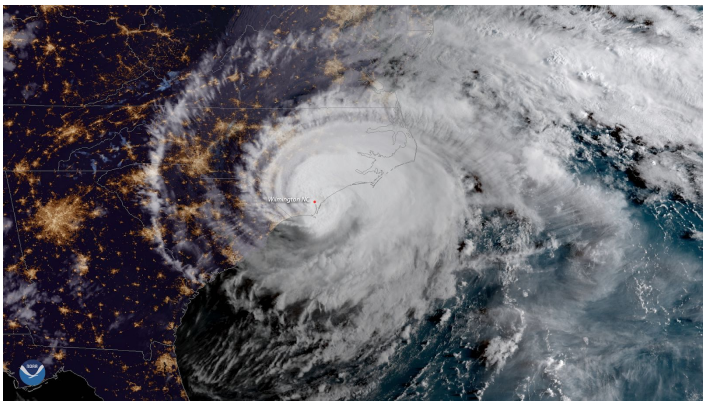
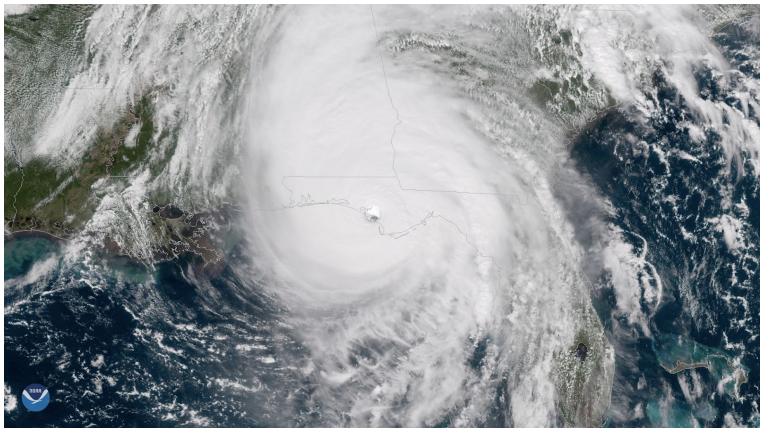
Service Assessment

2018 Hurricane Florence and Hurricane Michael



Hurricane Florence at Landfall 7:15 a.m. EDT September 14



Hurricane Michael at Landfall 12:30 p.m. EDT October 10

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Weather Service
Silver Spring, Maryland

Service Assessment

September-October 2018 Hurricane Florence and Hurricane Michael

March 2020

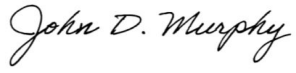
National Weather Service
John D. Murphy
Chief Operating Officer

Preface

Hurricane Florence was a destructive hurricane that produced historic flooding in parts of North Carolina and South Carolina. Hurricane Florence made landfall near Wrightsville Beach, North Carolina at Category 1 intensity, weakening from Category 4 intensity four days earlier over the Atlantic. In a seven-day period, many areas received 15 to 35 inches of rainfall over southeastern North Carolina, causing catastrophic flooding, as the system stalled across the area. With peak accumulations of 35.93 inches, Hurricane Florence produced the most rainfall on record from a tropical cyclone in North Carolina. Hurricane Michael was a catastrophic hurricane that produced historic storm surge and wind damage across parts of Florida, Alabama, and Georgia.

Hurricane Michael made landfall near Mexico Beach, Florida at Category 5 intensity with peak winds of 160 mph, intensifying and increasing in forward speed as it moved north and northeastward across the Gulf of Mexico. The peak winds of 160 mph ranks as the fourth highest on record for a hurricane striking the continental United States and strongest from a hurricane making landfall within the continental U.S. since Hurricane Andrew in 1992. Extensive storm surge and wind damage resulted across parts of the Florida Panhandle from Hurricane Michael.

Because of the highly significant impacts of these two very different hurricane events, the National Weather Service assembled a service assessment team to evaluate its performance before and during Hurricane Florence and Hurricane Michael. NWS's operational leadership will review and consider the findings and recommendations from this joint assessment. As appropriate, the recommendations will then be integrated into the Annual Operating Plan to improve the quality of operational products and services and enhance the National Weather Service public education and awareness materials related to flooding and other tropical cyclone hazards. The ultimate goal of this report is to help the National Weather Service meet its mission to protect life and property and enhance the national economy.



John D. Murphy
Chief Operating Officer
March 2020

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Executive Summary

The 2018 Atlantic hurricane season featured above normal activity with 15 named storms, eight hurricanes, and two major hurricanes: Florence and Michael. In the public warning phase for Hurricanes Florence and Michael, the process of developing messaging across multiple National Weather Service (NWS) organizations required significant internal coordination within the agency. NWS Weather Forecast Offices, River Forecast Centers, and the National Centers for Environmental Prediction used multiple ways to message the increasing threat of extreme rainfall, historic flooding, storm surge, and tornadoes in the Carolinas as well as the storm surge and extreme wind threats in Alabama, Florida, and Georgia. Overall, the media, emergency managers, and partnering federal agencies praised the efforts and effectiveness of the NWS.

Hurricane Florence emerged from the west coast of Africa on August 30, 2018, becoming a major hurricane as it traveled toward the U.S. Atlantic seaboard. Florence intensified to a strong Category 4 the afternoon of September 10, reached its peak intensity the next day (September 11), then began to weaken that evening. This weakening trend continued until Florence made landfall at Wrightsville Beach, NC, on September 14 as a Category 1 hurricane on the Saffir-Simpson Hurricane Wind Scale (SSHWS). The rapid intensification and subsequent weakening of wind speeds presented a number of challenges in messaging non-wind related storm hazards. Many emergency managers interviewed by the assessment team in the Carolinas indicated the public primarily tied expected impacts to only wind strength, saying this was a detriment to getting the public to focus on the key messaging of overall impacts and severity of the non-wind related storm hazards. As noted in previous service assessments for tropical cyclones, riverine flooding, not wind, was the major cause of damage and loss of life in Florence. Damages from Florence are estimated to be $24.2 billion. There were 22 direct fatalities from the storm (direct fatalities criteria is defined in National Weather Service Instruction 10-1605 for Storm Data Preparation effective July 16, 2018). Recovery efforts from the extensive flooding in Florence continued well into October. These recovery efforts were prolonged by impacts from Hurricane Michael as it moved inland and impacted areas previously affected by Florence.

In contrast to Florence, the rapid intensification and forward speed of Hurricane Michael presented a very compressed timeline for NWS offices to communicate critical information for preparedness and response activities. The Columbus Day holiday on Monday, October 8 was a major factor in compressing this timeline as most federal, state, and local agencies and businesses, including financial institutions, were officially closed. The afternoon of Saturday, October 6, the National Hurricane Center (NHC) issued its first advisory and graphics package for Potential Tropical Cyclone 14. NHC's 5-day forecast track graphic showed the cone of uncertainty stretching from the Louisiana-Mississippi border eastward across the Florida Panhandle. The next day, Sunday, October 7, the 5:00 a.m. EDT NHC discussion carried the

first indication that Michael could become a hurricane. With rapid intensification, NHC's advisory issued at 5:00 a.m. EDT Monday, October 8 (Columbus Day) called for Michael to intensify to a high Category 2 but noted that there was the possibility for the storm to strengthen into a major hurricane (Category 3, 4 or 5).

Michael made landfall on the afternoon of October 10, as a Category 5 hurricane, only the fourth storm to do so in U.S. history. Storm surge at the coast and extreme wind speeds (extending well inland) were the most significant causes of damage and loss of life. Damages from Michael are estimated to be approximately $25 billion and there were 16 direct fatalities. The damage along the path of Michael in the Florida Panhandle was catastrophic, especially for Bay County, FL. In Mexico Beach, FL almost 95 percent of the community's buildings were damaged (1584 buildings out of a total of 1692) with nearly half destroyed. Tyndall Air Force Base, where the storm made landfall on October 10, suffered extensive damage. Michael maintained tropical storm strength for over 24 hours as it moved into South Carolina. As a result, the storm produced major damage to structures, agriculture, and forestry well inland into Alabama and Georgia. Tropical storm force winds occurred over the coastal areas and coastal waters of Georgia and South Carolina.

Service Assessment Report

1. Introduction

1.1. NWS Mission

The mission of the National Oceanic and Atmospheric Administration (NOAA) National Weather Service (NWS) is to protect life and property by providing weather, hydrologic, and climate forecasts and warnings for the United States, its territories, adjacent waters and ocean areas, and to enhance the national economy. NWS disseminates centrally produced data, weather products, and guidance to 122 local Weather Forecast Offices (WFO), 13 River Forecast Centers (RFC), and 21 Center Weather Service Units (CWSU), and to users outside the NWS. The forecasters at the WFOs and RFCs issue forecasts and hazardous watches, warnings, and advisories to the public. They also interface closely with local emergency managers (EM) and other federal, state and local government partners in the provision of weather, water, and climate Impact-based Decision Support Services (IDSS). WFOs and RFCs also collaborate significantly with media partners and other non-government entities in the distribution and explanation of impact weather information. CWSUs are co-located with Federal Aviation Administration (FAA) Air Route Traffic Control Centers (ARTCC) and provide comprehensive IDSS to air traffic controllers, traffic management units, traffic control centers and control towers in their areas of jurisdiction.

The National Hurricane Center (NHC) issues forecasts for tropical cyclones. It also collaborates with its NWS partners to issue hurricane, tropical storm, and storm surge watches and warnings for the U.S. coast, and a variety of probabilistic products for tropical cyclone hazards, in addition to providing national and state-level IDSS and messaging for tropical cyclone events. NHC is a key member of the FEMA Hurricane Liaison Team. The Ocean Prediction Center (OPC) and the Tropical Analysis and Forecast Branch (TAFB) provide marine and tropical forecasts, warnings, and support to NWS core partners. The Weather Prediction Center (WPC) produces a wide range of national weather forecast and analysis products, including Quantitative Precipitation Forecasts (QPF), excessive rainfall products, medium-range and probabilistic rainfall guidance, surface analysis, and a daily weather map. The National Water Center (NWC) delivers timely national hydrologic analyses and water forecast information, data, and guidance. These centers, and seven others comprising the National Centers for Environmental Prediction (NCEP), collaborate closely with NWS field offices and with EMs and media partners in the creation, distribution, and interpretation of NWS guidance, outlooks, and hazardous watch/warning information.

The NWS Headquarters (NWSH), in Silver Spring, MD, and six regional headquarters provide policy and administrative guidance to the WFOs and RFCs. Each of these regional headquarter offices also staffs a Regional Operations Center (ROC) that, along with the NWS

Operations Center (NWSOC), provides tactical field office support and decision support to state and region-level federal partners.

1.2. Purpose of Assessment Report

The NWS may conduct national service assessments for significant hydrometeorological, oceanographic, or geological events when they result in one or more of the following conditions:

- Multiple fatalities
- Numerous injuries requiring hospitalization
- A significant impact on the economy of a large area or population
- Extensive national public interest or media coverage
- An unusual level of attention to NWS operations by the media, EM community, or elected officials

Service assessments evaluate NWS performance and ensure the effectiveness of NWS products and services in meeting its mission. The goal of service assessments is to improve the ability of NWS to protect life and property by identifying and sharing best practices in operations and procedures, recommending service enhancements, and addressing service deficiencies.

This document presents findings and recommendations resulting from the evaluation of NWS performance during Hurricane Florence (August 30-September 19, 2018) and Hurricane Michael (October 4-October 16, 2018). The objectives of this assessment were to identify significant findings and issue recommendations and best practices related to the following key areas:

- Systems and Service Backup and Recovery
- Mutual Aid and Deployments
- Impact-based Decision Support Services (IDSS) Results, Tools, and Resources
- Training and Proficiency
- Fully Integrated Field Structure (FIFS)

1.3. Methodology

NWS formed a service assessment team on November 7, 2018. The 20-member team and subject matter experts consisted of employees from WFOs and RFCs, NWSH, Aviation Weather Center (AWC), National Ocean Service (NOS), NOAA Office of the Chief Financial Officer, US Geological Survey (USGS), North Carolina Sea Grant, South Carolina Sea Grant, and the NOAA Center for Atmospheric Science and Meteorology. The team completed the following activities:

- Performed on-site evaluations in North Carolina, South Carolina and Georgia from November 26-30
    - Visited and conducted staff interviews at:
        - WFOs Charleston, Columbia, and Greenville/Spartanburg, SC; Newport/Morehead City, Raleigh, and Wilmington, NC
        - Southeast River Forecast Center Peachtree City, GA
        - US Army Corps of Engineers, South Atlantic Division, Atlanta, GA
    - Interviewed local, state and federal EMs, media, and other government officials in the primary impacted areas and jurisdictions
- Performed on-site evaluations in Florida, Georgia, Alabama, Texas, and Washington, D.C., from December 10-19
    - Visited and conducted staff interviews at:
        - WFOs Birmingham and Mobile, AL, Tallahassee and Jacksonville, FL, and Atlanta, GA
        - Southeast River Forecast Center
        - National Hurricane Center
        - National Water Center
        - NWS Southern Region Headquarters and Southern Region ROC
        - NWS Operations Center
        - NWS Office of Dissemination
        - Ocean Prediction Center
        - Weather Prediction Center
        - Environmental Modeling Center
        - NCEP Central Operations
        - Office of Water Prediction
        - NWS Analyze, Forecast, and Support Office:
            - Digital and Graphical Information Support Branch
            - Water Resources Services Branch
            - Marine, Tropical, and Tsunami Services Branch
- Interviewed local, state and federal EMs, media, and other government officials in the primary impacted areas and jurisdictions
- Conducted remote interviews with staff members of:
        - National Ocean Service
            - Center for Operational Oceanographic Products and Services
            - National Geodetic Survey
            - Office for Coastal Management
            - Office of Response and Restoration
            - Office of Coast Survey
        - NWS Office of the Chief Learning Officer: Forecast Decision Training Division
        - WFO Columbia, SC
        - WFO Miami, FL
        - WFO Austin/San Antonio, TX

- Evaluated products, messages, and other services produced by involved NWS offices
- Compiled a core list of common themes discovered during onsite and remote interviews
- Identified significant findings and recommendations to improve the effectiveness of NWS products, services, communication, and coordination

After a series of internal reviews, the report on the service assessment was approved and signed by the NWS Chief Operating Officer and issued to the American public.

2. Hydrometeorology[1]

2.1. Hurricane Florence - August 30 through September 19, 2018

Hurricane Florence originated from a convectively active tropical wave accompanied by a broad low pressure system that moved off the west coast of Africa on August 30.

The wave moved west-northwestward accompanied by a steady increase in convective organization. It is estimated that a tropical depression formed around 1800 Coordinated Universal Time (UTC) August 31, centered about 90 nautical miles (nm) southeast of Santiago Island in the southernmost Cape Verde Islands. The depression strengthened into a tropical storm 12 hours later when it was passing about 110 nm west-southwest of the southernmost Cape Verde archipelago. For the next several days, Florence maintained a steady west-northwestward motion at about 15 knots while moving around the southern periphery of a massive Bermuda-Azores ridge. The "best track" chart of the tropical cyclone's path is given in **Figure 1**, with the wind and pressure histories shown in **Figures 2 and 3**, respectively.

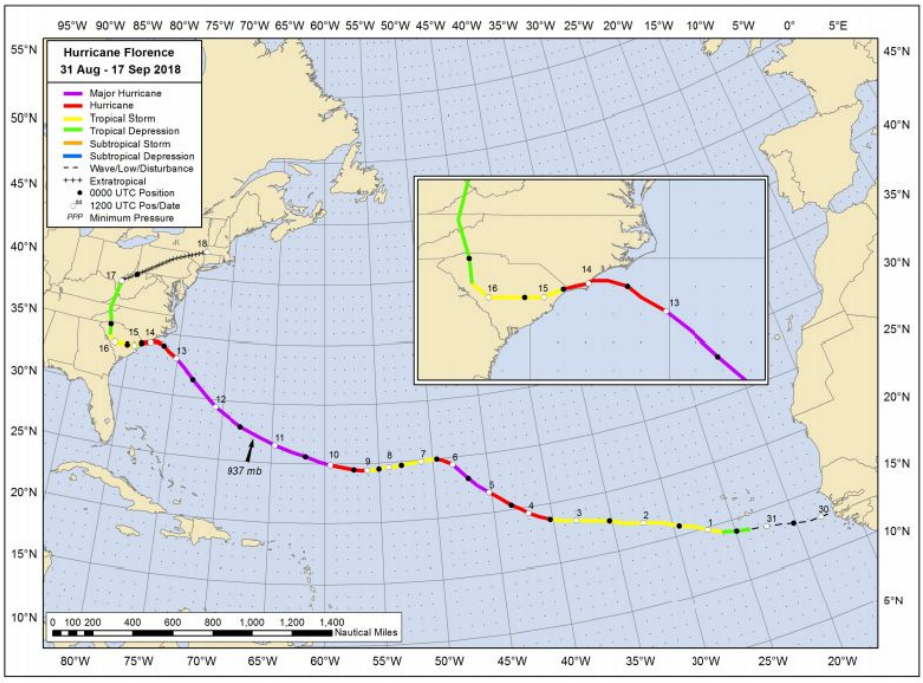


Figure 1: Hurricane Florence tropical cyclone track and intensity. *Source*: *National Hurricane Center (NHC) Tropical Cyclone Report for Hurricane Florence.*

[1] Prepared with storm information and data from the National Hurricane Center (NHC)

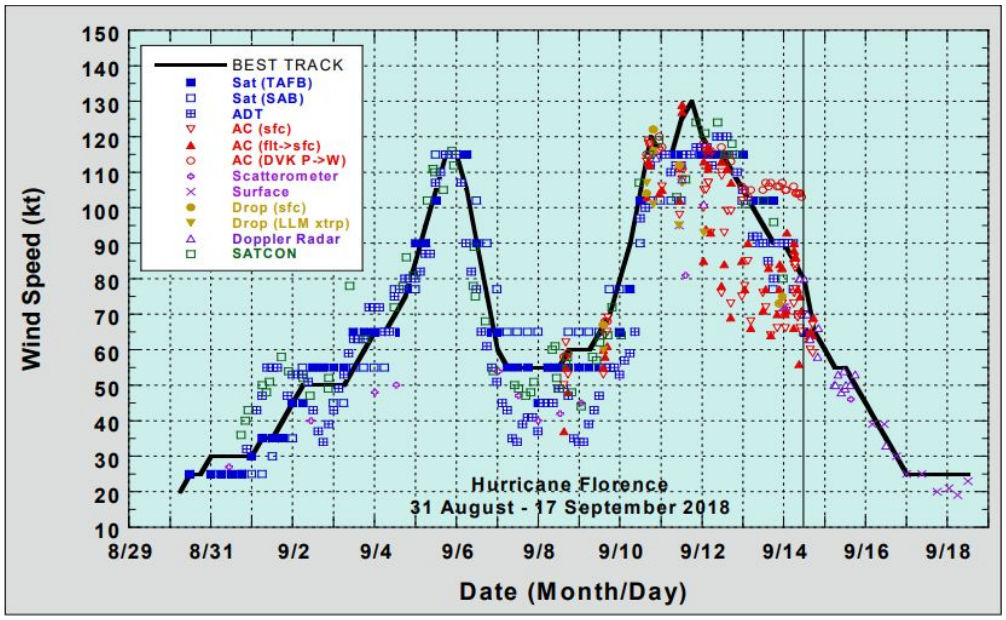


Figure 2: Hurricane Florence wind history. *Source: NHC Tropical Cyclone Report for Hurricane Florence.*

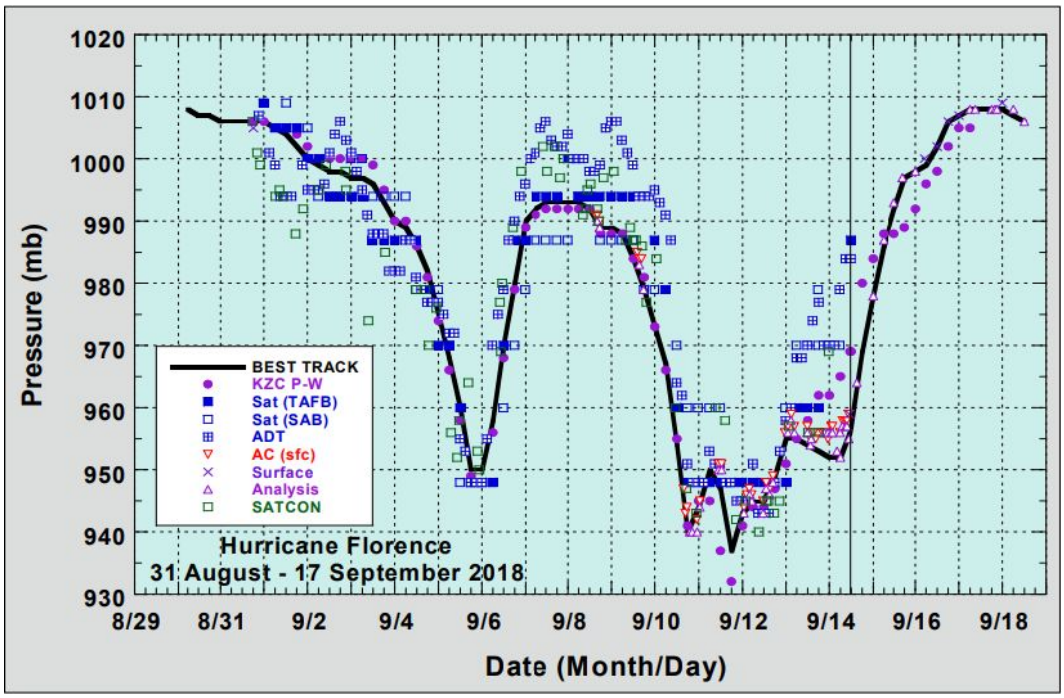


Figure 3: Hurricane Florence pressure history. *Source*: *NHC Tropical Cyclone Report for Hurricane Florence.*

Despite being embedded within a vertical-wind-shear regime of about five knots, one that can favor quick intensification, only slow strengthening occurred during the next 48 hours, partially due to the storm moving over sea surface temperatures (SST) around 26.5°C and

entraining cooler and drier air from the north, all limiting factors on the intensification rate. The storm became a 65 knot hurricane around 1200 UTC September 4 when the cyclone was about 1200 nm east-northeast of the Lesser Antilles. Florence underwent a period of rapid intensification (increase of at least 30 kt in 24 hours) over the next 30 hours to become a 115 knot, Category 4 hurricane by 1800 UTC September 5 while centered over the central Atlantic about 1200 nm east-southeast of Bermuda. Within 12 hours after becoming a Category 4 hurricane, Florence began a period of rapid weakening through 0000 UTC September 7 when Florence was downgraded to a tropical storm.

Early on September 9, vertical wind shear in the vicinity of now Tropical Storm Florence had decreased to 5–10 knots. By 1200 UTC that day, Florence began moving toward the west northwest and had regained hurricane status. The storm then exhibited pronounced outflow and underwent a second RI period with wind speeds increasing 50 knots during the 24-hour period ending at 1800 UTC September 10. Florence reached its peak intensity of 130 knots around 1800 UTC September 11 when the hurricane was about 725 nm east-southeast of Cape Fear, NC.

While maintaining a steady west-northwestward motion, Florence's winds once again began to slowly decrease, mainly due to the effects of cold upwelling. Florence's peak winds dropped below major hurricane status by 1200 UTC September 13 when the cyclone was located about 150 nm east-southeast of Wilmington, NC.

As the wind speeds in the center of Florence continued to decrease, the hurricane approached the southeastern coast of North Carolina late on September 13. Steering currents collapsed resulting in a slow westward motion of around 5 knots. Florence made landfall as an 80 knot hurricane, its center coming ashore near Wrightsville Beach, NC, around 1115 UTC September 14.

After landfall, Florence made a slight jog toward the west-southwest while maintaining a slow forward speed. This allowed the storm to remain close to the warm waters of the Gulf Stream just offshore. Florence became a tropical storm by 0000 UTC September 15 when the cyclone was over eastern South Carolina just north of Myrtle Beach. The tropical storm turned westward and moved slowly across central and northern South Carolina, becoming a tropical depression by 1800 UTC September 16 while centered about 35 nm south of Florence, SC. The depression then accelerated northward on September 17, passing over western North Carolina, eastern Tennessee, and western Virginia. That day at 1200 UTC, the storm became extratropical as it entered western West Virginia.

Florence's wind field expanded before landfall. As a result, Florence generated a devastating storm surge that traveled well inland north of the center. A prolonged period of easterly winds induced by Florence had already raised water levels on the western side of Pamlico Sound and in coastal rivers. The storm surge coupled with already elevated water levels, pushed water up river channels. This combination of factors created maximum storm

inundation heights estimated to be 8 to 11 feet above ground level along the shores of the Neuse River and its tributaries where they empty into Pamlico Sound. A USGS storm tide pressure sensor deployed across the Neuse River from downtown New Bern, NC, recorded a storm tide water elevation of 10.08 feet above the North American Vertical Datum of 1988 (NAVD88) (**Figure 4**), which converts to about 10.4 feet above Mean Higher High Water (MHHW).

Florence established new records in North Carolina and South Carolina for rainfall directly associated with a tropical cyclone. The slow forward speed of Florence prolonged the period in which rainbands moved inland from the Atlantic Ocean. As a result, areas in eastern North Carolina and northeastern South Carolina received at least 20 inches of rain from September 13-18 with areas from Wilmington, SC to Elizabethtown, NC, receiving 30 to 36 inches of rainfall (**Figure 5**). North Carolina's new rainfall record of 35.93 inches occurred about 6 nm northwest of Elizabethtown, well exceeding the state's previous record of 24.06 inches of rainfall at Southport that occurred during Hurricane Floyd in 1999. In South Carolina, the new state record for rainfall directly associated with a tropical cyclone was set at Loris, SC, with 23.63 inches of rain. This total exceeds the previous record of 17.45 inches near Lake Jocassee during Tropical Storm Beryl in 1994.

In southeastern and south-central North Carolina and northeastern South Carolina, rainfall exceeded 10 inches in many areas including the headwaters for major river systems flowing to the coasts of North Carolina and South Carolina. With near historic runoff upland of the coast, river flood crests travelling downstream exacerbated ongoing flood conditions on coastal rivers and their tributaries. As a result, there was extensive lowland and river flooding across much of southeastern and south-central North Carolina and northeastern South Carolina. Many rivers rose above record flood stages set during Hurricane Matthew in 2016 (which broke records previously set during Hurricane Floyd in 1999). According to the USGS, 18 sites in North Carolina and 10 in South Carolina established new records for streamflow. Half of the 28 gages where streamflow records were broken had periods of record of 30 or more years. In addition to those sites setting all-time streamflow records, another 45 streamgages with observational records of 10 years or more in North Carolina and four in South Carolina recorded streamflows in the top five measured at their respective site.

Twenty two USGS streamgages in North Carolina and 11 in South Carolina set new records for river stages as a result of Florence. Two locations observed flows not seen in more than 70 years. The river stage for the Waccamaw River at Freeland, NC, reached its highest stage since 1940 with a new crest of record on September 19 of 22.61 feet. In South Carolina, the Little Pee Dee River at Galivants Ferry set a new crest of record on September 21, with a river level of 17.21 feet, the highest river stage observed in the 77 years a streamgage has operated at the site. Based on a historical floodmark recorded by a resident of Galivants Ferry, it is likely that Hurricane Florence produced the greatest flooding in that area since 1928.

Most damages and fatalities produced by Hurricane Florence were the result of flooding. The damages from Hurricane Florence were estimated at $24 billion, and there were 22 direct fatalities. 16 fatalities were associated with vehicles caught in floodwaters.

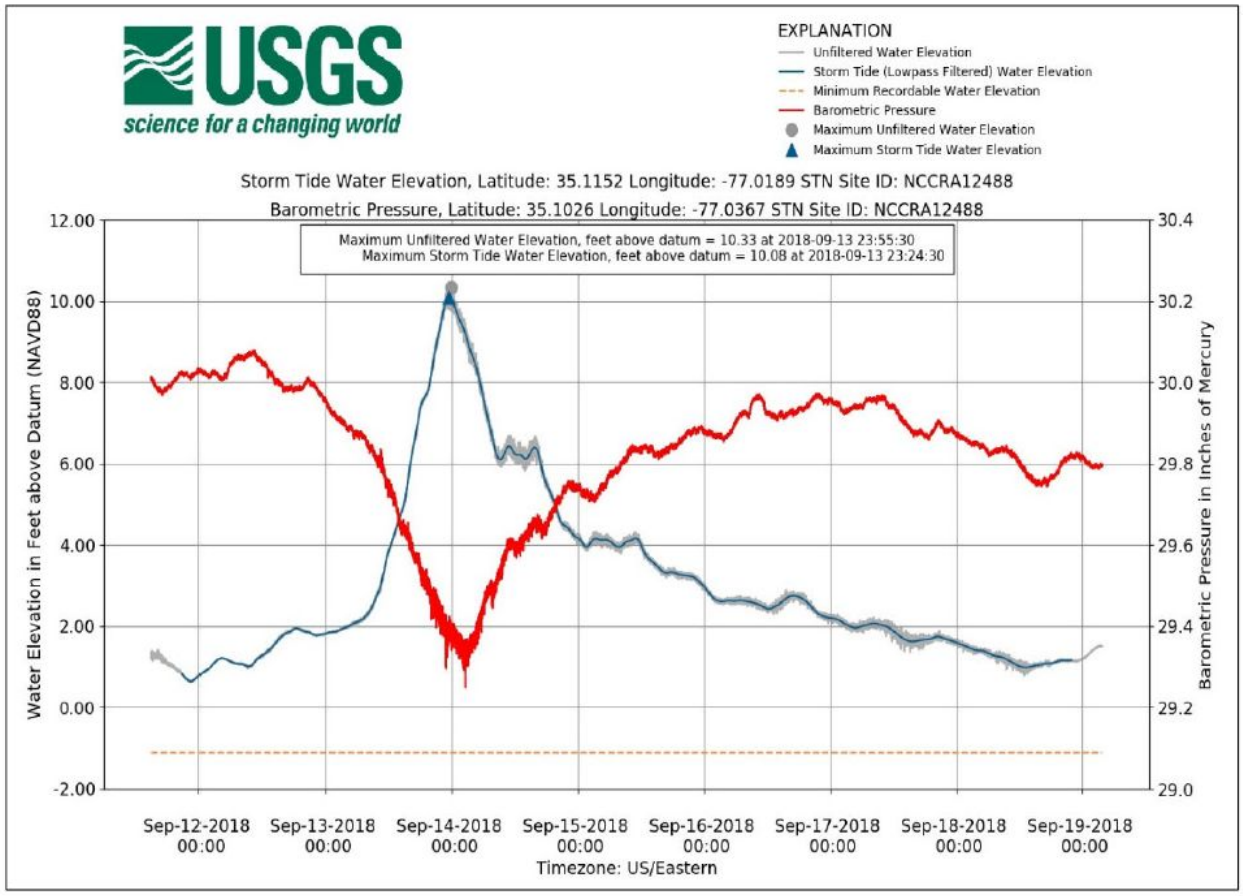


Figure 4: Instantaneous water level (gray, feet above NAVD88), wave-filtered water level (blue, feet above NAVD88) and barometric pressure (red, inches of mercury) recorded from a USGS sensor installed across the Neuse River from downtown New Bern, NC. Data were collected during the period September 11-19, 2018. *Source: USGS.*

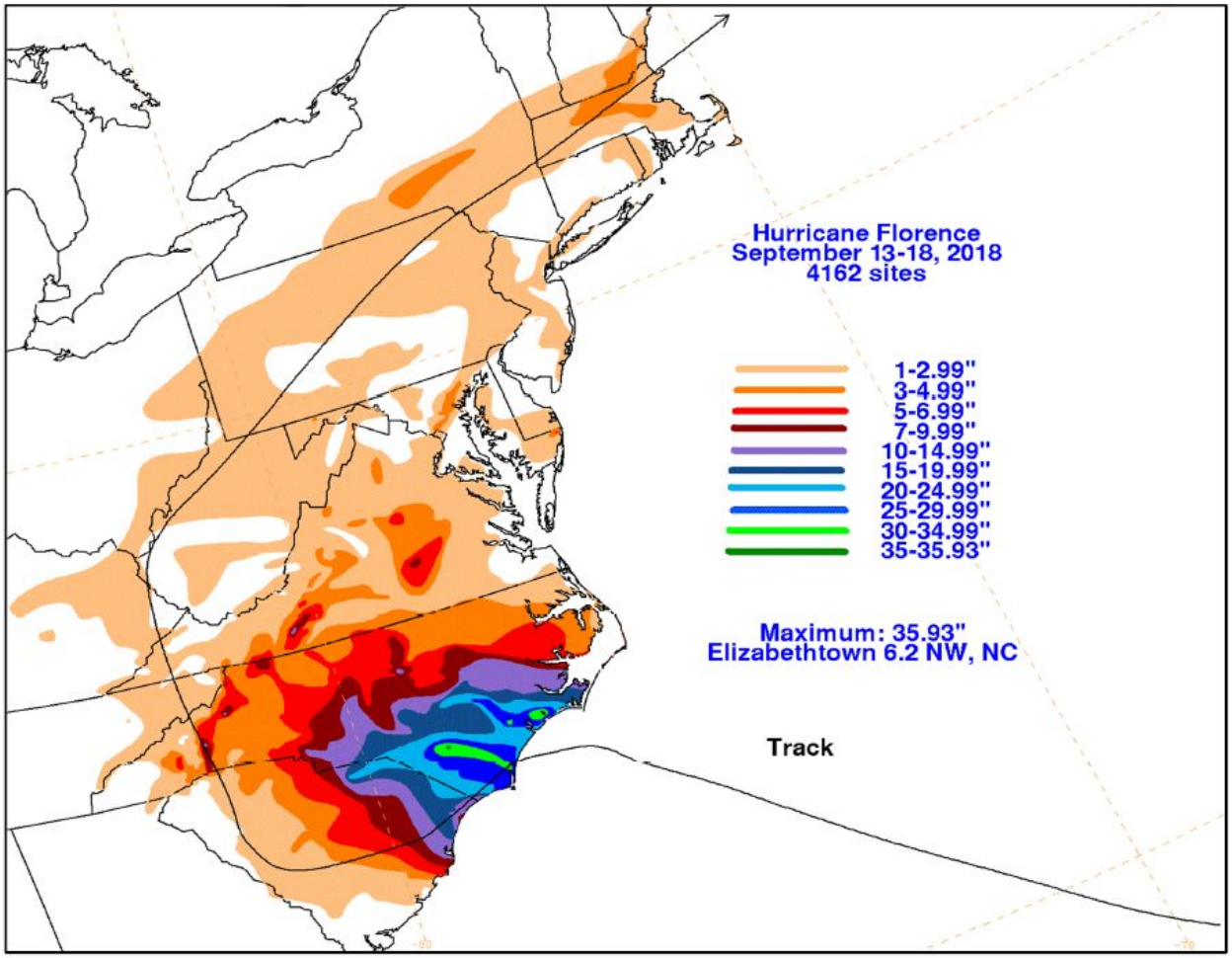


Figure 5: Hurricane Florence U.S. rainfall analysis (inches) during the period of September 13-18, 2018, which includes extratropical phase. *Source: NOAA Weather Prediction Center.*

2.2. Hurricane Michael - October 4 through October 16, 2018

Hurricane Michael was a completely different type of storm from Florence and had a complex origin and prolonged genesis process. A large area of disturbed weather formed over the central and western Caribbean Sea and absorbed the remains of Tropical Storm Kirk on October 1–2. A convective burst on October 2, possibly associated with a tropical wave moving into the region, led to the formation of a small-scale surface low southwest of Jamaica on October 3. This system moved west-southwestward into northeastern Honduras the next day. By October 5, this low became embedded within a large cyclonic gyre over Central America. Although the system was located in an environment of moderate westerly vertical wind shear, the circulation and convection associated with the low gradually became better organized, and it is estimated that a tropical depression formed around 0600 UTC October 7, centered about 130 nm south of Cozumel, Mexico (**Figure 6**).

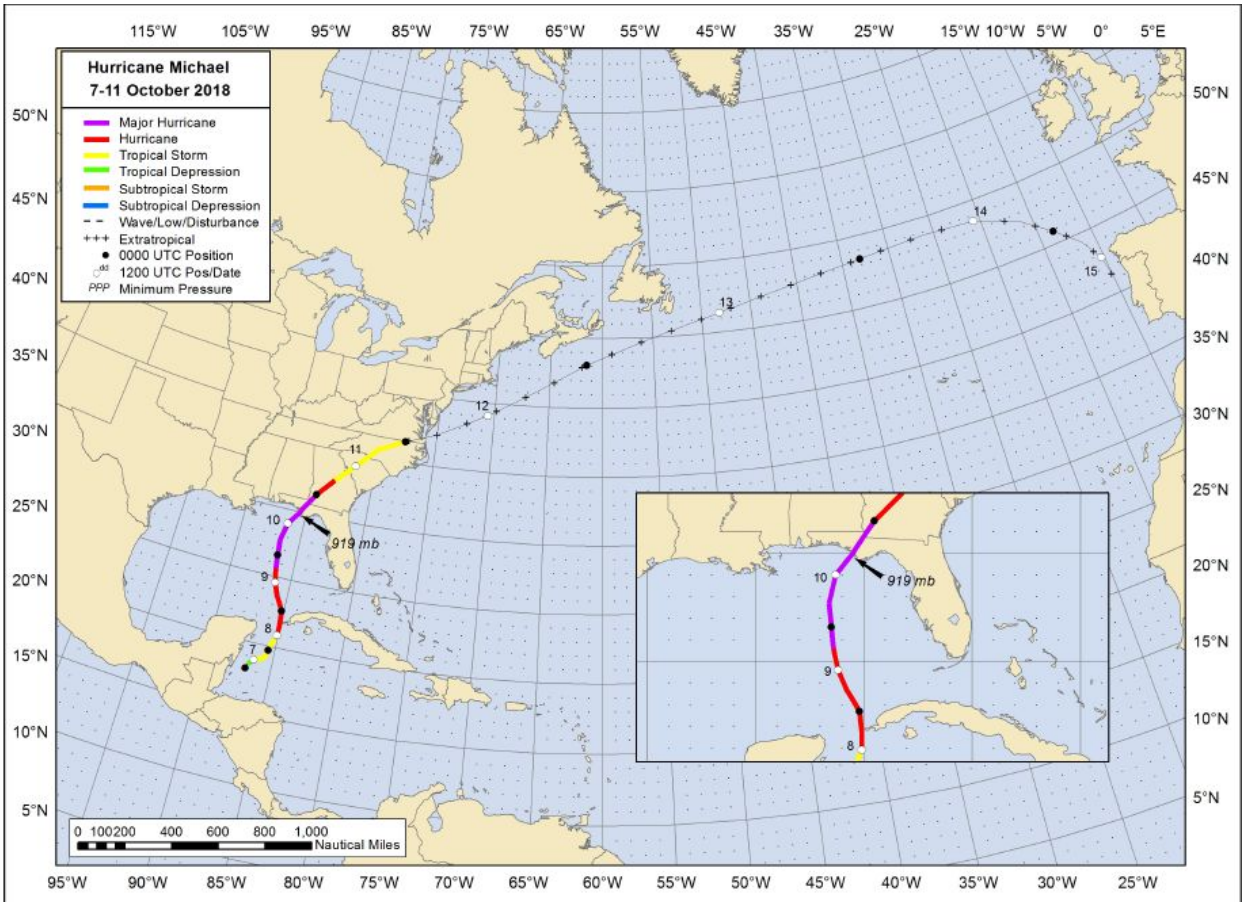


Figure 6: Best track positions for Hurricane Michael, October 7-11, 2018. The track during the extratropical stage is partially based on analyses from the NOAA Ocean Prediction Center. *Source: NHC.*

Despite moderate to strong southwesterly wind shear caused by an upper-level trough over the central Gulf of Mexico, Rapid Intensification (RI) occurred, with the cyclone becoming a tropical storm six hours after genesis and a hurricane a day later by 1200 UTC October 8 (**Figures 7 and 8**). This intensification may have been aided by upper-level diffluence caused by a nearby trough compensating for the shear. The maximum sustained winds reached 85 knots as the center of Michael passed just west of Cabo del San Antonio, Cuba, near 1830 UTC that day **(Figures 7 and 8**).

