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**U.S. DEPARTMENT OF COMMERCE**

***ARE WE READY FOR THE NEXT HURRICANE SEASON? STATUS OF PREPARATION AND RESPONSE CAPABILITIES FOR 2018***

**COMMITTEE ON COMMERCE, SCIENCE, AND TRANSPORTATION**
**U.S. SENATE**

**APRIL 12, 2018**

Good morning Chairman Wicker, Ranking Member Nelson, and Members of the Committee. It is my honor to testify before you today about the work the National Oceanic and Atmospheric Administration (NOAA) has done to improve our hurricane watches and warnings, and how all that work has saved lives and accelerated recovery throughout the 2017 hurricane season. The 2017 hurricane season—with 17 named storms, including three Category 4 hurricanes that made landfall in the United States—was one for the record books. Three of the top five most economically damaging hurricanes in U.S. history occurred in 2017—Harvey, Irma, and Maria.[1] Despite the severity, communities were warned far in advance by NOAA's reliable forecasts. Based on preliminary data, the National Hurricane Center's (NHC) Atlantic track predictions for 2017 set an all-time record low position error across all forecast hours, which improved on the 5-year mean error by about 25 percent.

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, science and operations agency, NOAA is responsible for global satellite observations, atmospheric and oceanic research (both in-house and collaborative research with our valued external and government partners), operational weather and water forecasts, the delivery of critical products and services, and the stewardship of our marine resources. NOAA provides environmental information and forecasts to American citizens, businesses, and all levels of government to enable informed decisions on a range of issues and scales—local to global and short-term to long-term. Through the National Weather Service (NWS), NOAA 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, and does so by working closely with emergency management officials on the federal, state, local, and tribal level.

This past hurricane season was "all hands on deck" for NOAA—ranging from our well-known hurricane watches, warnings, and Hurricane Hunters, to our response and recovery efforts to re-

[1] https://www.nhc.noaa.gov/news/UpdatedCostliest.pdf

open Gulf and Atlantic ports that are economic lifelines to coastal communities, to conducting damage assessment overflights, and assisting fisheries recovery. Before, during, and after these storms—as with all major weather events that impact the United States—NOAA provides products, tools, and services used by emergency mangers (EMs), emergency responders, coastal planners, individuals, and businesses to help save lives, protect property, and mitigate damage.

## Hurricane Forecasts and Warnings

Track and intensity forecasts for this past hurricane season were the best the NHC ever produced. The NHC official track forecast errors have decreased every decade since the 1960's. The average position error at 48 hours has been reduced from 260 nautical miles in the 1960's to about 75 n mi in the 2010's. The 5-day forecasts (storm location) are now better than day-and-a-half (36-hour) forecasts were in the 1970's. There has also been a 25% reduction of intensity errors at day-5 in 2010-2016 as compared with 2000-2009. (See Figure 1)

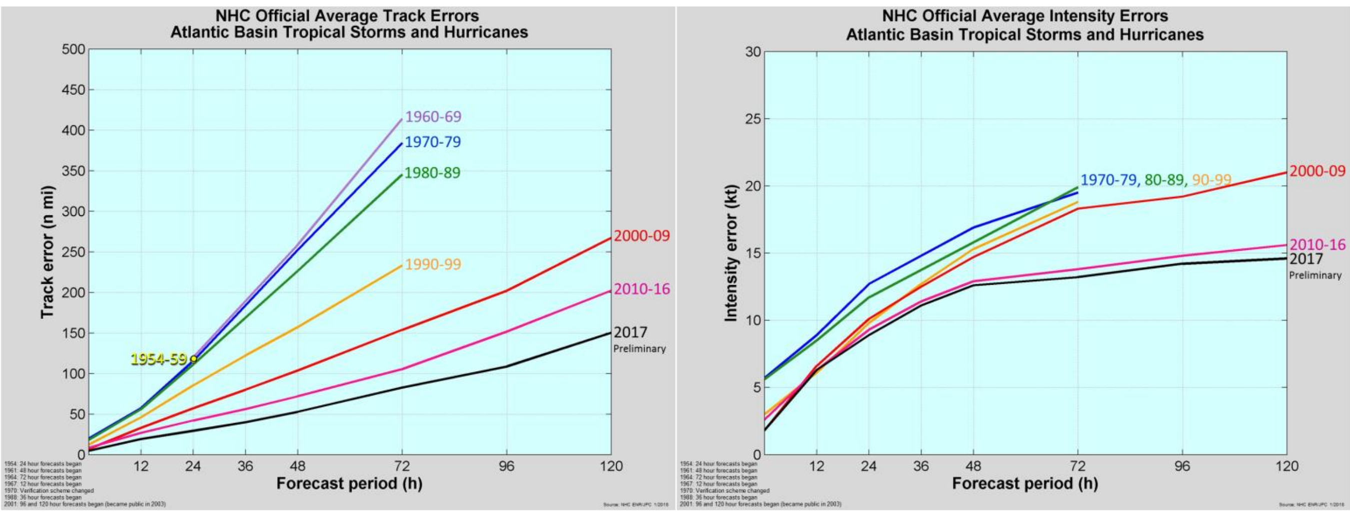

Figure 1. Official Hurricane Track and Intensity Errors from 1970 – 2017.

