they were given. I am wondering if you have any observations on what can be done to improve the responses of everyone from public officials to citizen groups to citizens themselves?

Dr. KNABB. Sure. I mentioned earlier the national hurricane program, which is a Federal partnership between NOAA, our agency, and FEMA and U.S. Army Corps of Engineers. That national hurricane program is currently going through a modernization. It has already been very effective to date in providing tools, training, and the resources, and the real-time decision support, for State and especially local emergency managers to make more effective evacuation and other decisions.

But that program is currently being modernized, and one of the most exciting parts about it is that the modernized tools for emergency managers will be developed in lockstep with new National Hurricane Center products and warnings, so they are ready to utilize it in their systems when those products become available.

In addition, we are, with many different partners, government and outside of government, enhancing how we conduct our outreach and education, and provide messages in a far more personal and emotional level to make people realize that we have to prepare our families just as much as other people do. So our Hurricane Preparedness Week recently focused on messages having to do with putting your personal and family evacuation plan together, buying your supplies in advance, getting an insurance checkup in advance, doing whatever you can now to strengthen your home.

I am doing those things. By telling the public that I am doing those things, hopefully people realize that it is something that they ought to be doing as well.

So those are just some of the things that we are doing to get people and our partners more prepared. When people see us as government partners getting more prepared, hopefully they have more confidence in their government and they get prepared as well.

Senator BLUMENTHAL. How about the media, in terms of the way it depicts or provides warnings? Have you interacted with them a

lot? Because that is the way most people figure out whether they are going to move or stay put.

Dr. KNABB. Yes. Despite the increased use of social media, television is still the main way that people get their information as a hurricane approaches. We have developed and continue to maintain and try to enhance our relationships with our media partners, both national outlets and local ones.

Some of them come to the Hurricane Center. We engage them at a variety of off-season conferences. I talked to some of them yesterday on a webinar. One thing that we have emphasized going into this hurricane season is making sure they fully understand how to interpret this new potential storm surge flooding map, and the new prototype storm surge warning graphics, so they are conveying the right, consistent message.

So our relationships with our media partners are absolutely vital, and we have increased the amount of training we provide to them. And they were involved in some of the development of this new storm surge product.

Senator BLUMENTHAL. They have their own meteorologists. Do they ever push back or differ with you as to what they think the response should be or whether your interpretation of the data is correct?

Dr. KNABB. There are at least a couple reasons why that isn't a huge problem. Number one is that because we develop the relationships with them, they understand why we are conveying what we are conveying in our forecast. Our discussion products convey the reasoning.

And, usually, any disagreements on exactly where the forecast should have been placed are well within the bounds of uncertainty. If you put 20 different meteorologists, even at the Hurricane Center, in the same room, it will not be the exact same forecast. But all the opinions that might be out there I think are still well within the bounds of the areas that we are trying to alert with regard to the wind and water hazards that they might experience.

But we have enhanced the content of our products. Just last year, during Hurricane Joaquin, and then during eastern Pacific Hurricane Patricia, primarily for the benefit of the media, we inserted in our discussion product that they are very familiar with some key messaging points, main issues that we want our media partners to be focused on conveying.

That is not just for the on-camera meteorologists, but for the producers and the people populating the crawls and the reporters and the anchors. The media feedback from that, plus our proactive use of social media to let them know what is coming in terms of Hurricane Center product, very good feedback from media partners. So that dialogue goes on year-round.

Senator BLUMENTHAL. Thank you very much.

Thank you, Mr. Chairman.

Senator RUBIO. Thank you, Senator Blumenthal.

Dr. Knabb, let me touch on a couple points.

Number one, let me just say that there is obviously a lot of negativity today about government and politics, things going on in our country. But our men and women who serve us in public service, in various different fields, do an excellent job on our behalf, and

one of those places is in the National Hurricane Center. I had a chance to visit there previously, once as a State legislator and now again as a U.S. Senator. I'm just incredibly impressed with the work that you do, and we want to thank you.

The level of expertise and the resource that you provide, as was pointed out to me, which I understood before as well, it is not just to the men and women of the United States, but so many liaison partners around the world that don't have a National Hurricane Center of their own rely on our expertise as well. So that service you also provide to so many partner nations who have come to rely of the United States as the authority on these issues.

By the way, almost as if on cue, and no one can accuse me of having anything to do with this, but already I see there is a special tropical weather outlook report. There is a system developing in the western Atlantic. Development is not anticipated for the next couple of days, but environmental conditions are expected to become more conducive for tropical or subtropical development on Friday.