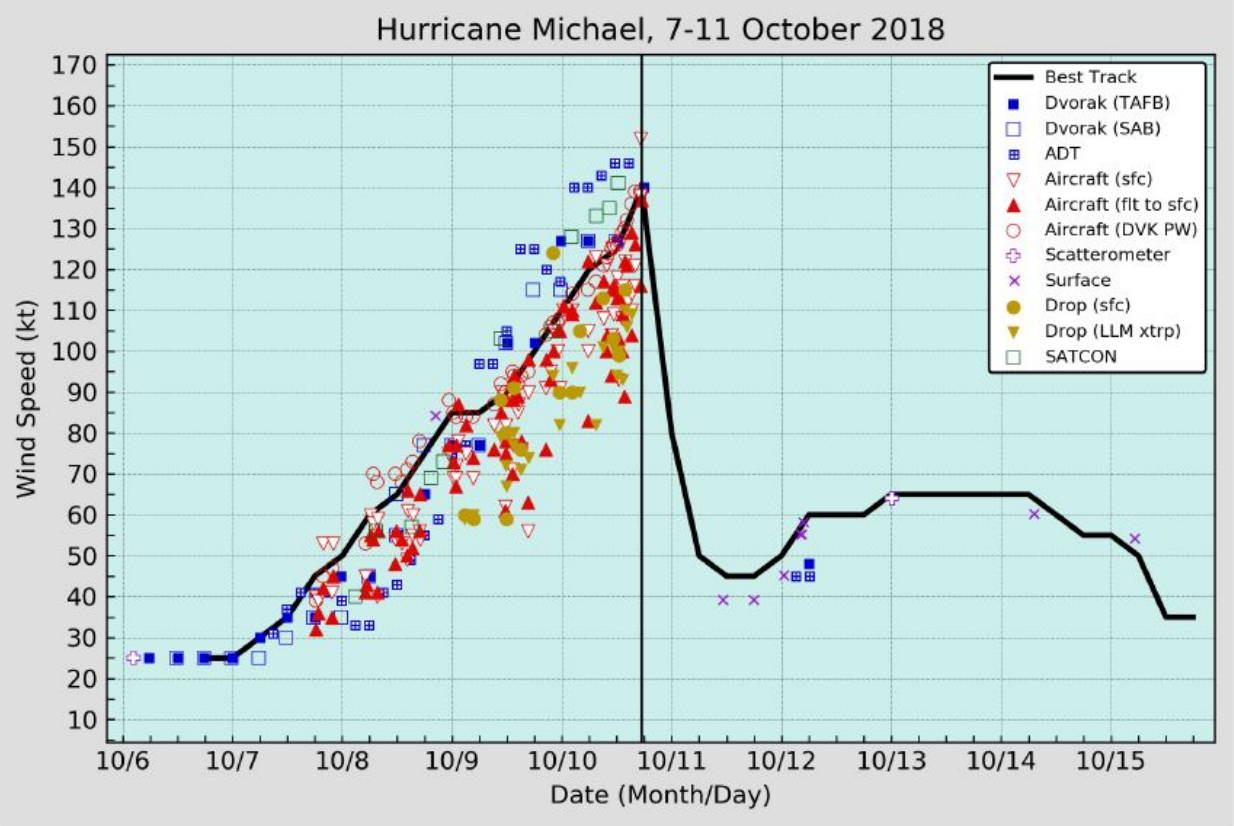


Figure 7: Selected wind observations and best track maximum sustained surface wind speed curve for Hurricane Michael, October 6–15, 2018. Aircraft observations have been adjusted for elevation using 90 percent, 80 percent, and 80 percent adjustment factors for observations from 700 millibars, 850 millibars, and 1500 feet, respectively. Dropwindsonde observations include actual 10 meter winds (sfc), as well as surface estimates derived from the mean wind over the lowest 150 meters of the wind sounding (labeled “LLM” in the legend). Advanced Dvorak Technique estimates represent the Current Intensity at the nominal observation time. Satellite Consensus (SATCON) intensity estimates are from the Cooperative Institute for Meteorological Satellite Studies. Dashed vertical lines correspond to 0000 UTC, and solid vertical lines correspond to landfalls. *Source: NHC.*

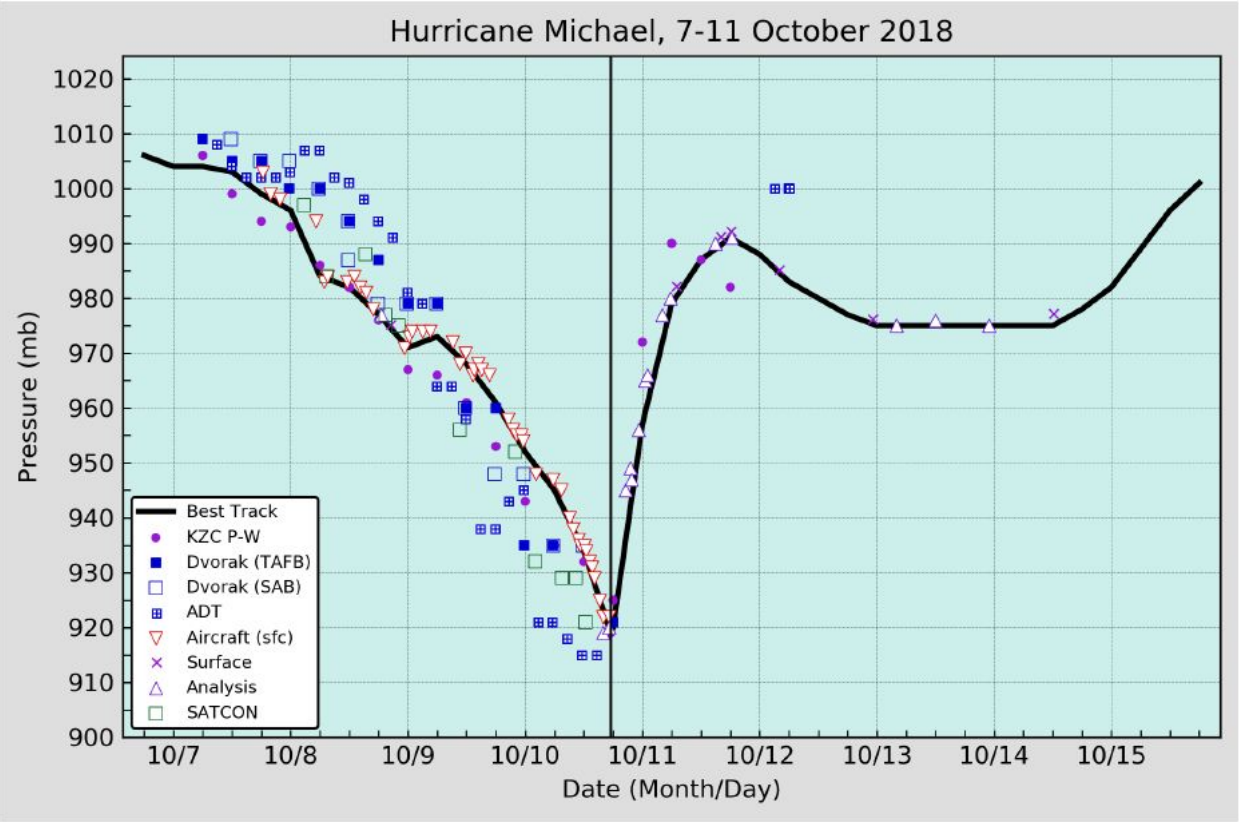


Figure 8: Selected pressure observations and best track minimum central pressure curve for Hurricane Michael, October 6–15, 2018. Advanced Dvorak Technique estimates represent the Current Intensity at the nominal observation time. SATCON intensity estimates are from the Cooperative Institute for Meteorological Satellite Studies. KZC P-W refers to pressure estimates derived using the Knaff-Zehr-Courtney pressure-wind relationship. Dashed vertical lines correspond to 0000 UTC, and solid vertical line corresponds to landfall. *Source: NHC.*

Decay of the eyewall convective structure (possibly from shear, dry air intrusion, and a cold water eddy) caused a pause in Michael's intensification as it reached the southeastern Gulf of Mexico late on October 8 (**Figures 7 and 8**). The pause was temporary, and RI resumed by 1200 UTC October 9. The hurricane turned north-northwestward that day. A northward motion followed early on October 10 as Michael moved between a ridge and a mid-latitude shortwave trough moving through the western Gulf Coast states (**Figure 6**). The trough created a strong outflow channel to the north that enhanced outflow and may have aided the RI that continued until landfall. This track resulted in the eye making landfall at Tyndall Air Force Base (AFB) in the Florida Panhandle, southeast of Panama City, near 1730 UTC that day (**Figure 9**). By that time, the maximum sustained winds had increased to an estimated 140 knots corresponding to a Category 5 on the Saffir-Simpson Hurricane Wind Scale (SSHWS).

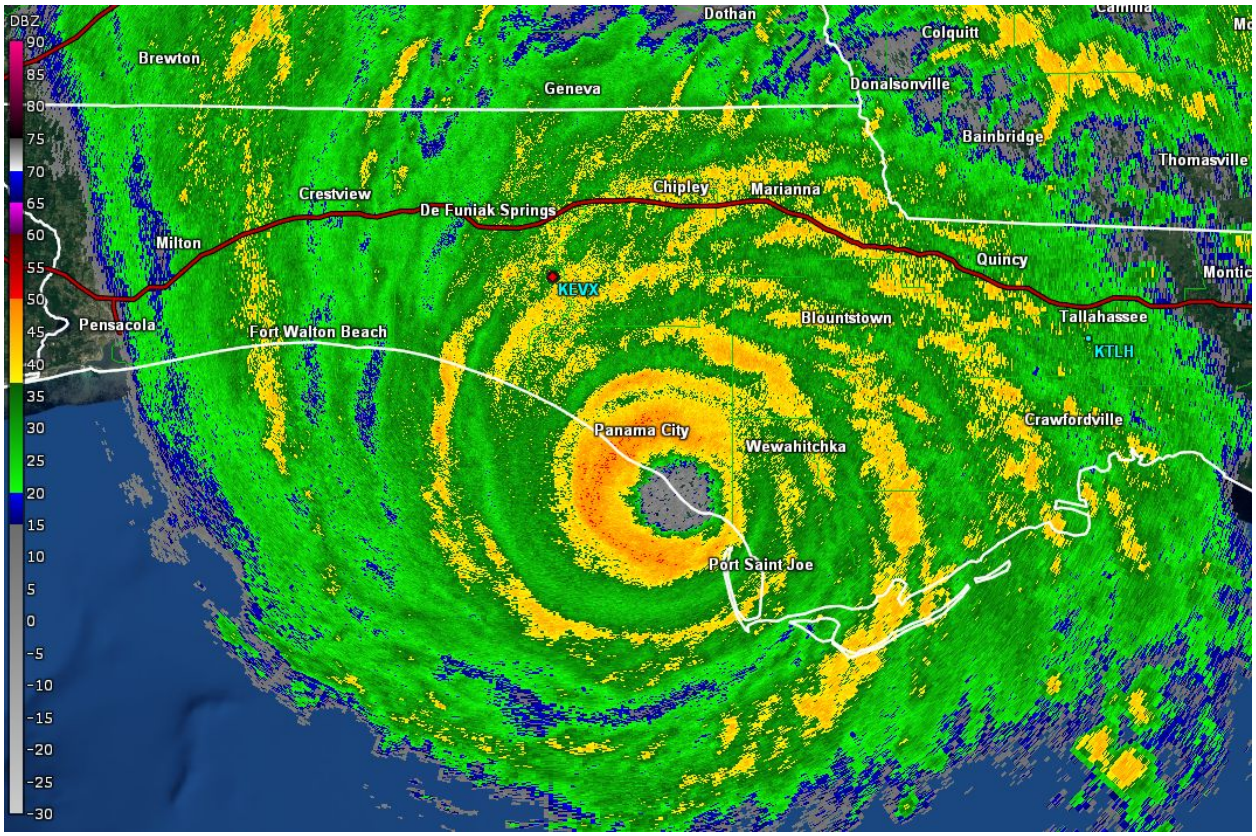


Figure 9: Eglin AFB WSR-88D image of Hurricane Michael at 1:22 p.m. EDT. October 10, 2018. *Source: WFO Tallahassee.*

Michael's winds rapidly decreased after landfall as it accelerated northeastward across the central Florida Panhandle. The maximum winds dropped below 100 knots (the minimum threshold of Category 3 intensity on the SSHWS) before the eye moved into southwestern Georgia around 2130 UTC October 10 (**Figures 7 and 8**). Continuing northeastward, the center passed just west of Augusta, GA before crossing into South Carolina near 1100 UTC October 11 (**Figure 6**). By this time, winds in the central core had decreased below tropical-storm force. However, tropical-storm force winds continued over the coastal areas and waters of Georgia and South Carolina. The storm's center continued northeastward and entered North Carolina by 1500 UTC, and three hours later it was centered just south of Greensboro, NC (**Figure 6**).

Michael started its extratropical transition as it moved into North Carolina, with the central pressure falling and the winds intensifying to the west and northwest of an increasingly elongated center. The transition was complete by 0000 UTC October 12. As it transitioned, Michael turned east-northeastward, with the center passing north of Raleigh, NC. At this time, nearly 1.2 million customers lost power, distributed as: Georgia, 424,744; Florida, 400,666; and North Carolina, 361,879. The power outages can be seen in the difference in satellite imagery from **Figure 10** to **Figure 11**.

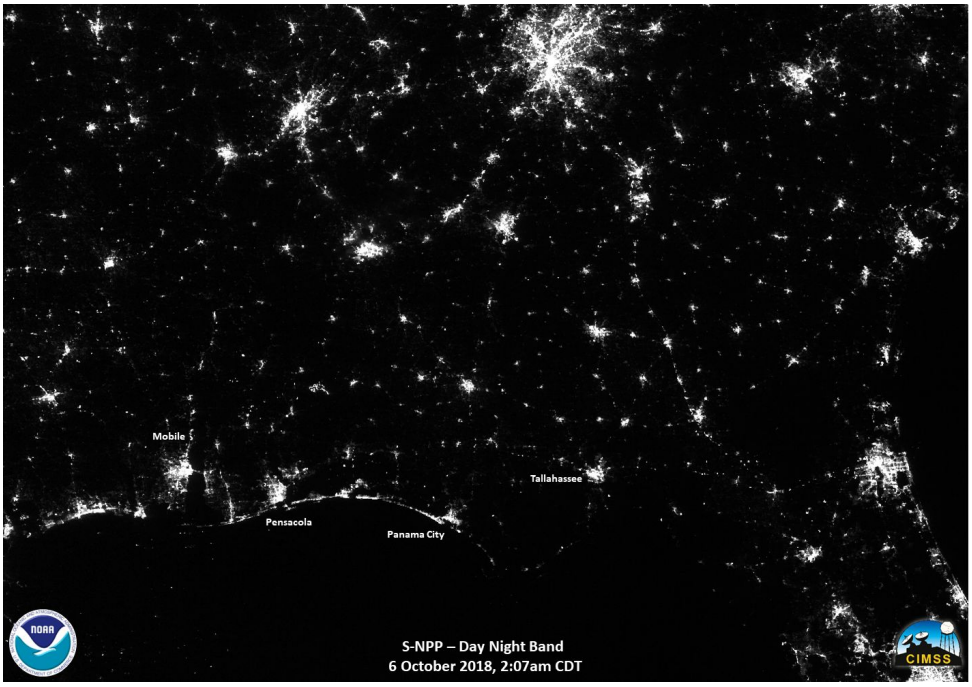


Figure 10: Visible Infrared Imaging Radiometer Suite (VIIRS) Day Night Band Visible (0.70 µm) Imagery from NOAA-20 on October 6, 2018. *Source: Cooperative Institute for Mesoscale Meteorological Studies (CIMMS) University of Wisconsin.*

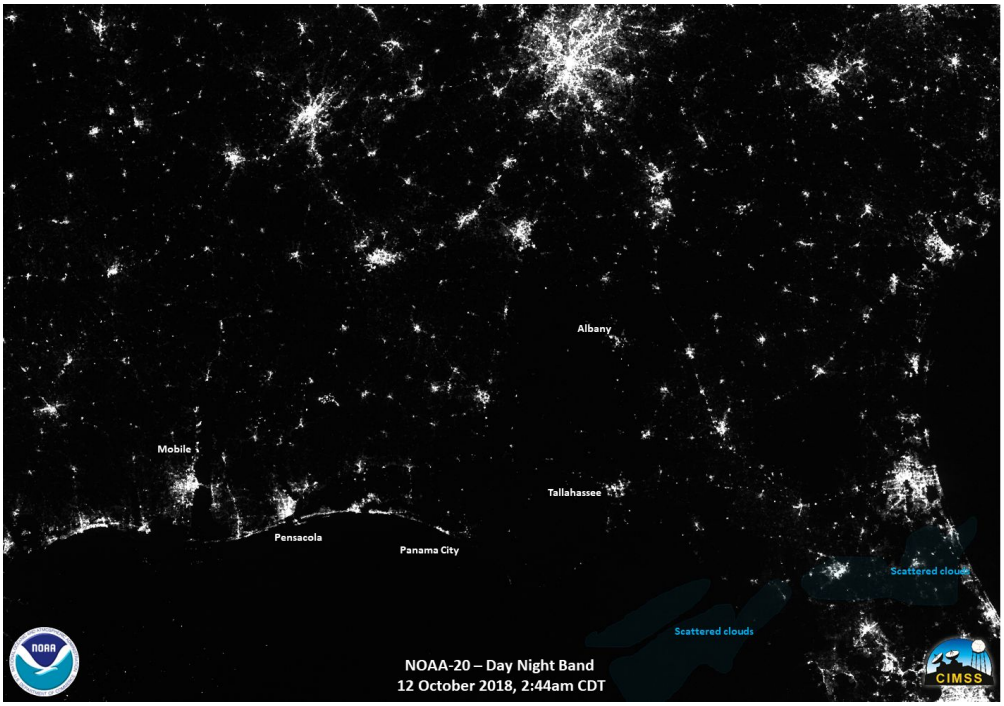


Figure 11: VIIRS Day Night Band Visible (0.70 µm) Imagery from NOAA-20 on October 12, 2018. *Source: Cooperative Institute for Mesoscale Meteorological Studies (CIMMS) University of Wisconsin.*

Michael's center moved across the Norfolk, VA, area and into the western Atlantic by 0600 UTC October 12. Accelerating east-northeastward in the westerlies, the extratropical cyclone regained hurricane-force winds on October 13 over the open ocean south of Nova Scotia and Newfoundland. A subsequent rapid eastward motion carried the system into the northeastern Atlantic where it moved around the northeast side of the subtropical ridge and began to decrease in wind speed. The system dissipated late on October 15 just west of northern Portugal.

Michael produced storm surge inundation heights estimated at 9–14 feet above ground level (AGL) along a portion of the Florida Panhandle coast from just southeast of Tyndall AFB to Port St. Joe in Bay and Gulf counties (**Figure 12**), respectively, with the highest inundation occurring in Mexico Beach. A USGS storm tide pressure sensor installed on the Mexico Beach pier recorded a wave-filtered water elevation of 15.55 feet above the North American Vertical Datum of 1988 (NAVD88), which converts to about 14.7 feet above Mean Higher High Water (MHHW). These data suggest that normally dry areas near the average high tide line in Mexico Beach likely experienced as much as 14 feet of inundation due to storm surge. The USGS sensor data also indicated significant wave activity in addition to the surge, which exacerbated the catastrophic damage that occurred within the first several blocks of the beach. High water mark surveys in Mexico Beach yielded similar observations.

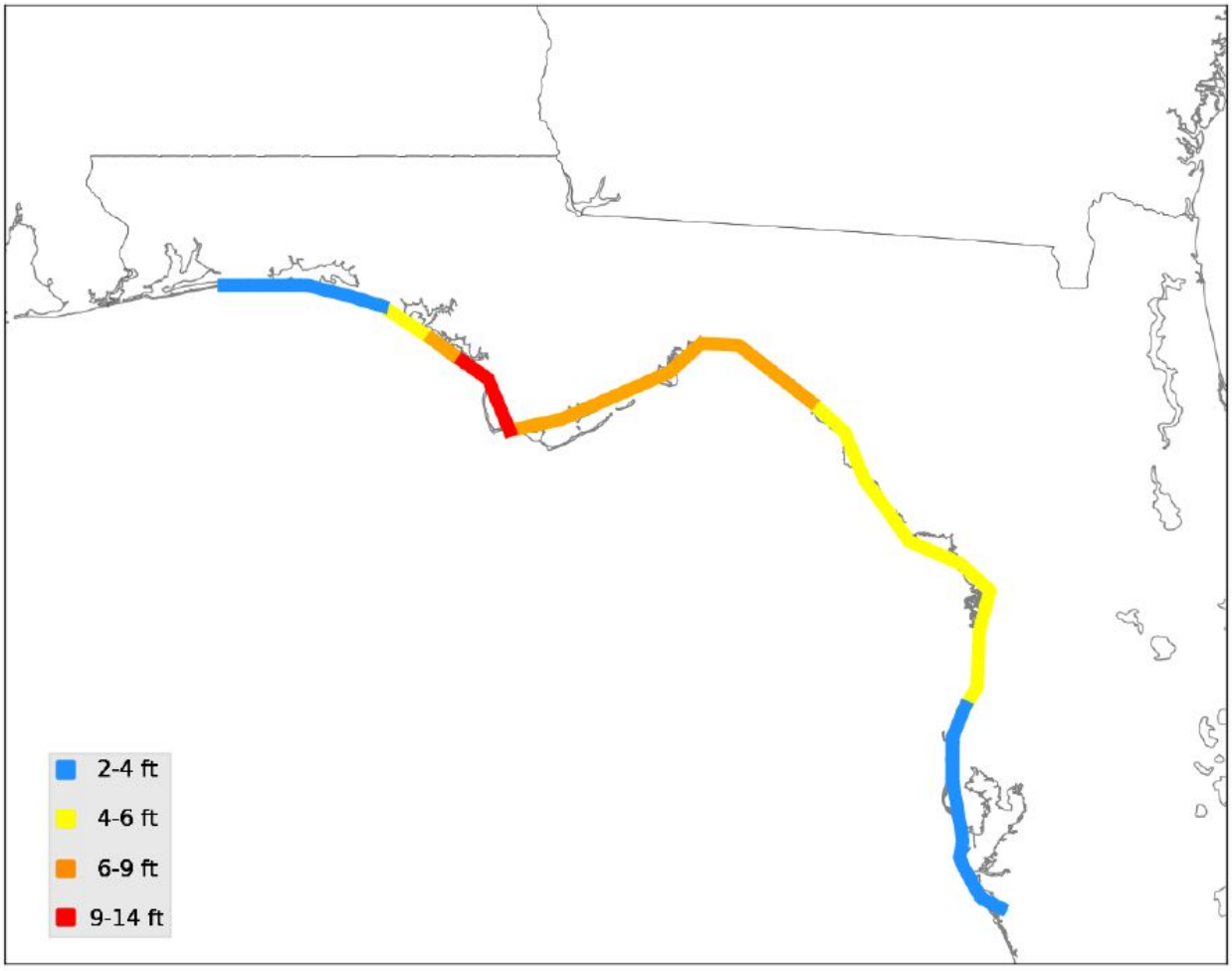


Figure 12: Estimated maximum storm surge inundation levels (feet AGL) along the Florida coast due to Hurricane Michael. Estimates are based on USGS and NWS high water mark observations, NOS tide station observations above MHHW, USGS storm tide pressure sensors, and a hindcast from the Sea, Lake, and Overland Surges from Hurricanes (SLOSH) model. *Source: NHC.*

Michael produced rains of 3 to 6 inches and localized rainfall totals in excess of 10 inches (**Figure 13**). The maximum storm total rainfall reported was 13.01 inches near Black Mountain, NC, while Lynn Haven, FL, reported a storm total of 11.62 inches. Intense rainfall in southern Virginia on October 11 caused flash flooding, resulting in five deaths (all in vehicles).

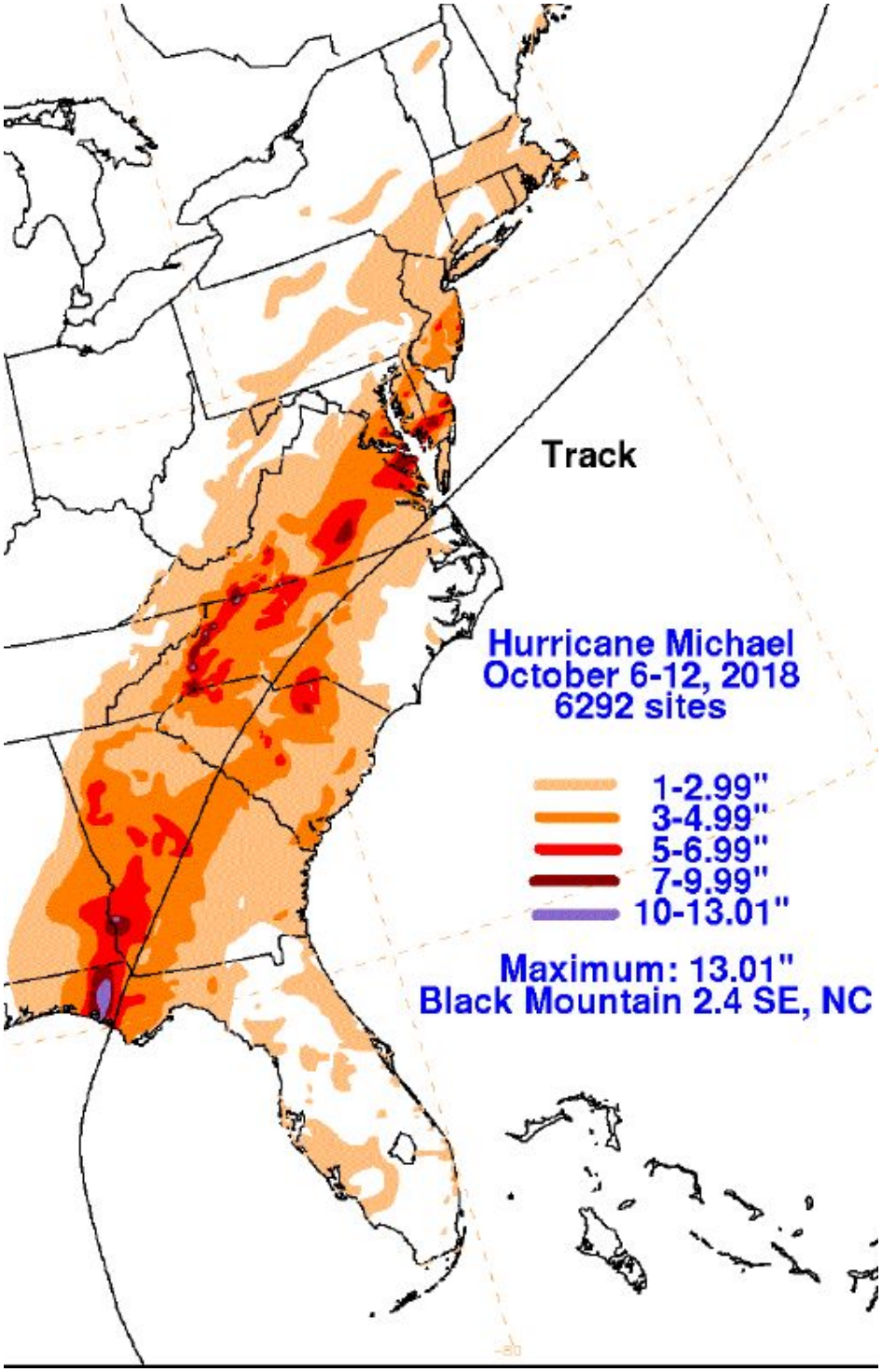


Figure 13: Analysis of storm total rainfall (inches) for Hurricane Michael.
Source: NOAA Weather Prediction Center.

Michael became the fourth hurricane to make landfall in the United States as a Category 5 hurricane on the SSHWS. Damages from Hurricane Michael were estimated at $25 billion, and there were 16 direct fatalities.

3. Findings, Recommendations, and Best Practices

3.1. Impact-Based Decision Support Services

3.1.1. IDSS Definition and Best Practices

Fact: The Impact-based Decision Support Services (IDSS) document (NWS policy directive 10-24 issued April 9, 2019) states that NWS should provide relevant information and interpretative services to enable core partners' decisions when weather, water, or climate has a direct impact on the protection of lives and livelihoods. The different types of IDSS include:

- Episodic IDSS: for specific events or incidents
- Recurring IDSS: for support throughout the year to improve partner mitigation, preparation, response, and recovery, as well as support for routine high value decisions

IDSS is provided by the NWS at three different service levels (examples of these are provided in NWS policy directive 10-24):

- General partners and the public (e.g., generic NWS information provided to all)
- Core partners (e.g., general services, plus episodic IDSS)
- Deep relationship core partners (e.g., core partners plus recurring IDSS)

Core partners are those directly involved in the preparation, dissemination, and discussions involving weather, water, or climate related NWS information that supports decision making for routine or episodic high impact events.

Deep relationship core partners are core partners whose decisions/actions have the greatest impact on protecting lives and livelihoods.

For the purposes of this assessment, both core partners and deep relationship core partners will be referred to as core partners.

Fact: Core partners (e.g., emergency managers and media) overwhelmingly praised proactive IDSS from NWS local, regional, and national offices. These partners have repeatedly stated that face-to-face relationships built over time breed success and establish a foundation of trust. NWS briefings get wide distribution because core partners act as force-multipliers by sharing the content within their agencies/communities.

Figure 14: NOAA "Postcard From The Field" showing WFO Tallahassee staff along with two deployed NWS team members from WFO Miami and WFO Houston/Galveston. *Source: NOAA Communications Office.*

Best Practice: WFO Tallahassee deployed staff members to three different locations: Bay County Emergency Operations Center (EOC), Leon County EOC, and the Florida State University (FSU) EOC. Staff at WFO Tallahassee worked with deployed meteorologists and emergency managers to facilitate a last minute "push" of messaging the night before landfall (**Figure 14**); Hurricane Michael was rapidly intensifying and emergency managers wanted to strongly encourage those that were still left behind to evacuate. This included a combination of a WFO-hosted midnight webinar, Wireless Emergency Alert (WEA) messages, and Facebook Live broadcasts. Law enforcement did a door-to-door search in Mexico Beach, FL the night before landfall. The end result is that the number of people remaining on Mexico Beach went from 250 the evening before landfall to 50 the morning of landfall. These deployments were highly beneficial during Hurricane Michael. All EMs with deployed staff said the deployments made a big difference regarding decision-making during the event.

Best Practice: The WFO Atlanta Meteorologist In Charge (MIC) called the emergency managers in 15 of their inland Georgia counties on the morning of October 10, just prior to WFO Atlanta's issuance of Hurricane Warnings for these counties. These calls were to ensure that their core partners understood the meaning of a Hurricane Warning and predicted impacts given the expected winds. The MIC discussed the potential scenarios with partners in non-technical terms (trees will be down) and emphasized the timing of those impacts (outside daylight hours)

and potential complications (trees down on homes and first responders' inability to access locations). Having a senior member of the WFO staff contact EMs increased the emphasis of the messaging.

Best Practice: The NHC Storm Surge Unit (SSU) coordinated extensively with local WFOs, as well as with NWS core partners such as the state emergency management offices in North Carolina, South Carolina, and Virginia, and Bay County, FL, Emergency Management Division to help interpret storm surge guidance and aid in their broader decision-making process.

Best Practice: The FEMA Hurricane Liaison Team (HLT), embedded at NHC, provided calls and briefings for the states of South Carolina, North Carolina, and Virginia; FEMA Headquarters, FEMA Region 4, and FEMA Region 3; and participated in numerous federal and state video-teleconferences for Hurricane Florence. During Hurricane Michael, the HLT provided support via teleconferences to the state of Florida, which reached its peak the day before and into the overnight hours that preceded Michael's landfall on October 10. NHC-led federal and state video-teleconference briefings continued through landfall and into October 11 as Hurricane Michael moved through the eastern U.S.

Best Practice: The Ocean Prediction Center (OPC) and the Tropical Analysis and Forecast Branch (TAFB) coordinated closely with the U.S. Coast Guard (USCG) during both Hurricanes Michael and Florence. Per leadership at OPC, this coordination began in 2018 as an informal pilot project, following the El Faro incident in 2015. This coordination is now a routine practice to improve coordination efforts and provide better situational awareness for the USCG and mariners. This was lauded by staff following Hurricanes Florence and Michael at NWSH and NHC as highly beneficial for both the agencies.

The team received substantial feedback on local office IDSS efforts, including webinars, emails, special phone briefings, etc., and also substantial positive feedback on the efforts that the NWS has made to build and maintain relationships year-round. For example, WFO Raleigh stakeholders lauded the WFO's efforts to provide additional conference calls to readily expand its IDSS to respond to the evolving needs of the core partners before, during, and after the storm.

Fact: The team learned that while the information provided by NWS national centers is important, WFO core partners relied on local webinars, briefings, and other IDSS to break down the information on a local level for decision-makers.

Best Practice: WFO Columbia held pre-storm meetings with the South Carolina EMD, SC governor, and the governor's senior staff prior to the primary executive briefing with full leadership during an actual event. This meeting was considered to be real-time support, not an exercise or training.

Best Practice: All of the WFOs in the affected area hosted Integrated Warning Team (IWT) workshops, participated in table top exercises, and other key planning events throughout the year. NHC provided support for some of these exercises, including a hurricane scenario that was used for local exercises with WFO Tallahassee core partners in spring 2018. This process helped streamline the process to build relationships ahead of significant weather events, bolstering the knowledge and use of local WFO expertise to assist local decision-makers.

3.1.1.1. Application of IDSS and Resources

There were highly successful results when NWS personnel deployed to EOCs for onsite IDSS, but the team found inconsistencies in the standard and ability to deploy to core partners. At the time of these events, a formal policy instruction for Deployment-Ready IDSS within the NWS was still being formalized conceptually with the understanding that the NWS has been deploying personnel for years. In addition, some emergency management agencies were unaware of the possibility of having a meteorologist or hydrologist deployed to their EOC leading up to and during a high impact event. The impact of staffing shortages with respect to the effective delivery of IDSS was noted in finding and recommendation 1 of the *Historic South Carolina Floods of October 1-5, 2015 Service Assessment*.

Fact: The NWS WFOs have a finite number of forecasters that are categorized as being "deployment ready" resulting in limited staffing to support onsite requests.

Fact: Some offices had more requests than personnel available to deploy.

Finding 1: NWS offices would likely have deployed more personnel to EOCs for onsite support if it were not for staffing shortages in the office. Additionally, some EMs did not know they could request a deployment-ready (DR) meteorologist or hydrologist for onsite IDSS during high impact events. Conversely, resources were deployed to a site where only marginal impacts were being predicted.

Recommendation 1: The NWS should make every effort to provide on-site support to an EOC where on-site support has been requested. If NWS is not capable of providing on-site support to an EOC where the support has been requested, then there should be an alternate means of engagement in place which satisfies the partner, such as reliable virtual support. Examples of virtual support include Skype, GoToWebinar, Adobe Connect, Zoom, and Google Hangouts. (Note: virtual support will only work in cases where connectivity is still up.)

There were internal NWS questions regarding why WFO Raleigh did not deploy resources to the North Carolina State EOC while WFO Columbia deployed personnel to the South Carolina State EOC. WFO Raleigh annually engages with its state level partners in North Carolina to identify the needs for EOC deployment. In contrast to neighboring states, North Carolina employs its own meteorologists within the EOC. Each WFO serving North Carolina works through the local regional divisions of the Emergency Management Agency to serve

regional and county EMs. The state-employed meteorologists at the North Carolina EOC use NWS products and coordinate with WFO Raleigh for consistent messaging to state and local level decision-makers throughout WFO Raleigh's County Warning Area (CWA).

The same coordination occurs between WFO Columbia (state liaison WFO for South Carolina) and the state level EMs. Following this coordination, NWS Columbia decided it was best for state interests in South Carolina for the NWS to deploy a meteorologist to the state EOC.

Best Practice: WFO Morehead City conducted a pre-hurricane season tabletop exercise with Onslow County, NC. This exercise helped county EMs feel comfortable with not requesting WFO Morehead City deployments to the EOC. The pre-season tabletop exercise enabled Onslow County, NC, EMs to specifically request the appropriate tropical products.