For Irma alone, the state of Florida used NWS forecasts to declare a State of Emergency six days before landfall. That, in and of itself, is amazing and is due largely to NWS efforts to provide Impact-based Decision Support Services (IDSS), as codified in the Weather Act. The storm was still east of the Lesser Antilles, yet the emergency managers had enough confidence in our forecast track (Figure 2) and intensity to begin evacuations and preparations nearly a week before the hurricane made landfall. The long lead time allows EMs to evacuate and improve preparation before the storm.

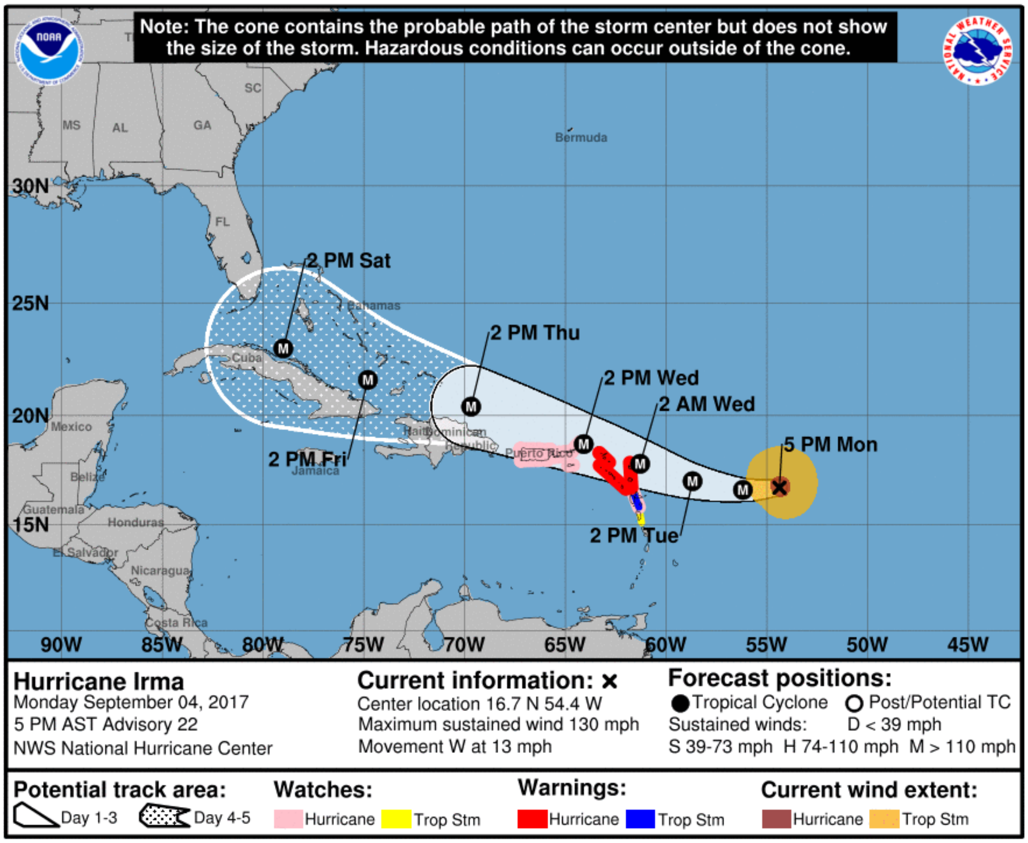

Figure 2. National Hurricane Center 5-day forecast for Irma issued at 5 PM EDT September 4, 2017.

The accurate predictions are the culmination of the ongoing process of transitioning model improvements made by the NWS Environmental Modeling Center (EMC) and NOAA's Office of Oceanic and Atmospheric Research (OAR) into production, where the sophisticated code is run operationally on the upgraded NOAA supercomputers. These high-resolution models, including multiple ensembles, provide our forecasters with the detailed probabilistic guidance they need to make accurate predictions.