So just a reminder that even as we are meeting here today, everything is starting up. And hurricane season is a date on the calendar, but a reminder to everyone that you can have storms before that date. We had storms last year, I believe, after that date, or close to the end of the season, late in the season.

So it doesn't matter when it is. It is a real issue.

I talked in my opening statement about the legislation that Senator Nelson and I have worked on. We introduced it last year. It would require NOAA to improve guidance for hurricane tracking, intensity, storm surge forecast. It builds on important work that has already been deployed, which is the Hurricane Forecast Improvement Project. But it has not yet been congressionally authorized. Now the President's budget is recommending a cut of \$3 million.

So I am not asking you to opine on the congressional process or on the budget recommendation, but I am asking you to speak a little bit about how valuable this project is, the forecast improvement project, and how forecasting would be impacted should a future administration further cut or, worse, absent any legislation, end the program entirely.

Dr. KNABB. Sure. I want to take this opportunity to thank you, Senator Rubio and Senator Nelson, for your support of the national hurricane program and what we do with our partners. That support is very much appreciated.

It is obvious from what we have already accomplished through the Hurricane Forecast Improvement Project that investments in advanced modeling capabilities pay off, and they are already paying off.

The good news is that HFIP is not going away. It is going on. Again, we have been able to improve our Hurricane Weather Research and Forecast model, the HWRF. And again, during the past three hurricane seasons combined, it has remarkably become our best-performing intensity model. That is a tremendous accomplishment.

Because we have been able to make some improvements so far in meeting these 5-year goals with HFIP, there is promise for con-

tinued improvements, given a proper level of investment. Again, those areas of investment have to be multifaceted and include the data you need from inside the hurricane and the environment, scientific advancements, including from data like the Coyote and other platforms to increase our understanding of hurricanes, models that can use those data, and the supercomputer power to run those more advanced models, and, importantly, to have the staff that we need in order to do the development work and leverage the improvements that come from these scientific advances.

The faster we can hire our vacancies, the better off we are going to be, and that has been a challenge recently.

So all of those things require investments to move forward. It is always the case, and it is the case heading into this hurricane season, that the National Hurricane Center is fully prepared to carry out its operational mission, but we always have more difficulty in applying and having the resources to apply to advance our products and warning suite, and have the research resources, mainly in terms of people, to enhance the computer forecast models that has been happening during HFIP.

Senator RUBIO. You also, in your testimony, talked about the next evolution of the geostationary operational environmental satellite, which is set to be launched from Cape Canaveral, I believe later this year. This satellite is going to provide high-resolution images of storms up-to-the-minute every minute, and, as a result, more accurate tracking and intensity forecast.

Once that satellite is launched, do you have an estimate as to how long it will take to come online and begin providing this data?

Dr. KNABB. Yes. I will also say, before I directly answer that, that the National Hurricane Center has already been preparing itself, as have other components of the National Weather Service, to get ready for these new data by participating in what is called the GOES-R proving ground. Some of our forecasters have already directly had their hands on the operations floor on some proxy data sets that prepare us for what GOES-R is going to be providing.

We have also installed in our backyard at the Hurricane Center, as you saw when you visited, the three dishes getting ready to bring down the GOES-R data.

Once those data start flowing, after the satellite is launched, my understanding is that it could take up to a year for calibration, validation, and checkout to occur. But that means that perhaps at some point during the 2017 hurricane season, calibrated, validated data from GOES-R could be flowing.

We have tried also to prepare our computing infrastructure for that, because we are going to have three times as many channels on the satellite, four times as much spatial resolution, and five times as much temporal resolution in the data, so tremendous advances are coming. We are very excited about what is ahead.

Senator RUBIO. In my statement as I was opening up the hearing, I talked a little bit about hurricane amnesia and the ability to forget over time about what this is like.

I do recall 2004 and 2005, living in South Florida, we experienced storms, if I'm correct—I believe Katrina was in September, and there was one again a month later. So we lost power. We did not see the extensive damage of Andrew obviously in Florida, but

Katrina went on to do extensive damage in the gulf coast, Louisiana and Mississippi.

But time passes and people forget. You have been on the road now for the better part of last week traveling the gulf coast, primarily in Florida, talking to people about what they needed to be doing to get ready.

What is your assessment? How aware are people that hurricane season is upon us? How prepared are they? What is your sense of the standing today among the public about the upcoming season?