The Florida Division of Emergency Management (FDEM) follows the same model as North Carolina. It employs its own meteorologists at the state level and the NWS provides support to the Florida state meteorologists. The state-employed meteorologists at the EOC use NWS products and coordinate with WFOs throughout Florida for consistent messaging to state and local level decision-makers.

Fact: The lack of a deployment to a state EOC is not necessarily an indication of poor support or a poor relationship between the NWS and its deep core partners. Each state requires different levels of support for core partners. During Hurricane Florence, WFOs in North Carolina and South Carolina worked together to identify unique needs of state level partners and tailored the IDSS mission to fit those different needs.

Fact: EMs from some of the counties affected by Hurricane Michael had not visited their local WFO office in more than four years.

Finding 2: EMs are not always making regular visits to WFOs.

Recommendation 2: Local WFOs should encourage EMs to visit their local WFOs at least once every three years. A best practice would be inviting EMs to NWS open house activities yearly.

3.1.1.2. Tropical Program Expertise at WFOs

NWS has long had a service model depending on a few key NWS staff members in a local office who are trusted by stakeholders. This trust is built over time and it is important for this trust to be well established prior to a major event.

Fact: Some NWS partners reported a level of trust with only a single person from their partner WFO, while others reported working with and trusting a range of individuals from their partner office.

Finding 3: The number of individuals trusted by partners varies greatly from office to office.

Recommendation 3: The NWS local offices should prioritize the "whole office" approach of core partner support. Local offices must expand the number of staff members who have trusted relationships with core partners to alleviate a "single point of failure" if that person is not there.

3.1.1.3. IDSS and Staffing Levels

Core partners stressed that their relationship with the NWS was strengthened when NWS personnel deployed for realistic scenario-based exercises. They also emphasized the beneficial results of having a sufficient number of trained NWS personnel deployed to their locations during hazardous events to provide direct access to NWS skill sets. Partners said based on the success of having NWS personnel embedded with EOCs, they anticipate their requests for on-site deployments will only increase with time. In the case of the Tallahassee WFO, core partners commented they wanted two NWS staff members deployed to the EOC instead of one.

Fact: With existing vacancies, surge staffing brought both WFOs Morehead City and Wilmington, NC up to one below their standard staffing. These numbers limited each office's ability to provide onsite IDSS.

Finding 4: IDSS requests have increased, while resources have sometimes fallen short in supporting these requests.

Recommendation 4: NWS should look at existing models (e.g. IMETs, CWSUs, USACE) where external partners provide reimbursable funding to support non-local NWS staff member deployment on a full-time or part-time basis to address core-partner IDSS needs that cannot be met with current NWS resource levels.

3.1.1.4. IDSS on Periphery of Event

The role of IDSS was important not only in communicating where the most critical impacts were likely to occur, but also where impacts were less severe. This information enabled agencies and jurisdictions in these areas to save money, time, and resources in supporting these locations. It also allowed neighboring communities to rapidly support response for "ground zero" locations.

Fact: Core partners in Mobile County used information from WFO Mobile and NHC (timing of arrival and storm surge forecast graphics) to plan for lower impacts as Hurricane Michael

approached landfall. Officials with the Port of Mobile were able to keep the port open through the storm resulting in a significant cost savings. In addition, following the storm the Port deployed ships to Panama City, FL to aid storm response and recovery.

3.1.1.5. WFO One Page Briefings

The Hurricane Florence team received feedback from stakeholders that localized and tailored webinars and IDSS briefings during storms were beneficial. Core partners also used the one-pager weekly briefings to maintain situational awareness as to when to start paying attention to upcoming weather events.

Best Practice: In addition to webinars, partners used one-pagers and briefings. Partners were able to cut and paste diagrams and charts and appreciated that they were able to share accurate and credible information.

Best Practice: NHC also issued key message talking points in graphics distributed via social media and the NHC webpage, and forecast discussions.

3.1.2. IDSS Specific for Hydrologic Operations

NWS stakeholders generally praised RFCs and WFOs for providing IDSS specific for hydrologic operations for Florence and Michael. Water managers with the U.S. Army Corps of Engineers (USACE) South Atlantic Division noted that Southeast River Forecast Center (SERFC) forecasts for flood inflows into reservoirs and one-on-one communication were critical to its reservoir operations decisions. The USACE emphasized that this interaction with SERFC allowed them to mitigate effects for areas downstream of its reservoirs. Other stakeholders noted RFC forecast dissemination times were vital and they were very satisfied with the dependable delivery of RFC products in Florence.

The onset, magnitude, and duration of the Florence flood event pushed the boundaries of NWS Hydrology IDSS capacities. These expanding IDSS requirements will require examination of workforce training, effective messaging, the complexity of flood watch/warning/advisory products, and staffing profiles.

As a first effort to meet these IDSS challenges, some offices adopted a team approach to hydrologic operations. At WFO Raleigh, all staff members are trained in hydrologic operations. At WFO Morehead City, the team approach is necessary to overcome the lack of a Service Hydrologist (SH) position. Without a position formally designated as an SH, WFO Morehead City developed a hydrology team within its forecast unit.

In both of these examples and others, it is critical to understand that WFOs, RFCs, and National Centers have worked within the reality of a zero sum solution to address the increasing need for IDSS specific for hydrologic operations. Without any additional staffing resources to

dedicate to this program area, NWS offices made the decision to institute the hydro team approach understanding they were pulling resources from other office programs. The historical magnitude and duration of flooding in Florence severely tested this approach. Rivers in South Carolina flooded when Florence made landfall in the middle of September. In the case of the Pee Dee River Basin, these flood waters did not recede until the first week of October. Shift logs and schedules documented the tremendous amount of overtime SERFC and the NC and SC WFOs incurred to meet the long-lived IDSS requirements of Florence before, during, and after the storm. Bringing in staff proficient in IDSS specific for hydrologic operations was helpful to relieve WFO and RFC forecasters.

Finding 5: Some WFOs (e.g., WFO Morehead City) do not have SHs despite having repeated significant flooding during high impact events in their Hydrologic Service Areas (HSA).

Recommendation 5: Staffing models must be reviewed to ensure that all WFOs affected by repeated high impact flooding prioritize an on-station SH position to provide hydrologic IDSS expertise.

Best Practice: WFOs (even those with SHs) are adapting their staff resources to address core partner needs for increased hydrologic forecasting and water level IDSS.

IDSS specific for hydrological operations is locally driven. A common theme from WFO stakeholders was the need for information at locations that are not NWS river forecast points. WFO Wilmington, NC partners noted the hydrology briefings were good, but they also needed more information on non-forecast points. The WFO Morehead City hydro team built an impacts database to provide an enhanced level of support for critical locations that were not RFC forecast points.

It is important to note that high-impact hydrologic events require a probabilistic approach to modeling. Deterministic models can present a false sense of security/endangerment to partners in the period when they are making decisions (e.g. more than two days out).

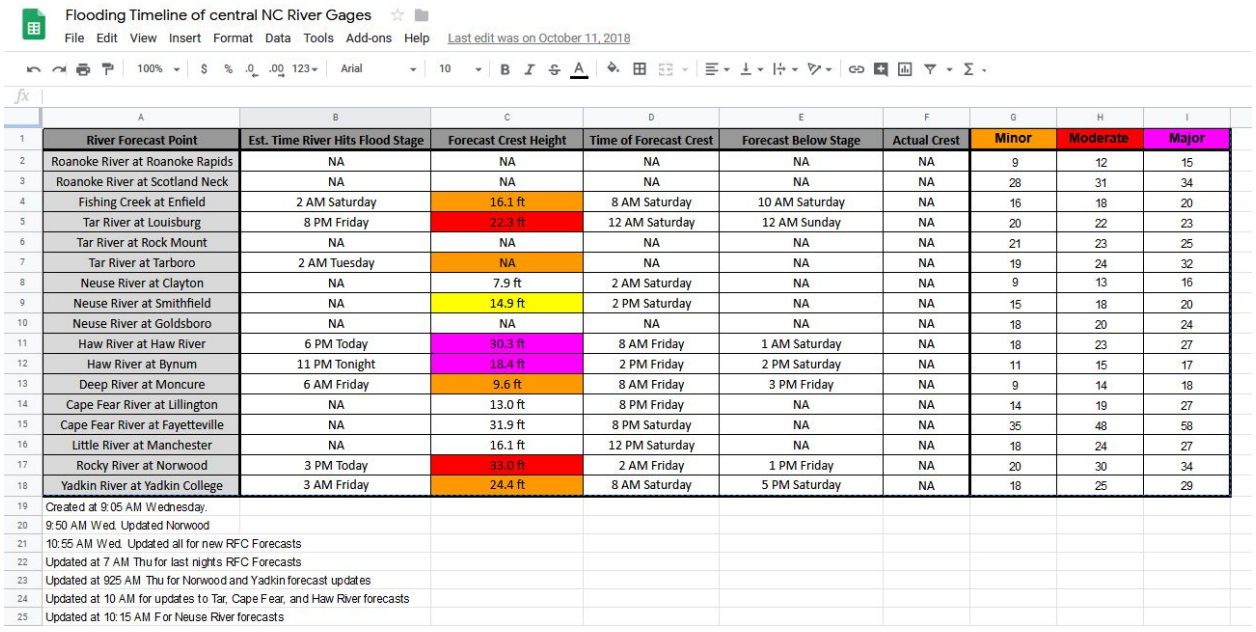
Finding 6: Stakeholders need hydrologic information for locations other than the existing inventory of NWS river forecast locations. During Hurricane Florence, many of these additional locations were in tidally-influenced basins.

Recommendation 6a: The Office of Water Prediction (OWP) should expand efforts underway with the DOC Agency Priority Goal to complement other Federal agency inundation mapping datasets and enhance collaboration with federal water agencies to deliver inundation mapping that fulfills the needs of core partners beyond the current NWS inventory of inundation map locations.

Recommendation 6b: The OWP and RFCs should continue to work with NOS and the NHC to develop and demonstrate the capability to provide routine total water forecasts in the coastal zone.

3.1.2.1. River Flood Forecasting

Best Practice: WFO Raleigh developed a "River Flood Table" briefing tool, which garnered positive feedback from core partners. This tool was adapted from the Meteorological Model Ensemble Forecast System (MMEFS) ensemble table that RFCs produce, and displayed via a local webpage for briefings (**Figure 15**).



Flooding Timeline of central NC River Gages

File Edit View Insert Format Data Tools Add-ons Help Last edit was on October 11, 2018

River Forecast Point	Est. Time River Hits Flood Stage	Forecast Crest Height	Time of Forecast Crest	Forecast Below Stage	Actual Crest	Minor	Moderate	Major
Roanoke River at Roanoke Rapids	NA	NA	NA	NA	NA	9	12	15
Roanoke River at Scotland Neck	NA	NA	NA	NA	NA	28	31	34
Fishing Creek at Enfield	2 AM Saturday	16.1 ft	8 AM Saturday	10 AM Saturday	NA	16	18	20
Tar River at Louisburg	8 PM Friday	22.3 ft	12 AM Saturday	12 AM Sunday	NA	20	22	23
Tar River at Rock Mount	NA	NA	NA	NA	NA	21	23	25
Tar River at Tarboro	2 AM Tuesday	NA	NA	NA	NA	19	24	32
Neuse River at Clayton	NA	7.9 ft	2 AM Saturday	NA	NA	9	13	16
Neuse River at Smithfield	NA	14.9 ft	2 PM Saturday	NA	NA	15	18	20
Neuse River at Goldsboro	NA	NA	NA	NA	NA	18	20	24
Haw River at Haw River	6 PM Today	30.3 ft	8 AM Friday	1 AM Saturday	NA	18	23	27
Haw River at Bynum	11 PM Tonight	18.4 ft	2 PM Friday	2 PM Saturday	NA	11	15	17
Deep River at Moncure	6 AM Friday	9.6 ft	8 AM Friday	3 PM Friday	NA	9	14	18
Cape Fear River at Lillington	NA	13.0 ft	8 PM Friday	NA	NA	14	19	27
Cape Fear River at Fayetteville	NA	31.9 ft	8 PM Saturday	NA	NA	35	48	58
Little River at Manchester	NA	16.1 ft	12 PM Saturday	NA	NA	18	24	27
Rocky River at Norwood	3 PM Today	33.0 ft	2 AM Friday	1 PM Friday	NA	20	30	34
Yadkin River at Yadkin College	3 AM Friday	24.4 ft	8 AM Saturday	5 PM Saturday	NA	18	25	29

Created at 9:05 AM Wednesday.
9:50 AM Wed. Updated Norwood
10:55 AM Wed. Updated all for new RFC Forecasts
Updated at 7 AM Thu for last nights RFC Forecasts
Updated at 925 AM Thu for Norwood and Yadkin forecast updates
Updated at 10 AM for updates to Tar, Cape Fear, and Haw River forecasts
Updated at 10:15 AM For Neuse River forecasts

Figure 15: Example of the auto-updating MMEFS spreadsheet from WFO Raleigh, which included crest forecast information from the RFC. *Source: WFO Raleigh.*

Fact: A meteorologist and planner from the North Carolina Office of Emergency Management (OEM) noted, “We think they [*ensemble forecasts for hydrology*] can be valuable in the days leading up to an event, if explained well. However, we thought they were creating lots of questions when they were included in email briefings and one of our seven NWS offices included them during the event, when all other offices moved to strictly using the actual forecast hydrographs.”

Fact: Since 2012, RFCs serving Eastern Region stakeholders have successfully used the Meteorological Model-based Ensemble Forecasting System (MMEFS) to produce short-term probabilistic river forecasts. Extensive internal and external training materials have been fielded to enhance the usefulness and understanding of MMEFS-derived products by NWS staff, the water resources enterprise, as well as the general public.

Fact: The Hydrologic Ensemble Forecasting System (HEFS) has technical limitations and was not available for many NWS river forecast locations. For example, while HEFS quantifies and bias-corrects for meteorological uncertainty, to date HEFS lacks the capability to bias-correct for known hydrologic model error.

Finding 7: The state of North Carolina OEM heavily used ensemble river forecasts, which were vital for state decisions. However, discussions with other users on conclusions they drew from the ensemble river products indicated the need for clarification of product limitations and additional assistance interpreting the forecast results.

Recommendation 7a: The NWS should invest resources in developing a suite of HEFS data services and derived products that serve a range of potential users.

Recommendation 7b: Leveraging the groundwork laid by the MMEFS program, the NWS should engage social scientists in producing internal and external training materials to enhance the usefulness and understanding of HEFS-derived products. This training should be included with the annual tropical training.

Hurricane Florence, in contrast to Hurricane Michael, was a long-lived slow moving storm that forecasters predicted would move slowly along the South and North Carolina coasts. WFOs, RFCs, WPC, NHC, and NWC were all highlighting the potential for life threatening, catastrophic flooding from historic rainfall up to five days prior to landfall. RFCs customarily issue forecasts for a five-day period using a predetermined duration of future rainfall. In the case of Florence, the depiction of forecast information on the Advanced Hydrologic Prediction Service (AHPS) web page did not indicate major flooding in the days leading up to landfall. This information differed from the messaging in social media and forecast products from WFOs, RFCs, WPC, and NHC which were advertising a more significant impact. This discrepancy was the result of the limitation of AHPS of only showing deterministic river forecast results produced using 72 hours of QPF. Stakeholders expressed the need to visualize the potential for river flooding several days before impacts from tropical cyclones arrive and to know how much rainfall was incorporated into the official NWS forecast.

Fact: Each RFC and WFO presents information differently to convey potential flooding threats in the longer forecast ranges beyond what AHPS traditionally presents using QPF.

Best Practice: SERFC adjusted its typical operating procedures to ensure it conveyed the true nature of the forecast hazard. In this case, the RFC moved from its typical operating procedure of using 48-hr QPF to using 72-hr QPF closer to the onset of impacts from Hurricane Florence. This adjustment was necessary for AHPS to display at least major river flooding as the storm neared landfall.

Fact: In the case of Hurricane Florence, the River Forecast (RVF) product issued by SERFC showed the forecast for the Pee Dee River at Pee Dee, SC incorporated 72 hours of future rainfall totalling 13.25 inches (**Figure 16**). The AHPS hydrograph page does not display this information.

Finding 8: Current RFC operations use a predetermined QPF time horizon to generate deterministic forecast hydrographs for use by decision-makers. Maintaining the QPF horizon at this standard duration can undermine the IDSS messaging and effort to help communities prepare more effectively.

Recommendation 8: RFCs should be adaptable and use a proactive approach for collaborative discussions with core partners, neighboring offices, and WPC to determine the appropriate QPF duration for initialization of deterministic hydrologic models.

Finding 9: The existing AHPS web site does not present the complete hydrologic story between official forecasts based on a controlled duration of forecast rainfall (QPF), other scenarios from deterministic durations of QPF, and scenarios provided by ensemble modeling and probability of exceedance statistics. The lack of capability to provide this information continues to create confusion among the public and partners for use in decision making support.

Recommendation 9: Deterministic and probabilistic river forecasts should be displayed together on the same website. Users need the functionality to display multiple products to maintain situational awareness of current, as well as potential, hydrologic conditions.

Finding 10: Stakeholders expressed the need to know how much rainfall NWS forecasters are incorporating in their official NWS river forecast. The AHPS hydrograph page does not display this information.

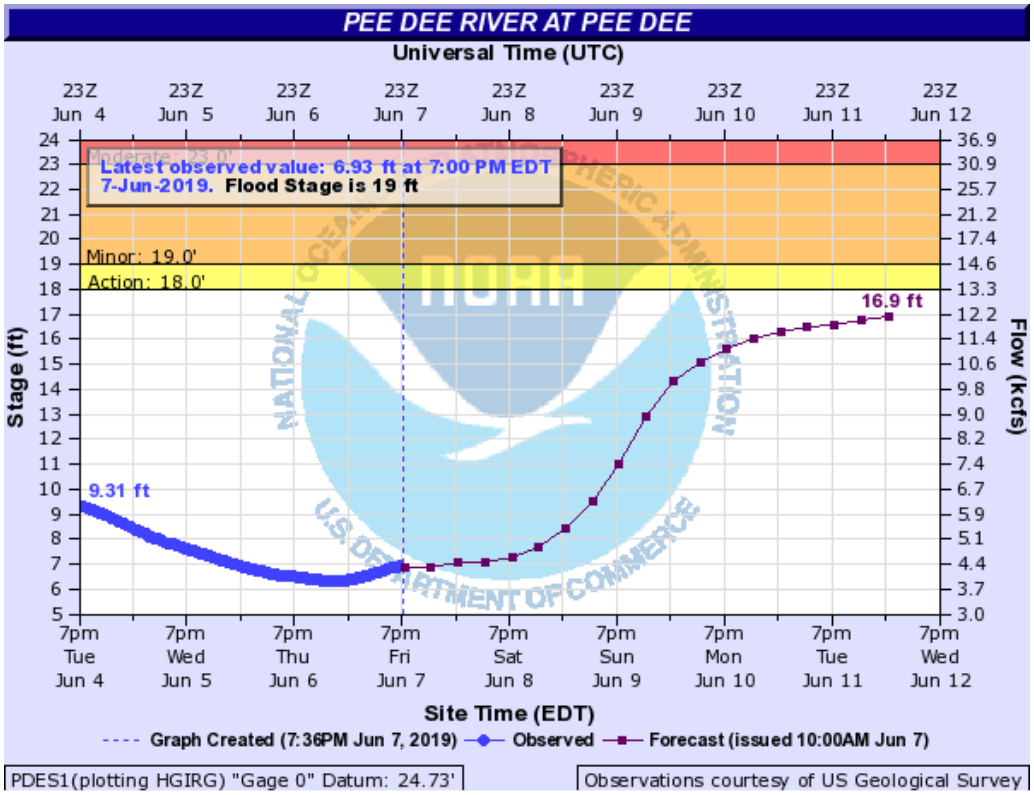


Figure 16: Example hydrograph for Pee Dee River at Pee Dee, SC. *Source: NWS AHPS web page.*

Recommendation 10: The existing requirement for the display of QPF values used to produce the official NWS river forecast on hydrographs appearing on the AHPS webpage that is in the AHPS to IDP project needs to be accelerated.

Finding 11: Stakeholders noted that flood categories and impact statements associated with the AHPS hydrograph page were not always correct or updated.

Recommendation 11: Regional HQs should insure that Hydrologic Program Managers (HPM) are adhering to NWS Instruction 10-924 that instructs the HPM to review the data stored for a gage location, and thus displayed on the gage's AHPS page, a minimum of once every five years and within 30 days of a significant event.

The state of North Carolina core partners use the North Carolina Flood Inundation Mapping and Alert Network (FIMAN) system (see https://fiman.nc.gov/#) that was developed by the state of North Carolina following the historic flooding associated with Hurricane Floyd in 1999.

Finding 12: Because the NWS could not meet user requirements for Flood Inundation Mapping (FIM), NWS core partners turned to alternative sources such as FIMAN for these mapping products. The FIMAN system provides public-facing observations and forecast information that

is valued by core partners in North Carolina; however, the information presented may conflict with NWS IDSS messaging at times because, while NWS products are used, NWS does not have a direct role in FIMAN forecast generation.

Recommendation 12: NWS should work with core partners to ensure consistent IDSS messaging inclusive of FIM and forecast uncertainty products.

3.1.2.2. AHPS Pages and Graphically Representing Flooding for IDSS

Hydrographs and listed impacts on the AHPS web page are beneficial and often cited by partners as the primary source for hydrologic information. However, partners do not have enough information to communicate detailed impacts, such as which communities are at risk, from inland flooding without inundation mapping. It is challenging for those in the NWS to tell the story about flooding using only single point forecast hydrograph data.

The issues surrounding how the NWS communicates impacts to partners and the public were identified as key findings in the *Hurricane Irene, August 21-30, 2011 Service Assessment*. Recommendation 59 and 60 from that service assessment are relevant to what this service assessment has found.

Finding 13: Core partners lack the ability to visualize potential inundation and risks to specific areas when using single river stage forecasts as traditionally presented by AHPS.

Recommendation 13: The OWP and RFCs should collaboratively develop flood inundation mapping services, such as tools being proposed like the NWS GIS Viewer, and/or tools already available in ArcGIS Online (AGOL), that would enable partners to better comprehend and message the potential impacts from inland flooding.

Finding 14: Partners were concerned that current storm surge graphics do not reflect the anticipated total water height.

Recommendation 14: The NWS should support ensemble modeling for total water level to enable the production of graphics depicting the water height inclusive of freshwater flow, storm surge, tides, and waves.

3.1.3. NWS Coordination with Partners

3.1.3.1. NHC Media Pool

Best Practice: The NHC media pool was used during both Hurricanes Florence and Michael to quickly amplify the messaging for both storms to a wide range of media partners.

Fact: The NHC media pool provided 256 live interviews during Hurricane Florence, including 101 to national TV networks, 23 with local TV stations in the affected areas, 71 to Spanish language networks and via Skype, 59 generic summaries made available to all users, and two print interviews on site. The NHC media pool was in operation from September 10 through 14 for Florence. A limited pool opened on 10 September from 7:00 AM to 9:30 a.m. EDT, followed by the full media pool that opened at 7:00 a.m. EDT on September 11 and closed at 12:05 p.m. EDT 14 September.

Fact: During Hurricane Michael, NHC provided more than 100 broadcast interviews in English or Spanish in addition to over 100 interviews by phone and through radio and print media. The NHC media pool began operations on October 7 and remained in place through October 10.

3.1.3.2. Extent of Watches/Warnings near Landfall

Core partners with the state of Florida expressed that, in their perception, Watches/Warnings were kept in effect over too large an area as Hurricane Michael neared landfall, despite high confidence in the track forecast. This perception of overalerting resulted in, their view, a messaging challenge at times in areas at the periphery of the storm.

Per leadership at NHC, the areal extent of tropical watches and warnings is not explicitly tied to wind speed probability values or exceedance levels. They also remind users that the actual risk along a stretch of coastline (e.g., a county coastline or stretch bounded by "breakpoints") is the integrated probability over that stretch, not the lower point probability that applies at a given location within it. NHC specialists look at the track, size, intensity, timing and level of uncertainty and come up with a proposed coastal watch/warning area which can be updated with each major 6-hour forecast cycle. They coordinate the proposed watches/warnings with the local offices prior to issuing the new advisory. Typically, specialists do not make a lot of changes from one advisory to the next and avoid making significant changes every forecast cycle to maintain continuity between forecasts. The main reasoning for this continuity is that a significant trimming of watches/warnings could take the public focus off the event as a whole. It can be problematic to downgrade warnings when hazards have not yet arrived.

The state of Florida DEM stated that, in their view, excessive resources were expended in some counties on the west coast of Florida due to watches and warnings that were not scaled back as the track and storm impacts became more certain. The state of Florida DEM also reported that four counties in west Florida (Pinellas, Hillsborough, Pasco, and Hernando counties near the Tampa Bay Area) activated their respective EOCs despite relative confidence their areas were outside the forecast impact zone. Hernando and Pasco counties were under a Storm Surge Warning until 11 p.m. EDT Wednesday, several hours after landfall. Pinellas and Hillsborough counties were under a Storm Surge Watch until 4 p.m. Wednesday, shortly after the time of landfall. According to Florida DEM, these areas ended up with very few storm impacts. However, the state reported that Pasco County officials spent $300,000 on activation.

According to the NHC, storm surge reached 2 to 4 feet above ground in these counties. Storm surge of 3 feet or greater above ground meets the criteria of the Storm Surge Watch/Warning. According to the WFO Tampa Post Storm Hurricane Report, the storm surge value reached 3.61 feet above ground at an NOS tide station in Clearwater Beach in Pinellas County. In Pasco County, coastal flooding occurred around Green Key. In Hernando County, coastal flooding occurred in Pine Island.

Florida DEM emphasized that watches and warnings (both wind and storm surge) were kept in effect over too large an area on the periphery of Hurricane Michael, specifically the counties on the west coast of Florida in the Tampa Bay area. Impacts were minimal in these areas; however, the criteria for the Storm Surge Watch/Warning was exceeded in portions of the counties on the west coast of Florida near the Tampa Bay area.

3.1.3.3. Timeliness of Watches/Warnings and Storm Surge Products

The times when evacuation decisions are made varies by state, impacting IDSS efforts differently. For some deep core partners, these products and warnings sometimes serve more as a confirmation tool rather than a decision tool. By the time the storm-based storm surge products (e.g. pSurge, Potential Storm Surge Flooding Map) are released (36 to 48 hours prior to the arrival of tropical storm force winds), some NWS core partners have already made key evacuation decisions.

For example, the South Carolina governor made the evacuation decision the afternoon of Monday September 10 prior to Hurricane Florence. In order to make this decision, the governor needed storm surge information approximately 72 hours prior to the arrival of tropical storm force winds and 96 hours prior to landfall.

The team also received similar feedback from NWS partners following Hurricane Michael: partners want to see storm surge forecast information released earlier in the decision-making process. For example, the Georgia Emergency Management and Homeland Security Agency said contraflow is typically initiated at 48 hours prior to the arrival of tropical storm force winds. Although their evacuation decisions are based on these timelines more than storm surge forecast information, they requested more expedited storm surge information to aid this decision-making process. Finding and recommendation 9 of the *August/September 2017 Hurricane Harvey Service Assessment* are relevant to this point.

Finding 15: Some NWS core partners, e.g., the Georgia Emergency Management and Homeland Security Agency expressed the desire for an earlier release of information, such as storm-based storm surge forecasts.

Recommendation 15: The NHC should look into extending the release of real-time storm-based storm surge guidance from the current standard of 48 hours in advance of the arrival of tropical storm force winds to 72 hours.

3.1.3.4. IDSS Provided by NHC SSU

The NHC SSU provided considerable support to state-level partners in North Carolina and South Carolina for Hurricane Florence. The SSU realized an opportunity, due to the slow forward speed of Florence, to provide enhanced IDSS to the North Carolina Department of Emergency Management (NCDEM) including specialized GIS surge inundation mapping products. The SSU also provided high-resolution hindcast mapping after the storm. These efforts, per input from NCDEM, directly contributed to the state being well-prepared.

Fact: The NCDEM used IDSS from the NHC SSU to plan the pre-positioning of swift boat teams in New Bern, NC to aid in emergency rescues. In addition, the NHC SSU directly briefed the VA Governor and the Legislature. The NHC SSU provided specialized GIS inundation data to assist them in the decision to pull back on activating a Cat 4 evacuation (Zones 1-4) and instead doing a more targeted evacuation of Zone 1. Finally, the NHC SSU directly assisted SCEMD and a NWS representative that was deployed to SCEMD. This was summarized as a best practice within section 3.1.1 of this assessment.

3.1.3.5. Communicating the Storm Surge Forecast

Some core partners at the county and local levels affected by Hurricane Florence reported that the forecast for storm surge was not always clearly understood by the public and some decision-makers, and they didn't understand the difference between "most likely" and "reasonable worst case" scenario. One town manager in coastal North Carolina reported that "Storm surge messaging can be confusing based on what people look at." Some emergency managers want to also see a graphic "most likely storm surge" not just the 10 percent exceedance forecast which is often termed the "reasonable worst case scenario." The effective messaging of storm surge products was also referenced in Finding and Recommendation 5 of the *October 2016 Hurricane Matthew Service Assessment* and Finding and Recommendation 17 of the *Hurricane/Post-Tropical Cyclone Sandy, October 22-29, 2012 Service Assessment.*

Meteorologists at NHC analyzed storm surge forecast information (both "most likely" and "reasonable worst case scenario") following Hurricanes Florence and Michael. In both cases, the "most likely" forecast maps underpredicted the surge. For example, the "most likely" storm surge forecast for Hurricane Michael one day prior to landfall at Mexico Beach (the hardest hit location) was approximately 4 ft NAVD88 whereas the actual observed value was 15.5 ft NAVD88.

Fact: Of the "most likely" and "reasonable worst case" (10% exceedance) storm surge forecasts for both Hurricanes Florence and Michael, only the "reasonable worst case scenario" forecast actually captured the observed storm surge in both events.

Finding 16: A few local-level core partners in North Carolina requested a "most likely" storm surge forecast in addition to the existing "reasonable worst case" storm surge forecast. In addition, some NWS core partners stated there is still confusion regarding the appropriate use of the "reasonable worst case" storm surge forecast for planning purposes.

Recommendation 16: The NWS should identify information pathways and community partnerships to aid in education programs to ensure that NWS core partners are informed on the appropriate use of the "reasonable worst case" scenario and "most likely" storm surge forecast scenario.

The team received feedback from NWSH that local NWS offices are sometimes using the wrong datum when referencing storm surge, or not mentioning a datum at all. NWS Directive 10-601 on Weather Forecast Office Tropical Cyclone Products updated in May 2017 mandates that official NWS products that contain water levels associated with coastal flooding or storm surge must reference ground level. Note: the "above ground" reference and the Mean Higher High Water (MHHW) datum are not necessarily the same. MHHW is a good proxy for "above ground" near the coast or at a site reporting relative to MHHW, but once you move away from there they are not the same, especially in areas that are not typically subject to tidal fluctuations and therefore have no MHHW reference.

Finding 17: There were instances where NWS local offices were not including the above ground reference or not referencing any datum (as required by NWS Policy Directive 10-601) when providing the storm surge forecast.

Recommendation 17: The NWS should strongly emphasize the policy of including the above ground reference through annual tropical training. The NWS should reach out to other federal partners, inclusive of NOS, to leverage their training resources on this topic.

3.1.4. IDSS Graphics

3.1.4.1. Forecast Graphics from NHC

NHC wind speed probability, time of arrival graphics (**Figure 17**), and storm surge inundation graphics (**Figure 18**), are being used to make decisions and are highly valued by public and EM audiences. Often these groups are using these graphics to make decisions before any watches or warnings are posted. Different groups are using the "Earliest Reasonable" and the "Most Likely" time of arrival of tropical storm force wind graphics as their main source of decision making depending on their risk assessment (**Figure 17**).

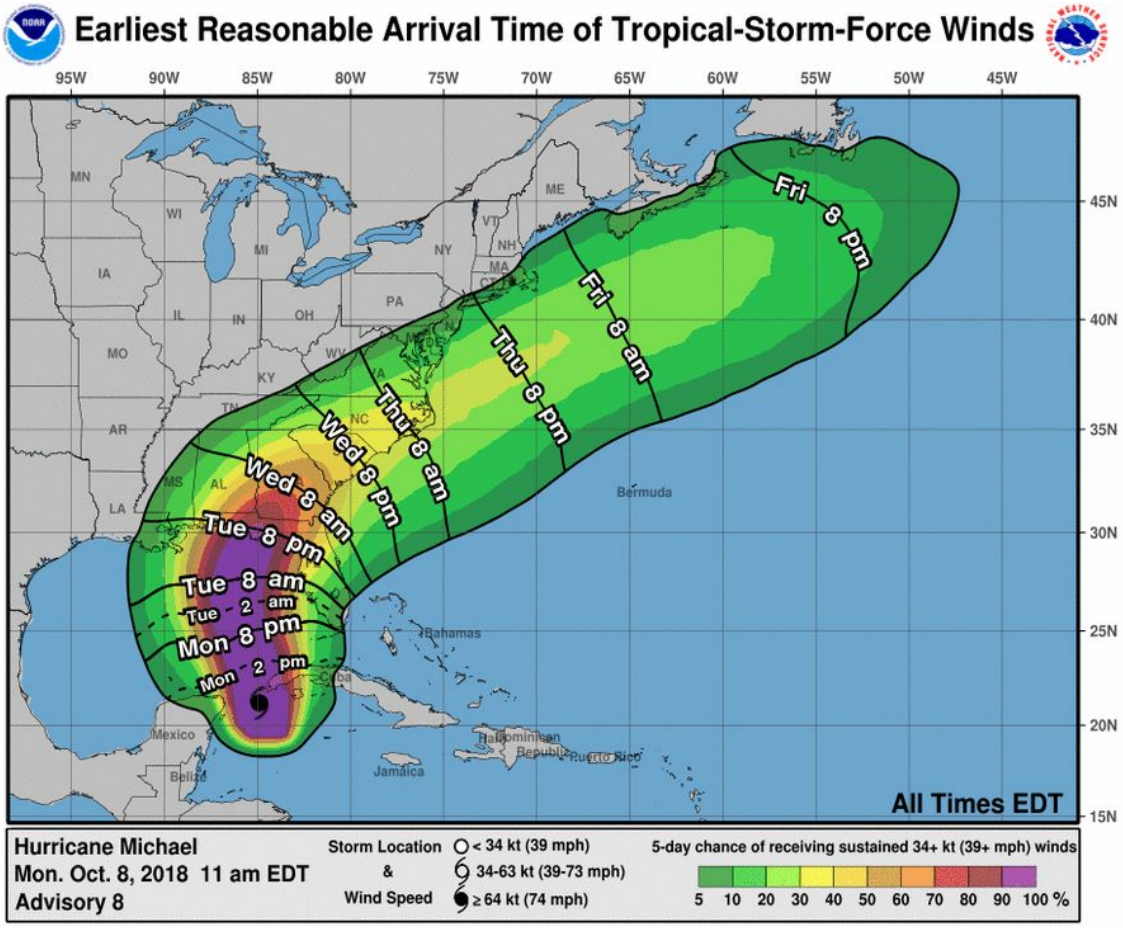


Figure 17: Example of NHC Time of Arrival forecast graphic which was widely used in decision-making by NWS partners for both hurricanes. *Source: NHC.*

One direct example of a core partner using NHC graphics for decision making was leadership at Tyndall AFB. The base commander stated both the NHC time of arrival graphics and the Friday email briefing from WFO Tallahassee were very helpful in making evacuation decisions. The base commander used this guidance to aid the base in making evacuation decisions prior to the watch being issued. The base commander decided to evacuate all personnel (around 13,000 people), except emergency essential employees, and to secure or move $10.5 billion in aircraft prior to the storm.

Several NWS emergency management partners, including staff from Bay County, FL Emergency Management, reported that the Potential Storm Surge Flooding Map was critical in aiding them in their evacuation decisions (**Figure 18**).

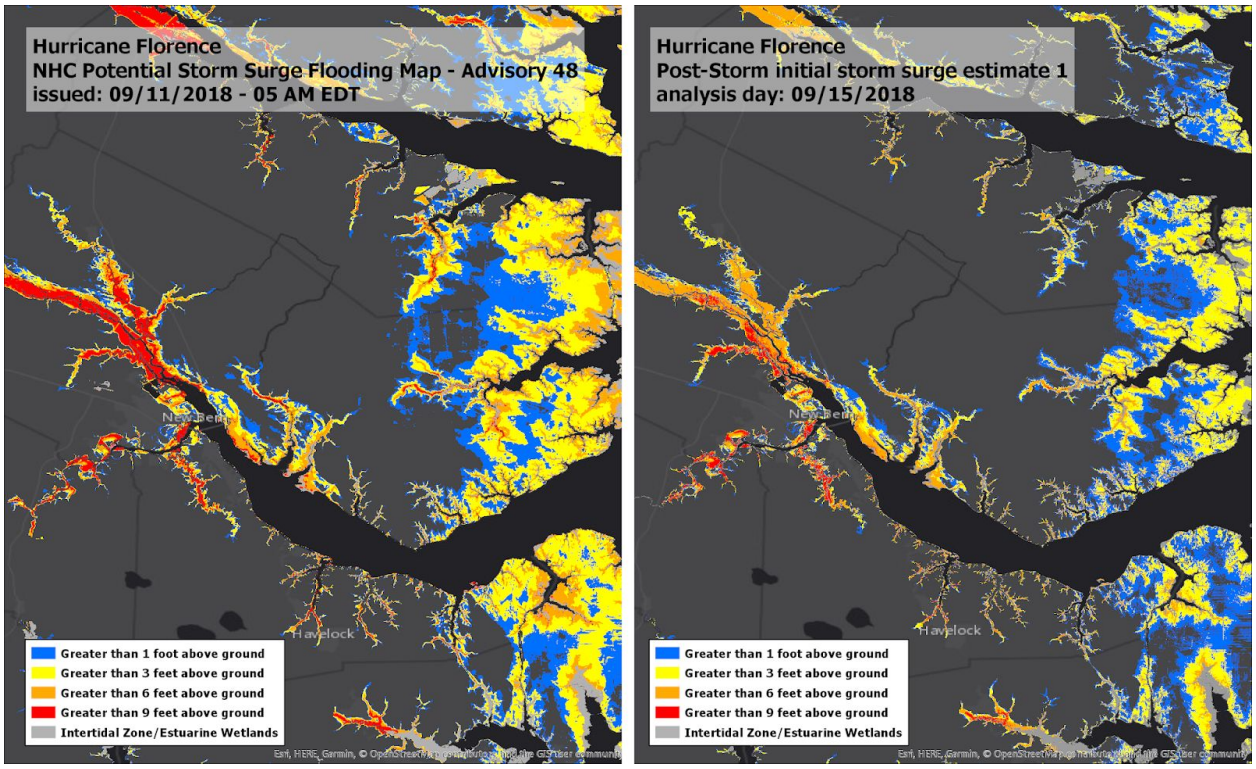


Figure 18: Example of NHC Potential Storm Surge Flooding Map from Hurricane Florence (left). The Potential Storm Surge Flooding Map was widely used by NWS partners for decision-making in both hurricanes. The graphic on the right shows the first initial storm surge estimate and indicates the accuracy of the storm surge forecast for Hurricane Florence. *Source: NHC Storm Surge Unit.*

Best Practice: NHC wind probability, time of arrival, and storm surge inundation forecast graphics were widely used by partners to make critical decisions.