Funding provided for the Hurricane Forecast Improvement Program (HFIP), and Disaster Relief Appropriations Act of 2013, referred to as the "Sandy Supplemental," along with our annual appropriation, has afforded NOAA resources 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-performance computing, enabling these models to be run at higher resolutions with better dynamics and physics. With the Sandy Supplemental funding and our base funding, our operational computing capacity has increased from 1.6 Petaflops in 2015 to 8.4 Petaflops in 2018. We thank you for providing the resources to continue these improvements.

NOAA's hurricane forecast improvement has resulted in a narrowing of our "cone of uncertainty," increasing the confidence of emergency manager in deciding to evacuate. In addition to saving more lives, we are taking advantage of several opportunities that now enable us to take numerical weather prediction to a new level. HFIP activities were conducted to: improve the prediction of rapid intensification and track of hurricanes; improve the forecast and communication of storm surges from hurricanes; and incorporate risk communication research to create more effective watch and warning products. The research and development in HFIP has been a joint effort between NOAA (primarily NWS and OAR) and academic partners. The result is that NOAA is meeting the five-year HFIP goal to reduce hurricane forecast track and intensity errors by 20%, and to extend the useful range of forecasts to seven days.

Storm surge poses the greatest threat for a large loss of life and property in a single day from hurricanes. Consequently, NWS began issuing storm surge watch and warnings in 2017 based on a collaborative process between NHC, local forecast offices, numerical guidance, and an ensemble-based probabilistic surge model. Preliminary information shows there were no storm-surge related deaths in the United States in 2017. This is a significant contrast to 2012, when storm surge from Sandy took 41 lives, more than half of all the fatalities in that storm.

There was considerable attention over the 10-year development timeframe of the storm surge watch and warnings product. Storm surge watches and warnings provide vital information about where and when life-threatening inundation will occur. This includes easy-to-understand graphics, co-developed with emergency managers and social scientists, which clearly display the areas in harm's way. (Figure 3)

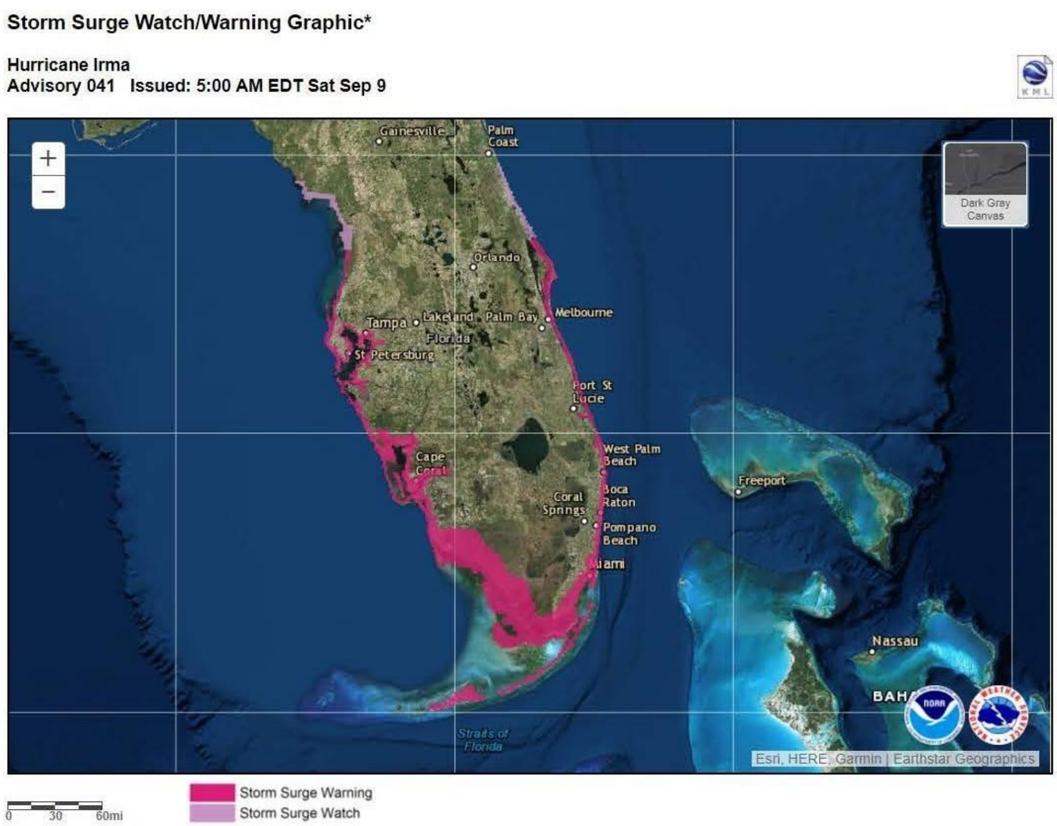


Figure 3. Hurricane Irma storm surge watch/warning graphic issued for Florida on Sept. 9, 2017.