Dr. KNABB. I'm still very concerned that way too many people in the public in Florida and other states are not as prepared as they need to be. One of the concerns is not only has it been more than a decade since the last Florida hurricane, but in that timeframe, we have gained something like three million new residents in the state of Florida.

Other metropolitan areas are similar. I just visited Houston, Texas, last week. Since Hurricane Ike struck there in 2008, they have something like a million new residents in their metropolitan area.

So not only do you have people who might have been through a hurricane in the past and maybe they have gotten out of the habit of preparing, or maybe they experienced the fringes of a hurricane in the past and they haven't really been through the core of a major hurricane, or maybe they are new to the problem, and they have never prepared for a hurricane at all. I think there are way too many of those people still out there, which is why last week during the hurricane awareness tour, which was merged with the presidentially-declared National Hurricane Preparedness Week, the themes each day focused on things that people, residents of our states, need to be doing to get ready for the next hurricane.

That is why we focused on planning your evacuation route and destination in advance, buying your supplies in advance, updating your insurance now, because of those 30-day waiting periods for flood insurance, for example, and doing whatever you can today to strengthen your home.

And again, by telling people that I'm doing those things personally, hopefully, we are reaching people a little bit more on an emotional level so that they realize that all of us share in this problem. I welcome anyone who is willing to go out there and share what they do to get ready for the next hurricane to set an example for what the public can be doing.

Senator RUBIO. One of the things we discussed, and I heard this discussed previously, is that one of the most devastating potential storms would be one that went right into the Tampa Bay area and right into the bay. We saw some models of what that would look like, rough models.

But in essence, I think this is important. I think this is an area that hasn't had that event happen, at least not in modern times.

Could you describe briefly for people living in the Tampa Bay area what that storm situation would look like and what level of intensity would require for the worst-case scenario? I was particularly impressed, I should say, and impacted by some of the flooding and storm surge projections where there were communities not nec-

essarily on the water that could see extensive amounts of flooding as a result of a storm of that magnitude.

If you could briefly take this moment, if you were talking to people in the Tampa Bay area, what would that event look like for them, and just sort of worst-case scenario, which, unfortunately, 1 day will happen, just by matter of statistics?

Dr. KNABB. Yes, Senator. It certainly is a matter of when, not if. The Tampa Bay area is one of those many areas that I am very, very concerned about.

They last experienced a direct hit of a major hurricane back in October 1921. So nearly a century later, there are a lot more people and a lot more infrastructure in harm's way there. And it is important for people to realize there that the storm surge flooding risk in many portions of the Tampa Bay area goes not just across the street from the beachfront property, not just blocks inland, but, in some locations, miles inland from the coast.

So it is vital that people, even if you can't see the water from where you are at your home, find out today if you live in a hurricane surge evacuation zone and figure out today where you would go and how you would get there, if told to evacuate.

For folks who live far enough inland, in whatever part of Florida or any other hurricane-prone states, if you are not in one of those storm surge zones, find someone you care about who is and plan now to be their inland evacuation destination.

But again, that storm surge hazard in the Tampa Bay area, like in many other areas, goes miles inland. That is why it is even more important that we are going operational this year with our potential storm surge flooding map, because if people haven't gotten it by that time, then when that product comes out, if a hurricane is threatening that area, then we will be showing people just how far inland from the immediate coastline the storm surge flooding could go in that scenario.

Senator RUBIO. How could someone, whether it is in the Tampa Bay area or anywhere else, see whether their home is in that? Where would they go? Where is the resource they can go to, to see whether their property or where they are living is located in that zone?

Dr. KNABB. The best advice is to contact your local emergency management agency in your county, your city. In the state of Florida, you shouldn't have too much trouble getting information from them about what evacuation zone, if any, that you live in.

Your local emergency managers have prescribed those evacuation zones, in large part based on guidance from the Hurricane Center on who is vulnerable to storm surge. So when they prescribe those evacuation zones, they are doing it for good reason. When they call for evacuations and tell people to evacuate, it is vital that they go because they will do that based on advice from the National Weather Service on who is vulnerable to storm surge in that situation.

Senator RUBIO. To that, I would just add, oftentimes, this is anecdotal, but I've heard from people who live on the sixth floor of a building and their argument is that there is not going to be water on the sixth floor. That is not really the point. The point is if you live on the sixth floor but the street is heavily flooded, you can't

get out, nothing can get in. And if, God forbid, you have a medical emergency, responders can't get there either.