Fact: Several partners voiced the desire for a "Time of Departure" of tropical storm force winds graphic. Several EMs and others were interested in a graphic that can highlight when the tropical storm force winds would cease or end. This graphic would aid emergency management operations to plan for recovery or relief efforts.

Fact: There is a standing AWIPS requirement for the “time of departure” data for WFO IDSS. NHC and WFO Miami submitted those requirements in response to a request from the NWS in the spring of 2018.

Finding 18: The NWS currently lacks a graphic that depicts the timing of when tropical storm force winds would cease.

Recommendation 18: The NWS should explore the development of a Time of Departure Wind Graphic. The graphic should be labeled clearly that it is not meant to depict an "all clear" to the public because other hazards may still exist.

3.1.4.2. Hurricane Threat and Impact (HTI) Graphics

Some federal core partners, as well as some national and local media partners stated they did not use the Hurricane Threat and Impact (HTI) graphics for decision making purposes; however, one state deep core partner did use the HTI graphic for planning purposes.

A meteorologist with the state of Florida said the NWS underutilizes the HTI graphics, and that they are not used enough in NWS briefings or in Facebook Live. This person also stated that the graphics “are only created in watch/warning situations.”

There were several issues with the HTI graphics during Hurricane Michael. The output from the graphics were inconsistent between WFOs.

There is a mandate that tropical offices issue HTI graphics when watches and warnings are in effect, which may result in sharp boundary issues across CWAs. There may be gaps in coverage once the NWS issues a state-wide HTI graphic; however, most planning decisions are made before watches and warnings are in effect.

Finally, there are examples of where a HTI graphic differed from messaging going out in other NWS products and services. For example: Okaloosa County (FL) stayed in the extreme wind category in the HTI graphical output for Hurricane Michael even though the deterministic wind forecast was only 35 to 40 mph.

The team did not receive much feedback on the HTI graphics from most core partners impacted by Hurricane Florence. Where the HTI was used by state level partners, inconsistencies were noted between WFOs on threat levels.

Staff at the South Carolina Emergency Management Division did provide positive feedback on the HTI graphics: "Critical decisions and actions often occur well in advance of the issuance of tropical weather watches and warnings in South Carolina. Due to the time it takes to evacuate our coast, the decision to evacuate is made up 72 hours prior to the onset of tropical storm force winds. Having the Hurricane Threat and Impact Graphics available in advance of watches and warnings would greatly assist us in conveying the potential threats to key decision makers in our state." However, currently the HTI graphics are generally not produced by the WFOs in advance of the tropical cyclone watches and warnings.

Finding 19: Feedback received from core federal partners and national and local media outlets was that they did not use the HTI graphics for decision making purposes. Those that did use the graphics highlighted several issues, namely: 1) difficult to find; 2) not generated early

enough for planning purposes; 3) contained information inconsistent between WFOs; 4) do not depict the timing of the hazard.

Recommendation 19: The NWS should consider absorbing the current HTI functionality into the newly developed graphical "enhanced" Hazardous Weather Outlook (eHWO). The eHWO affords a more consistent and seamless approach to spatially and temporally communicate wind, storm surge, tornado, and flood hazards expected in a five-day forecast period.

3.1.4.3. Rip Current Graphics

Rip currents are a deadly hazard. The NWS issues rip current risk forecasts and has built relationships with beach officials to spread this information. The NHC often will use verbiage in its products to convey areas along the coast that could experience rip currents because the rip current threat often extends well away from the tropical cyclone itself. WFOs serving the affected areas also message rip currents threats in forecast products and social media releases.

Those who look at the NWS output for hurricane information are not necessarily concerned with rip currents. However, people who may actually benefit from the rip current information would not think to look at NWS hurricane forecast information, particularly if they are outside the hurricane impact zone.

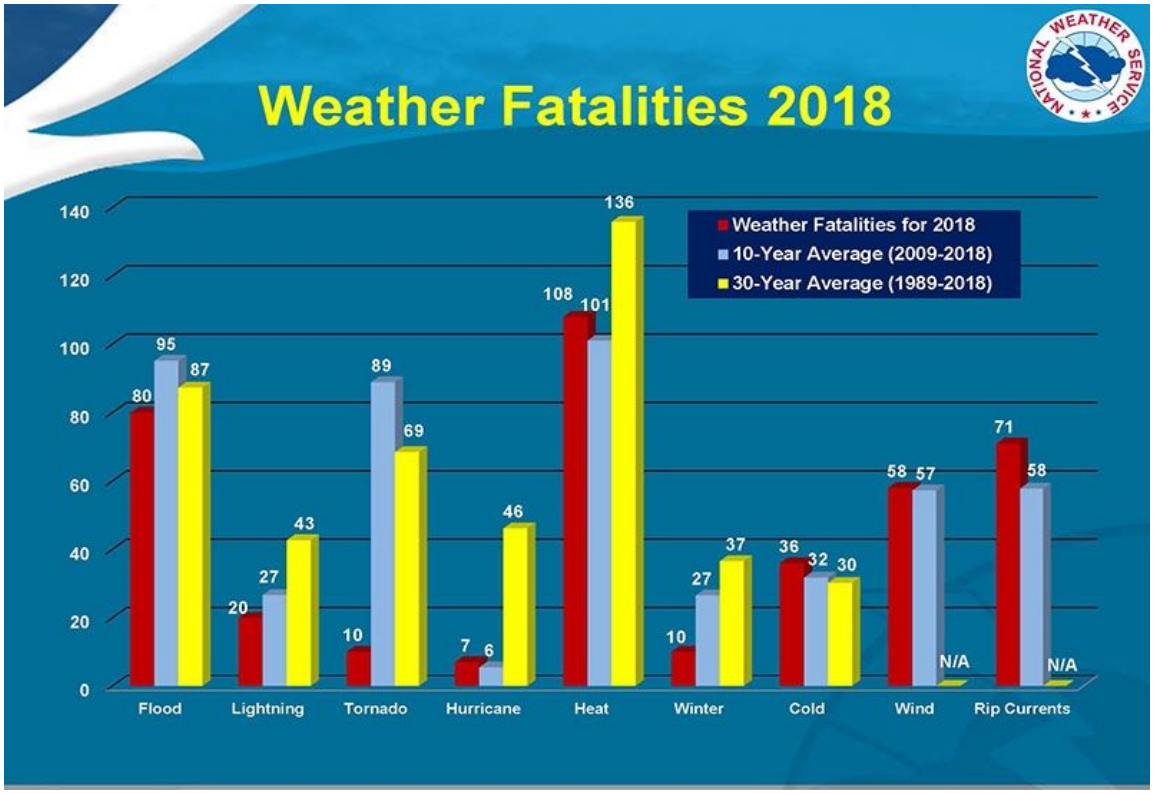


Figure 19: Top weather related fatalities in the U.S. in 2018. *Source: NWS.*

Fact: Rip currents are one of the largest sources of weather-related fatalities in the U.S. in coastal areas (**Figure 19**).

Fact: A prominent national media outlet highlighted the need for a national rip current graphic days 1 through 3. Per their feedback, this is a deadly hazard and requires a national depiction.

Fact: WFO Mobile produced a graphic in the days leading up to Hurricane Michael's landfall that depicted the increasing rip current threat several days in advance. This graphic was automatically produced when the forecast staff issued the routine Surf Zone Forecast (SRF) product, and was automatically posted on the WFO's webpage. This information was also shared on their social media sites (**Figure 20**).

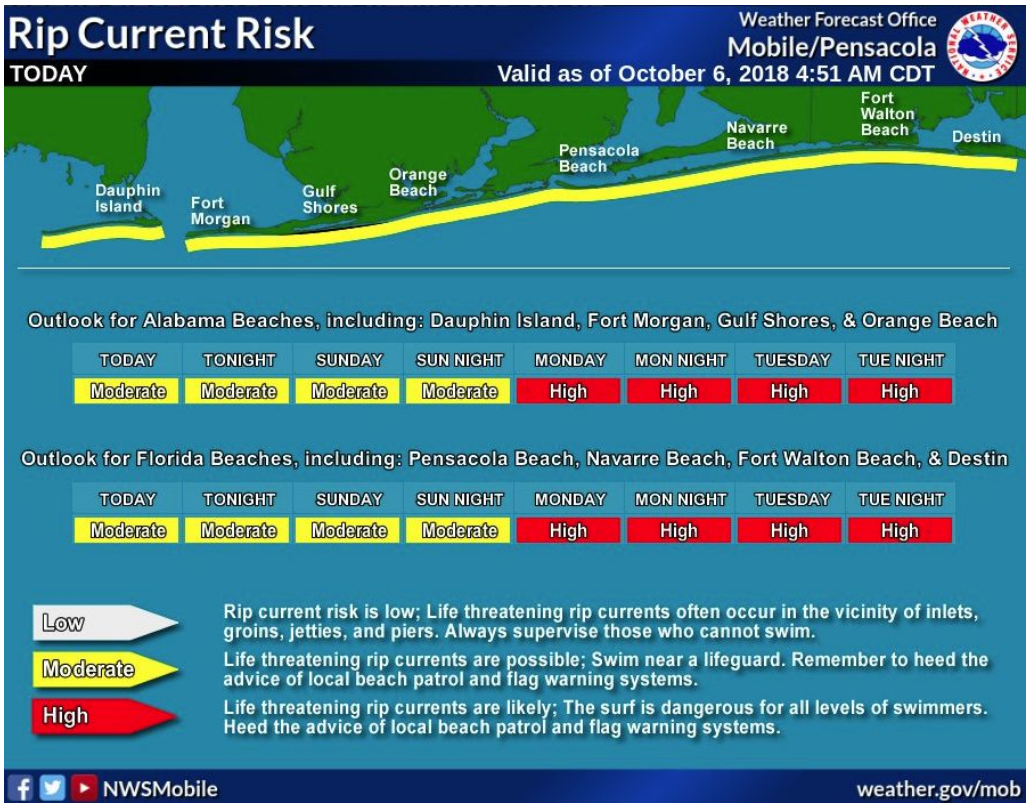


Figure 20: Image from NWS Mobile website depicting rip current risk from October 6, 2018. *Source: WFO Mobile.*

Fact: Each coastal WFO runs a version of the Nearshore Wave Prediction System (NWPS) configured for their local area on WCOSS. Only 10 WFOs currently have NWPS configurations capable of producing experimental rip current probabilistic guidance to support rip current forecasting. Of the 10 WFOs, only Tampa Bay and Miami provide rip current forecast guidance for Florida utilizing the NWPS configuration. This rip current guidance is available on the NWS Environmental Modeling Center (EMC) page (**Figure 21**). In addition to these offices, other

offices such as WFO Mobile are producing scientifically-based rip current forecasts for their core partners (**Figure 20**).

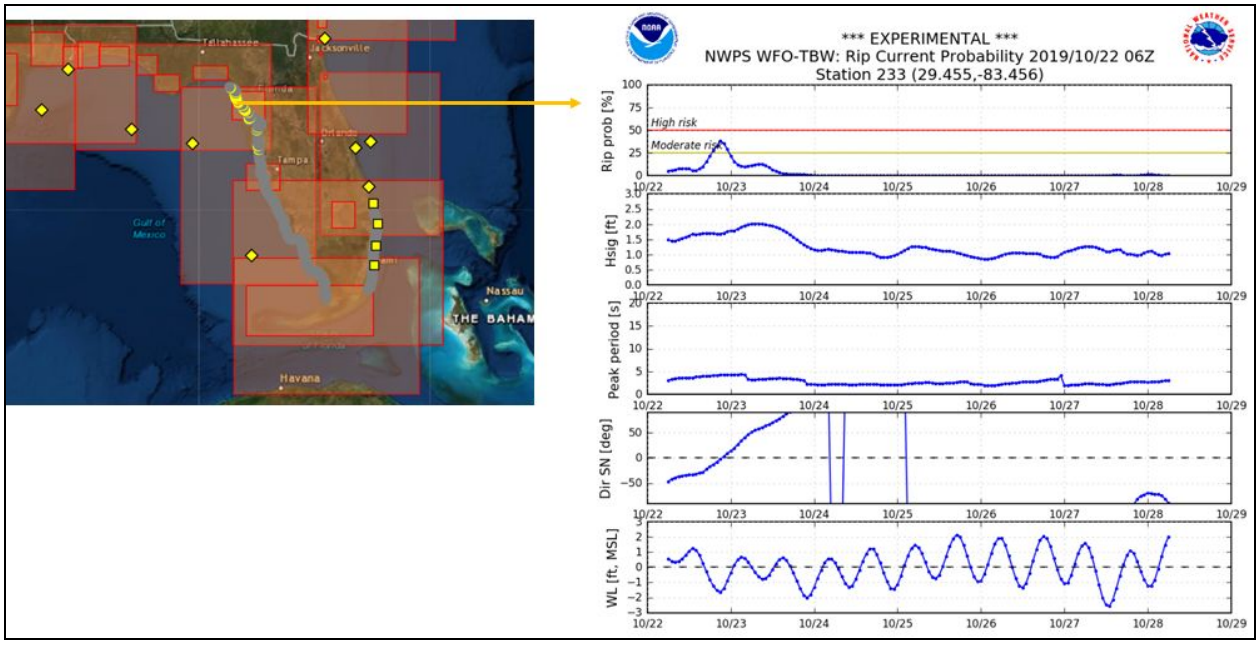


Figure 21: Left image shows the NCEP Environmental Modeling Center NWPS web viewer. Right image is the 7-day rip current forecast for Station 233 located in WFO Tampa's county warning area. *Source: NOAA NWPS webpage.*

Finding 20: The NWS lacks a coordinated/mosaic-style rip current risk/warning graphic that could be used to highlight areas along the coast, outside the potential impact zone, where life-threatening rip currents are expected.

Recommendation 20: The NWS should examine the current inventory of existing risk/warning rip current graphics and if needed reach out to other NOAA line offices and federal partners (e.g. USGS) to leverage their existing tools to develop a consistent product suite of surf zone risk information for at least a three day forecast period. This information can then be modified for graphical use by local and national media partners.

3.1.4.4. Creating State-wide Decision Support Information

Fact: GEMA and SCEMD specifically stressed the importance of having state-wide graphics in preparing for an event.

There is a challenge for WFOs that serve as state liaison offices to create decision support materials that coalesce forecast parameters and threat areas from several WFOs. For example, WFO Columbia is the state liaison office for South Carolina. In briefings at the state EOC, the WFO Columbia meteorologist was responsible for compiling products from their own

WFO, WFO Greenville/Spartanburg, SC, WFO Charleston,SC, and WFO Wilmington, NC into a single map for the state and the individual storm hazards associated with Florence and Michael.

Fact: SCEMD Staff: "We have Charleston, Wilmington, Columbia, and Greenville Spartanburg that all have to synchronize that picture that we are going to give to decision makers and the community for that life safety information. What Columbia has done for us has been huge in synthesizing this information and speaking with one voice."

Best Practice: WFO Atlanta created a website to create state-wide forecast graphics. This website allowed forecasters to see inconsistencies between offices for watches, warnings, and advisories across northern Georgia. Any inconsistencies were adjudicated by coordination with WFO Greenville/Spartanburg, SC, which resulted in consistency within WWA products and forecasts for Hurricane Michael (**Figure 22**).

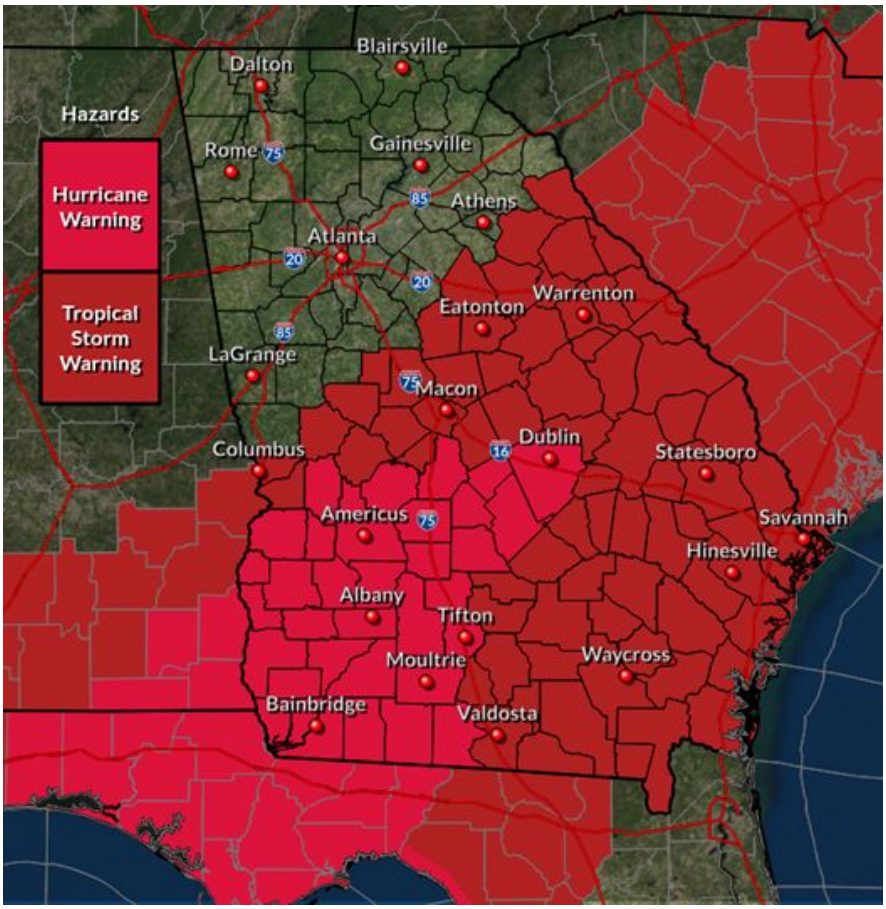


Figure 22: Example of statewide graphic created by WFO Atlanta and included in briefing for Hurricane Michael. *Source: WFO Atlanta.*

Fact: The Daily River and Lake Summaries (RVDs) issued by the North and South Carolina WFOs have different forecast periods, product sections, and boilerplate text.

Finding 21: There can be a lack of consistency for graphics, text products, watches, warnings, and advisories when part of the state is in different County Warning Areas (CWAs).

Recommendation 21a: The NWS should investigate existing tools (e.g. GraphiDSS) to develop an enterprise solution for a customizable tool that automates the production of state-wide forecast graphics at state-supporting WFOs, RFCs, and National Centers.

Recommendation 21b: There should be agreement across WFOs and RFCs on a common format for text products that have different formats between local offices.

Fact: GEMA, SCEMD, and the Georgia Forestry Commission requested the creation of post-event impact graphics from local WFOs on both a local and state level to aid them with post-storm response and recovery efforts. WFOs Atlanta and Columbia received requests from core partners for post-event impact graphics following Hurricanes Florence and/or Michael. Both WFOs created post-event graphics for these core partners which indicated the peak wind gusts and rainfall amounts (**Figure 23**).

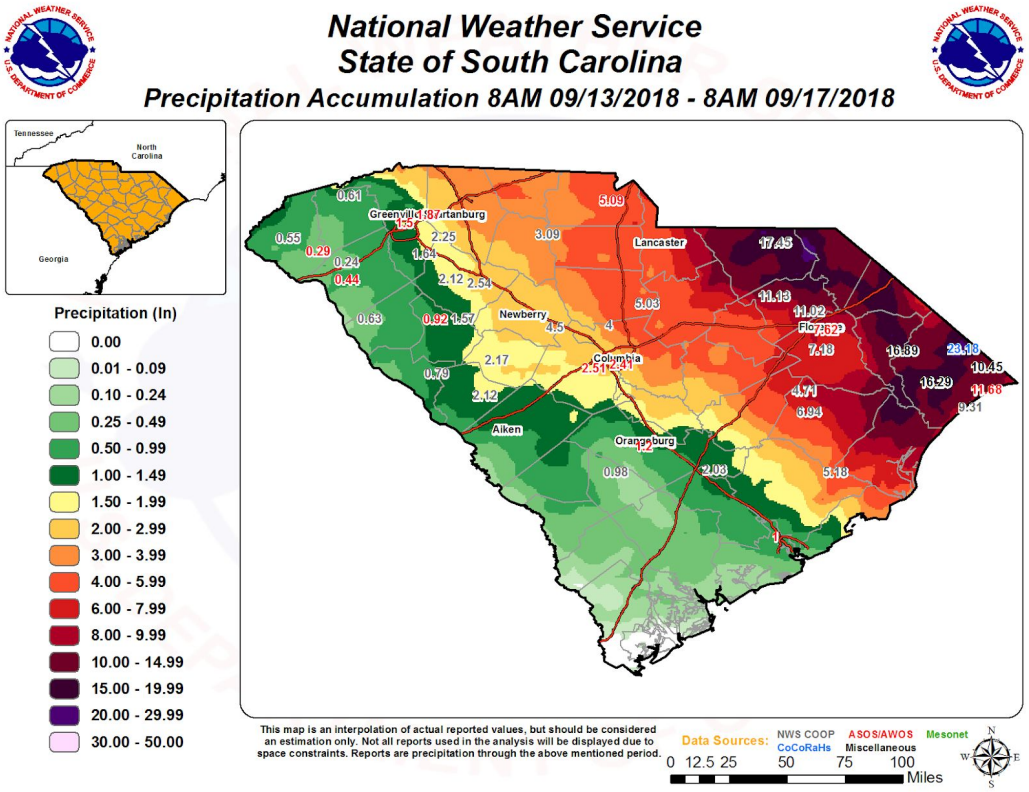


Figure 23: Example of statewide post-event graphic created by WFO Columbia after the impact of Hurricane Florence to support SCEMD for response and recovery purposes. *Source: WFO Columbia.*

Creating a state-wide post-event map and/or listing a summary of observations is a challenge. Partners, especially at the state/regional level, often require graphics depicting preliminary observed conditions (e.g. peak wind gusts, rainfall) after an event for response and immediate recovery efforts. These graphics can be difficult to generate given limited/inconsistent data sources and a lack of GIS expertise in some WFOs. In addition, these graphics are usually requested immediately post-event when staffing at a WFO is being used for post storm assessments and other activities.

Finding 22: Partners send requests to local WFOs to generate graphics depicting observed conditions (e.g., peak wind gusts, rainfall) after an event for response and recovery purposes. These graphics can be difficult to generate given limited/inconsistent data sources, a limited range of software to produce the graphics, and a lack of GIS expertise in some WFOs. In addition, these graphics are usually requested immediately post-event when staffing at a WFO is being used for post storm assessments and other activities.

Recommendation 22a: NWS should investigate methods for local offices to efficiently create summary graphics documenting storm impacts on local and state level scales for dissemination to core partners. These graphics should be coordinated with NWS national centers to ensure consistent messaging.

Recommendation 22b: Consolidate and publicize where real-time data (e.g., surge, wind) are available (e.g., other NOAA line offices and core partners such as USGS) so that partners can better plan re-entry or recovery activities.

Finding 23: Per feedback from NWSH, creation of post-event graphics of observed conditions could put local offices in the position of violating the COASTAL Act. The COASTAL Act is not well understood at the regional and field office level.

Recommendation 23: The NWS should provide guidance to local offices on what type of post-event graphics can be allowed under the COASTAL Act, with the understanding that the graphics being created by local offices are considered “preliminary”, and are being created to meet the immediate needs of core partners.

3.1.4.5. Tropical Cyclone Track Forecast Cone and Watch/Warning Graphic

Fact: The Tropical Cyclone Track Forecast Cone and Watch/Warning Graphic remains the most viewed NWS graphic in hurricane forecasting and messaging.

Fact: The initial wind field has been added to the Tropical Cyclone Track Forecast Cone and Watch/Warning Graphic to highlight the current range of impact with a storm.

Finding 24: The cone in the Tropical Cyclone Track Forecast Cone and Watch/Warning Graphic continues to be misinterpreted as a “cone of impact” by NWS core partners. Finding

and Recommendation 3 from the *October 2016 Hurricane Matthew Service Assessment* and Finding and Recommendation 41 from the *Hurricane Irene, August 21-30, 2011 Service Assessment* are relevant to this point.

Recommendation 24: As noted in the *October 2016 Hurricane Matthew Service Assessment*, NOAA and NWS should continue their examination of how users make decisions based upon the Tropical Cyclone Track Forecast Cone and Watch/Warning Graphic. Furthermore, the organizations should support adequate resourcing for projects involving the Tropical Cyclone Track Forecast Cone and Watch/Warning Graphic through the Hurricane Forecast Improvement Program.

Finding 25: The NHC Tropical Cyclone Track Forecast Cone and Watch/Warning Graphic can misrepresent the placement of coastal tropical cyclone watches and warnings (**Figure 24**). Feedback indicates this is likely a function of how the software code draws the delineation line(s) and its pre-defined thickness for the line(s).

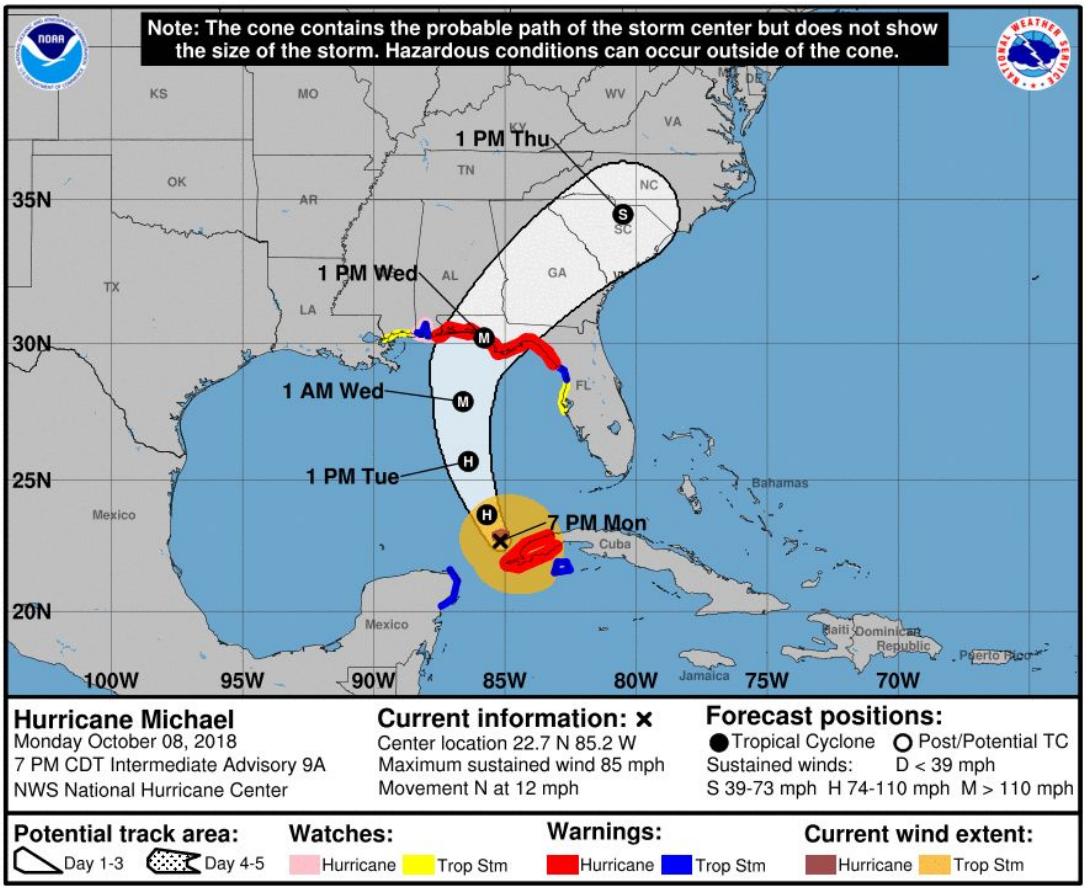


Figure 24: Tropical Cyclone Track Forecast Cone and Watch/Warning Graphic from 7 p.m. CDT Monday, October 8, 2018, showing hurricane warnings over parts of southern Alabama (Baldwin County coast), while warnings in the official NWS text products officially stopped at the Alabama/Florida state line. *Source: NHC.*

Recommendation 25: NHC should ensure its publicly disseminated Tropical Cyclone Track Forecast Cone and Watch/Warning Graphic includes correct placement of all tropical cyclone watches and warnings, including those for inland areas.

3.1.5. IDSS Tools

3.1.5.1. Facebook Live

NHC staff used Facebook Live for Hurricanes Florence and Michael to enhance its messaging.

Fact: During Florence, NHC staff generated 16 updates with Facebook Live, garnering a total of around 1.5 million views. The NHC Director and staff at WFO Raleigh relayed that media partners complimented the use of this platform during Hurricane Florence. These partners stated it was "more personal than anything they've gotten." One media outlet commented, "This is where I get my information. Thank you." A member of the public said "I saw a guy from NOAA in a Facebook Live video who was very very serious talking about the catastrophic damage expected." During Hurricane Michael, NHC provided 16 Facebook Live video updates which garnered more than one million views.

WFO Tallahassee was not an experimental office for Facebook Live, but requested and received quick approval from Southern Region Headquarters (SRH) the day before Hurricane Michael's landfall to use the platform.

The first Facebook Live post from WFO Tallahassee had over 12,000 views. A post from the middle of Tuesday night, right before landfall, had over 60,000 views (**Figure 25**). The WFO Tallahassee MIC stated, "we are convinced that this saved lives".

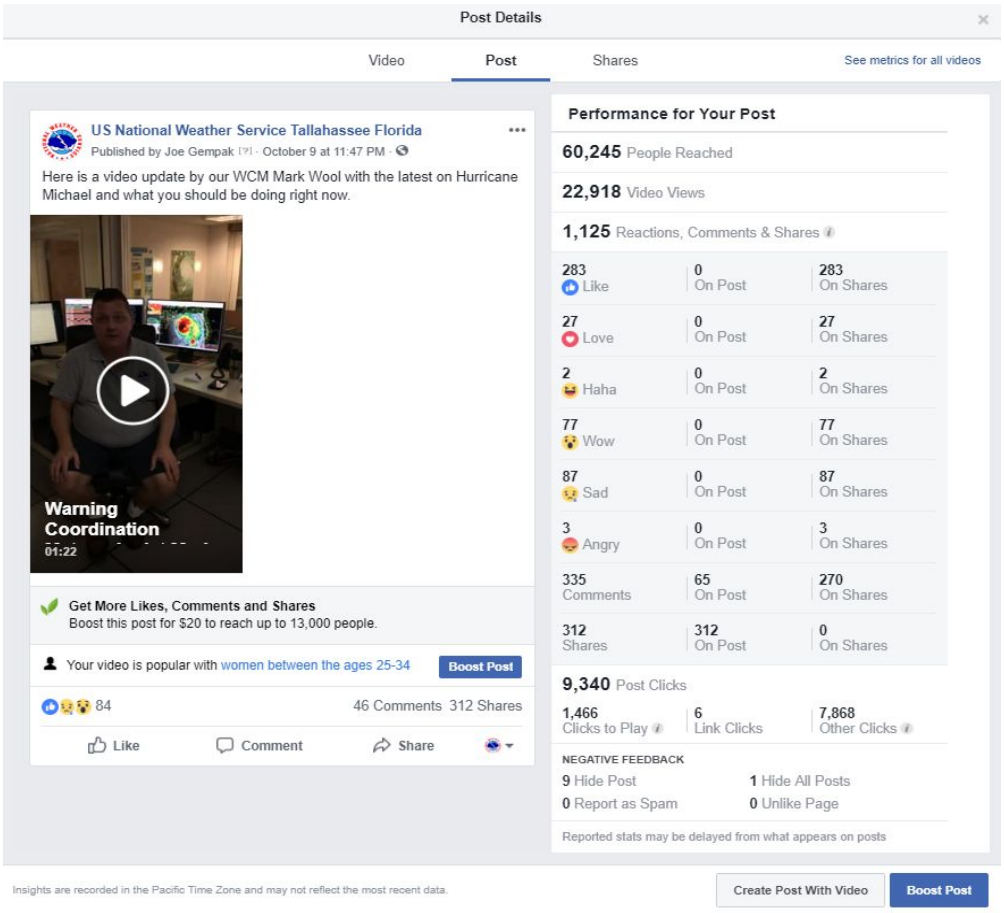


Figure 25: Facebook Live post from WFO Tallahassee at 11:47 p.m. on Tuesday, October 9, 2018, the night before Hurricane Michael's Landfall. The post reached more than 60,000 viewers. *Source: WFO Tallahassee.*

Finding 26: NHC, WFO Tallahassee, and WFO Raleigh made quick decisions to use Facebook Live during the hurricane(s), which greatly enhanced the reach of NWS messaging.

Recommendation 26: During a high-impact event, all offices should be able to use non-traditional platforms (e.g., Facebook Live) that reach the largest possible audience given the appropriate circumstances. Facebook Live and other similar platforms should move beyond experimental and be incorporated into the full suite of available tools a WFO or office can use to disseminate key communications.

3.1.5.2. Virtual Web-Hosting Conference Services

GoToMeeting and Join.me are examples of web-hosting services for online meetings and conferencing. They are widely used within the NWS to provide virtual briefings to core partners. These services are a key part of providing decision-makers with quick information

tailored to their areas. They provide opportunities for deep core partners to ask questions, typically at the end of the briefings, of NWS meteorologists.

Fact: Staff at WFO Atlanta found that its Join.me account and the use of a Southern Region GoToMeeting license for up to 500 attendees provided an insufficient number of slots for its partners to participate. As a result, WFO Atlanta had to prioritize which partners could join which prevented others from participating. At one point, the Georgia State Operations Center was locked out of webinars.

Fact: GoToMeeting does not have a dedicated web address for a webinar producer. Unlike assigned conference call lines and passcodes that do not change, WFOs have to send out new information for each webinar to participants. This increases the workload for already busy offices.

Fact: NWS Regions independently manage webinar capabilities (join.me/GoToMeeting) within authorized budgets. Current funding precludes at least some regions from providing offices with both an adequate operating budget (local travel, training, supplies) and regionally contracted webinar services that can support an unlimited number of participants.

Finding 27: One size does not fit all when it comes to virtual conferencing tools needed for NWS IDSS. Offices differ in the number of core partners they are briefing in high impact events.

Recommendation 27: NWS should incorporate scalable options for WFOs and RFCs to utilize during times of increased online briefing needs for core partners. Specifically, NWS should allow WFOs with a larger number of core partners to use more expansive licensing that allows for more participants based upon their IDSS needs.

3.1.5.3. NWSChat

NWSChat is a secure interactive web tool with which the weather enterprise and core partners can use to converse with NWS employees. The team received consistent feedback from local, regional, and national partners that NWSChat was a valuable tool that connected users with critical observation and forecast information. By using NWSChat on their tablets or on-set computers, TV meteorologists were able to share updates and storm reports from local WFOs as the information came into the chat rooms.

Best Practice: NWSChat was reported as a primary means for EMs and the media to receive timely information from the NWS. Local offices used NWSChat to request that partners emphasize certain critical messages about the storm.

3.1.6. Geospatial Data and Display Services

3.1.6.1. Data Visualization

Different states detailed how they used existing NOAA, inclusive of NWS, data services and visualization platforms. In North Carolina, emergency management officials used the National Digital Forecast Database webpage, WPC Geographic Information System (GIS) products, and the NWS Enhanced Data Display (EDD) to brief North Carolina state leadership. In Georgia, the state emergency management agency stated that using the NHC Potential Storm Surge Flooding Map geospatial web services provided through the IDP-hosted NOAA nowCOAST platform saved them valuable time ingesting and manipulating the data in its own system for ultimate use in decision making.

For Hurricanes Florence and Michael, the NWC demonstrated emerging capabilities to produce visualization products on an ad-hoc basis for partners. These NWC static products are not available on a data server or on a web portal where users can manipulate the data. The NWC must manually push these products to NWS field organizations and federal users.

Fact: NWS core partners use different NWS and NOAA tools to ingest and display NWS data fields that vary with their individual needs and preferences.

Fact: WFOs and RFCs use a variety of display platforms and tools to maintain situational awareness across their service areas of responsibility (e.g. IRIS is used heavily at Western Region WFOs but was not used by WFOs affected by Hurricanes Florence or Michael). At some WFOs during Hurricanes Florence and Michael, NOAA NowCOAST data services were used in combination with existing visualization systems, one being EDD, for situational awareness.

Users also noted that there were times that the data content, format, and system reliability were issues. Users such as Georgia Emergency Management Agency (GEMA) and Columbia University reported that some mapping services, such as storm surge inundation, consistently caused the map to either fail, or only very slowly load, or sometimes load without the nowCOAST layers. The nowCOAST team also received several email complaints from users describing slow response times. GEMA reported that nowCOAST performance issues inhibited its ability to get critical storm surge inundation information to incorporate into the decision making. In Hurricane Florence, the EDD site was not fully operational during parts of the Hurricane Florence response because it is still considered an experimental platform.

Fact: EDD was first approved for experimental use by the NWS in August 2013. EDD is currently in version 4.6.1 and is still considered experimental by the NWS. Due to it being experimental: if it goes down, it has a low priority for restoration.

Fact: NOAA NowCOAST is a NOS managed system hosted on NWS IDP infrastructure. NWS only has control over the reliability of the infrastructure nowCOAST sits on.

Fact: The NWS has two ongoing, nationally supported, GIS-related projects intended to address partner needs: RIDGE2 and National Viewer. The National Viewer will address the requirements which were validated in 2017 via CaRDS 16-037 and funded through the 2018 Hurricane Supplemental funding. Plans are for the water and tropical interfaces to be operational by the end of 2020.