In the days leading up to all three major hurricanes, NOAA's National Ocean Service (NOS) monitored and disseminated observations of water levels, currents, and weather information through Storm QuickLook. This product has been issued since 2004 and is initiated when NWS issues a tropical storm or hurricane warning to provide scientists and forecasters with reliable real-time observationsfrom strategically located water level stations along the coastline to validate or adjust forecasts. Storm QuickLook ensures emergency responders and regional decision makers have actionable water level information to make critical safety decisions. (See Figure 4 depicting the paths of Harvey, Irma, and Maria.)

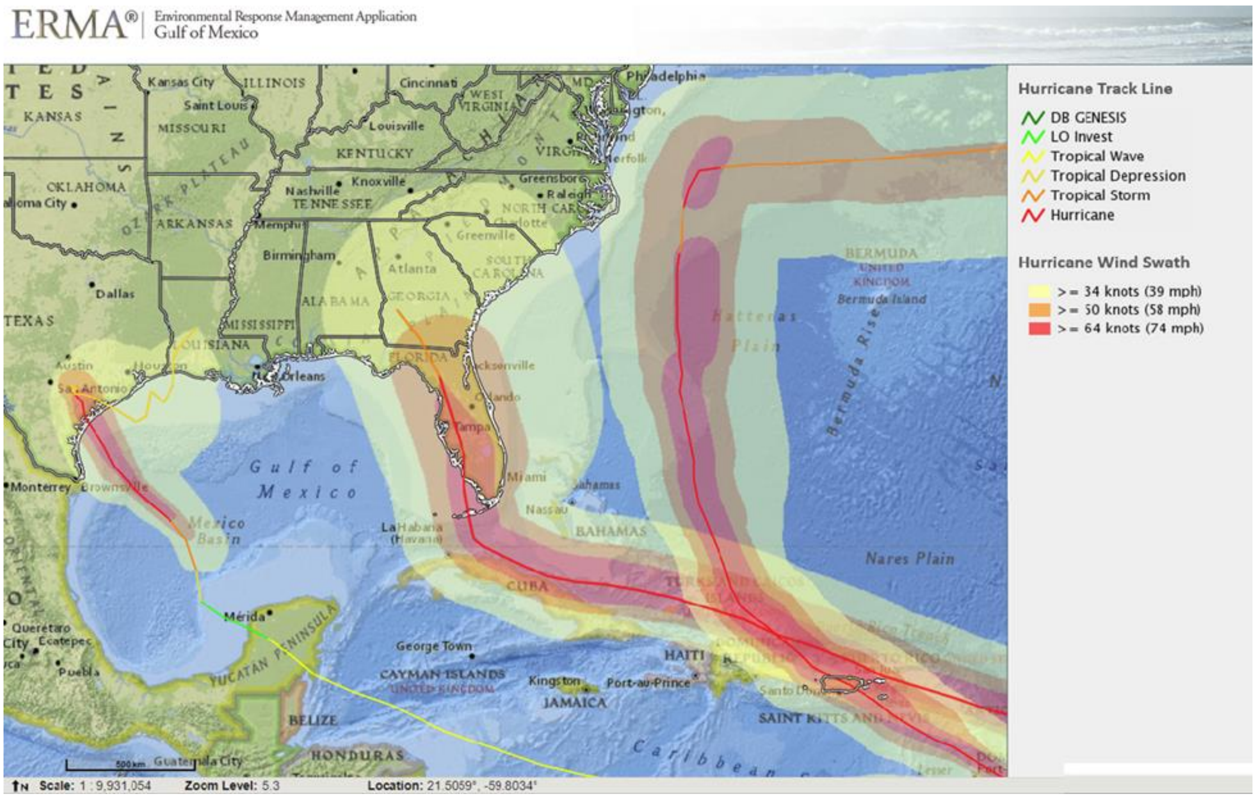

Figure 4. Tracks and wind fields for Hurricanes Harvey, Irma, and Maria.

An important contributing factor behind NOAA's forecasting success this hurricane season was our embedding with emergency managers at federal, regional, state and local levels. For example, prior to landfall of Harvey, Irma, and Maria, at the request of FEMA, NOAA (NOS) was working on-site in the FEMA National Response Coordination Center to provide critical connections between FEMA and NOS post-storm response operations.