So people need to understand that being in the zone, it doesn't matter if you're on the tenth floor of a big building. That doesn't mean you'll be able to get out for days to come in a worst-case scenario, such as the one you described.

Senator Markey?

**STATEMENT OF HON. EDWARD MARKEY,
U.S. SENATOR FROM MASSACHUSETTS**

Senator MARKEY. Thank you, Mr. Chairman. And thank you for this very important hearing.

Although it was a Nor'easter that delivered the perfect storm, Massachusetts is not immune to hurricanes. We saw the effects from Hurricane Noel in 2007, Hurricane Earl in 2010, and Hurricane Irene in 2011; storms that began off the coast of Africa, traveled across the Atlantic, hang a right, and sometimes find themselves in New England.

And if they are anything like Boston drivers, they do so without a turn signal.

[Laughter.]

Senator MARKEY. That is what we get hit with.

But with the National Hurricane Center at the wheel, we have the best science and technology to predict where the storms are going to go. You are our needed turn signal, and we thank you for that.

But there is still room to improve. There are still many questions about hurricanes. Answers to them will enhance the prediction of track intensity and when a storm may transition into an extratropical system, one that is powered by differences in atmospheric temperatures rather than ocean temperatures that drive hurricanes.

One of the big questions remaining is: what will hurricanes look like in a warmer world? Scientists expect stronger storms with a higher frequency of the most intense storms, and heavier rainfall. In addition, sea level rise will enhance the threat from coastal storms and flooding.

While hurricanes are sometimes such that we can only predict and prepare for them, we can do something to steer the path of climate change, and we must do that. Now that is of concern to us because of all the places on the planet, the entire planet, it is the sea surface temperatures off of New England that are warming faster than any place else on Earth.

As temperatures continue to warm along the mid-Atlantic and New England coast, how might the northern extent of these storms change, Doctor?

Dr. KNABB. Certainly, there is a lot that we know about how the climate has changed up to this point. It is rather uncertain how much the numbers and strength of hurricanes have changed in the decades prior to leading up to now, mainly because we haven't had current monitoring tools as long as people might think. We have only had the satellites for half a century, and aircraft reconnaissance since the 1940s.

Then looking forward, there still remains a lot of uncertainty with regard to what will change in terms of the numbers and strength of hurricanes.

Senator MARKEY. So especially the kinds of storms that lose strength as they head north? What could it mean in the future as our ocean gets warmer and warmer in terms of the intensity of these storms further north as they get that extra fuel out of the ocean?

Dr. KNABB. We have many, many events in the northeastern U.S. to point to in the last many decades to show it is a relatively frequent occurrence to have systems, hurricanes, major hurricanes moving north and then having tremendous impact up in the Northeast.

In fact, one of these days, Senator Rubio, we are going to start having hurricanes in Florida like they do in the Northeast. We have had them hitting the Northeast with quite a bit of frequency the last few years.

The main concern I have with regard to how hurricane impacts are going to change in the future, and many cities and states in the Northeast are no exception, is that even if the numbers and strength of hurricanes don't change, and even if the behavior of the storms that move up the East Coast and into the Northeast don't change, the potential for rising sea levels, the increased population, and the increased infrastructure, I am really worried about increased impacts from storm surge, from heavy rainfall.

And that, to me, is the biggest challenge that we face in coastal regions over the years and decades to come.

Senator MARKEY. When we had that huge 111-inch snowstorm last winter, a series of snowstorms that just came week after week, they were measuring temperatures in the ocean off of Boston 20 degrees warmer than normal. This was off the coast of Boston in the winter.

As that cold air hit them, that warmer water is really what led to that Gronkowski-like spike of snow that came down on us. It was a very simple phenomenon.

Obviously, we are getting more concerns as our waters warm in terms of what the implications can be, because it was a "there but for the grace of God" situation that the storm that hit New Jersey and New York did not hit us just 3 years ago.

Can you discuss some of the forecasting challenges with extratropical transition and why it is hard to predict exactly when the changes from a tropical storm to something that looks more like a Nor'easter will occur?

Dr. KNABB. Yes, as Sandy and many other storms in the past have shown, it is in real time rather uncertain, in many cases, to forecast exactly when a tropical cyclone, a tropical storm, a hurricane, will lose its tropical characteristics.