Finding 28: NWS core partners expressed the need for a reliable visualization platform to display various parameters, such as radar data, watch/warning/advisory information, and current conditions. NWS core partners are utilizing GIS platforms such as EDD which are still considered experimental by the NWS after many years.

Recommendation 28: NWS should ensure NOAA and NWS data visualization platforms are robust, reliable, nationally-supported, and well advertised to partners. This will support partner data requirements to support a long term vision and pathway for NOAA data services and GIS capabilities.

3.1.6.2. Data Services

The NWS has many organizations that provide data sets in formats that can be imported directly into GIS, map viewers, or web pages. As previously noted, the states of North Carolina, Georgia, and Columbia University, among others, downloaded data to customize to their specific needs. Emerging operational capacities at NOAA facilities will develop new data sets that will need to reside in locations and formats that users can easily access. In Florence, the National Water Center served as one example.

Fact: NWC leadership stated: "During the course of NWC activities in Florence, supporting NWS staff deployed to FEMA Region 4 as well as coordination among federal agencies, it was clear the federal partners expect access to true geospatial data services. When asked where provisional products could be accessed from a RESTful endpoint, our answer was there isn't one. This really hampered coordination, in some cases the conversation stops! Our partners expect the ability to integrate multiple sources of inundation information into a common operating picture. They can't do this with static maps sent as PDFs or slides. We must quickly evolve our geospatial services in order to realize the full benefit investments in improved water resources predictions."

Fact: NWS Office of Dissemination is partnering with NWC on the national viewer and IDP GIS web services to transition their operational data to dissemination systems (cloud or IDP).

Finding 29: The lack of dissemination capabilities at the NWC will impact the NWC's ability to provide effective IDSS in the future.

Recommendation 29: The Office of Dissemination (DIS) should work with the Office of Water Prediction (OWP) to either leverage existing data services/portals or help the NWC create its own data service/web portal to allow partners to download raw data or output.

Fact: The weather.gov/gis site is where the NWS is making data services available currently by hosting on IDP. The NWS Office of Dissemination registers these data in the NOAA geoplatform.

Finding 30: A collection of overlapping or similar GIS or Geospatial data services exist within the NWS and NOAA. Some of these platforms and services are not well known throughout the NWS or by its partners. Various platforms (both regionally and nationally developed within NOAA and the NWS) were used by many NWS partners and NWS offices to support their individual decision support services.

Recommendation 30a: NWS should develop a vision for consolidating all of those services under one capability that provide the data for partners who have the resources to pull the raw data and display it on their platforms, as well as a visualization capability for those that do not have that capability.

Recommendation 30b: NOAA, inclusive of the NWS, needs additional hardware to handle increased user demand during high-impact weather events. NOAA should also investigate and explore the feasibility of migrating legacy and future data services and visualization capabilities to a commercial cloud infrastructure using open source software, thus allowing scalable solutions to meet user load, particularly during high-traffic events like land-falling hurricanes.

3.1.6.3. Damage Assessment Toolkit

Post-landfall information is helpful for damage assessments. WFO Tallahassee issued a polygon using the Damage Assessment Toolkit (DAT) for areas that received the strongest winds. This information was then used by federal and state partners, including over far inland areas where tree damage was extensive (**Figure 26**), to determine the potential impacts in the most heavily damaged areas with confidence knowing that it was coming from a trusted source.

Fact: The DAT was used by WFOs Tallahassee, Mobile, and Atlanta to depict areas that experienced the highest winds by drawing a polygon using Multi Radar Multi Sensor (MRMS) data. The DAT was later used for post-storm damage assessments to show actual observed damage by storm survey teams in the field.

Figure 26: Photo taken in the Florida Panhandle of tree damage from Hurricane Michael. Tree damage was widespread and extended hundreds of miles inland. *Source: Hurricane Michael Service Assessment Sub-Team.*

For example, the Georgia Forestry Commission (GFC) used the data to determine areas that it needed to survey and were able to refine wind estimates based on observed timber damage. Thanks to help from the DAT, GFC was able to rapidly deploy teams to the impact areas. GFC estimated there were over 37 million tons of timber (estimated to be worth over $700 million) lost in Georgia due to Hurricane Michael. The GFC was able to use this finding for justification for a state-issued $200 million tax credit assistance for landowners and additional emergency assistance for timber debris cleanup.

Best Practice: DAT was used by WFOs to expediently provide storm impacts and summaries following Hurricane Michael's impact, which were in turn further used by partners (e.g., GFC and Federal Emergency Management Agency (FEMA) Region 4) to calculate damages and losses, and to deploy assets appropriately.

Fact: Per NWSI Directive 10-1604, the DAT is a tool WFOs *should* use despite it not being deemed fully operational software by the NWS. The DAT is being used by offices in multiple NWS regions. Per the communities.geoplatform.gov site, the DAT has been "utilized experimentally since 2009 to assess damage following tornadoes and convective wind events."

Fact: The output of the DAT are files that go to external partners such as FEMA. From NWSI Directive 10-1604: "the DAT fulfills a core partner (e.g., emergency managers) requirement to geospatially share wind damage impacts during the operational response and recovery."

Fact: NCO is now beginning to provide some support for the DAT, and eventually the program will be hosted on a central server. Improvements will still be made by the Science and Operations Officer at WFO Tallahassee and staff at SRH.

Fact: The capability of DAT to be used for flood events is currently being field tested.

Finding 31: The DAT is an essential tool for WFOs to document impacts from hazardous weather events and share these with NWS core partners.

Recommendation 31a: The DAT should become an official tool, with appropriate funding, that WFOs may use to document damage from hazardous weather events, and as such should receive national support.

Recommendation 31b: The DAT, and its associated editor and viewer platforms, should be expanded to document storm surge, flooding, and tropical wind damage.

3.1.7. NWS Products and Wording

3.1.7.1. Use of "Catastrophic" or "Emergency" Wording

Wording for several recent hurricanes has taken on the descriptor "catastrophic." The team received mixed feedback about this terminology. Verbiage such as "dangerous" and "life-threatening" is important for certain impacts, but sometimes not appropriate for effects on the edges of storms. For example: storm surge forecasts for the Charleston, SC area for Hurricane Florence were for one to two feet which is often considered minor flooding.

Fact: In a meeting with media and EMs, the Florence team heard some confusion regarding the difference between "catastrophic" and "substantial." The use of the word "catastrophic" by the Raleigh WFO was deemed a "best practice" by one EM. Stakeholders in South Carolina remarked that if you always say everything is life threatening and say everything is catastrophic then the public will not know when this is actually true.

Fact: At least one EM in WFO Raleigh's CWA stated he/she did not want the office to use the term "flash flood emergency" in the Flash Flood Warning.

Finding 32: Partners interpreted the language describing threat impacts differently.

Recommendation 32a: The NWS, in concert with core partners and social scientists, should develop standard language to describe the impacts of storms. This language should allow for a gradation, or a range of language, for storm impacts based on level of effect in warnings other than a blanket term category for the entire storm.

Recommendation 32b: WFOs should use existing communications resources, such as social media and NWSChat to core partners, to let them know what the term "flash flood emergency" means when it is included in a warning. WFOs can refer to NWS Directive 10-922 (sections 5.3.4 and 6.3.4) for the criteria for flash flood emergency.

Recommendation 32c: WFOs should include education regarding the use of flash flood emergency in partner training such as IWT meetings, tabletop exercises, etc.

3.1.7.2. Hurricane Local Statement Product

Media partners from WFO Mobile's area stated that they use the Hurricane Local Statement (HLS) text product but only review the "situation overview" section. EMs from two counties in the Florida panhandle indicated that they use the HLS for decision making (Santa Rosa and Escambia Counties, FL); however, a representative with the Alabama State EMA Office stated that he found the HLS "totally useless," and that it was not the best tool for getting impact information. This feedback was similar to that reported in the *August/September 2017 Hurricane Harvey Service Assessment*. Finding and recommendation 2 of that assessment is pertinent to the findings and recommendations of this service assessment.

Fact: One television station partner from Morehead City, NC lost all studio and graphics capabilities during Hurricane Florence. They reported that WFO Morehead City information from their two-time a day briefing graphics were critical to their messaging.

Finding 33: The majority of the partners, including the media, did not use the HLS in their decision-making process.

Recommendation 33: The NWS should work in concert with social science partners to determine whether/how the HLS and the corollary TCV products are being used and whether they should be improved or terminated.

Finding 34: The Hurricane Florence team found that webinars, briefing packets, and emails were used most by EMs and media for decision making. Legacy NWS text products appeared to be secondary in use for decision making for many partners. Core partners noted that briefings started well ahead of landfall. EMs distributed briefing packets via their social media accounts.

Recommendation 34: NWS needs to reassess its suite of legacy text products and determine which products are still important and which should be discontinued. Identifying unnecessary

products allows more time to focus on widely used and disseminated webinars, briefing packets, and e-mail.

3.1.8. Saffir-Simpson Hurricane Wind Scale (SSHWS)

The SSHWS is used to categorize the strength of a hurricane's wind field and is particularly focused on damage to structures using a combination of engineering and meteorology.

Intensity categorization is based on the highest sustained wind *anywhere* within the system, not necessarily representing the broad impact of the storm. This fact is particularly true for areas outside of the eyewall and can lead to a belief that lower category hurricanes are not much to worry about.

The SSHWS garners significant focus from the media and the public. Yet, the scale fails to address what are often the most deadly aspects of tropical cyclones. According to a 2014 study appearing in the Bulletin of the American Meteorological Society[2] study roughly 90 percent of tropical cyclone fatalities from 1970-1999 "occurred in water-related incidents, most by drowning."

The *Hurricane Irene, August 21-30* service assessment identified the same issue that occurred in Florence where NHC used the term "weakening" to describe changes in the storm's intensity based on the SSHWS despite the existence of significant non-wind related threats. Recommendation 45 of that service assessment remains valid for this service assessment.

Fact: Hurricane Florence was rated a Category 4 storm and eventually "weakened" to a Category 1 storm prior to landfall. While the wind intensity diminished, the risk of devastating flooding, the primary threat, did not diminish similarly to wind. The media repeatedly used the term "weakened to..." keying into the SSHWS even though NHC and WFO forecasters tried to divert attention away from the scale with their messaging in most products.

Fact: Headlines in most NHC advisories focused on the life-threatening storm surge and rainfall expected with Florence, but there were two Public Advisories (advisories 54a and 55) where the wording of "weakening" was used in the headline of the advisories to describe the evolution of storm intensity (**Figure 27**).

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[2]Rappaport, E.N. (2014) Fatalities in the United States from Atlantic Tropical Cyclones: New Data and Interpretation. *Bull. American Meteorological Society* Vol 95, No. 3 Online publication date: 1-Mar-2014. DOI: 10.1175/BAMS-D-12-00074.1.

...FLORENCE WEAKENS A LITTLE MORE...
...LIFE-THREATENING STORM SURGE AND RAINFALL STILL EXPECTED...

Figure 27: Headline from NHC Hurricane Florence Public Advisory Number 55, issued 1100 p.m. EDT September 12, 2018. *Source: NHC.*

Fact: NHC products during Florence referenced the SSHWS almost exclusively when the storm was well offshore and increasing in category or was especially strong (e.g., category 3 or 4), but almost never referenced the scale while the storm was at lower categories (e.g. Category 1 or 2). Of the 17 NHC advisories issued when Florence was defined as a Category 1 storm, none of the respective advisories made reference to the SSHWS. When Florence was a Category 2 storm, only two of the 22 advisories mentioned the category with one of the advisories highlighting that the storm was increasing from Category 1 to a Category 2 intensity. In contrast, all eight advisories when Florence was a Category 3 storm and all 15 advisories when Florence was at Category 4 intensity mentioned the respective SSHWS concurrent category.

Best Practice: There are several examples where NHC and local forecast offices focused messaging on storm hazards and expected impacts. This messaging was evident in several IDSS deliverables and HLS headlines from local offices, WPC social media, and with NHC's "Key Messages" which were prominently displayed on its website and integrated into messaging at all levels of the agency (**Figures 28** and **29**).

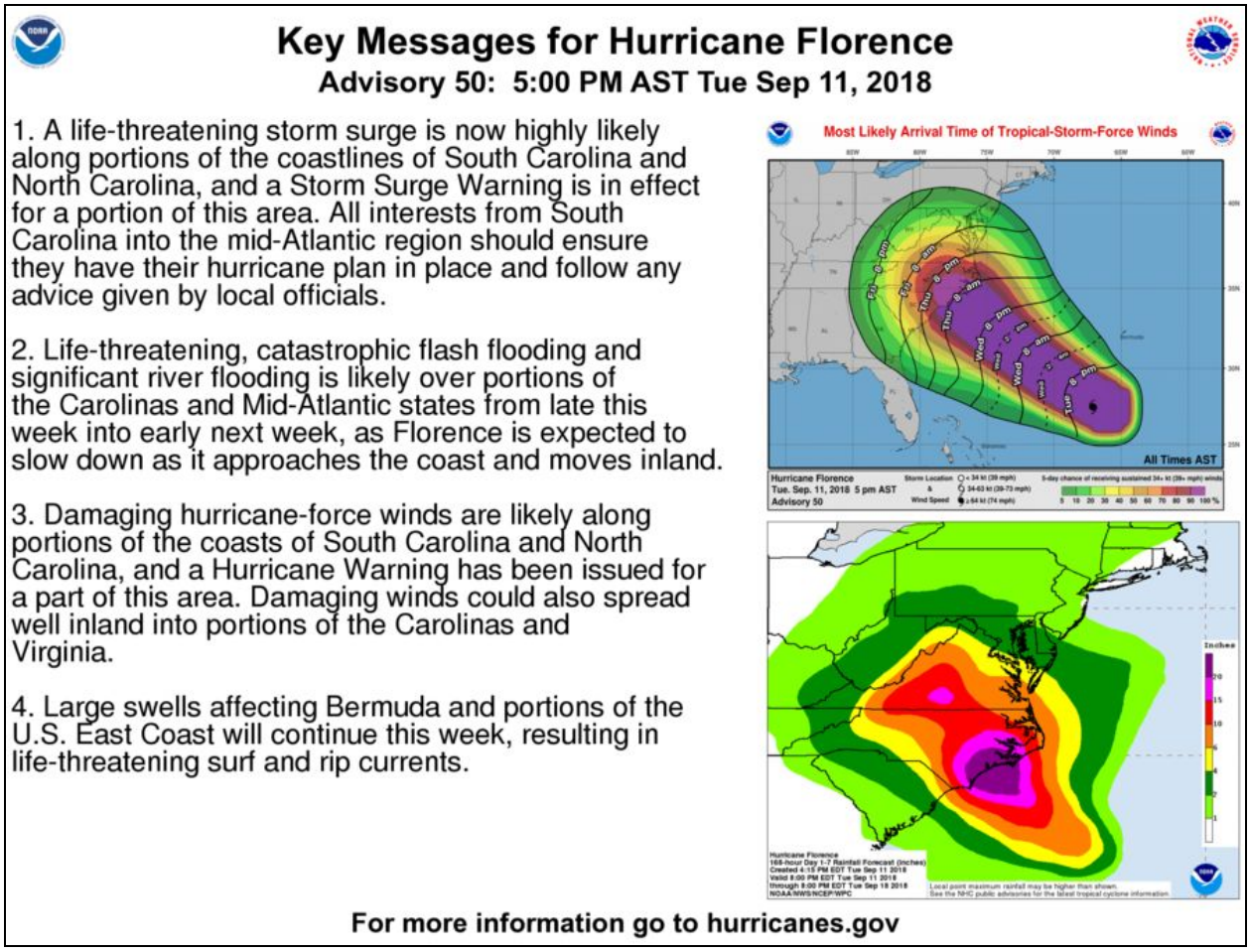

Figure 28: Key Messages for Hurricane Florence issued by the NHC at 5 a.m. AST/EDT September 11, 2018. *Source: NHC.*

DANGEROUS HURRICANE FLORENCE IS BRINGING LIFE-THREATENING STORM SURGE AND POTENTIALLY HISTORIC RAINFALL WITH CATASTROPHIC FLOODING TO PORTIONS OF EASTERN NORTH CAROLINA

Figure 29: Hurricane Florence headline issued by the NHC at 2:07 a.m. EDT Friday, September 14, 2018. *Source: NHC.*

Fact: The following are direct quotes from NWS core partners following Hurricane Florence regarding the SSHWS:

- "The Saffir-Simpson Scale let us down."
- "Need to do away with it, tell me how bad the impacts will be."
- "People relaxed when the storm weakened."
- In particular, one local television station chief meteorologist in North Carolina said, "Please stop (emphasis added) using [the Saffir-Simpson scale] altogether."

Finding 35: Several officials stated the SSHWS negatively impacted the Hurricane Florence flood messaging when the storm was downgraded in wind intensity. Many partners also noted that the change in storm category likely impacted some people's decision not to evacuate.

Recommendation 35a: The NWS should establish a multi disciplinary working group of scientists to investigate the advantages and disadvantages of the SSHWS as it pertains to multi-threat impact-based decision support services to set a foundation for an organizational discussion on the use of intensity scales in hurricane messaging.

Recommendation 35b: Work with the tropical training program to emphasize messaging the impacts from each unique storm, and downplay the SSHWS.

Recommendation 35c: Develop an outreach effort that targets media, EMs, and the public to focus on the holistic hazard potential of tropical cyclones, and de-emphasize the SSHWS. This outreach effort should particularly focus upon news producers and directors, not just those tied to the production of weather segments.

Recommendation 35d: NWS needs to evaluate the impact of using descriptive terms for storm trends (e.g. weakening) that may lead to conflicting perceptions of risk due to the overall threat level.

Finding 36: Core partners requested more information regarding potential tropical cyclone intensity at landfall; they specifically requested an additional forecast point at landfall.

Recommendation 36: The NHC should explore developing probabilistic landfall intensity information.

3.2. NWS Mutual Aid

3.2.1. MAS Team

The Multimedia Assistance in Spanish (MAS) team includes Spanish-speaking employees from throughout the NWS. The team began in 2017 at the regional level in the NWS Southern Region and expanded its role by providing Spanish language interviews during the 2017 hurricane season. The services provided by the MAS team was identified as a best practice in the *August/September 2017 Hurricane Harvey Service Assessment.*

This team played a huge role during Hurricanes Florence and Michael. During Hurricane Florence, members of the MAS team conducted 104 Spanish language media interviews from September 10 through 15, 2018. The team became “overwhelmed” by the demand for interviews and changed their plan for Hurricane Michael by fielding one interview at a time. Spanish interviews are nearly always requested during any hurricane event. At WFO Miami

alone, five meteorologists conducted Spanish interviews. Many of the Spanish networks headquartered in Miami conducted interviews on site (e.g., Telemundo, CNN Español, and Univision).

The MAS team was primarily focused on media interviews during Hurricanes Florence and Michael; however, the team was also responsible for helping local NWS offices and NHC to develop Spanish language social media posts (**Figure 30**). WFO San Juan staff translated the NHC "Key Messages" into Spanish. The MAS team will be asked to provide backup to WFO San Juan for the translation of the key messages for any storms in 2020.

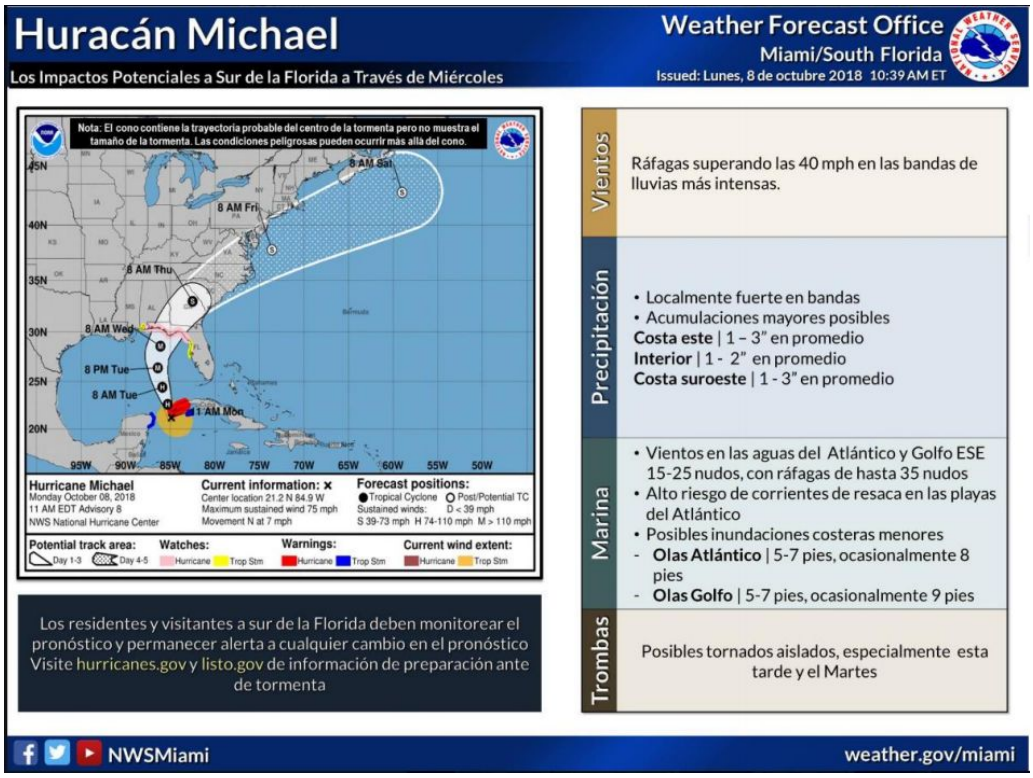

Figure 30: Spanish language social media post created by MAS team to aid WFO Miami during Hurricane Michael. *Source: NWS MAS Team.*

Fact: Feedback from the Director of Public Works in Knightdale, NC: *"The Spanish summaries/updates that you [NWS] provided with the hurricanes were very helpful for our Public Information Officer."*

In recent months, the team has expanded its scope to help translate WEA messages for the NWS. This effort has been commended by the NWS Office of the Chief Operating Officer (OCOO). The team is also expanding its scope to provide translations to NWS text products in Spanish. The MAS team hopes to translate NWS text products in the future.

Currently the NWS has two Spanish teams: the MAS team and also the NWS Spanish Outreach team, which translates outreach and preparedness material, websites, pamphlets, large documents or fact sheets. These teams are volunteer-based. Creating a Program Leader position at NWSH would aid in increasing support for these teams and coordinating their efforts. Additionally, dedicated resources (e.g., either federal employees or contractors) would enable translations more quickly and would also help ensure a consistent and minimum level of capability exists versus the current volunteer method. The Program Leader would ensure the long term sustainability of the MAS program.

Best Practice: The NWS MAS team proved vital in aiding the NWS with Spanish language social media translations and media interviews during Hurricanes Florence and Michael.

Fact: During Hurricane Florence WFO Raleigh said Spanish-language social media posts were well-received, but took longer than expected to translate.

Fact: The MAS Team is covered in some areas of NWS training such as the Effective Hurricane Messaging (EHM) course.

Fact: The MAS Team was approved by the NWS Mission Delivery Council to expand to all regions in 2018.

Finding 37: The MAS team was underutilized in Hurricane Florence.

Recommendation 37a: The NWS should establish a Program Leader at NWSH to formalize and coordinate Spanish-language services. This Program Leader would coordinate Spanish translation services and other relevant services.

Recommendation 37b: The skills and services of the MAS team should be more thoroughly marketed throughout the NWS and regularly used by the agency, particularly for major events.

3.2.2. SAVI Team

The NWS Supplemental Assistance Volunteer Initiative (SAVI) Team is an agency-wide group of volunteers that can aid offices in data mining social media posts during major events.

SAVI was activated three days ahead of Hurricane Michael to help WFO Tallahassee with social media support. The team uses a dedicated NWSChat room in which the SAVI volunteers talked with meteorologists and hydrologists at the office they are supporting. The SAVI team focused on identifying critical comments and data WFO Tallahassee staff needed to see. WFO Mobile provided a lot of social media support for WFO Tallahassee. NOAA leadership provided a commendation for WFO Mobile following Hurricane Michael.

Feedback from WFO Tallahassee stated the information flow during Hurricane Michael was rapid, and it was helpful to receive SAVI reports, even if they were from accounts the office normally followed and monitored. The SAVI reports might have been a slight duplication of the WFO staff's efforts; however, the information flow was so rapid (including the need to get information out), it proved helpful to review these messages again. WFO Tallahassee received several reports from the SAVI team that would have otherwise been missed.

Best Practice: The NWS SAVI team proved vital in aiding WFO Tallahassee with social media efforts during Hurricane Michael.

Fact: The NWS MDC reviewed and approved the expansion of SAVI across all NWS regions in 2018.

Finding 38: SAVI was utilized significantly during Hurricane Michael, but not during Hurricane Florence.

Recommendation 38: The SAVI program should be used by NWS WFOs during major events. The program should be more thoroughly marketed throughout the agency with the assistance of the NWS regional offices.

3.2.3. Storm Surge Surveys

Post-event surveys of storm surge are regularly conducted following major hurricanes to determine the extent of impact of storm surge and to help provide verification of hurricane storm surge water level forecasts, as mandated by the Coastal Act.

The NWS has a long history of working closely with USGS and other agencies on storm surge forecasting and post-event surveying, dating back to the 1980s. FEMA, and for much of the period, the USACE, have helped fund NWS storm surge efforts over that period. For operations, this coordination begins pre-storm, when the NHC SSU helps USGS decide where to place sensors and also where to deploy staff after the storm.

The NHC provides a high resolution "hindcast" of storm surge impacts on an ad hoc basis to aid USGS; this hindcast was completed following both Hurricanes Florence and Michael. NHC received feedback from the USGS that this coordination was beneficial because it helps survey teams in the field better coordinate and identify areas upon which to focus.

Recognizing its limitations in storm surge survey expertise, the NWS reached out to NOS through the NOAA Regional Collaboration Team several days prior to Hurricane Michael for help with post-event storm surge surveys. Staff from the USGS, Harris County (TX) Flood Control District, and the NOS/Center for Operational Oceanographic Products and Services (CO-OPS) Gulf Coast team were selected to conduct storm surge surveys following Hurricane Michael.

The assessment team learned that an interagency collaborative process for conducting storm surge surveys is continuing for this hurricane season. Staff from NWS, NOS, and the USGS met in August 2019 to discuss protocols for high-water mark surveys associated with storm surge and inland flooding.

Best Practice: The NHC SSU provides a "hindcast" of storm surge impacts to aid NWS core partners with post-event surveys and recovery activities.

Finding 39: The USGS and core partners shared expertise and assisted the NWS in conducting post-event storm surge surveys following Hurricane Michael.

Recommendation 39a: The NWS should continue to leverage relationships with NWS core partners, other NOAA line offices such as NOS, USGS, and private entities who have expertise in surveying water levels, in conducting post-event storm surge surveys.

Recommendation 39b: The NWS should follow the guidance provided in the USGS report, *Identifying and Preserving High-Water Mark Data,* by Koenig and others (2016). This will help to ensure consistency in identifying high-water marks and assigning vertical accuracy.

3.2.4. Deployment of Hydrology Subject Matter Experts

There are many examples of the deployment of hydrology subject matter experts during Hurricane Florence. The NWS deployed the Warning Coordination Meteorologist (former SH) from WFO Boulder to WFO Raleigh to provide support. WFO Raleigh found the deployed hydrologist was extremely helpful answering questions on river flooding and assisting with IDSS efforts. The NWS also deployed several individuals from SRH to FEMA Region 4 to work with the FEMA Hurricane Specialist. The Senior Service Hydrologist (SSH) from WFO Cleveland was deployed to WFO Morehead City. The SSH at WFO Cleveland also worked with WFO Wakefield once they assumed backup responsibility for Morehead City. These deployments were described to the service assessment team as being extremely helpful.

Best Practice: Deploying hydrology subject matter experts to either local NWS WFOs or to core partners in potential hurricane flooding areas is very useful.

3.2.5. RFC Support to Local Offices and Partners

Horry County, SC, received offsite hydrological modeling support from a staff member of the Ohio RFC (OHRFC) for nine to ten days. This support was due to a relationship built during an onsite deployment during Matthew. Horry County had lots of praise for this employee's work. OHRFC staff used the Hydrologic Engineering Center - Reservoir System Simulation (HEC-RAS) model provided by Horry County.

Prior to Hurricane Florence, Southeast RFC (SERFC) staff identified areas where they thought they would need help should the storm evolve as it did. The Southern Region Hydrologic Services Branch put together a group of Subject Matter Experts (SME) to help SERFC in the case of dam or levee failures. The Development and Operations Hydrologist (DOH) of the OHRFC helped with hydraulic modeling for coastal rivers. Both these actions were noted as a best practice by SERFC.

Hydrology staff at SRH contacted SERFC to find out what its potential needs would be to support dam break situations, levee breaches, and hydraulic modeling requests requiring the use of HEC-RAS. There were at least two conference calls to develop the deployment/support pool that resulted in the OHRFC helping with the Horry County modeling request for IDSS.

Finding 40: The remote support provided by staff at OHRFC is a good example of how the NWS can best leverage expertise across NWS regions to better serve a local core partner and support major events.

Recommendation 40: OWP, collaboratively with NWS Regions and RFCs, should maintain a cadre of SMEs with modeling and interpretive expertise for dam break and levee breach situations. Adequate training and material resources should be allocated for the SMEs to maintain operational proficiency and deployment readiness status.

3.2.6. Surge Staffing for Major Events

Several offices in the path of the hurricanes used deployed staff. Many of the deployed staff had past experience with tropical weather and/or the geographic areas to which they were being deployed. On an ad hoc basis (when tropical weather develops), many NWS RHs will conduct calls to identify staff who have prior tropical experience or have worked in the office previously.

Best Practice: SRH works to develop a deployment pool that covers multiple regions to leverage resources nationwide. Per SRH feedback: “Incident Command System (ICS) principles are being followed in Southern Region regarding deployment of resources to offices for mutual aid or IDSS. Local office assesses their support needs and resources. In particular, a key component is the role to be fulfilled - in-office product generation (grid editing, etc) or deployment to provide IDSS. If offices exceed their local capability to support, then they contact region (either through a defined email address, the ROC, or call someone on the phone) to request assistance. SRH evaluates all requests and prioritizes following the RD’s or Incident Commanders guidelines. Note - the RD has the ultimate responsibility to authorize expenditures. We search within the region for people to deploy. We will reach outside of the region (i.e. go national) for resources if necessary. This includes financial approval from AFS or qualified personnel from other regions.”

3.3. Fully Integrated Field Structure

3.3.1. NWS Coordination and Messaging

The majority of the NWS core partners interviewed indicated they had received a consistent NWS message they could use to make decisions and communicate to their constituents. Any inconsistencies in messaging and collaboration were isolated.

There were multiple examples of smooth internal coordination between local offices, RHs, ROCs, and National Centers (e.g., WPC and NHC), and NWSOC.

NHC staff reported that the interaction between NHC and the local offices during Hurricanes Florence and Michael was "the best it's ever been." The NHC has strengthened relationships with WFOs and RFCs in the last several years through the EHM course and dedicated NWS field office visits.

3.3.1.1. Messaging Tropical Threats in the Medium to Long Range

Despite the accurate track forecasts, there was a perception from some core NWS national and state level partners (including FEMA and FDEM) of an information void related to Hurricane Michael leading into the holiday weekend. The shorter lead-time made preparations more difficult.

Many local WFOs have evolved into impact-based messaging, and in tropical situations might begin IDSS messaging seven or eight days before landfall. NCEP provides guidance at the medium range through the Tropical Weather Outlook (TWO) and through the medium range conference calls. Forecasters at local NWS offices will begin communicating with core partners at this time range, but the messaging is not necessarily tied to explicit thresholds laid out in NCEP guidance. In fact, the medium range conference call is primarily used to discuss the track forecast and is rarely used to discuss messaging to core partners. The below describes the timeline for messaging in advance of Hurricane Michael. For further examples on this issue for Hurricane Florence, where WFOs were also working to provide core partners ample advanced notice of potential impacts, see **Appendix C**.

Date: Thu, Oct 4, 2018 at 3:22 PM
Subject: Potential Tropical System in Gulf of Mexico Middle to Late Part of Next Week

Good Afternoon,

I'm sure all of you have been following the potential for development of the disturbed area of weather that is currently down in the western Caribbean Sea. Here is what we know as of late this afternoon.

Most of our weather models have been slowly coming into better agreement that this disturbance may develop into a more organized tropical system over the next 5 to 7 days, and possibly move north into the central Gulf of Mexico by mid week. The National Hurricane Center now gives the system a 40 percent chance of development over the next 5 days.

While models do show a trend toward development of this system, there is still quite a bit of uncertainty with regard as to speed and direction of movement of the system, and as to what the intensity of the system will be. As we move into the middle part of next week, this system will likely need to be monitored for local impacts, but for now due to the uncertainties mentioned above it is still far too early to begin talking about any specifics.

The primary point we want to make at this time is that this system poses no local threat over the upcoming holiday weekend. Any potential impact or threats would not present themselves until the middle to late part of next week.

If you have any questions or concerns please contact us at *xxx-xxx-xxxx*.

Figure 31: WFO Mobile email briefing to partners from Thursday, October 4, 2018. *Source: WFO Mobile*.

Fact: On Thursday, October 4, WFO Mobile began sending formal briefings in email format on the potential system to core partners (**Figure 31**). SRH began calls with local WFO management on office preparedness. Broadcast meteorologists in Panama City, FL contacted station managers, which initiated storm coverage, staffing and backup planning. From the WFO Mobile MIC: "We have learned over the years not to put our emergency managers into a void going into a holiday weekend."

Fact: On Friday, October 5, WFO Tallahassee began sending core partners formal briefings in email format on the potential system. From a meteorologist at WFO Tallahassee: "The fact that the weekend was coming up and that it was a holiday weekend for many were two major factors in the decision."

From WFO Tallahassee briefing to core partners on Friday, October 5:

"Regardless of development, this system will bring increased rain chances for the FL Big Bend and Panhandle towards the middle of next week. Continue to monitor this system through the holiday weekend".

Fact: Staff at SRH were working with local offices and NHC on Thursday, October 4 and Friday, October 5 to ensure offices were prepared for the event. SRH offered to deploy an IDSS coordinator to NHC if necessary.

Fact: The NHC answered questions from FEMA Regions 4 and 6, and FEMA HQ on Friday, October 5. The NHC also had an informal conference call with FDEM to establish an official briefing for Sunday, October 7. Also, on October 5, SR ROC offered an IDSS Coordinator to the NHC.

Fact: The NHC Tropical Weather Outlooks from 2 p.m. and 8 p.m. CDT Friday, October 5 did not mention the possibility of tropical storm or hurricane conditions impacting the northern Gulf Coast (**Figure 32**).

The tropical weather outlook from Friday at 2 p.m. EDT:
1. A broad area of low pressure centered near the northeastern coast of Honduras is drifting northwestward and producing disorganized shower and thunderstorm activity from Central America east-northeastward across the Western Caribbean to Hispaniola. Although strong winds aloft persist just to the north of the system, the upper-level environment is expected to be conducive enough to allow slow development. A tropical depression could form by late this weekend or early next week over the northwestern Caribbean Sea or Gulf of Mexico while the system moves northwestward to northward. Regardless of tropical cyclone formation, this disturbance will continue to bring torrential rains primarily to portions of Central America and the Yucatan peninsula during the next few days.
** Formation chance through 48 hours...medium...40 percent.*
** Formation chance through 5 days...high...70 percent.*

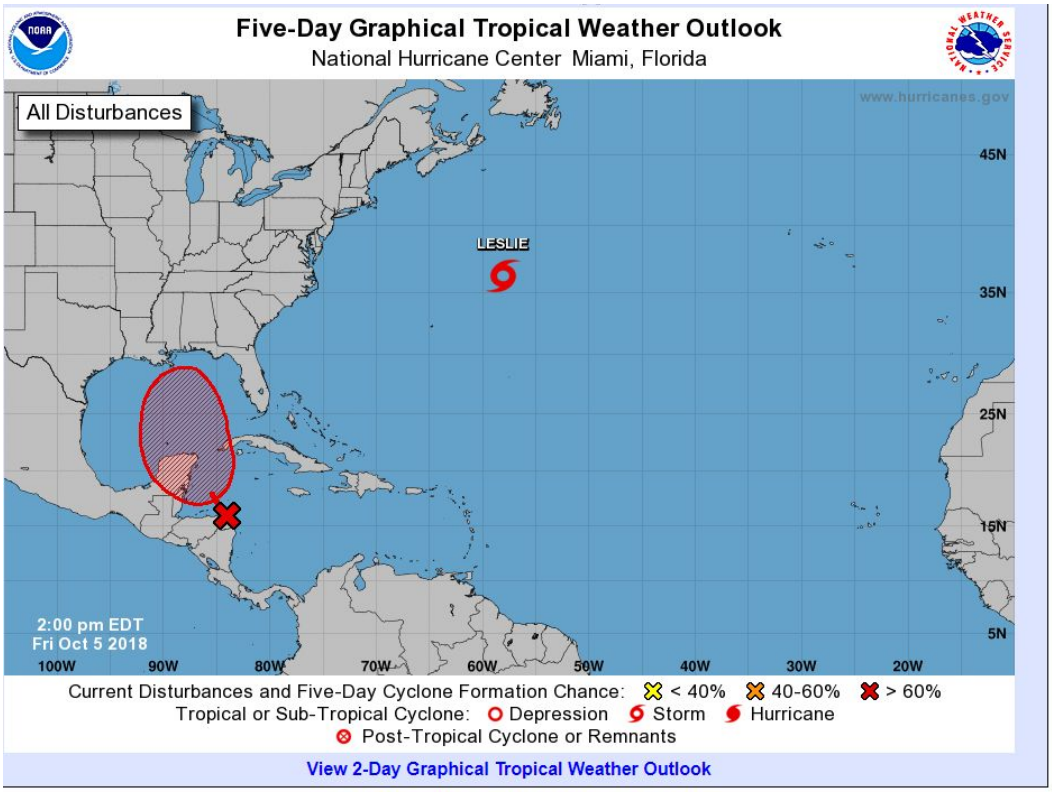

Figure 32: Tropical Weather Outlook from 2 p.m. EDT Friday, October 5, 2018. *Source: NHC.*

Fact: The SR ROC briefing to FEMA Region 4 on Friday, October 5 did not indicate a tropical threat. The SR ROC briefing to FEMA Region 4 first inserted a tropical threat in the threat matrix for the northern Gulf Coast in the Saturday, October 6 briefing (**Figures 33 and 34**).