As the storms approached, NOAA's Regional Navigation Managers—who work directly with pilots, mariners, port authorities, and recreational boaters to help identify maritime navigational challenges—were on-site at U.S. Coast Guard (USCG) Incident Command Centers to coordinate post-storm surveys, and Scientific Support Coordinators were present to assist with hazardous materials response efforts. Such utilization of NOAA by other agencies illustrate the unique value and expertise we provide to the nation's coastal safety and sustainability.

At the same time, the U.S. Integrated Ocean Observing System (IOOS), and the regional associations, collected data used by NWS models, and provided information to inform communities before, during, and after all three storms using shore stations, moorings, high-frequency radars and gliders.

Forecasting rainfall amounts from tropical systems is another area of significant improvement. Hurricane Harvey dumped an unprecedented five feet of rain over portions of East Texas. Our forecasters recognized the potential and were working directly with local EMs by providing IDSS to enable them to make evacuation decisions, and even the decision to close Downtown Houston in anticipation of the record setting rainfall. (Figure 5 is the observed 5-day rainfall from Harvey.). Emergency managers have credited NOAA with saving numerous lives. It is our dedicated workforce that makes all of this happen. NOAA forecasters stayed on the job during all of the hurricanes, working closely with EMs to provide life-saving forecasts and warnings, with full recognition that their own homes and families were under threat from the storms. Their dedication is unparalleled. Additional forecasters were deployed to the affected offices from other locations ahead of the storms, in anticipation of the work and decision support services that would be needed during the storms.

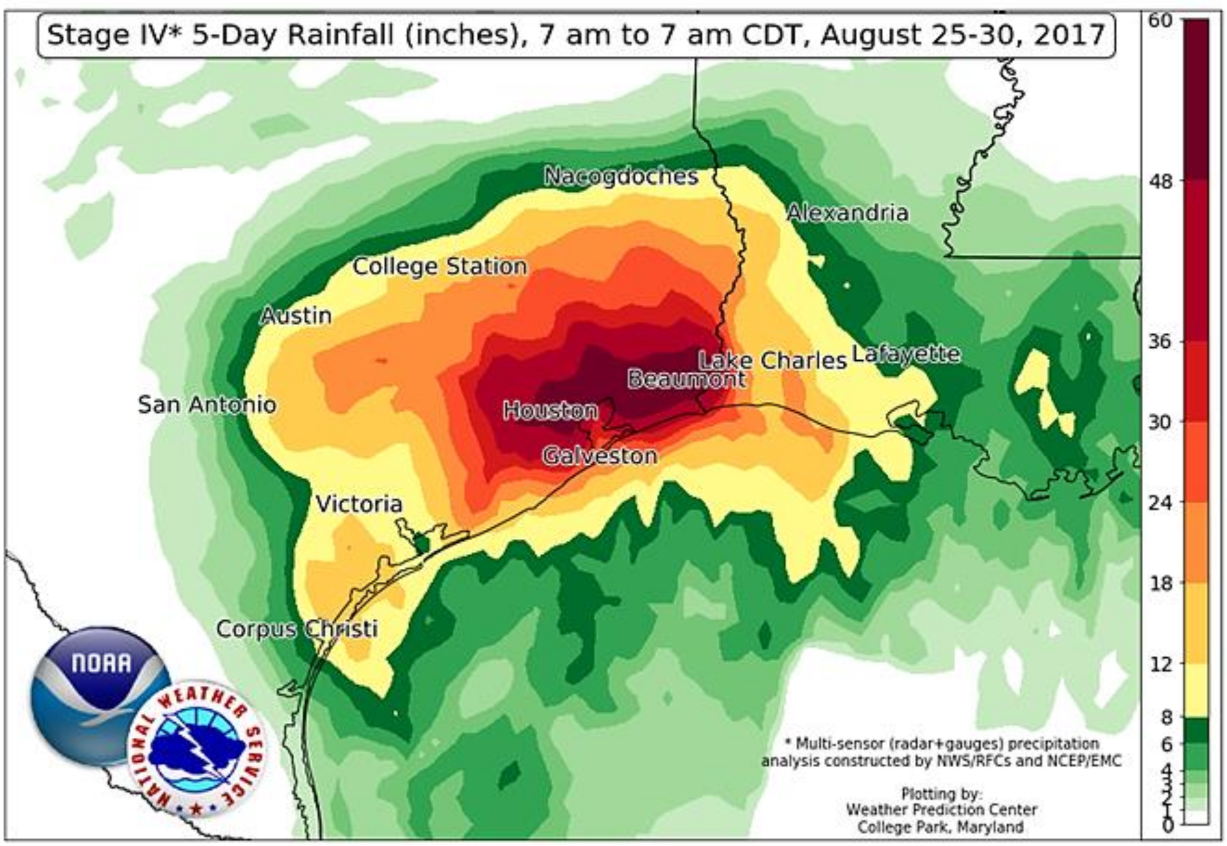

Figure 5. Five-day observed rainfall totals from 7 a.m., Friday, August 25 to August, 30.