The reason that is difficult is that involves the changes in the inner core structure of a hurricane. That is very difficult to forecast. Computer forecast models are getting better at forecasting that. But because that is so difficult, and because that kind of transition can happen near the coastline, after the dilemma we faced in Sandy going forward, we can continue to issue National Hurricane Center forecasts and advisories even after a hurricane has

lost its tropical characteristics. We can maintain or issue tropical storm or hurricane watches and warnings. We can do that also for the storm surge watches and warnings, once they become operational in 2017, for a tropical system, a hurricane that loses its tropical characteristics.

In addition, for a purely extratropical situation, NOAA is taking a proactive approach in looking at all of the components of our agency that could bring to bear forecast products and warnings for extratropical storm surge.

Senator MARKEY. May I ask one final question, Mr. Chairman? Thank you.

In recent years, we have seen more land-falling storms in the Northeast, in the mid-Atlantic, than we have in Florida. Can you talk about that phenomenon and what you think might be occurring?

Dr. KNABB. Where the hurricanes go from year to year, from decade to decade, is a very chaotic system. It is not very predictable at all.

We have had periods in the past, like the 1950s, that were very, very busy for the East Coast, the mid-Atlantic, and northeastern hurricanes. Then we saw what happened in 2004 and 2005 with Florida receiving unprecedented back-to-back hurricane impacts in each of those years.

No one knows where this year's hurricanes are going to go. I have not seen convincing research that tells us we can predict who is going to get more hurricane landfalls in the future.

But I do know that for any of us, Texas to Maine, and places inland from the coast, it is simply a matter of when, not if, the next tropical storm or hurricane brings wind, water, or both to your community worse than you have ever experienced. So no one is off the hurricane hook this year or in future years.

Senator MARKEY. Thank you for your good work.

Thank you, Mr. Chairman.

Dr. KNABB. Thank you, Senator.

Senator RUBIO. Thank you, Senator Markey.

I want to thank you, Dr. Knabb, for being here today. It is a timely hearing that hopefully, in addition to informing members of this panel and the Senate about the important work you do and what needs to happen, I hope it will also serve to inform the public about the constant threat we face from these weather events. It is no longer just a southern U.S., southeastern U.S., Gulf of Mexico issue, but, in fact, one that is increasingly impacting other parts of our country, as we have heard here today. So I thank you.

The hearing record is going to remain open for two weeks. During this time, Senators are asked to submit any questions they might have for the record.

Upon receipt, Dr. Knabb, I ask that you submit your written answers to the Committee, if there are any, as soon as you possibly can.

With that, that concludes our hearing.

I want to thank you again for appearing today.

The hearing is adjourned.

[Whereupon, at 3:28 p.m., the hearing was adjourned.]

A P P E N D I X

RESPONSE TO WRITTEN QUESTION SUBMITTED BY HON. JOHN THUNE TO
DR. RICHARD KNABB

Question. We have been monitoring the situation of the necessary relocation of NOAA's Aircraft Operations Center (AOC). Our understanding is that moving forward NOAA plans to award a short-term lease option on, or before, January 2017, that will not exceed 10 years. In order to retain AOC's highly specialized staff and meet the Atlantic hurricane mission requirements, NOAA has focused its short-term airfield and hangar options within 50 road miles of the MacDill AFB main gate. For the long-term solution, NOAA plans to initiate a Nationwide Business Case Analysis. If a nearby location for the long-term airfield and hangar solution cannot be found, what other locations would meet NOAA's mission requirements?

Answer. NOAA's aircraft mission requirements cover many areas ranging from snow water equivalent detection, to air chemistry research, to winter storms, El Niño, and of, course, hurricanes. NOAA aircraft fly missions in areas spanning the entire United States, to include the central and eastern Pacific Ocean, and covering most of the Atlantic Ocean. Supporting NOAA's hurricane missions are arguably NOAA's most critical requirement and locating the NOAA aircraft Operations Center in the southeastern states, especially Florida, is most effective for meeting that particular mission. Extensive costs to "pre-stage" aircraft to be able to support the hurricane missions make other locations farther away from this region much less favorable and not affordable.

RESPONSE TO WRITTEN QUESTIONS SUBMITTED BY HON. MARCO RUBIO TO
DR. RICHARD KNABB

Question 1. Technology has taken us from a time where the only forecasting available was from the conditions fishermen and mariners were able to relay to shore, to a time of satellites, super computers, intelligent minds and a fleet of aircraft. What would you credit as the biggest advancement in hurricane forecasting?