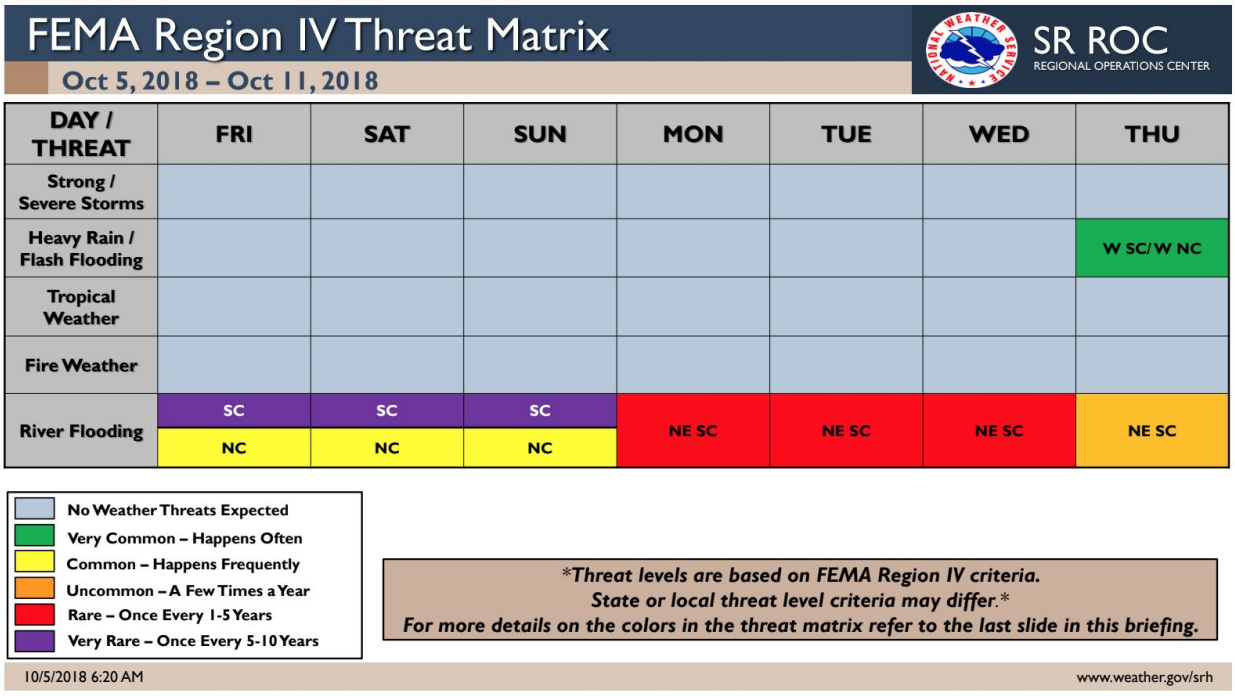

Figure 33: Threat matrix in the ROC FEMA Region 4 briefing from Friday, October 5, 2018 which does not indicate a tropical weather threat. *Source: NWS Southern Region ROC.*

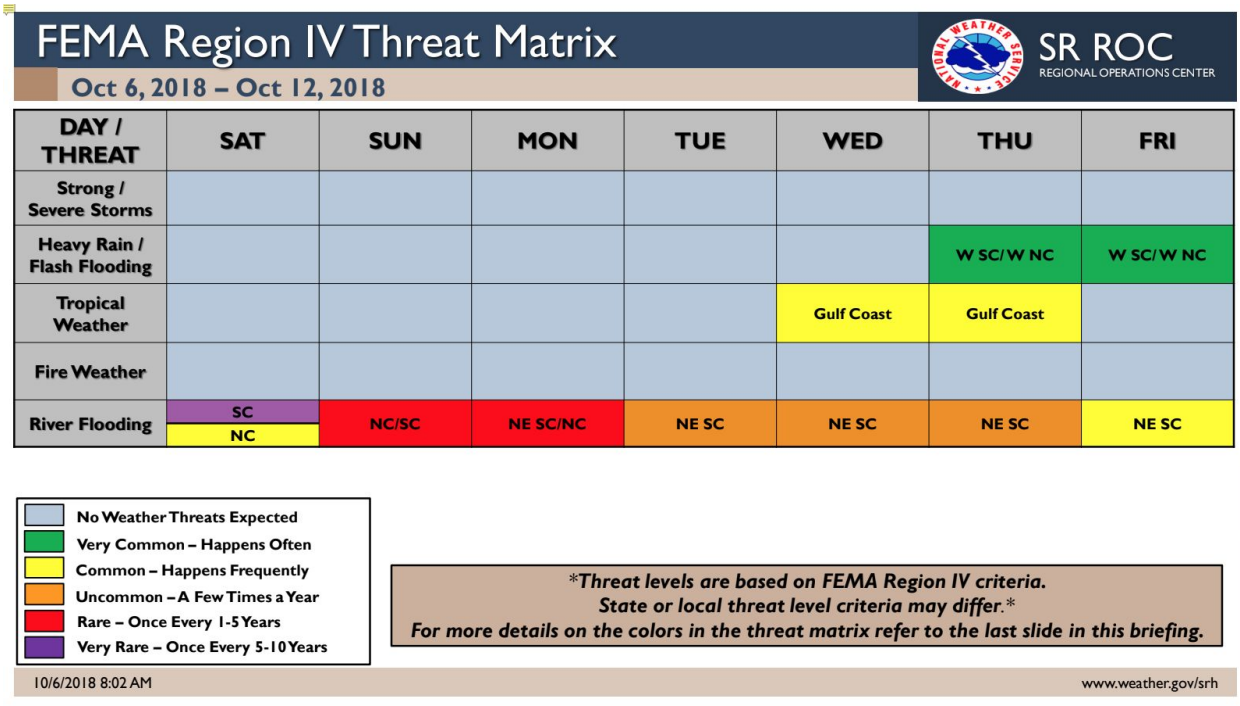

Figure 34: Threat matrix in the ROC FEMA Region 4 briefing from Saturday, October 6, 2018 which does indicate a tropical weather threat for the Gulf Coast. *Source: NWS Southern Region ROC.*

Staff from FEMA Region 4 stated they were alerted to the potential for a hurricane in the Gulf on Saturday of a holiday weekend. FEMA scrambled to call in staff because 50 percent were already deployed for Florence response/recovery.

Fact: NHC issued the first Potential Tropical Cyclone Advisory on Michael at 2100 UTC Saturday, October 6. NHC also provided updates to FEMA Regions 4 and 6 and NWSH.

NHC issued the first "forecast discussion" on what would eventually become Hurricane Michael at 5 p.m. EDT Saturday, October 6. The discussion contained these key messages (**Figure 35**):

Key Messages for Potential Tropical Cyclone Fourteen (October 6, 2018):

1. This system is expected to produce heavy rainfall and flash flooding over portions of Central America, western Cuba, and the northeastern Yucatan Peninsula of Mexico during the next couple of
days. The system is also forecast to become a tropical storm by Sunday night and tropical storm conditions are expected over portions of western Cuba where a Tropical Storm Warning is in effect.

2. The system could bring storm surge, rainfall, and wind impacts to portions of the northern Gulf Coast by mid-week, although it is too soon to specify the exact location and magnitude of these impacts. Residents in these areas should monitor the progress of this system.

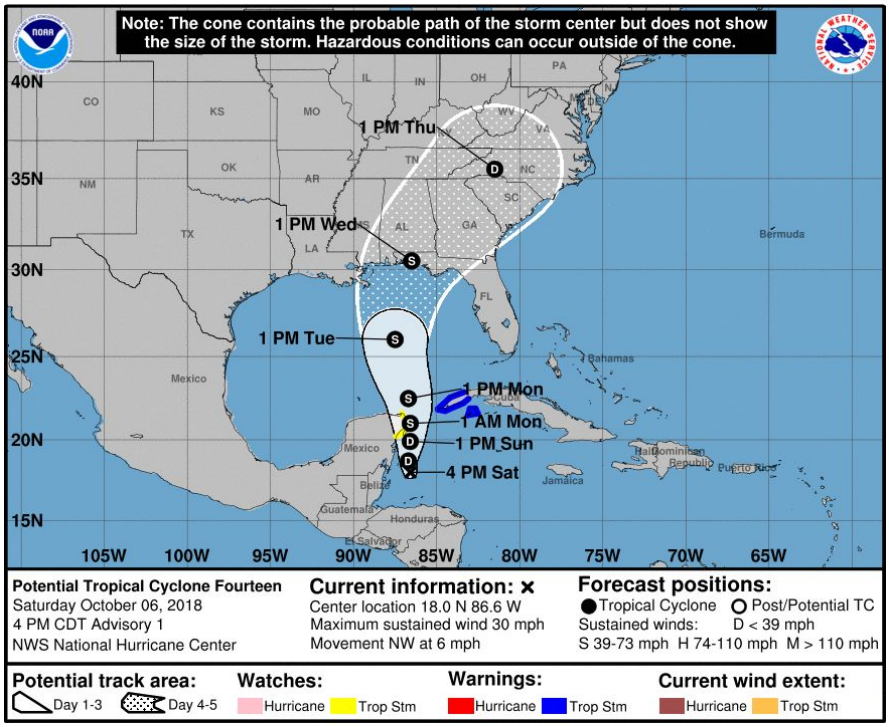

Figure 35: First Advisory on Michael (Potential Tropical Cyclone Fourteen) from

5 p.m. EDT/4 p.m. CDT Saturday, October 6, 2018. *Source: NHC*.

Fact: The first formal NHC and FDEM briefing to state EMs was held on Sunday, October 7.

Protocols for providing IDSS at local NWS offices have evolved to meet the needs of EMs who require significant advanced notification of even low-level probability of high impact events. Extenuating circumstances such as a holiday weekend, where partners may be less focused on an event, can play into the decision to begin issuing IDSS briefings. This was noted with local offices disseminating messages which indicated more of a threat than the regional or national messaging indicated. The lack of regional or national public message going into a holiday weekend was noted by larger core partners such as FEMA and some state-level emergency management organizations that rely on national and regional centers for their primary IDSS needs.

Fact: On Thursday, October 4, NWS began internal coordination (e.g., pre-positioning additional staffing, topping off generator fuel, etc.) and local offices began coordinating with their core partners for a potentially significant event the following week. Beginning on Thursday, October 4 and Friday, October 5, regional and National Centers were also providing IDSS to FEMA and core state partners.

Finding 41: There were inconsistencies in the prioritization of the threats, recommended actions, and timelines for future impacts in the messaging from local, regional, and national offices as the storm gained strength in the southern Gulf of Mexico prior to the issuance of NHC advisories on the system. It was not until Sunday, October 7, that a Fully Integrated Field Structure (FIFS) concept emerged with a consistent depiction of threats, impacts, and timeline for core partners. Some of this was due to the rapidly evolving nature of the threats.

Recommendation 41: When internal contingency planning occurs within the NWS in advance of a potential high impact event, an external message needs to be crafted and shared with core partners so they can begin their own contingency planning. As part of a FIFS, this message should be developed collaboratively and its dissemination coordinated between local, regional, and national offices even in advance of the issuance of tropical cyclone advisories. This coordination is particularly important when extenuating factors exist such as an upcoming holiday weekend or when recently impacted communities are potentially in play.

An IDSS briefing slide more than 72 hours before landfall of Hurricane Florence from a local WFO stated that the highest sustained winds could reach up to near minimal Category 5, while mentioning that it was too early to determine impacts; however, the NHC products did not have the storm reaching Category 5 in their 5:00 a.m. EDT advisory products. Other language in this briefing included, “storm surge and tides could lead to inundation (water height above ground) of 20+ feet” and “widespread deep inundation; many buildings washed away/heavily damaged.”

Fact: Feedback from NHC indicates that the NHC/WPC Medium Range Conference Call is a communication vehicle that is used primarily to coordinate the track forecast of existing or developing systems. However, it is rarely used to collaborate on the messaging to NWS core partners in the case of a developing or upcoming tropical system.

Finding 42: In the case of Florence, three days prior to expected impacts, NHC products conveyed a large amount of uncertainty in the forecast intensity. However, a WFO slide deck used in briefings for core partners issued around the time of the NHC product implied a false level of confidence in conveying that the maximum winds for Hurricane Florence could "reach up near a minimal Category 5." This wording triggered officials to put into place evacuation orders incurring significant activation costs. From a FIFS standpoint, this conflict in messaging provides one example of why better coordination of messaging is needed in the three to seven day time period at all levels of the agency.

Recommendation 42: The team recommends a larger collaboration role between the WFOs, ROCs, and National Centers on messaging to the public during the three to seven day time period that includes appropriate expressions of uncertainty. This would ensure a well collaborated message at the local, regional and national levels. As an example, the NWS should consider the use of the internal NHC/WPC Medium Range Conference Call on the hurricane hotline as an official conduit for coordination of messaging for a potential event in the medium range from NWS national, regional, and local offices. Extenuating circumstances such as an upcoming holiday weekend should be considered at all levels of the agency in consistent messaging of potential impacts to federal, state, and local core partners.

3.3.1.2. Messaging Flood Hazards and Catastrophic Rainfall

WPC forecasts highlighted record rainfall for Hurricane Florence. WPC conducted numerous collaboration calls and worked with field offices to message a historic rainfall event three days in advance. WPC issued a rare 'High' risk over southeastern North Carolina in the Excessive Rainfall Outlook that supplemented the NWS information used by FEMA and state agencies to pre-position assets to respond to over 30 inches of rain and catastrophic flooding.

The team received input from multiple national media outlets about their desire to see WPC highlight its excessive rainfall products for the potential for catastrophic flooding, similar to the "hatched area" for Storm Prediction Center (SPC) products. FEMA Region 4 expressed the desire to see a more storm-specific outlook display for the WPC excessive rainfall product similar to what is done for QPF products.

In terms of rainfall, the Department of Commerce launched a high-profile Agency Priority Goal to mitigate flood impacts that included delivering an enhanced excessive rainfall outlook product that extends the lead time of high risk predictions from two days to three days. The WPC Excessive Rainfall Outlook is probabilistic and has descriptive terms of marginal, slight, moderate, and high risk that now are produced out to three days.

Fact: During Hurricane Florence, the Excessive Rainfall Outlook from WPC highlighted a High Risk with three days of lead time on four consecutive days.

Finding 43: The NWS did a good job of messaging catastrophic flooding in its products during Florence, but some users felt it would have been useful to see something graphically to differentiate between a high risk of flash flooding and widespread catastrophic flooding on a regional or national scale.

Recommendation 43: OWP should look into a graphical way of messaging the threat of catastrophic flooding that goes above and beyond the standard high risk designation in the WPC Excessive Rainfall Outlook and the threat levels for present and future conditions depicted in the Significant River Flood Outlook.

Finding 44: The WPC Excessive Rainfall Outlook is depicted on a smaller storm-specific map scale (**Figure 36**), but is not available on state or FEMA region scales.

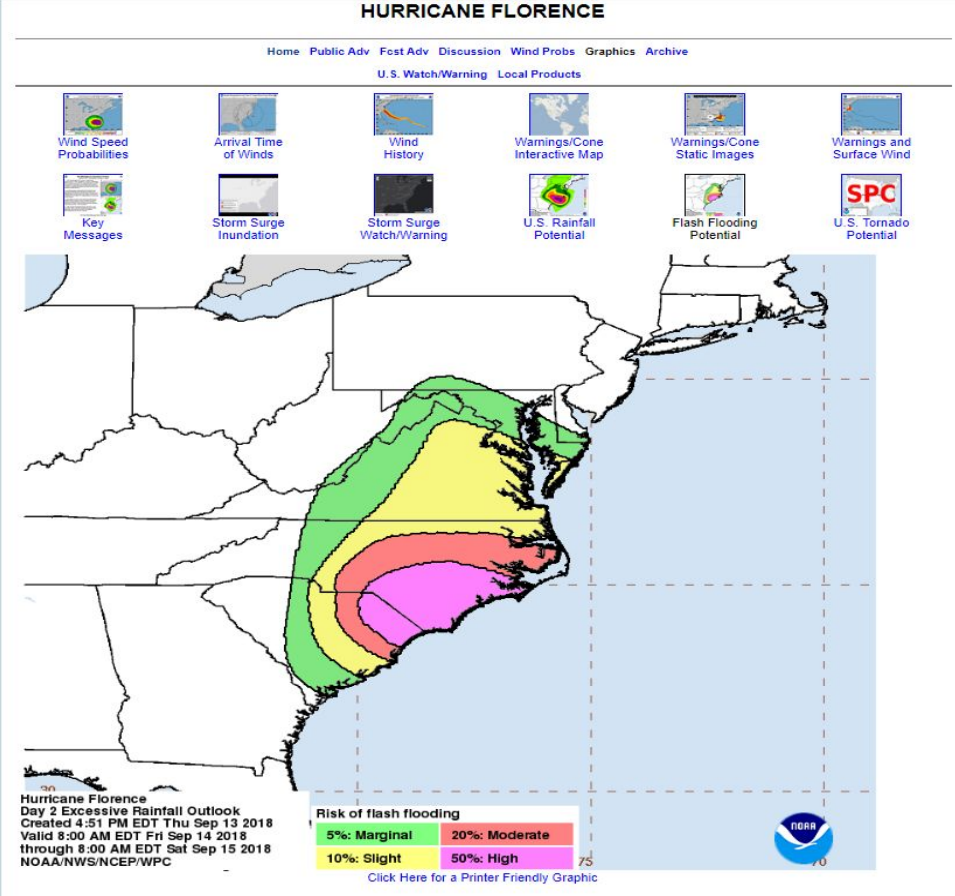

Figure 36. The WPC Day 2 Excessive Rainfall Outlook for Hurricane Florence issued 4:51 p.m. EDT Thursday, September 13, 2018. Source: WPC.

Recommendation 44: The WPC Excessive Rainfall Outlook should be available on customizable geographical scales.

WFO Raleigh staff and core partners mentioned that multiple flood products were issued and bookkeeping became an issue managing numerous river flood warnings, flood advisories, and flash flood warnings. This issue is most evident in those areas that have inland and coastal flood issues, and will experience significant workload issues to handle messaging and product issuances. Furthermore, WFO Raleigh mentioned that there were messaging issues when transitioning from flash flood to areal flood products.

Finding 45: Hydrologic hazards messaging, through the complexity of NWS products, remains a significant challenge for core partners.

Recommendation 45: Similar to winter hazards simplification, additional work should continue to be supported to simplify the products and messages issued regarding flood hazards.

Partners in North Carolina reported confusion among multiple flash flood warnings with multiple expiration times. This confusion was noted particularly at WFO Raleigh where the staff was issuing multiple smaller area Flash Flood Warnings due to the polygon vertex limit in Warngen. Feedback from WFO Raleigh indicated that the meteorologists wanted to issue larger Flash Flood Warnings for multiple counties, but the limited number of vertices allowed in AWIPS Warngen caused complications.

Fact: The numerical limit on vertices is due to AWIPS Warngen software limitations.

Finding 46: The vertex limits in AWIPS Warngen can make it difficult for WFOs to issue the best warnings based on the science and potential impacts.

Recommendation 46: NWS needs to explore the possibility of increasing the vertex limit, as well as addressing the land/marine zone interface display issues.

3.3.1.3. WFO Consistency with Wind Products

The NCDEM commented that while WFOs Greenville/Spartanburg and Raleigh had similar wind forecasts for Hurricane Florence, they did not use the same products, watches, warnings, or advisories to represent the hazards. During Hurricane Florence, WFO Raleigh issued tropical cyclone watches or warnings, while WFO Greenville/Spartanburg issued wind advisories. WFO Greenville/Spartanburg chose not to issue tropical cyclone products given the expectation of lower wind speeds in their CWA and their understanding of pre-determined ER guidance for inland WFOs to initiate issuance of tropical cyclone products. WFO Greenville/Spartanburg, however, did issue tropical cyclone products during Hurricane Michael.

In addition, state partners in North Carolina mentioned that these watches, warnings, and advisories did not match up well with the specific point and click web-based forecasts or Zone Forecast Products. For this multi-hazard storm event, the agency also noted that the wind warnings also detracted from the flood messaging. A lot of decisions are based on sustained tropical storm force winds. These partners decided to move resources based on the warnings, but the actual wind forecast would have allowed resources to remain in the field.

Fact: During Hurricane Florence, WFO Raleigh issued tropical products, but WFO Greenville/Spartanburg did not issue these products.

Finding 47: During Hurricane Florence, North Carolina OEM meteorologists commented on inconsistencies with watches, warnings, and advisories between North Carolina WFOs and that the wind warnings did not match up with the forecasted winds.

Recommendation 47a: From a FIFS standpoint, the ROCs should help coordinate and alleviate watch, warning, advisory consistency issues between WFOs, especially in a tropical situation.

Recommendation 47b: WFOs should collaborate on state-level messaging and issue pertinent tropical products (e.g., Tropical Storm Warning) when a tropical cyclone impacts their area of responsibility.

3.3.1.4. NWS Websites

Integrated web services are an essential element for a fully integrated NWS data dissemination framework to deliver consistent decision support services to core partners from multiple NWS organizations. To provide partners the most efficient pathway to access information online there are two areas that need to be improved. The first is content inclusive of how to correctly display deterministic and probabilistic information.

Multiple WFOs reported that the display of both probabilistic and deterministic forecast information on the point-and-click forecast on weather.gov detracted from the key messages for the storms. The point-and-click forecast can sometimes indicate deterministic wind speeds that are well below what is stated in the expressions of uncertainty (e.g. “hurricane conditions possible”).

Fact: On Tuesday, October 9, the point-and-click forecast for Atlanta, GA included "tropical storm conditions possible" for the night of Wednesday, October 10, while the corresponding point-and-click wind forecast was 20 mph. WFO Atlanta staff spent considerable time explaining this discrepancy for the metropolitan area which was located on the periphery of the storm. The effort to explain the discrepancy took considerable time away from providing IDSS for critical hazards and impact areas.

Fact: WFO Mobile stated that at one point during Hurricane Michael, Okaloosa County, FL, stayed in the "extreme" wind category but the point-and-click deterministic wind forecast only showed winds of 35 to 40 mph.

Some NWS core partners pointed out this discrepancy as well. WFO Tallahassee media partners, specifically in Dothan, GA, reported similar findings with the point-and-click forecast. Finally, similar feedback was received from North Carolina OEM during Hurricane Florence.

Finding 48: The point-and-click forecast feature on weather.gov can serve to undermine key NWS IDSS messaging. By using this feature, users can receive forecasts that conflict with ongoing NWS hazards due to the combination of both deterministic and probabilistic information.

Recommendation 48: Revise the underlying computer code in the NWS point-and-click forecasts that merges deterministic forecasts with probabilistic forecasts. Only probabilistic information should be emphasized in the point-and-click forecast when expressions of uncertainty are triggered.

Finding 49: There is a larger, philosophical issue for the NWS on when the agency should use deterministic forecasts in messaging and when it is best to solely use probabilistic information.

Recommendation 49: NWS should form a team comprising social scientists and EMs to investigate how best to infuse probabilistic information with deterministic forecasts. This team should include representation from NHC, OCLO, and other major NWS program offices with tropical program responsibilities. The team should evaluate what content is currently available from the NWS tropical training program which is currently leading this effort.

The second is organization and ultimately structure of web pages and user interfaces. In the current configuration of NWS web services, a user must navigate more than one website to access all of the information necessary to be better informed during tropical cyclone events. The Hurricane Florence assessment team found that several partners commented NWS webpages are too overwhelming and not user friendly. As found in finding 8 of the *Hurricane/Post Tropical Cyclone Sandy, October 22-29, 2012 Service Assessment,* critical information was not easy to find from the front page and the site is not mobile friendly.

Note: Issues with the NWS AHPS/Hydro web pages are covered in Section 3.1.2.2.

Fact: Several NWS partners from Hurricane Florence commented that NWS webpages are too overwhelming and not user friendly. The critical information was not easy to find from the front page and the site is not mobile friendly.

Finding 50: During tropical cyclone events, the NWS website (weather.gov) lacks a "one-stop shop" for national and local information.

Recommendation 50: NWS should hire or contract with web design experts and use state of the art technology and user experience research to develop a more intuitive, consistent, and user-friendly experience across all NWS online web based interfaces (including mobile devices) that effectively prioritizes communication of critical information. The information should be organized for total, storm specific information including NHC's track and surge information with local impact information from the WFOs including flooding, rip currents, etc.

3.3.1.5. Warning Coordination Meteorologist (WCM) Position at NHC

The team received feedback from NHC leadership that the WCM position at NHC is heavily overtaxed especially during tropical weather events.

The WCM position at NHC is considered one of the full time six senior hurricane specialists. This individual works a full time shift load during hurricane season which differs from the WCM position at local WFOs where this position has a smaller shift load in most circumstances and can spend more time focusing on leading IDSS efforts with core partners. A similar situation exists at SPC, AWC, and WPC, where the WCM is part of the operational rotation.

Finding 51: The WCM position at NHC is considered a full time hurricane specialist and must work a full shift load during hurricane season which detracts from the time this person spends focusing on and leading IDSS efforts.

Recommendation 51: The NWS should investigate staffing flexibilities for NHC to meet increasing IDSS needs during the tropical cyclone season.

3.3.1.6. NHC Communication with WFOs

Both the Hurricane Specialist Unit (HSU) and SSU at NHC used NWSChat during Florence to communicate with coastal WFOs. This communication included early coordination of potential changes to track forecasts and coastal storm surge watches and warnings prior to NHC Tropical Coordination calls so WFO concerns could be worked out on the call. The SSU also used NWSChat to confirm storm surge grids produced by the individual WFOs were received by the SSU.

Best Practice: The use of NWSChat by both the HSU and SSU streamlines the coordination process for storm surge levels, watches, and warnings between NHC and the WFOs.

3.3.1.7. Office of Water Prediction (OWP) Support

OWP successfully demonstrated prototype capabilities during Hurricane Florence and coordinated aerial reconnaissance missions that extended farther inland than usual. The NWC Operations Center worked with internal and external partners to develop inundation graphics for locations to meet federal partner requests to assist with protection of critical infrastructure.

OWP is leading the development of the National Water Model (NWM). The NWM continues to evolve as it works its way from research to operations. In Hurricanes Florence and Michael, the NWM did produce water simulations that were available on a publicly-facing OWP web page. OWP is using tools such as the Water Resources Evaluation Service to assess the probability of detection, false alarm ratio, etc., to characterize model uncertainty of NWM and RFC forecasts.

Fact: OWP staff provided material to NWSH for its leadership briefings and answered requests from FEMA by coalescing information from multiple RFCs and ROCs. The staff of the NWC Operations Center reached out to SERFC in Hurricanes Barry and Michael to find out how they could help the RFC with any IDSS materials.

Finding 52: Feedback from within the NWS is that the roles and capabilities of both OWP and the NWC are not well understood.

Recommendation 52a: The NWS needs to proactively engage with other parts of NOAA to clearly communicate NWC's roles and capabilities in a major tropical or hydrologic event. OWP inclusive of the NWC Operations Center needs to have their role defined prior to the onset of a tropical system rather than during the event.

Recommendation 52b: An explanation of NWC’s roles and responsibilities should be added to NWS tropical training curriculum such as EHM and Seasonal Readiness Training (SRT).

3.3.1.8. QPF Collaboration

The assessment team received feedback from some local WFO meteorologists that the timing of the WPC QPF collaboration calls was late in the forecast creation process at ER WFOs.

When staffed, ER ROC helps arrange coordination calls between WPC and the WFOs. Usually the SPC and WPC time their coordination calls to be ahead of their product release times (excessive rainfall, etc). There is usually a brief statement from WPC on the NHC hurricane hotline calls about heavy rainfall.

Finding 53: The timing of the QPF collaboration calls between the WFOs and WPC during Hurricane Florence was occurring late in the WFO forecast creation process. This made the timeline for collaborated forecast creation difficult for the WFOs.

Recommendation 53: WPC, NWS RHs, and WFOs should investigate ways prior to the tropical cyclone season to set the timing of the QPF collaboration calls to be earlier in the WFO forecast product creation process.

3.3.1.9. Role of the Regional Operations Centers (ROC)

The role of the ROCs in both Florence and Michael was critical in overall collaboration of services across many WFOs and RFCs to ensure resources were available to each WFO and RFC to meet NWS mission needs. The ROCs also demonstrated the ability to assist WFOs in troubleshooting deficiencies in web services and WFO network capabilities. In addition to these roles, the ROCs also identified NWS resources to help them address information requests from core federal partners (e.g., FEMA, FAA, etc.). Over the past several years, the NWS has continued to add additional resources to its ROCs. The ROCs continue to evolve to meet the ever increasing coordination needs involving regional messaging and resources ahead of significant weather events.

Fact: In 2018, SRH had staffed its ROC with full-time Emergency Response Specialists to assist with regional IDSS messaging roles. During the 2018 tropical season, the ER ROC did not have staff fully dedicated to the ROC. ER staffed the ROC with ERH personnel trained to perform ROC functions as collateral duties. Since 2018, ER has filled two Emergency Response Specialist positions which are dedicated full time at the ER ROC.

Finding 54: At the time of Hurricanes Florence and Michael, not all NWS ROCs were equally staffed.

Recommendation 54: NWS should define and implement ROC Final Operational Capability (FOC) staffing to address present and emerging IDSS demands during high impact events such as tropical cyclones.

3.3.1.10. IDSS Coordinator

To ensure consistency in briefings, messaging, and impacts across the NWS, an IDSS coordinator is deployed to the NHC during potential high-impact U.S. tropical cyclone events. The IDSS coordinator facilitates internal coordination between WFOs, RFCs, HLT, NHC, and deployed NWS personnel. This key position ensures key messages from each NHC advisory are consistently conveyed in all tropical NWS briefings.

Fact: The IDSS coordinator position is filled from a pool of NWS volunteers who are deemed “tropical experts” (e.g., significant experience conducting operations and providing support for tropical cyclones). Feedback from NWSH is that there is a limited pool of individuals available to serve the role of IDSS coordinator.

Fact: One person was deployed as the IDSS coordinator for each hurricane (Florence and Michael). The IDSS coordinators for both Hurricanes Florence and Michael reported working 14 hour days on average and were tasked to support offices running tropical software. The need for additional staff to support 24X7 operations was addressed in finding 10 of the *August/September 2017 Hurricane Harvey Service Assessment*.

Finding 55: There is a limited pool of volunteers with tropical experience to fulfill the role of IDSS coordinator and this presents a challenge to meet IDSS and internal messaging needs.

Recommendation 55a: The NWS should ensure, when possible, that there are at least two tropical experts deployed to NHC as IDSS coordinators to provide continuous coverage for each tropical cyclone event threatening the United States.

Recommendation 55b: The NWS should ensure there is a substantial pool of volunteers with tropical experience to fulfill these support roles. These volunteers should meet minimum training standards with required approval to be tropical deployment ready. These training standards are documented on the NWS Tropical DSS Coordinator Google Sites page.

3.3.2. NOAA-wide Coordination

3.3.2.1. Administrative Processes During Emergencies

Leadership at SRH and WFO Tallahassee secured lodging for the employees prior to the storm's arrival to ensure they had a safe place to stay to support the event.

Best Practice: SRH and local leadership proactively made the decision to secure lodging prior to the event; this is not the standard practice. The WFO Tallahassee MIC found one of only a few hotels that had emergency backup power before reserving rooms. The hotel was within a short drive or walkable if necessary.

Fact: NWS Directive NWSI 1-208, Delegation of Authority for Food/Lodging Expenditures in Advance of or during Major Weather Emergencies or Disasters, was established in March 2017 to provide the authority and guidance for Financial Management Centers (FMCs) or WFOs to procure lodging at a nearby hotel for employees and to purchase emergency food supplies during significant events including tropical cyclones.

SR leadership and the Administrative Management Division expressed concern and frustration about their lack of control over emergency funds. These groups expressed the need for a more streamlined and well-documented approach for applying these funds. The procurement of lodging with purchase cards in an emergency situation currently requires several time-consuming approvals.

Finding 56: The process for making emergency purchases in the NWS is complicated. The rules are unclear, they lack flexibility, and each purchase has a long approval process.

Recommendation 56a: The NWS should determine if NWS Directive NWSI 1-208 goes far enough in providing sufficient, flexible, and consistent guidance for emergency purchases and procurement of lodging for WFO employees during tropical events.

Recommendation 56b: The NWS should provide an annual review of administrative processes, guided by NWS Directive NWSI 1-208, that FMCs and WFO leadership should follow in emergencies.

Recommendation 56c: The Chief Financial Officer (CFO), in conjunction with appropriate finance offices, should develop a "deployment ready" team to promptly support the Financial Management Centers during emergency procurement and evacuation decisions, ensuring that senior officials can maintain employees' safety during a high impact tropical event.

Recommendation 56d: The NWS should reach out to other federal agencies to gather best practices for handling administrative policies, practices, and procedures in emergencies.

3.3.2.2. WFO Facilities and Employee Preparedness

WFO Wilmington, NC used the total office concept during Hurricane Florence. Electronics Technicians helped with damage and flood surveys. The Administrative Support Assistant slept three nights at the office to ensure constant support of administrative needs, food, and other logistical needs.

Staff at SRH and WFO Tallahassee arranged for the Atlanta-based Facilities Engineering Tech (FET) to be deployed to WFO Tallahassee ahead of Hurricane Michael. The FET was deployed for one week. He charged all the batteries and tested systems ahead of the event.

SRH worked with WFO Tallahassee management to purchase supplies early in the season so the office was well stocked. SRH Systems Operations Division coordinated with the local office to have supply trucks and generators arrive shortly after the storm.

Best Practice: WFO Wilmington, NC used the total office concept by empowering non-meteorological staff to provide additional logistical support throughout the entire tropical event.

Best Practice: ERH deployed FETs to WFOs during Hurricane Florence. SRH deployed the FET to WFO Tallahassee in advance of Hurricane Michael to aid with preparation and recovery issues.

Fact: ERH deployed Regional Maintenance Specialists (RMSs) to WFOs during Hurricane Florence. SRH would have deployed the Tampa-based RMS during Hurricane Michael, however the position was vacant. This impacted SR's ability to provide electronics support during the storm.

Best Practice: SRH worked with WFO Tallahassee management to purchase bedding and towels pre-season, and emergency food and supplies such as paper towels and toilet paper leading up to the event.

ERH also reported that equipment access issues occurred at WFO Morehead City, NC and Wilmington, NC (discussed further in **Section 3.4.11**).

Fact: Staff at some NWS offices stated that on-site sleeping and shelter-in-place spaces for additional staff were inadequate.

Fact: From the Director of the Facilities Management Division within the NWS Office of Facilities: "Shelter-in-place resources at our facilities must extend well beyond having the necessities of food, water, cots, showers and requires a broader analysis, understanding and acceptance of risk thresholds for our workforce. Not all of our facilities have a hardened space in which to safely shelter-in-place during a direct hit (or potentially indirect hit). In many cases, the structural engineers that performed hurricane assessments on select coastal facilities, could not validate that even the hardened locations were capable of withstanding their design strength. Many of our facilities are 20-25 years old and hurricane shutters, window frames and the anchors that secure these systems may have degraded over time when exposed to salty conditions."

Finding 57: There is inconsistency between office to office in shelter-in-place capabilities for major events.

Recommendation 57a: Where possible, NWS should investigate additional ways to incorporate shelter-in-place resources at WFO and RFC facilities, or use core partner locations. The team agrees with Finding 37 of *Hurricane Irene, August 21-30, 2011 Service Assessment* that before the tropical season, the NWS should investigate the potential to modify storage areas and equipment room spaces to facilitate shelter-in-place needs for sleep and basic hygiene needs.

Recommendation 57b: There should be a consultation from NWS Operations with the Facilities Division Directors at HQ as well as the Regional HQ Facilities POCs to make the most informed decision regarding sheltering-in-place at the WFO, moving to another partner location, or going into service backup.

3.3.2.3. The Relationship between NWS and NOS

Feedback from the team meetings with NOS leadership showed a lot of positive collaboration between NOAA line offices. NOS leadership coordinated closely with NWSH leadership and also with OWP.

During Florence and Michael, the NOS CO-OPS coordinated with the NOS Headquarters Communications and Education Division to provide daily digital media updates on elevated water levels during tropical storm events. When coastal water levels began dissipating during Hurricane Florence, water levels on the Cape Fear River continued to rise. To ensure accurate and consistent messaging to reflect this fact, NOS held a coordination call with SERFC, Analyze Forecast and Support Office (AFSO), and NWC staff to coordinate messaging on when anticipated peak water levels were expected to occur at the Wilmington, NC tide gauge. This information was ascertained by consulting the NOAA Water Model and USGS tide gauges upriver from the NOS tide gauges. The NOS Twitter account served as the main communication tool for information on water level plots with corresponding messages about anticipated peak water levels. The NWS Communication Office and NHC retweeted these messages to amplify them.

See **Appendix D** for further explanation of the NOS roles and offices.

Best Practice: NOS/CO-OPS participated in NWSOC daily briefings during Hurricane Florence to provide information on significant water level observations.

Best Practice: NOS/CO-OPS and NHC kept lines of communication open and SSU regularly engaged with NOS leadership during Florence and Michael. The SSU sent CO-OPS requests for water level validation for transforming datums at non-NOAA gauges. NOS/CO-OPS participated in storm surge surveys following Hurricane Michael at the request of WFO Tallahassee.

Best Practice: WFO Mobile worked closely with OCS by participating in Port Coordination Team meetings. OCS was also included in NWS briefings. The information provided by the WFO was critical to decisions on port openings/closures from Mobile, AL eastward to Panama City, FL.

Fact: There were many positive examples of the NWS and NOS working together during Hurricanes Florence and Michael; however, most of these activities were done on an *ad hoc* basis.

Finding 58: There is no formal procedure for getting information from NOS to NWS and vice versa at the line office level.

Recommendation 58: Formalize how NOAA line offices (e.g., NWS and NOS) work together in all phases of a tropical cyclone, including preparation and recovery (see **Appendix D** for further discussion of NOS roles). NOAA's Homeland Security Program Office, the NOS Incident Management Team, and the Tropical IDSS Coordinator could facilitate this line office coordination. In addition, the NOAA Regional Teams can work to help build relationships and establish protocols between NOAA line offices.

3.3.3. Multi-Agency Coordination

3.3.3.1. Creation of Post Storm Reports

Creating and completing a post storm report for a tropical cyclone is tedious and complicated, requiring efforts from local, regional, and federal entities. There is no easy way to gather all of the data, such as water level observations and highest wind speed values, from these different entities.