NOAA's flood forecasting has also improved. The National Water Model (NWM), which is run at the National Water Center, provided information that was used by NOAA River Forecast Centers to issue the flood forecasts that were used by EMs during the massive flood in Texas caused by Harvey's unprecedented rainfall. It is equally important for EMs to know what areas would not be flooded, so they could position recovery assets in the right locations. This information allowed local officials and teams on the ground to quickly determine where to deploy limited resources, plan for evacuations, where to focus their recovery efforts. Improvements to the NWM will continue with one focus being inundation mapping.

**NOAA Response and Recovery Efforts**

NOAA has made significant advances in our response, recovery, and restoration services as well. One example is NOS's capability to rapidly survey coasts and ports to facilitate resumed operations as soon as possible. Prior to each storm, Navigation Response Teams (NRTs) from NOS mobilized immediately to provide emergency hydrographic services to affected port areas. The NRTs rely on forecasts from NHC to stage their operations close enough to be able to respond quickly, and safe enough to not be impacted by the storm. When conditions are safe again for operations, these emergency response teams conduct initial rapid surveys to detect submerged obstructions and areas of shoaling, then summarize the data into information that the USCG relies on to make critical decisions to reopen ports. For example, within seven hours of Irma's passage, a NOAA survey team traveled from Mobile, Alabama, to Florida and was in the Port of Miami conducting survey operations. Staff worked relentlessly to process and deliver data to the USCG Captain of the Port, who then approved the reopening of both the port's north and south shipping channels within 38 hours of Irma's passage. Data from NOAA's work enabled emergency supplies to be delivered, cruise ships to return to port, and for commerce to resume in southern Florida, saving Port Miami approximately $69 million a day in potential losses. [2]

In total, NOAA helped reopen over 26 ports and approaches following the three major hurricanes. Critical ports, such as Corpus Christi, Galveston, Houston, Miami, Key West, Tampa, and San Juan provide lifelines to communities for essential products like fuel, and serve as these local communities' economic engines. The estimated cumulative loss of trade for ports closed in 2017 was roughly $500 million per day. These losses would have continued over many days if NOAA's emergency response capabilities had not been available to enable the USCG to reopen the waterways.[2]

NOAA aerial survey missions also assess damages to hurricane affected areas and help guide the incident response. Since Sandy, NOAA has made significant improvements in our ability to quickly, efficiently, and reliably provide this information. NOS and the NOAA Office of Marine and Aviation Operations (OMAO) have jointly advanced our capability to capture high resolution mapping imagery to support NOAA's emergency response and safety of navigation requirements. Aerial survey teams process the data upon landing and quickly deliver it to users, often within hours of their flying the mission. The emergency responders and coastal managers use the imagery of coastal areas, sensitive habitats, and navigation routes to help direct aid to where it is most needed, facilitate search and rescue strategies, identify navigation hazards and HAZMAT spills, locate errant vessels, and provide documentation necessary for damage assessment. These publically accessible images are typically the first views that evacuated

[2] NOAA estimates based upon data published by https://www.ustradenumbers.com/ports/port/port-of-corpus-christi-texas/

residents have of their property after the storm. For Harvey, Irma, Maria, and Nate, NOAA aircraft flew nearly 40,000 miles for hurricane recovery support missions collecting more than 65,000 images that covered just shy of 10,000 square miles; roughly the area of the State of Maryland.

In support of the removal of HAZMAT and vessels displaced by Hurricane Irma, staff from the NOS Office of National Marine Sanctuaries and Office of Response and Restoration served in support of the Emergency Support Function 10 (ESF-10) Florida Incident Command Post Environmental Unit. This NOAA team provided concise and consistent guidance supporting pollution response and the removal of vessels/debris in the Florida Keys, while considering impacts to sensitive natural and cultural resources.