Answer. Multiple technological advancements during the past several decades have simultaneously contributed to our increased understanding of hurricanes and to improvements in our forecasting capabilities. Geostationary satellites arguably provide our forecasters with their most fundamentally critical observational data for monitoring all stages of a hurricane's development and life cycle, leading to indispensable benefits to timely forecasts and warnings. Data from polar orbiting satellites are also extremely important, for our computer models to correctly depict and then forecast the state of the atmosphere on a larger scale, and these data also enhance human analyses of tropical cyclone internal structure and environmental factors that contribute to better forecasts. Advances in physical sciences knowledge, coupled with these improvements in observing, have also led to improvements in understanding and modeling. Aircraft reconnaissance data provide much needed smaller-scale data from within tropical cyclones and developing disturbances that are vital to our operational forecasts and warnings, and these data are also increasingly utilized by higher-resolution hurricane forecast models, including those currently in operational use and those still under development via programs like the Hurricane Forecast Improvement Project (HFIP). Overall, the combinations of advancements in satellite data observations, improvements in the understanding of the physical factors, and advanced computer model forecasts, augmented by aircraft reconnaissance in our areas of responsibility, have together produced the advancements in hurricane forecasting that we have seen and that we expect will continue.

Question 2. Speaking of advancements, NOAA has been testing a small unmanned aircraft system (UAS) that is deployed directly from the P-3 Hurricane Hunter. This UAS, named "the Coyote," is expected to better capture atmospheric data in areas of a storm where manned aircraft cannot travel. This technology is promising, especially as the costs of the unit can decrease. What is the status of the Coyote and

its use for the 2016 season? Where do you see the technology taking us—what, in your opinion, is the next step in hurricane forecasting advancement?

Answer. NOAA has six Coyote UAS aircraft available to test in 2016. The goal is to fly these Coyote into mature hurricanes and transmit critical data in real time to NOAA's operational centers (National Hurricane Center and Environmental Modeling Center). While not currently a significant part of our operational analysis and forecasting process, operational forecasters can view and evaluate data from the Coyote, providing feedback to researchers. The goal for the NOAA UAS Coyote is to transform this promising R&D technology into a more economical operational tool. Operational forecasters are eager to see how this technology evolves, because platforms like the Coyote offer the potential to linger at specified flight levels and collect data in portions of the hurricane circulation where more data are needed more frequently. Modifying instruments currently used on the GPS dropsondes and integrating them with the targeted low level flight capabilities of the Coyote UAS has the potential to allow scientists to regularly and reliably sample the lowest regions of the hurricane for an hour or longer which could be valuable for increased understanding of hurricane physics, and ultimately operational model and forecast improvements. We still envision that the manned aircraft used by NOAA and the U.S. Air Force will continue to be our primary operational sources of aircraft data within hurricanes for the foreseeable future, due to many characteristics such as their fast speed, ability to survey a storm in the period of time needed for operational forecasts and warnings, and ability to carry a full payload of necessary instrumentation.

NOAA is pursuing other technological advancements that could prove important in advancing hurricane prediction, including the capability to enhance wind measurements in and around hurricanes through the use of Doppler Wind Laser Radar (Lidar) and evaluating the impact of real time weather data gathered by the NASA Global Hawk Unmanned Aerial System on weather and hurricane prediction models.

We are also looking forward to the detailed data that will be available from GOES-R—which is scheduled to be launched later this fall.

Question 3. I wholeheartedly agree that we need to be a Weather-Ready Nation, where our people, businesses and governments are prepared for, and able to respond quickly to, severe weather events. In terms of collaboration with Federal, state and local officials, can you speak to how important those partnerships are, and what, if any gaps exist?

Answer. The collaboration with Federal, state, and local officials and the much broader community is essential to achieving a Weather-Ready Nation. We now have over 3,500 Weather-Ready Nation Ambassadors who are our partners, committed to working with NOAA and other Ambassadors to strengthen national resilience against extreme weather. In effect, the Weather-Ready Nation Ambassador initiative helps unify the efforts across government, non-profits, academia, and private industry toward making the Nation more ready, responsive, and resilient against extreme environmental hazards. We are seeing much more weather awareness than ever before, and we are hoping this trend will continue as we realize our vision of a Weather-Ready Nation. Part of meeting this goal will be increased emphasis on social science research to complement NOAA's physical sciences research and operational activities. As an example of our proactive approach to promoting hurricane resilience, we collaborated more closely than ever before with numerous Weather-Ready Nation Ambassadors in conducting the NOAA Hurricane Awareness Tour this past spring, resulting in increased media and public attention on tangible steps that individuals, families, and businesses must take well in advance of the next hurricane.

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