Fact: Per NWS Directive NWSI 10-601 ("Weather Forecast Office Tropical Cyclone Products"), WFOs are required to generate the preliminary Post Tropical Cyclone Report (PSH) within five days following the transmission of the last HLS. WFOs can amend reports as needed, with the final reports issued no later than 15 days after the last HLS. It normally takes longer than this (up to two weeks) for storm surge surveys to be completed.

Finding 59: Creating the PSH within the required timeframe for a tropical cyclone is a long, complex process, particularly given the level of coordination required for events of this magnitude.

Recommendation 59a: The NWS should investigate methods to automate, where possible, the process of creating PSHs.

Recommendation 59b: The NWS should review Directive 10-601 and to ensure adequate time is provided for the completion of inter-agency storm surge surveys for inclusion in the PSH.

3.4. Systems and Service Backup

3.4.1. NWS Dissemination Issues

Software scripts and dissemination pathways hindered the timely production of foundational gridded data fields used to produce NWS tropical products, specifically NWS watches, warnings, and advisories. It is evident in interviewing SMEs in various NWS organizations that a lack of routine end-to-end testing of tropical weather applications severely impacted WFO tropical dissemination services during Hurricanes Florence and Michael.

WFO Wilmington, NC could not issue a product due to a zone change from 2016 that had not been thoroughly tested. As a result, the WFO's first watch/warning forecast package for Florence was delayed by three hours.

During Tropical Storm Gordon and Hurricanes Florence and Michael, the NDFD did not update for up to an hour after grids were published at a local WFO. As a result, WFO grids upload at different times on NDFD, giving the appearance of a lack of coordination between offices. Additionally, this timing discrepancy can lead to errors in WFO verification scores. This issue also exacerbates discontinuity between grids in two different CWAs during tropical events.

NCO determined that the root cause for this issue is the continuous switching between servers in College Park, MD and Kansas City, MO. NCO staff and management said these switchovers are operating "as expected," even with a one-hour delay.

Fact: Additional issues with dissemination showed up during Hurricane Florence:

- On September 10, WFOs Newport-Morehead City and Charleston, SC were unable to run the AWIPS software script associated with the TCFloodingRain tool to produce their hazard grids.
- On September 11, the hourly Quantitative Precipitation Estimates (QPE) graphics were not updating on NWS web pages.
- The morning of September 11, WFOs via NWSChat noted that HTI graphics were not displaying on NWS websites.
- There were several occasions during Hurricane Florence when AHPS graphics were not updating on NWS websites. This resulted in contradictory information being displayed via AHPS when compared to RFC IDSS briefings or direct phone contacts.

There were also issues with the NHC Storm Surge Watch/Warning (SSWW) display on weather.gov during Hurricanes Florence and Michael. This issue resulted in the SSWW being depicted improperly.

Fact: SSWW data did not properly display on the watch/warning/advisory graphics during Hurricane Florence on NWS websites (e.g. weather.gov). The display of the watches and warnings on the NWS main website (weather.gov) did not properly reflect what NHC was showing on its website (hurricanes.gov.)

Fact: The problems with the SSWW depiction on weather.gov pages were due to code changes made for the implementation of snow squall and dust storm warnings during the 2017-2018 offseason which caused the code to only look for one segment within the warning product. The WFO TCV product has one segment per zone. Therefore, the weather.gov pages only showed a SSWW in the first zone in the TCV product and ignored all other zones.

Fact: For one year ahead of the 2018 hurricane season, NWSH organized bi-weekly meetings to facilitate the implementation of a dissemination pathway for the storm surge watch/warning

(SSWW).

Fact: NWS added a zone-based version of the SSWW to the National Hazards KMZ (Keyhole Markup Language - Zipped File) based solely on the Valid Time Event Code (VTEC) listed in the TCV product. The visualization using this method differs from the SSWW graphic found on the NHC web page.

Fact: The SSSW graphic on the NHC web page (available in Keyhole Markup Language, KML, format for GIS users) is correct as it shows the hazard grid that is collaborated between NHC and the WFOs which is tailored to the area at risk along the coast (**Figure 37**).

Fact: The National Hazards KMZ depiction using the VTEC method of displaying the SSWW grossly over-warned the threat area, on some GIS-based platforms such as NOAA NowCOAST. The National Hazards KMZ product overwarned areas that, in some instances, were major metropolitan areas inhabited by millions of people (**Figure 38**).

Fact: By adding the incorrect full-zone depiction of the warning to the National Hazards KMZ, work that had previously been done to ensure that the SSWW KML file from NHC was the only depiction of the SSWW on GIS map services such as NOAA NowCOAST was overwritten.

Fact: A trouble ticket was opened on September 13, 2018 concerning the National KMZ depiction of the SSWW (during Hurricane Florence). The ticket was assigned to be fixed in November 2018. The Tropical Program asked leadership during tropical cross portfolio consideration meetings held on September 25, 2018 and October 30, 2018 but it was never accelerated. The NWS Office of Dissemination (DIS) did not address the ticket until November.

Fact: After the 2018 hurricane season, DIS determined that it would be too difficult for them to implement the capability of only showing the NHC SSWW KML in their KMZ file. The NWS Tropical Program and NHC found this solution unacceptable, and it was agreed to remove the SSWW hazard from the National Hazards KMZ altogether for the 2019 season.

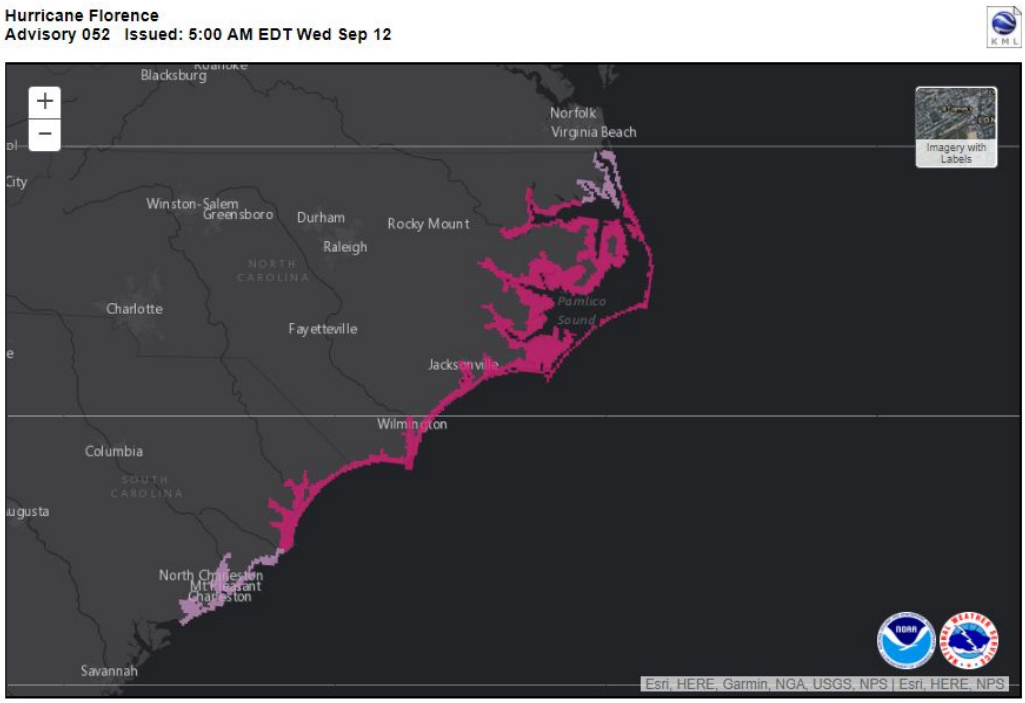

Figure 37. Correct depiction of SSWW for Hurricane Florence on NHC webpage. *Source: NHC.*

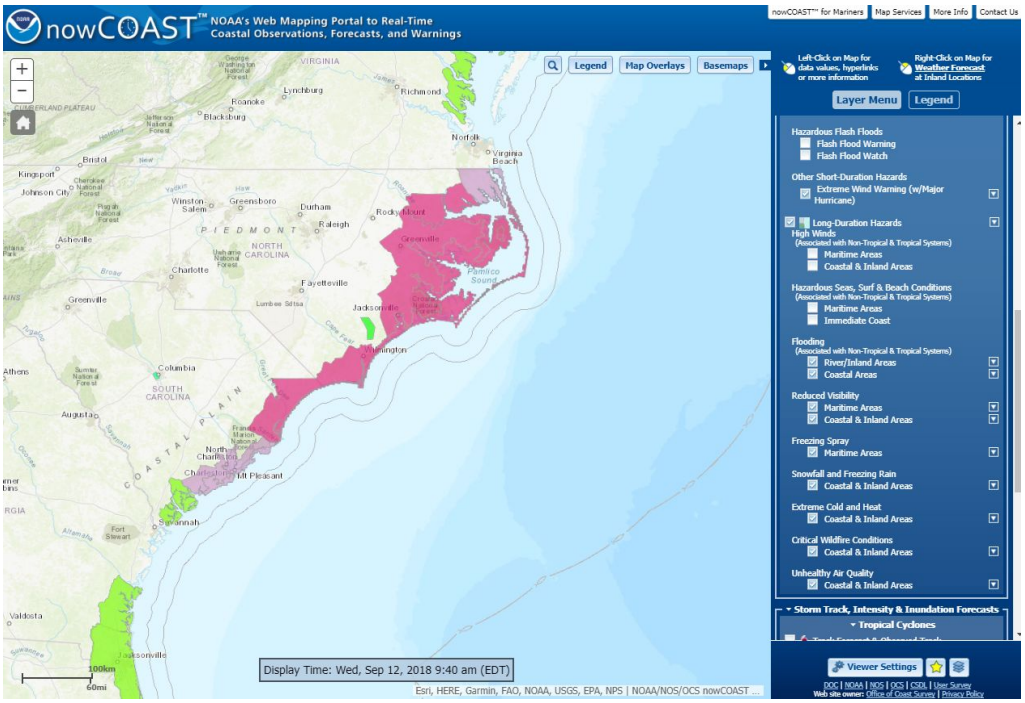

Figure 38. Incorrect depiction of SSWW for Hurricane Florence using the national hazards KMZ depiction on NOAA NowCOAST. *Source: NOAA.*

Finding 60: The issue with the SSWW incorrectly displaying on weather.gov pages was triggered by code changes for non-tropical program areas.

Recommendation 60: Changes to any code that may affect tropical product dissemination should be tested for a tropical scenario prior to implementation.

Finding 61: The SSWW was incorrectly displayed over too large an area in some GIS-based platforms such as NOAA NowCOAST due to an incorrect depiction of the SSWW in the National Hazards KMZ file.

Recommendation 61: DIS should fix the National Hazards KMZ file so that it shows the correct depiction of the gridded SSWW collaborated between WFOs and NHC. This should be made a high priority as it concerns a warning being improperly displayed during an event when critical decisions are being made to protect life and property.

Finding 62: The one-hour time lag for NDFD updates after forecast issuances impacted NWS' effective messaging of hazards on NWS websites, a primary communication tool.

Recommendation 62: NWS should conduct an external evaluation of the Integration Dissemination Program (IDP) that includes the system's configuration, configuration changes, latency in displaying information generated by NWS offices, and ability to withstand user load during high impact weather events. In the meantime, the NWS should include use of a disclaimer to alert users of delays in posting WFO grids during major events.

Finding 63: The failure to install a critical HTI patch prior to Florence is one example of the existing AWIPS Discrepancy Report review process not working effectively. In this specific case, the patch was not given the correct priority level to be implemented quickly which impacted watch/warning operations at multiple WFOs.

Recommendation 63: The Advanced Weather Interactive Processing System (AWIPS) Discrepancy Report review process should be evaluated to ensure that mission critical software patches and bug fixes are in place consistently.

3.4.2. Software Implementation and Testing

Before tools are implemented in NWS operations, tools typically undergo testing as identified by the NOAA R2O funnel (**Figure 39**).

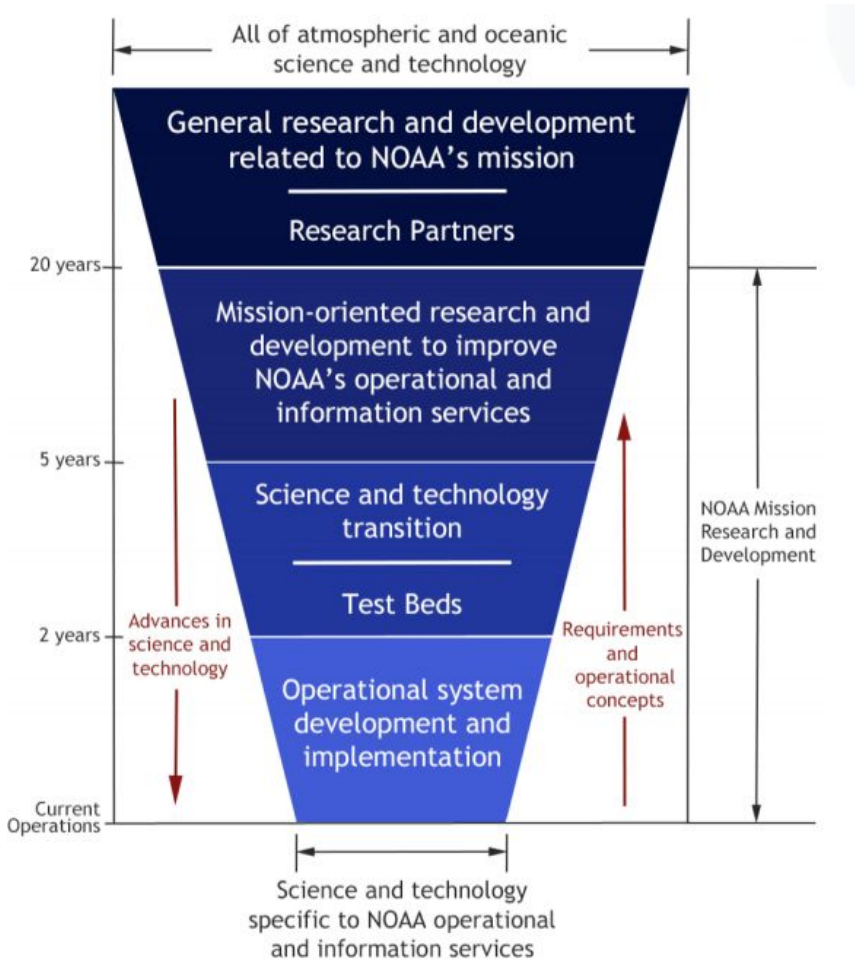

Figure 39: The NOAA Research and Development Funnel outlining the research to operations process. *Source: NOAA Administrative Order (NAO) 216-105b: Policy on Research and Development transitions and the associated handbook.*

A test was conducted in May 2018 between NHC, WPC, OPC, SRH, ERH, and local WFOs in Southern and Eastern Regions. This test assessed the levels of coordination between local offices and the NHC, the ability to collaborate in GFE, the receipt of storm surge and wind forecast information, and the ability to generate the national TCV VTEC message.

The following capabilities were verified during this test:

- Connectivity of the new Hurricane Coordination Hotline.
- Accessibility of NWSChat rooms for tropical collaboration.
- Receipt of pre-TCV and associated banner pop-up at test coastal sites.
- Receipt of gridded Tropical Cyclone Marine Advisory (TCM) wind input and ability to run the new gridded tropical cyclone wind tool (gTCM) in GFE practice mode.
- Ability to create a tropical wind hazard grid.

- Ability of WFOs to run the TCStormSurgeThreat procedure using the InterSite Coordination (ISC) option (with grids from the NHC SSU rather than with Probabilistic Extra-Tropical Storm Surge (P-ETSS) or P-Surge directly).
- Ability to generate National TCV by NHC from the WFO hazard grids.
- Review of WFOs test results.

Despite this annual test, the NWS remains unable to do full end-to-end testing of the tropical program product suite. Staff interviews included descriptions of situations where WFO meteorologists were troubleshooting software scripts and dissemination pathways during Hurricane Michael and Florence events. The assessment team discovered additional situations by data mining discussions conducted in NWSChat Rooms and NOAA Virtual Lab (VLab) forums as well as the shift logs of individual NWS field offices. The deployment of the gridded tropical cyclone wind tool and subsequent level of post-deployment troubleshooting illustrates the critical need for a robust end-to-end testing framework.

Fact: A national test is conducted each spring involving NHC, WPC, OPC, SR, ER, NWSH, and local WFOs throughout the Gulf and East Coasts. This test includes connectivity of the Hurricane Hotline, use of NWSChat, receipt of pre-TCV, receipt of gridded TCM forecasts, and verifying tropical surge hazards. However, it does not include testing of AWIPS product generation and NWS dissemination.

The NWS decided to make a new gridded tropical cyclone wind tool (gTCM) available for experimental evaluation during the 2018 tropical season to run alongside the legacy TCMWindTool. These tools are used by meteorologists in local WFOs to generate wind forecasts for a tropical cyclone. WFOs were encouraged to test the ingest of the data after receiving software documentation and tool instructions. WFO staffs expected the upgraded gTCM would be “better than” and “much easier to use” than the legacy TCMWindTool.

In the summer of 2018, WFOs discovered additional technical issues with the gTCM displaying its data field in AWIPS. A fix to the new gTCM was created only a week before Hurricane Florence and tested at two WFOs and two NWS regions. The implementation of this fix was blocked by the Critical Weather Day (**Section 3.4.3**) designation for newly formed Hurricane Florence. At that time, the NWS Chief Operating Officer declared that all WFOs were to roll back to the legacy TCMWind tool for the duration of the Hurricane Florence event. It is the understanding of the team that the most impacted WFOs used the legacy TCMWindTool to generate wind forecasts during Hurricane Florence.

In late September, SRH approved installing the newer gTCM tool at its WFOs. On October 3, the NWS OCOO and AWIPS Program Office approved the use of the newer gTCM tool. Following this decision, all Southern Region WFOs impacted by Hurricane Michael used the new gTCM tool to generate wind forecasts.

The team received widespread feedback from meteorologists at local WFOs regarding the editing of data produced by the new gTCM. These meteorologists noted they spent considerable time (up to 45 minutes) in post-processing and post-editing data generated by the gTCM to generate perceived improvements to the wind forecasts. Meteorologists also perceived that the wind forecasts generated by the gTCM were consistently too low. This resulted in inter- and intra-office coordination issues with wind forecasts over inland areas and areas where wind forecasts did not match ongoing hazards. It was found that the forecasts generated in the TCV and Zone Forecast Product (ZFP) use a 15% moderated maximum wind which means the highest 15% of values are thrown out. Especially in a tropical event, those 15% represent the highest forecast wind speeds. Thus, the software program artificially lowers the produced forecast wind values.

In addition, differences showed up between the wind data that the tool loaded into AWIPS GFE and the wind radii being advertised in NHC's Public Forecast, which remains a highly visible product.

Fact: A member of the gTCM development team shared verification work presented at the 2018 NOAA Hurricane Conference that the winds generated by the gTCM were not too low and showed the gTCM results verified well using hurricane best track when compared to observations.

Fact: The development team will be revisiting and revamping the gTCM. The project timeline calls for the new tool to be internally evaluated in 2020 with a projected date in 2021 for the tool to be operational in AWIPS.

The issues associated with the roll out of the gTCM are not exclusive to this one tool. End-to-end testing must include all dissemination mechanisms (product issuance, web, Common Alerting Protocol, iNWS, etc). The NWS currently does not have a system that is built this way. The problem is compounded in the tropical program in that collaboration between National Centers and WFOs can only take place using the operational forecast grids. There is no way to assess National Center-to-WFO collaboration in a test environment.

To address this issue, the leadership of the NWS tropical program drafted Capabilities and Requirements Decision Support (CaRDS) 17-017: AWIPS Product Test Environment Capable of Multi-Office/Center Digital Collaboration.

There is a particular need in the tropical program to have a responsive problem solving, development and test environment during tropical events. Many parts of the system are only used during actual storms which can be infrequent. When problems arise, it is extremely difficult to get timely resolutions, and the problems can impact the agency's ability to message the event and lead to a degradation of products and services. The lack of robust software testing and evaluation prior to field deployment was noted in Finding and Recommendation 13

as well as Finding and Recommendation 18 of the *August/September 2017 Hurricane Harvey Service Assessment.*

Fact: In 2018, local WFOs implemented the new gridded TCM (gTCM) tool on an experimental basis to run in parallel with the legacy TCMWindTool for the 2018 Hurricane Season. The legacy TCMWindTool was used by all WFOs impacted by Hurricane Florence, while the newer gTCM was used as the primary tool for generating wind forecasts during Hurricane Michael.

Fact: The AWIPS code "check in" process recommends that software changes in AWIPS be coordinated at the NOAA Hurricane Conference two seasons before implementation.

Fact: The agency did not follow either of the known testing processes with the implementation of the new gTCM tool. A WFO MIC commented, "slow down on the fixes and patches; once things are stable let them ride for a year." However, other comments received from a senior NWS National Center official revealed that "As an agency we seemed to have accepted a two-year lag between requirements and operationalization. This is not good, certainly not the nimble organization that is needed to respond quickly to the needs of our users and to necessary advances identified internally."

Finding 64: The NWS does not have a formal testbed process for testing changes to tropical program software.

Recommendation 64: The NWS should use the NWS Operations Proving Ground to develop a tropical testbed for testing new or updated WFO tropical software. The testbed must have the ability to run parallel operations during an event, but with no risk of interfering with operations. This system could be the focal point for testing, validation, or modifications. If the tropical program had such an end-to-end system, training scenarios could easily be run on a local, regional, and national scale.

Finding 65: The NWS needs to allow for a sufficient period of operational testing and experimental use before new software is declared operational.

Recommendation 65a: The NWS needs to follow the AWIPS code "check in" process for implementation of new or experimental software releases. Any new or experimental software should be tested in parallel to the operational system before it is implemented or approved for operational use.

Recommendation 65b: NWS should use the following best practice, as outlined in the 2011 guidance on www.testbeds.noaa.gov and currently used by several of the NOAA Testbeds and NWS Operations Proving Ground to follow a deliberate, repeatable process for developing, testing, and transitioning to operations. Similarly, the process described in NWS Directive 10-102 outlines the dissemination and evaluation process, along with a defined mechanism for customer feedback.

Finding 66: The national test conducted each spring involving national centers, regions, and local offices for the tropical program falls short of the needed true end-to-end testing technique as it does not include the testing of AWIPS product generation and NWS dissemination.

Recommendation 66: The NWS should conduct a collaborative national end-to-end test of a tropical cyclone scenario pre-season, which includes all relevant national, regional, and local offices, and includes NWS dissemination and AWIPS product generation to ensure agency readiness. There is precedent for conducting end-to-end tests; this has proven to be a valuable component of the tsunami warning program's system readiness.

Finding 67: The forecasts generated in the TCV and Zone Forecast Product (ZFP) use a 15% moderated maximum wind which means the highest 15% of values are thrown out. Especially in a tropical event, those 15% represent the highest forecast wind speeds. Thus, the software program artificially lowers the produced forecast wind values.

Recommendation 67: The issue of the AWIPS software throwing out the highest forecast wind speeds in the TCV and ZFP text products needs to be addressed.

3.4.3. Critical Weather Day (CWD)

The Forecast Application (e.g., WWA map, point-and-click forecast) on weather.gov only displayed the SSWW for one zone in each affected CWA during Hurricane Florence and Tropical Storm Gordon. A trouble ticket was opened on this issue following Tropical Storm Gordon. NCO Software Development Branch (SDB) accelerated a fix for this issue in advance of Hurricane Florence. The fix was successfully tested on September 10 but not implemented because there was a CWD designation in effect.

Fact: During Hurricane Florence, the CWD designation on September 10, 2018 prohibited the installation of a crucial fix to the SSWW display. NWS Directive 10-2203 dated June 22, 2018 outlines the guidelines for the initiation process and declaration of a CWD.

Fact: The CWD declaration during Hurricane Florence lasted many weeks after landfall due to flood warnings in effect. This period was about 25 days from the onset of Florence to the recession of flood waters. Toward the end of this period the operational pace had slowed and system preventative maintenance (which is not possible during the CWD) may have improved service.

The NWS is still without a mechanism to ensure that fixes this crucial are communicated within NCO and allowed to be considered for implementation or accelerated prior to a CWD. This means that the NWS's most accessible web-based dissemination tool, the Forecast Application (e.g., WWA map, point-and-click forecast) on weather.gov did not alert users about a life-threatening hazard even though a tested fix was available.

Feedback from NWSH was that CWD designations are enacted to maintain stability in advance of major events.

Leadership at the AWIPS Program Office indicated the number of changes that can and should be made within AWIPS is constrained during a CWD. This limits the corrective actions that NCF, or other support personnel, can take without approval by the OCOO. When a waiver to the CWD is requested, it must go through the AWIPS Program Office and be presented to the OCOO, while acknowledging the associated risks. Until these actions are taken, the NCF (or other support personnel) are not authorized to change system/software configuration nor the software itself. This restriction was especially evident during Florence when several waivers were requested.

Finding 68: At the end of the multi-week CWD period, due to the extended period of inland flooding in Hurricane Florence, the overall operational pace had slowed as other threats waned. The multi-week CWD designation blocked implementation of bug fixes for critical software such as that used to create HTI graphics.

Recommendation 68a: The process to prioritize urgent software patches needs to be revisited to capitalize on these short-term opportunities in cases of multi-day or even multi-week CWD declarations to allow implementation of bug fixes to improve services.

Recommendation 68b: The NWS should develop an efficient, repeatable software and system testing and implementation process. This should limit the need for CWD waiver requests to perform software fixes or modifications.

3.4.4. Network Control Facility (NCF) Support

The team received feedback that during Hurricanes Florence and Michael, while the NCF did provide some support for tropical software issues (mainly during the daytime hours), it was unable to provide a full level of support to local offices. This includes the inability of NCF staff to provide support for standard and baseline GFE tropical formatter issues.

The team was told the tropical capability in AWIPS software is fully baselined within AWIPS and therefore falls within the contractual obligation of the NWS NCF to support. Only a small number of issues that are called into the NCF during a tropical cyclone event deal with local site configurations or non-baseline applications.

The NCF and AWIPS Support and Maintenance Team received some training in tropical software prior to the 2018 Hurricane Season.

Fact: NCF has participated in tropical software training only twice since 2014.

Fact: The team received the following information from the AWIPS Field Support & Infrastructure Team regarding NCF support for the tropical program:

> *The AWIPS prime contract with the AWIPS NCF [Network Control Facility] covers 24x7 support of all baseline AWIPS applications. This includes any local site configuration overrides of those baseline applications. The NCF will assist on a best effort basis to support non-baseline applications.*
>
> *The AWIPS program completed a knowledge transition process with the NCF and AWIPS Support and Maintenance team prior to the start of the 2018 Hurricane Season. The 2018 Hurricane season is the first tropical season where the AWIPS prime contract had the lead with respect to troubleshooting and diagnosing issues with the tropical software. The transition process included training on the fundamental tropical operations and tool usage. In addition, troubleshooting procedures were produced to assist the NCF in diagnosing any tropical issues. In FY19, the AWIPS program established an Annual Operating Plan milestone to provide additional information/training on troubleshooting and problem detection techniques. This work is currently underway as a process improvement.*
>
> *The NCF did not always consider trouble tickets from the impacted sites (WFOs or NHC) to be of a critical nature. Therefore, this delayed the response time of the NCF in troubleshooting, diagnosing, and restoring capability to the operational sites. The AWIPS program adjusted the Service Level Agreements associated with the AWIPS prime contract on September 1, 2018, to address the assignment of priority to trouble tickets in an effort to better define how trouble tickets should be handled when an operational site is under a watch, warning, or advisory.*
>
> *The AWIPS prime contractor showed limitations in their ability to troubleshoot and diagnose issues with the tropical software within the AWIPS baseline.*

To supplement the support NCF provides, a NWS Forecast Decision Training Division (FDTD) employee and some field personnel with expertise provide support during tropical cyclone landfall events as voluntary collateral duties. These NWS employees are consistently asked to perform these voluntary collateral tasks during tropical cyclones, sometimes in the middle of the night. As a consequence, these individuals may be a single point of failure. In addition to these volunteers, the employee assigned as IDSS Coordinator for Hurricane Florence was asked to provide technical support to offices running GFE software. This aid was well outside the scope of his assignment. Finding and Recommendation 24 of the *October 2016 Hurricane Matthew Service Assessment* is relevant to this issue.

Fact: The NCF has a contractual obligation to fully support the tropical program (software) and provide 24x7 support to WFOs during tropical events, similar to all other NWS operations.

Finding 69: The NCF showed limitations in its ability to troubleshoot and diagnose issues with the tropical software within the AWIPS baseline software structure; therefore, WFO tropical operations are effectively being supported by a small number of key NWS field experts who provide this support as a voluntary collateral duty.

Recommendation 69a: The NWS should implement a robust reporting system to gather occurrences of where NCF is not fulfilling its obligation to fully support 24x7 operations for baselined tropical software in AWIPS. Based upon findings from these investigations, the NWS should implement enhanced monitoring and responsiveness of the contractor and, if necessary, apply curative actions to ensure NWS field operations are fully supported 24x7.

Recommendation 69b: As part of a rigorous testing scheme, NCF staff should be required to take training for any software changes deployed as part of the NWS tropical program.

3.4.5. WFO Service Backup

Per staff at SRH, WFO Jacksonville was chosen to provide service backup for WFO Tallahassee since it is the primary backup site for the office.

Fact: All Southern Region offices provide backup with each of their primary supporting offices at least once per year to help ensure proficiency as well as including lessons learned and better knowledge of the challenges associated with backup. In addition, staff at the primary backup site (WFO Jacksonville) has greater familiarity with their primary backup site's (WFO Tallahassee) core partners and would theoretically provide better IDSS if needed.

Fact: A conference call was held the day before Hurricane Michael's landfall which included SRH, WFO Jacksonville, and WFO Houston with the anticipation that WFO Tallahassee's network would go down during Hurricane Michael's landfall. The decision was made at that time to have WFO Jacksonville provide backup for WFO Tallahassee for the storm. The use of a tertiary backup site for service backup (in this case WFO Houston) is more complicated because it requires more coordination and configuration, especially for hydrologic and AWIPS related items.

Fact: On the day of Michael's landfall, WFO Jacksonville was responsible for issuing multiple tornado warnings in their own CWA. In addition, they had a significant increase in their workload due to storm surge inundation along with widespread river flooding.

Fact: As the service backup for WFO Tallahassee, WFO Jacksonville staff had to handle the impacts of the eye coming on shore in WFO Tallahassee's CWA which included the issuance of several Extreme Wind Warnings.

Fact: WFO Jacksonville deployed forecasters to provide on-site IDSS to officials in the northwestern section of their CWA.

Best Practice: SRH provided two forecasters to WFO Jacksonville prior to the onset of Hurricane Michael to assist with service backup operations.

During Hurricane Florence, WFO Wakefield provided service backup for WFO Morehead City for several days after landfall. Secondary backup between WFO Wakefield and WFO Morehead City was enacted for the first time in 2018. Following the storm and during the assessment interviews, WFO Morehead City's emergency management partners noted that WFO Wakefield did not have familiarity with the hydrology specific to WFO Morehead City's CWA. WFO Morehead City staff noted it's difficult for a neighboring coastal office to provide backup during a high impact event, due to the likelihood they are seeing significant impacts as well. NWS ER offices do not have a tertiary backup.

WFO Morehead City was isolated by flooding during Hurricane Florence, but did not need service backup. Service backup was initiated in the days after landfall so that WFO Morehead City staff could address storm-related damage to their homes and assist with storm damage surveys. The WFO continued providing services, however, a vulnerability was exposed during Florence due to the office being isolated.

Best Practice: A number of ER and SR WFOs performed backups after the storm; this backup allowed staff to recover, check on family, conduct storm surveys, etc.

Finding 70: Feedback from WFO Jacksonville said that providing service backup on the day of Hurricane Michael's landfall pushed both forecast staff and the AWIPS system to its limits. WFO Jacksonville continued to provide service backup for WFO Tallahassee for a week or more after the storm. Per WFO Jacksonville feedback, once the storm had exited north Florida the service backup was no longer an issue for staffing or systems.

Recommendation 70: NWS should use non-adjacent WFOs, and those that are not being directly impacted by the tropical cyclone, to provide backup during high impact tropical cyclone events. Other options should be considered as well. For example, a pre-configured fully functional COOP site, perhaps the ROC, could be used.

Fact: NWS WFOs generate forecasts and watch/warning/advisory products from AWIPS using an assortment of tools that interface with AWIPS. While accessible within AWIPS, some tools are not fully integrated within the AWIPS framework making it difficult to standardize their configuration. For example, hydrology applications are configured locally and are historically difficult to standardize in their current state. This makes service backup tedious and time consuming, and requires advanced notice of service backup needs to test and update.

Finding 71: In a tertiary backup configuration, there are known configuration limits with certain parts of the AWIPS software (e.g., RiverPro, climate) running at the backup site. This prevents the tertiary backup site from providing full backup support.

Recommendation 71: The NWS should accelerate its phased approach work to fully integrate all forecast and watch/warning/advisory production into a standardized configuration setup to facilitate continuity of operations.

3.4.6. NWS Network Failures

NWS Tallahassee reported that their primary network (OneNWSNet) went down during tropical storm conditions, and the outage persisted for a week. As a result, staff at the office were no longer able to do any work within AWIPS (e.g., grid production or issuing products or warnings) and used full service backup for these portions of their duties.

NWS Tallahassee did have access to the FSU wireless network, which remained in service throughout the storm. They were able to use this network to create briefings for core partners and engage on social media.

Staff at NWS Tallahassee commented that Virtual Satellite (VSAT) "did not perform as advertised." The office found they were unable to issue forecasts or warnings while VSAT was activated. In addition, there was an issue with gridded data not being disseminated which led to one IDSS briefing being compiled with "old data." Per the SR Systems Operations Division, local offices are only getting around a 64K connection when having to deploy VSAT. It "doesn't cover what is needed" as backup internet at the offices. Finding and Recommendation 33 of the *Hurricane Irene, August 21-30, 2011 Service Assessment* also identified issues with VSAT and its effect on field operations.

Per the NWS Office of Dissemination, the current network backup system (VSAT) has technology that dates back to Hurricane Katrina (2005). VSAT is a T1 connection with dedicated space segment on the bandwidth. Every office using VSAT must split the connection. Local offices were getting around 1.5 megabytes of speed with the current system.

Fact: Backup network hardware, or network redundancy (e.g., use of cable modems or DSL) was removed from most local WFOs in 2015 and 2016. Some NWS offices (e.g., regional offices and NCEP centers) still have network backups, but most local WFOs do not.

Fact: In October 2019, the NWS Office of Dissemination announced to the NWS Regions that the remainder of the backup network hardware (secondary terrestrial fiber network backup circuits) at WFOs and RFCs were scheduled to be disconnected in FY19, resulting in a cost savings of $1.4 million annually to the NWS.

Fact: NWS is moving forward with an upgrade to the VSAT system. This new system would provide a 25 megabits per second download and three megabits per second upload at every site. The contract has been awarded and meetings are underway with the vendor (Hughes) for

the design and test phase. The NWS is planning to begin test installations in the first quarter of FY20.

Supporting core partners during high impact events is the cornerstone for executing IDSS in a Weather-Ready Nation (WRN). The communications infrastructure at local field offices is not presently built to reliably maintain support of core partners during natural disasters. Continuity of Operations (COOP) plans require Primary Mission Essential Functions be maintained. To meet WRN objectives it is crucial that local offices maintain event-driven IDSS communication with EMs, with whom they have built trust-based relationships, during critical events. To meet this goal, local office communication infrastructure must have robust backups able to perform in adverse conditions, such as tropical cyclone events.

Fact: The NWS network (OneNWSNet) failed at WFO Tallahassee during tropical storm (sub-hurricane) conditions.

Fact: The wireless network at the co-located Florida State University remained in service throughout Hurricane Michael.

Fact: The network backup provided to WFO Tallahassee, VSAT, failed to provide the function needed for WFO Tallahassee to maintain operations during Hurricane Michael. The office was unable to monitor observations or create forecast products in AWIPS.

Finding 72: Despite the OneNWSNet outage, WFO Tallahassee diligently ensured IDSS continuity (e.g., social media, email briefings to core partners, etc.), by using the Florida State University wireless network.

Recommendation 72: The NWS must ensure that a chosen upgrade to the network backup system (e.g., newer, enhanced VSAT system) meets field requirements for IDSS functionality when the primary NWS network goes down during major events.

3.4.7. Use of IDSS Tools and IT Hardware in Low Bandwidth Situations

Staff members at WFO Tallahassee had to use their personal laptops to complete their duties once the primary network (OneNWSNet) went down. They reported that office laptops were “locked out” because of issues with the NOAA/NWS security software Safeboot. In addition, WFO Tallahassee staff were not able to log into the office computers using their Common Access Cards (CAC) due to the failure of the NWS network and backup. Staff members had to come up with backup passwords in order to use their office computers.

NWS offices have difficulty providing IDSS using standard NWS IDSS tools (e.g., event-related webinars, NWSChat, video teleconferencing, tropical program specific software such as HurrEvac, and AWIPS thin client) during low bandwidth situations.

The Incident Meteorologist (IMET) program is built around meteorologists that consistently work in low bandwidth situations. The NWS Fire Weather program leadership has devised ways of operating in these situations that could be adopted by the IDSS DR program.

Fact: The NWS is unable to use now-customary IDSS tools that require robust communications (e.g., event-related webinars, NWSChat, video teleconferencing, tropical program specific software such as HURREVAC, and AWIPS thin client), to provide support to core partners during low bandwidth situations (following network failures) such as tropical cyclone events.

Fact: Once OneNWSNet went down, WFO Tallahassee personnel were not able to log into office desktop PCs or laptops; they had to resort to using personal laptops or a password login for PCs. In addition, due to the limited number of government laptops available in the office, WFO Tallahassee personnel would not have had enough laptops to use without their personal laptops.

Finding 73: Staff at WFO Tallahassee experienced significant issues using government-issued laptops once the OneNWSNet failed. To get around these issues, they used their personal equipment to access and work through the Florida State University network.

Recommendation 73: NWS should develop secure configurations that permit easier access to office desktop computers and laptops using wireless networks (when available) during emergencies.

Finding 74: The hardware NWS staff are required to use limits their ability to perform effective IDSS during low bandwidth situations that often occur during tropical cyclone events and when they are deployed.