**NOAA Shoreline and In-Water Restoration Efforts**

According to a new study published by *Nature* in *Scientific Reports*[3], conserving and restoring coastal reefs, wetlands, and mangroves can prevent flooding and abate hundreds of millions of dollars in storm damage. This study reports that wetlands protected areas of the East Coast from more than $625 million in direct flood damages from Sandy in 2012. Wetlands reduced damages by more than 22% in half of the affected areas and by as much as 30 percent in some states. NOAA has an extraordinary team of environmental engineers, conservation biologists, and ecological experts who are running programs to rebuild marshes, beaches, and breakwaters and I have seen the success of these efforts first hand with NOAA's National Marine Fisheries Service (NMFS) restoring a marsh in Bayou Dupont, Louisiana that is a very effective hurricane storm surge barrier. This area was underwater four years ago.

Since 1995, NMFS and partners have implemented over 300 wetland and coastal habitat restoration projects in the Caribbean, South Florida, and Gulf of Mexico—all areas that were impacted by 2017 hurricanes. When compared to adjacent sites that were not stabilized, NOAA restoration sites mitigated further erosion which reduced additional sedimentation of coral reef habitats while also protecting adjacent infrastructure (i.e., roads). For example, Texas restoration projects in the path of Hurricane Harvey generally sustained little to no damage. In Louisiana, 10 recent large-scale coastal wetland protection projects implemented through the Coastal Wetlands Planning, Protection and Restoration Act Program sustained little or no damage during Hurricanes Harvey and lesser known Hurricane Nate. The third landfall of Harvey passed over the Louisiana Oyster Bayou project during construction; however, only a small amount of material was lost and construction was able to quickly resume.

In the Caribbean, the paths of both Hurricanes Irma and Maria crossed nearly 100 watershed restoration projects located throughout the U.S. Virgin Islands and Puerto Rico. These projects are focused on stabilizing steep and eroding terrain to prevent sedimentation to nearshore habitats and generally appear to have sustained minor to no damage.

**Data**

[3] https://www.nature.com/articles/s41598-017-09269-z

The nation has made significant investments in developing, launching, and operating satellites that support the nation's weather enterprise. For hurricanes, data from satellites and reconnaissance aircraft are critical components of NOAA's observation network.

NOAA's National Environmental Satellite and Data Information Service (NESDIS) has operated Polar-orbiting Operational Environmental Satellites (POES) since 1966, and Geostationary Operational Environmental Satellites (GOES) since 1974. The Suomi National Polar-orbiting Partnership (Suomi NPP) initiated NOAA's overall strategy for providing improved and higher resolution data to support weather forecasting. On November 18, 2017, NOAA launched the first of its four Joint Polar-orbiting Satellite System (JPSS) series, JPSS-1 (now known as NOAA-20). The substantial data collection from these satellites allows us to more precisely analyze the oceans and atmosphere, which greatly influence the development and track of hurricanes.

Data from GOES are essential for observing and forecasting the formation and track of hurricanes. NOAA launched the first satellite in the GOES-R Series, known as GOES-16, on November 19, 2016. These satellites are the most sophisticated environmental satellites ever to be launched. They collect three times more data at four times better resolution, and scan the Earth five times faster than previous geostationary environmental satellites over North America. The technological advances of GOES-16 (now GOES-East) are absolutely astounding. For decades, geostationary weather satellites have supported weather and environmental monitoring programs that are relied upon by users in the U.S. and around the world.

NWS forecasters in Corpus Christi, Texas, tracked the eye of Hurricane Harvey using pre-operational GOES-16 imagery in concert with NEXRAD Doppler radar data. They worked closely with EMs who needed to evacuate people from vulnerable areas, but could not risk exposing the public to the harsh hurricane conditions. The forecasters used the information to identify a short window of opportunity to evacuate as the eye passed directly overhead. During Hurricane Maria, Puerto Rico's only NEXRAD Doppler radar was destroyed by the storm as the eye made a direct hit on the island. GOES-16 continued to provide detailed information that remained available to our forecasters. With information available every 60 seconds, forecasters could watch thunderstorms develop and were able to issue accurate flash flood warnings for the public.

On March 1, 2018, NOAA launched GOES-S (renamed to GOES-17 on March 12, 2018, when it reached geostationary orbit). Once GOES-17 becomes operational in late 2018 as GOES-West, along with GOES-East will provide superior coverage for the majority of the Western Hemisphere from the west coast of Africa all the way to New Zealand. Each satellite has six new, highly sophisticated instruments that will provide faster, more accurate and more detailed data than legacy satellites to track hurricanes and other potentially devastating events. The Global Lightning Mapper sensor on each will provide our forecasters and researchers with real-time in-situ lightning data for the first time over remote areas, such as open waters. These lightning data will help us better understand what is occurring within the storms, and it will also improve our warning capability for severe storms, including hurricanes.

NOAA continues 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. The NOAA G-IV and two Lockheed WP-3D Orions (P-3) are part of NOAA's fleet of highly specialized research and operational aircraft. These aircraft are operated, managed, and maintained by OMAO, based in Lakeland, 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." When flying a hurricane mission, military and NOAA P-3 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. The data also are transmitted in real-time for initializing the storms in operational numerical models for better analysis and forecast guidance and then used by researchers to better understand the processes contributing to intensity change.

NOAA, though NESDIS, leverages full and open exchanges of satellite data with NASA and the Department of Defense, as well as foreign National Meteorological Services to meet our observational data requirements. With Congressional support, in recent years, NOAA has been increasingly seeking opportunities for incorporating commercially acquired data into our weather models.

**Improved Observation through Unmanned Systems**

NOAA is working with the private sector and other federal agencies to identify, evaluate, and transition innovative and cost-effective Unmanned System (UxS) capabilities that meet NOAA's observing requirements, and help form a comprehensive observing strategy for the future. Unmanned Aerial Systems (UASs), for example, have improved Hurricane observation. This hurricane season, NOAA joined with NASA to fly the unmanned NASA Global Hawk ahead of and above Hurricanes Franklin and Harvey, launching dropsondes that collected data to be assimilated into the operational Global Forecast System model and HWRF. This year marked the first time that Global Hawk dropsondes were assimilated in real-time into the GFS model. Scientists also launched six small "Coyote" drones from a NOAA P-3 Hurricane Hunter during Hurricane Maria to collect unique data from within the eyewall in the lower part of the storm where it gains strength from the ocean. The low-level observations of wind speed, wind direction, atmospheric pressure, temperature, moisture, and sea surface temperature provide more detail on hurricane strengthening than dropsondes that record a single point of data. These observations can provide information needed to improve intensity predictions.

NOAA researchers partnered with NOS IOOS regions to deploy underwater gliders to better understand how the upper ocean contributes to hurricane intensity. These gliders collect information in the Atlantic Warm Pool, an area of the ocean commonly associated with hurricane development and intensification that has been expanding over the past two decades. Hurricanes Harvey, Irma, Jose, and Maria, passed directly over, or very close to the gliders, providing valuable information to NOAA researchers and forecasters. The ocean data collected by the gliders totaled over 4,000 temperature and salinity profiles. Correct representation of ocean conditions during a hurricane has been shown to significantly reduce the error in intensity forecast.

We anticipate data from new UxS technologies, to include Unmanned Surface Vehicles (USVs) will contribute significantly to improved understanding of tropical cyclone processes and ultimately to improvements in track and intensity predictions.

## Further Improvements

In addition to continuing the improvement cited above, we will look to transition other promising research and development work. For example, experimental models being developed at NOAA Research labs produced impressive results this hurricane season, holding out the promise for important gains in future years. These models will be further tested, refined and transitioned to day-to-day operations within the NWS. NOAA's experimental global model, or fvGFS, exceeded all other global models in forecasting the track of Hurricane Maria. FvGFS is powered by the NOAA Research-developed FV-3, which is transitioning to operations to become the heart of NOAA's next generation Global Forecast System.

The experimental, basin-scale version of the operational HWRF model, supported by HFIP, was run in real time for Hurricane Harvey. Tail Doppler radar wind data collected from the NOAA P-3 aircraft was assimilated into this system for the first time. Apart from near-perfect track predictions, the basin-scale HWRF accurately captured the rapid intensification of Harvey over several cycles in advance of the system's landfall.

The NOAA Research experimental High Resolution Rapid Refresh model, HRRRx, also showed great promise for future improvements to NOAA's only high resolution, hourly updating forecast model that can resolve weather down to the level of individual thunderstorms. Preliminary evaluations showed that HRRRx, accurately predicted the path of Hurricane Harvey, as well as the location and amount of rainfall from the storm for its range of prediction out through 36 hours.

Improvements in NOAA's hurricane prediction will continue to follow the guidelines outlined in the Weather Act. The Act expands on critical NOAA mission areas, including improvements through HFIP, improved modeling and computing capacity, working with the private and academic sectors to obtain the best possible data, improving NWS Impact-based Decision Support Services (IDSS) efforts, and using social science to better communicate critical messages and information to the public and our core partners.

## Conclusion

The improvements NOAA has made over the last decade in environmental observation, prediction, decision support, response and recovery were clearly validated during the 2017 hurricane season. Nevertheless, we can and will improve further by applying the FY18 Omnibus and Disaster Supplemental appropriations to continue transitioning research to operations, strengthening our vast network of partners, and implementing the Weather Research and Forecast Innovation Act.