Recommendation 74a: WFOs should have procedures to check all systems, including mobile hotspots, that a deployment-ready forecaster will use before each event if not more often. NWS should develop a deployment-ready checklist for each office before each event. This checklist could be best used by the Information Technology Officer and Electronic Systems Analyst for each WFO. Each ROC can help develop checklists.

Recommendation 74b: The NWS needs a cohesive plan to meet the remote IT needs for dedicated onsite IDSS during tropical events. This plan could leverage the best practices from the IMET program.

3.4.8. Issues with WSR-88D

The KEVX-88D (Eglin AFB) maintained operations during Hurricane Michael; however, the connection was unstable. If the connection failed, there would have been no radar sampling of the core of Hurricane Michael as it made landfall. The data from KEVX-88D were used to aid analysis of landfall intensity for Hurricane Michael.

Fact: During Hurricane Michael, the Tallahassee radar (KTLH-88D) experienced intermittent outages. In addition, WFO Tallahassee lost its primary (OPSNet) connection. KTLH-88D 4G backup communications were degraded. The Radar Operations Center was monitoring the 4G issues prior to the event and worked with Verizon and the WFO to restore the degraded 4G comms during the hurricane. Verizon flagged the KTLH-88D data as priority data since cell phone traffic was high.

Fact: WSR-88D backup communications are in place for every radar using commercial telecommunications service. This service is tested for readiness on a quarterly basis. The NEXRAD Radar Operations Center monitors telecommunication services prior and during all expected severe weather events to ensure high availability.

Fact: The electronics staff at WFO Tallahassee stated that the radar 4G backup is tested quarterly.

Finding 75: Only one WSR-88D provided adequate sampling of the core of Hurricane Michael at landfall.

Recommendation 75: The NWS should examine more resilient communication and network alternatives to provide backups during high impact events like Hurricane Michael; providing these resilient backups also supports the relevant goals and objectives outlined in the 2018 - 2022 Department of Commerce (DOC) Strategic Plan:

> Strategic Objective 2.3: Strengthen Domestic Commerce and the U.S. Industrial Base. Specifically, to "deliver data services, thus improving the public's ability to visualize and leverage our data."
>
> Strategic Goal 3: Strengthen U.S. Economic and National Security references states that we "share accurate weather information" along with Strategic Objective 3.3: Reduce Extreme Weather Impacts that will "enhance our long-term observation capabilities and infrastructure that directly inform understanding of weather variability, extreme events, and ecosystem processes."

KLTX (Wilmington, NC) WSR-88D has tree blockage along many radials. This blockage greatly impacts 0.5 and 0.9 degree scans. This limitation becomes an operational and media issue. The neighboring radars are too high up and beam width too wide for effective low-topped tornado detection. This issue was noted in Finding and Recommendation 29 of the *Historic South Carolina Flood of October 1-5, 2015 Service Assessment*.

In addition, the KLTX radar was down for 12 hours due to communication issues, which also impacted warning decisions. Finally, the Wilmington WFO is not co-located with its Next

Generation Weather Radar (NEXRAD), which makes it more susceptible to communication issues. Backup radars are located in Morehead City, NC, Charleston, SC, and Columbia, SC.

Fact: The KLTX (Wilmington, NC) WSR-88D has tree blockage among many radials.

Fact: The NEXRAD Radar Operations Center contracted a study (completed in 2016) to examine the tree blockage issue at the KLTX WSR-88D site. It was determined that cutting the trees or raising the tower higher than 30 meters is not possible. Moving the radar to another location is the most feasible solution.

Finding 76: The solutions laid out in the NEXRAD Radar Operations Center study for the issue of tree blockage along radials at the KLTX WSR-88D site have not been implemented.

Recommendation 76: The NWS should implement the solutions provided in the NEXRAD Radar Operations Center's report to resolve the KLTX blockage issue.

3.4.9. Observational Networks

Similar to other recent tropical events, numerous FAA Automated Surface Observing Systems (ASOS), county-run Automated Weather Observing Systems (AWOS), as well as NOS wind sensor stations failed early in Hurricane Michael and were unable to record data in the core of the storm. These sites failed due to a combination of power outages, communication failures, and damages to the site.

Fact: A private company placed an anemometer at Tyndall AFB that recorded three-second sustained winds of 130 mph after NWS observational infrastructure failed (telecommunications or otherwise).

Fact: Numerous FAA ASOS and individually owned AWOS stations failed with wind gusts well under 100 mph. The sensors and equipment were designed for and were likely up and running during higher winds, but the telecommunications failed well below that threshold.

Finding 77: Data from non-NWS observational networks (e.g., the University of Georgia Automated Environmental Monitoring Network and the previously mentioned private company) were consistently recorded under tropical cyclone conditions.

Recommendation 77: The NWS should continue working through the NWS National Mesonet Program to expand partnerships with the broader weather enterprise and further expand observational networks (including data for both wind and water level), which can remain operational during tropical cyclones.

Finding 78: There is no standard reference point for collecting wind observations.

Recommendation 78: The NWS should develop a standardized and automated method to normalize wind observations to 10-meter AGL elevation height.

3.4.10. NOAA Weather Radio (NWR) Communications

Fact: The NWR Panama City site failed during Hurricane Michael and was still down two months after Hurricane Michael's impact. The communication line was down to NWR Panama City.

Fact: NWS SRH completed a study to identify factors that contributed to the two-month outage of NWR Panama City. The first factor was that the NWR tower was located on NMFS property that incurred storm damage. This limited access to the tower. The second was that the damaged NWR tower was unsafe to climb. SRH resolved the issue of access to the site and then replaced the tower to restore NWR service from the Panama City transmitter.

Fact: During Hurricane Florence, WFO Wilmington, NC was unable to broadcast tornado warnings and other pertinent information at times at all of its NWR sites. In addition, WFO Raleigh was unable to broadcast one tornado warning on NWR.

Fact: WFO Wilmington, NC management reported, "Communications were the weakest link during the whole event [Hurricane Florence]."

Fact: A few NWR sites during Hurricane Florence were also flooded and lost power, and some of the NWR backup power generators ran out of fuel.

Fact: Backup offices have no way to send NWR broadcast signals to NWR sites.

Fact: Per the NWS Office of Dissemination, the NWS does not have backup for NWR transmitters, it is a "legacy" point-to-point connection. This deficiency can create a problem for backup offices connecting to NWR transmitters. The NWR system still uses analog technology that will be obsolete and not cost sustainable in two to four years.

Finding 79: There were multiple NWR communications issues throughout both hurricanes such as transmitters being unable to broadcast warnings and not having a robust backup in place for the transmitters. These issues persist primarily due to the analog point-to-point connection that is present at the site.

Recommendation 79: The NWS needs to investigate and invest in acceptable backup technologies for NWR. A robust backup system for NWR (including for backup offices) must be developed, which includes the priority of service response time, if the agency wants to continue using NWR as a primary communication tool.

3.4.11. System-Generated Forecasts on the Periphery of the Storm

Wording in WFO forecast products periodically switched back and forth between “tropical storm conditions possible” and “hurricane conditions possible” on the edges of the storm impact zone. For example, WFO Charleston, SC in its 3:31 p.m. EDT Coastal Waters Forecast issued on September 11 for zone 350 (south Santee River to Edisto Beach, SC out to 20 nautical miles), stated “tropical storm conditions possible” for Wednesday night, September 12. The 6:30 p.m. EDT issuance that evening upgraded the forecast to “hurricane conditions possible” and continued this in the 10:21 p.m. EDT issuance. In the 10:45 p.m. EDT issuance, the Wednesday night forecast changed back to “tropical storm conditions possible” and then reverted to the wording of "hurricane conditions possible" for Friday, September 14. The North Carolina EMD reported that “ the winds in the forecast didn’t match the tropical storm warnings that the Raleigh WFO was issuing.“ These and other examples were brought up by several core partners (media and emergency management) for both Hurricanes Florence and Michael where they mentioned that the inconsistency from forecast to forecast release caused some confusion with NWS core partners and the public.

Finding 80: Small changes in the NHC probabilities of tropical storm or hurricane conditions can result in significant changes to impact wording in the WFO text products, even when wind or wave forecasts remain unchanged. These changes can result in significant post production editing of text forecasts at the WFO level to maintain consistent messaging.

Recommendation 80: The NWS needs to employ a multi-disciplinary approach to identify the possible causes (e.g., grid formatter) that result in wording being removed or changed from “tropical storm conditions are possible” to “hurricane conditions are possible” in order to identify a path forward to resolve this inconsistency between forecast packages.

3.5. Training

3.5.1. Tropical Operations Training and Resources

The NWS has one GS-13 employee with the FDTD who is focused on tropical training development. This individual is often tapped to develop AWIPS/GFE tropical and non-tropical programs for field use/integration. This person is often tasked to develop complex tropical training in compressed timelines along with serving as an AWIPS developer, GFE troubleshooter, and a 24x7 contact during active tropical events.

Additionally, a small group of personnel at local WFOs and national centers are routinely solicited to make significant contributions to the national tropical training program on a voluntary basis. These same resources/personnel are used year after year to make major contributions to the training program (e.g., updating or creating training modules) as a voluntary activity in

addition to their normal duties. This group is sometimes asked to deal with training and software issues that arise during a hurricane event and may be asked to do this several times during a season. These volunteers help the IDSS coordinator, National Centers, and WFOs facilitate getting NWS products out to a high risk community during a hurricane event.

Fact: Normal practice at tropical WFOs is to hold an internal tropical operations workshop or staff training in late spring or early in the hurricane season.

Best Practice: WFO Tallahassee held a series of internal, local office, tropical operational workshops, with the last one held only a few weeks before Hurricane Michael, largely due to an influx of new employees at the office. The WFO had seven new employees at the time of Hurricane Michael. These workshops were cited as essential in getting employees prepared for the storm.

Fact: All new NWS meteorologists are given the Radar Applications Course (RAC), which includes several weeks of remote training and a mandated one week course in residence. The NWS uses dedicated contract positions to develop and facilitate the RAC. Unlike the radar training program, tropical operations training development does not have dedicated contract support.

Finding 81: NWS is not putting enough resources toward tropical operations training development.

Recommendation 81a: The NWS should add additional resources, specifically a dedicated position, that is dedicated to aid and enhance tropical training development.

Recommendation 81b: NWS meteorologists should receive pertinent, simulation-based training that can be executed within the limitations of the operational shift work schedule for each tropical season, recognizing they will not receive on-the-job proficiency due to the sporadic nature of tropical cyclones. A similar approach to the RAC should be employed for tropical hazards, where pertinent, based on the employee's mission requirements.

The NWS provides AWIPS system test and training cases to local offices via VLab. Local offices are responsible for running these test cases. As of May 2019, there are 13 cases available. Of these 13 test cases, 8 are available to the Gulf and East Coast WFOs. Staff from a local NWS office can choose a case that pertains to their area, and use it for software testing or for building operational experience or simulation-based training at their local office.

These AWIPS test cases can be used by management and tropical focal points at local offices to train staff. At WFO Mobile the Science Operations Officer and/or a designee oversees each staff member going through an entire advisory process with all assigned tasks. One MIC noted, "If not for this [AWIPS test case], we would be missing a vital part of our seasonal readiness. It makes a difference!"

Staff from one WFO affected by Hurricane Florence commented that they were unable to run the tropical simulation prior to hurricane season. They stated the simulation is outdated and does not work well. Some WFOs have found issues with loading the software properly, or problems with the software running appropriately.

Finding 82: Some local NWS offices develop GFE operations training for forecasters using the test cases available on the NOAA VLab; however, this practice is inconsistent across offices.

Recommendation 82: More robust tropical operational (test case) training needs to be developed for AWIPS II. The NWS should examine the existing library of test cases to determine their effectiveness in delivering effective simulation based training.

Finding 83: NWS does not have a testbed to conduct testing and evaluation of tropical procedures, products and training which focuses on local office tropical operations.

Recommendation 83: The NWS needs to follow the model of severe weather training and convective warning operations to develop a similar enterprise solution for NWS tropical training and software testing. This structure would include National Centers, NWS Regions training personnel, as well as WFO and RFC experts as members of the team who jointly develop the training program, meet on a regular schedule, and follow a codified and structured process for developing tropical training. The planning and training should be repeated annually and available for use before the start of the tropical season.

3.5.2. Tropical Messaging Training

The spectrum of weather phenomena inclusive of tornadoes, extreme wind, storm surge, flooding, high surf, and rip currents, account for hurricanes being one of the most destructive natural hazards that impact our nation. The complexity of messaging each of these threats while compiling an accurate overall statement of risk elevates the necessity for clear IDSS messaging.

Hurricanes garner the attention of a broad range of partners demanding vast services ranging from highly technical to support public infrastructure engineers, to more simplistic to support journalists and the general public. Thus the hurricane program employs a multitude of unique products and services. Not all products are appropriate for all partners; it is imperative the NWS forecasters delivering IDSS understand the nuances of these products and how best to address them, if at all.

The return rate of frequency for a hurricane impacting a WFO's area, and more-so a local community, is relatively rare. In some cases, hurricanes can be a once-in-a-career event for a forecaster or emergency manager. These low frequency-high impact events necessitate a constantly evolving hurricane program to meet emerging needs of partners and address

lessons-learned from past events. Most recently, NWS tropical forecast products have evolved to include aspects of deterministic and probabilistic expressions to convey the forecast confidence and uncertainty involved for each event.

These factors, when combined, underscore the need to develop and maintain a robust training program to ensure NWS forecasters and partners have a clear understanding of the latest products and services that are available for tropical events. Such a training program must include active exercises to allow forecasters to interact directly with partners to practice effective messaging skills given the complexity of IDSS during tropical events.

Core partners stated that active exercises that bring together multiple agencies inclusive of the NWS were critical to the success of effective messaging during Florence and Michael. For example, partners from WFO Mobile (Port of Mobile and U.S. Coast Guard) mentioned the "Industry Day" WFO Mobile participates in every spring that 50 to 60 NWS core partners attend. The NWS briefs its products and services and the Coast Guard briefs its seasonal changes to hurricane plans. WFO Mobile held an IWT and tropical workshop with core partners in May 2018 prior to Hurricane Michael and hosts this event every May. An annual COOP exercise is held at NOAA's Disaster Response Center in Mobile where each agency runs through their hurricane plans.

The IWT approach at the state and local levels can be key to providing this total "weather enterprise" team understanding to key messaging. As an example, pre-seasonal meetings are a good way to help partners understand items such as 10 percent exceedance on storm surge products (reasonable worst case scenario), time of arrival graphics, cone of uncertainty, etc. These pre-seasonal collaboration meetings can also be a conduit for WFOs to hear from core partners about which messaging challenges and required lead times (for hurricane evacuation clearances, etc.) they can expect going into the next tropical season.

Best Practice: WFO Columbia held an IWT in the spring prior to Florence focusing on understanding terminology with hydrology and flooding.

Best Practice: Local WFOs in the region heavily impacted by Hurricane Michael including WFOs Mobile, Tallahassee, and Jacksonville, conducted extensive training and interaction with their core partners in the spring and summer prior to Hurricane Michael. This training included tropical workshops, IWT meetings, and hands on exercises. NWS core partners provided positive feedback that the training and interaction helped them prepare for the storm.

Best Practice: Interactive, IDSS-oriented, exercise-based "roadshow" type training programs were given positive feedback by meteorologists in preparing them to work Hurricane Michael. Many employees cited hands-on training opportunities such as the NWS SR IDSS Roadshow as instrumental in preparing them for the event. One meteorologist at WFO Tallahassee who was deployed to Bay County Emergency Management stated that the SR IDSS Roadshow greatly helped him prepare for his on-site deployment.

A formal effort to address training issues regarding effective messaging was undertaken by the NWS through the development of the EHM Course. Meteorologists at several WFOs said the EHM Course has proven "critical" in preparing them for messaging during tropical cyclones. The EHM Course has been a valuable training tool for a number of meteorologists and hydrologists who have been tasked with providing support for tropical cyclones. This in-person course provides hands on experience that cannot be replicated through alternate training methods such as Commerce Learning Center modules or remote training. The course also fosters trust, understanding and stronger relationships between meteorologists and hydrologists in the field and staff at the NHC.

Fact: The EHM course evolved from an informal effort by volunteers to create a hurricane messaging course. This first iteration, presented by volunteers in 2012, was held for participants in the NWS pilot projects. The course has evolved to now being supported by OCLO as a national level training effort with involvement by COMET. The EHM course was held at least once every year (some years twice) from 2013 through 2019. Each course has had approximately 15 meteorologists and hydrologists attend, but is limited to no more than one student per NWS office at a time. Similar to other NWS training courses, such as those for radar operations, the course content is delivered primarily through simulation-based training focused on tropical operations and its specialized terminology and scientific principles.

Fact: OCLO sent surveys to EHM course alumni following the 2017 tropical season to assess the course's role in improving the forecaster's ability to provide effective messaging for tropical cyclones/hurricanes impacting the U.S. that year (Hurricanes Harvey, Irma, and Maria). The results from these surveys were shared with all of the NWS regions and at the NOAA Hurricane Conference in late 2017 and early 2018. Survey results indicated the course was very well received by attendees and improved their messaging skills used in IDSS for tropical events.

Fact: The state meteorologist in Alabama and meteorologists at WFO Birmingham stated that none of them had received formal NWS tropical messaging training (e.g., the EHM course) prior to Hurricane Michael. Meteorologists from WFO Birmingham (as the state liaison office) were responsible for briefing state level partners in Alabama. The WFO Birmingham staff stated that their forecasters needed significant training on tropical messaging as well. In 2019, following Florence and Michael, a state meteorologist from North Carolina and the WCM from WFO Birmingham were able to attend the NWS EHM Course.

Fact: The IMET program mandates in-person attendance at the IMET training course once every three years and virtual attendance at a course on the other years as a requirement for maintaining certification. The program sets a precedent of maintaining a high level of competency in on-site IDSS readiness. It sets a good agency example for how messaging training should be conducted on a national level.

Finding 84: The EHM has proven effective at providing tropical messaging training to a subset of NWS meteorologists and hydrologists, however resources remain limited.

Recommendation 84a: The NWS should maintain the EHM Course, and continue to prioritize attendance based on the attendees' roles in the tropical program (e.g., those responsible for messaging such as new managers and focal points with a role in the tropical program and deployment-ready staff) with the understanding that not every meteorologist or hydrologist that works in an office with tropical program responsibilities will be able to attend due to limited resources. EHM Course attendance should also be prioritized for those meteorologists working at National Centers, and for non-NWS state meteorologists where possible.

Recommendation 84b: The NWS should look into an additional, short, virtual version of the EHM course to serve as refresher training for staff that have attended the course and to capture larger portions of the staff at local offices that are unable to attend the course. This virtual class would supplement but not replace the classroom portion.

Finding 85: There are significant differences in philosophies and future goals for the tropical training program within NWS program areas charged with forecaster training and development programs.

Recommendation 85: The NWS should evaluate the current portfolio of tropical program training to identify strengths and weaknesses or gaps in the existing program inclusive of in person evaluation of existing courses, desktop exercises, and applicability of NWS training to forecaster readiness in real events.

Training for broadcast meteorologists in messaging NWS products remains a challenge. This is often compounded by limited budgets of small market TV stations. Smaller markets have a lot of turnover with many meteorologists from non-tropical areas. A broadcast meteorologist in Tallahassee stated that he had received very little training in tropical messaging. He stated an interest in training in the off-season, especially with station staff who have less experience with tropical weather.

Fact: WFO Tallahassee invites their broadcast partners to their tropical training sessions that they conduct on an annual basis.

NHC has a long partnership with FEMA providing training for NWS core partners. NHC, in partnership with FEMA's National Hurricane Program (NHP) and Emergency Management Institute (EMI), offers three one-week (L-324) training courses for local and state emergency managers from the Gulf, Southeast, and Northeast each year. These training courses teach EMs about typical NHC forecast uncertainty, hurricane hazards with a focus on storm surge, NHC products, and NHP tools that can assist EMs in evacuation decision making. Since this course began more than 25 years ago, more than 1500 EMs have participated. Within the past

decade, NHC and FEMA have also developed a three-day (L-320) state version of the course and a one-day (L-311) class that is taught at state and national hurricane conferences.

Finding 86: NWS and core partnering agencies find the discussed coursework offered by FEMA and NHC instrumental in preparing for the tropical cyclone season. Some state meteorologists and media partners in tropical cyclone impacted areas have not received any formal training on how to use or message NHC forecast and products.

Recommendation 86: NWS should work with FEMA to explore expansion of the residence or "roadshow" type simulation based training for tropical messaging to deep core partners such as broadcast meteorologists. The course should be a hybrid that fills the gap between the FEMA hurricane training that is more emergency management focused, and the NWS EHM Course that is more NWS meteorologist focused.

Best Practice: Remote video conferencing interviewing tools (including, Skype or Facebook Live) have proven beneficial for both broadcast networks and NWS in conducting interviews. Such tools provide a valuable and less intrusive way for both entities to deliver a common message to the public. The NWS has incorporated media training into some of its formal training including the EHM Course and the IDSS Deployment Boot Camp. The EHM Course participants have the opportunity to gain on-air interview experience through a partnership with the Weather Channel that conducts mock interviews during the final course exercise.

Finding 87: Feedback gathered from members of the national broadcast media indicated that they appreciate NWS participation in virtual media interviews (e.g. Skype) and feel it has been beneficial to have the local perspective that the WFO can provide. However, they also report that some NWS meteorologists are still not coming across as prepared and trained for these types of interviews. These partners suggested additional training for NWS operational personnel to effectively deliver key messages to a television audience.

Recommendation 87: The NWS should leverage existing OLCO and Regional Headquarters resources to achieve consistent quality in effectively communicating during media interviews. In addition to the IDSS Professional Competency Units (PCUs) provided in the Commerce Learning Center, WFOs and RFCs should establish local training initiatives to re-train annually on how to provide effective interviews with the media. This should include the effective use of digital platforms such as Skype and Facebook Live, where appropriate.

Appendix A: Acronyms

AFB	Air Force Base
AFD	Area Forecast Discussion
AFSO	NWS Analyze, Forecast, and Support Office
AGL	Above Ground Level
AGOL	ArcGIS Online
AHPS	Advanced Hydrologic Predictive Service
ARTCC	Air Route Traffic Control Centers
ASOS	Automated Surface Observing Systems
AST	Atlantic Standard Time
AWC	Aviation Weather Center
AWOS	Automated Weather Observing Systems
AWIPS	Advanced Weather Interactive Processing System
CAC	Common Access Cards
CDT	Central Daylight Time
CFO	Chief Financial Officer
CaRDS	Capabilities and Requirements Decision Support
CIMMS	Cooperative Institute for Mesoscale Meteorological Studies
CO-OPS	Center for Operational Oceanographic Products and Services
COO	Chief Operating Officer
COOP	Continuity of Operations
CPC	Climate Prediction Center
CRF	Contingency River Forecasts
CWA	County Warning Area(s)

CWD	Critical Weather Day
CWF	Coastal Waters Forecast
CWSU	Central Weather Service Unit
DAT	Damage Assessment Toolkit
DEM	Department of Emergency Management
DIS	NWS Office of Dissemination
DOC	Department of Commerce
DOH	Development and Operations Hydrologist
DR	Deployment Ready
ECMWF	European Center for Medium-Range Weather Forecasts Model
EDD	Enhanced Data Display
EDT	Eastern Daylight Time
EHM	Effective Hurricane Messaging Course
EM	Emergency Manager
EMD	Emergency Management Division
EMI	Emergency Management Institute
EMA	Emergency Management Agency
EMC	Environmental Modeling Center
EOC	Emergency Operations Center
ER	Eastern Region
ERH	Eastern Region Headquarters
FDTD	Forecast Decision Training Division
FAA	Federal Aviation Administration
FDEM	Florida Division of Emergency Management

FEMA	Federal Emergency Management Agency
FET	Facilities Engineering Tech
FIFS	Fully Integrated Field Structure
FIM	Flood Inundation Mapping
FIMAN	North Carolina Flood Inundation Mapping and Alert Network
FMC	Financial Management Center
FSU	Florida State University
FTE	Full-Time Employee
GEMA	Georgia Emergency Management Agency
GFC	Georgia Forestry Commission
GFE	Graphical Forecast Editor
GIS	Geographical Information System
gTCM	New (2018) Gridded Tropical Cyclone Wind Tool
HADS	Hydrometeorological Automated Data System
HEC-RAS	Hydrologic Engineering Center - Reservoir System Simulation
HEFS	Hydrologic Ensemble Forecast System
HLS	Hurricane Local Statement
HLT	Hurricane Liaison Team
HPM	Hydrologic Program Manager
HSA	Hydrologic Service Area(s)
HSU	Hurricane Specialist Unit
HTI	Hurricane Threat and Impact
HWO	Hazardous Weather Outlook

ICMSSR	Interdepartmental Committee for Meteorological Services and Supporting Research
ICS	Incident Command System
IDSS	Impact-based Decision Support Services
IDP	Integrated Dissemination Program
IMET	Incident Meteorologist
IMT	Incident Management Team
ISC	InterSite Coordination
IWRSS	Integrated Water Resources Science and Services
IWT	Integrated Warning Team
JHT	Joint Hurricane Testbed
KML	Keyhole Markup Language
KMZ	Keyhole Markup Language - Zipped File
LLM	Lowest 150 meters of dropsonde wind sounding
LSR	Local Storm Reports
MAS	Multimedia Assistance in Spanish
MDC	Mission Delivery Council
MIC	Meteorologist In Charge
MMEFS	Meteorological Model Ensemble Forecast System
MHHW	Mean Higher High Water
MRMS	Multi Radar Multi Sensor
NAVD88	North American Vertical Datum of 1988
NCDEM	North Carolina Division of Emergency Management
NCF	Network Control Facility
NCEP	National Centers for Environmental Prediction

NCO	National Centers for Environmental Prediction Central Operations
NDFD	National Digital Forecast Database
NEXRAD	Next Generation Weather Radar
NGS	National Geodetic Survey
NHC	National Hurricane Center
NHP	National Hurricane Program
NOA	NOAA Administrative Order
NOAA	National Oceanic and Atmospheric Administration
NOS	National Ocean Service
NSRS	National Spatial Reference System
NWC	National Water Center
NWM	National Water Model
NWPS	Nearshore Wave Prediction System
NWR	NOAA Weather Radio
NWS	National Weather Service
NWSH	National Weather Service Headquarters
NWSI	National Weather Service Instruction
NWSOC	National Weather Service Operations Center
NWSTC	National Weather Service Training Center
OCLO	Office of the Chief Learning Officer
OCM	Office for Coastal Management
OCOO	Office of the Chief Operating Officer
OCS	Office of Coast Survey
OEM	Office of Emergency Management

OFCM	Office of the Federal Coordinator for Meteorology Services and Supporting Research
OHRFC	Ohio River Forecast Center
OPC	Ocean Prediction Center
OR&R	Office of Response & Restoration
OWP	Office of Water Prediction
PCU	Professional Competency Unit(s)
P-ETSS	Probabilistic Extra-Tropical Storm Surge
PMDEPD	Weather Prediction Center Extended Forecast Discussion
PMDMRD	Climate Prediction Center Medium Range Discussion
PMDTHR	U.S. Hazards Outlook Product
PSH	Post Tropical Cyclone Report
QL	NOAA QuickLook Product
QPE	Quantitative Precipitation Estimate
QPF	Quantitative Precipitation Forecast
R20	Research to Operations
RAC	Radar Applications Course
RFC	River Forecast Center
RH	Regional Headquarters
RI	Rapid Intensification
RMS	Regional Maintenance Specialist
ROC	Regional Operations Center
RVD	River and Lake Summaries
RVF	River Forecast
RW	Rapid Weakening

SATCON	Satellite Consensus
SAVI	Supplemental Assistance Volunteer Initiative
SCEMD	South Carolina Emergency Management Division
SDB	Software Development Branch
SERFC	Southeast River Forecast Center
SH	Service Hydrologist
SLOSH	Sea, Lake, and Overland Surges from Hurricanes
SME	Subject Matter Expert(s)
SPC	Storm Prediction Center
SR	Southern Region
SRF	Surf Zone Forecast
SRH	Southern Region Headquarters
SRT	Seasonal Readiness Training
SSH	Senior Service Hydrologist
SSHWS	Saffir-Simpson Hurricane Wind Scale
SST	Sea Surface Temperature
SSU	Storm Surge Unit
SSWW	Storm Surge Watch/Warning
TAFB	Tropical Analysis and Forecast Branch
TCM	Tropical Cyclone Marine Advisory
TCV	Tropical Cyclone VTEC Watch/Warning
TWO	Tropical Weather Outlook
USACE	U.S. Army Corps of Engineers

USCG	U.S. Coast Guard
USGS	U.S. Geological Survey
UTC	Coordinated Universal Time (subtract 4 hours to convert to EDT)
VIIRS	Visible Infrared Imaging Radiometer Suite
VLab	NOAA Virtual Lab
VSAT	Virtual Satellite
VTEC	Valid Time Event Code
WCM	Warning Coordination Meteorologist
WEA	Wireless Emergency Alerts
WFO	Weather Forecast Office
WG/CAS	Working Group for Coastal Act Support
WG/DIAP	Working Group for Disaster Impact Assessment Plan
WPC	Weather Prediction Center
WRN	Weather-Ready Nation
WSR-88D	Weather Surveillance Radar-1988 Doppler
WWA	Watch/Warning/Advisory
ZFP	Zone Forecast Product

Appendix B: Findings, Recommendations, and Best Practices

Definitions

Best Practice: An activity or procedure that has produced outstanding results during a particular situation that could be used to improve effectiveness and/or efficiency throughout the organization in similar situations. No action is required.

Fact: A statement that describes something important learned from the assessment for which no action is necessary. Facts are not numbered, but often lead to recommendations.

Finding: A statement that describes something important learned from the assessment for which an action may be necessary. Findings are numbered in ascending order and are associated with a specific recommendation or action.

Recommendation: A specific course of action, which should improve NWS operations and services, based on an associated finding. Not all recommendations may be achievable but they are important to document. Recommendations should be clear, specific, and measurable. The team leader and Performance and Evaluation Branch will compose an action item for each recommendation.

Findings and Recommendations

Finding 1: NWS offices would likely have deployed more personnel to EOCs for onsite support if it were not for staffing shortages in the office. Additionally, some EMs did not know they could request a deployment-ready (DR) meteorologist or hydrologist for onsite IDSS during high impact events. Conversely, resources were deployed to a site where only marginal impacts were being predicted.

Recommendation 1: The NWS should make every effort to provide on-site support to an EOC where on-site support has been requested. If NWS is not capable of providing on-site support to an EOC where the support has been requested, then there should be an alternate means of engagement in place which satisfies the partner, such as reliable virtual support. Examples of virtual support include Skype, GoToWebinar, Adobe Connect, Zoom, and Google Hangouts. (Note: virtual support will only work in cases where connectivity is still up.)

Finding 2: EMs are not always making regular visits to WFOs.

Recommendation 2: Local WFOs should encourage EMs to visit their local WFOs at least once every three years. A best practice would be inviting EMs to NWS open house activities yearly.

Finding 3: The number of individuals trusted by partners varies greatly from office to office.

Recommendation 3: The NWS local offices should prioritize the "whole office" approach of core partner support. Local offices must expand the number of staff members who have trusted relationships with core partners to alleviate a "single point of failure" if that person is not there.

Finding 4: IDSS requests have increased, while resources have sometimes fallen short in supporting these requests.

Recommendation 4: NWS should look at existing models (e.g. IMETs, CWSUs, USACE) where external partners provide reimbursable funding to support non-local NWS staff member deployment on a full-time or part-time basis to address core-partner IDSS needs that cannot be met with current NWS resource levels.

Finding 5: Some WFOs (e.g., WFO Morehead City) do not have SHs despite having repeated significant flooding during high impact events in their Hydrologic Service Areas (HSA).

Recommendation 5: Staffing models must be reviewed to ensure that all WFOs affected by repeated high impact flooding prioritize an on-station SH position to provide hydrologic IDSS expertise.

Finding 6: Stakeholders need hydrologic information for locations other than the existing inventory of NWS river forecast locations. During Hurricane Florence, many of these additional locations were in tidally-influenced basins.

Recommendation 6a: The Office of Water Prediction (OWP) should expand efforts underway with the DOC Agency Priority Goal to complement other Federal agency inundation mapping datasets and enhance collaboration with federal water agencies to deliver inundation mapping that fulfills the needs of core partners beyond the current NWS inventory of inundation map locations.

Recommendation 6b: The OWP and RFCs should continue to work with NOS and the NHC to develop and demonstrate the capability to provide routine total water forecasts in the coastal zone.

Finding 7: The state of North Carolina OEM heavily used ensemble river forecasts, which were vital for state decisions. However, discussions with other users on conclusions they drew from the ensemble river products indicated the need for clarification of product limitations and additional assistance interpreting the forecast results.

Recommendation 7a: The NWS should invest resources in developing a suite of HEFS data services and derived products that serve a range of potential users.

Recommendation 7b: Leveraging the groundwork laid by the MMEFS program, the NWS should engage social scientists in producing internal and external training materials to enhance the usefulness and understanding of HEFS-derived products. This training should be included with the annual tropical training.

Finding 8: Current RFC operations use a predetermined QPF time horizon to generate deterministic forecast hydrographs for use by decision-makers. Maintaining the QPF horizon at this standard duration can undermine the IDSS messaging and effort to help communities prepare more effectively.

Recommendation 8: RFCs should be adaptable and use a proactive approach for collaborative discussions with core partners, neighboring offices, and WPC to determine the appropriate QPF duration for initialization of deterministic hydrologic models.

FInding 9: The existing AHPS web site does not present the complete hydrologic story between official forecasts based on a controlled duration of forecast rainfall (QPF), other scenarios from deterministic durations of QPF, and scenarios provided by ensemble modeling and probability of exceedance statistics. The lack of capability to provide this information continues to create confusion among the public and partners for use in decision making support.

Recommendation 9: Deterministic and probabilistic river forecasts should be displayed together on the same website. Users need the functionality to display multiple products to maintain situational awareness of current, as well as potential, hydrologic conditions.

Finding 10: Stakeholders expressed the need to know how much rainfall NWS forecasters are incorporating in their official NWS river forecast. The AHPS hydrograph page does not display this information.

Recommendation 10: The existing requirement for the display of QPF values used to produce the official NWS river forecast on hydrographs appearing on the AHPS webpage that is in the AHPS to IDP project needs to be accelerated.

Finding 11: Stakeholders noted that flood categories and impact statements associated with the AHPS hydrograph page were not always correct or updated.

Recommendation 11: Regional HQs should insure that Hydrologic Program Managers (HPM) are adhering to NWS Instruction 10-924 that instructs the HPM to review the data stored for a gage location, and thus displayed on the gage's AHPS page, a minimum of once every five years and within 30 days of a significant event.

Finding 12: Because the NWS could not meet user requirements for Flood Inundation Mapping (FIM), NWS core partners turned to alternative sources such as FIMAN for these mapping products. The FIMAN system provides public-facing observations and forecast information that is valued by core partners in North Carolina; however, the information presented may conflict with NWS IDSS messaging at times because, while NWS products are used, NWS does not have a direct role in FIMAN forecast generation.

Recommendation 12: NWS should work with core partners to ensure consistent IDSS messaging inclusive of FIM and forecast uncertainty products.

Finding 13: Core partners lack the ability to visualize potential inundation and risks to specific areas when using single river stage forecasts as traditionally presented by AHPS.

Recommendation 13: The OWP and RFCs should collaboratively develop flood inundation mapping services, such as tools being proposed like the NWS GIS Viewer, and/or tools already available in ArcGIS Online (AGOL), that would enable partners to better comprehend and message the potential impacts from inland flooding.

Finding 14: Partners were concerned that current storm surge graphics do not reflect the anticipated total water height.

Recommendation 14: The NWS should support ensemble modeling for total water level to enable the production of graphics depicting the water height inclusive of freshwater flow, storm surge, tides, and waves.

Finding 15: Some NWS core partners, e.g., the Georgia Emergency Management and Homeland Security Agency expressed the desire for an earlier release of information, such as storm-based storm surge forecasts.

Recommendation 15: The NHC should look into extending the release of real-time storm-based storm surge guidance from the current standard of 48 hours in advance of the arrival of tropical storm force winds to 72 hours.

Finding 16: A few local-level core partners in North Carolina requested a “most likely” storm surge forecast in addition to the existing “reasonable worst case” storm surge forecast. In addition, some NWS core partners stated there is still confusion regarding the appropriate use of the “reasonable worst case” storm surge forecast for planning purposes.

Recommendation 16: The NWS should identify information pathways and community partnerships to aid in education programs to ensure that NWS core partners are informed on the appropriate use of the “reasonable worst case” scenario and “most likely” storm surge forecast scenario.

Finding 17: There were instances where NWS local offices were not including the above ground reference or not referencing any datum (as required by NWS Policy Directive 10-601) when providing the storm surge forecast.

Recommendation 17: The NWS should strongly emphasize the policy of including the above ground reference through annual tropical training. The NWS should reach out to other federal partners, inclusive of NOS, to leverage their training resources on this topic.

Finding 18: The NWS currently lacks a graphic that depicts the timing of when tropical storm force winds would cease.

Recommendation 18: The NWS should explore the development of a Time of Departure Wind Graphic. The graphic should be labeled clearly that it is not meant to depict an "all clear" to the public because other hazards may still exist.

Finding 19: Feedback received from core federal partners and national and local media outlets was that they did not use the HTI graphics for decision making purposes. Those that did use the graphics highlighted several issues, namely: 1) difficult to find; 2) not generated early enough for planning purposes; 3) contained information inconsistent between WFOs; 4) do not depict the timing of the hazard.

Recommendation 19: The NWS should consider absorbing the current HTI functionality into the newly developed graphical “enhanced” Hazardous Weather Outlook (eHWO). The eHWO affords a more consistent and seamless approach to spatially and temporally communicate wind, storm surge, tornado, and flood hazards expected in a five-day forecast period.

Finding 20: The NWS lacks a coordinated/mosaic-style rip current risk/warning graphic that could be used to highlight areas along the coast, outside the potential impact zone, where life-threatening rip currents are expected.

Recommendation 20: The NWS should examine the current inventory of existing risk/warning rip current graphics and if needed reach out to other NOAA line offices and federal partners (e.g. USGS) to leverage their existing tools to develop a consistent product suite of surf zone risk information for at least a three day forecast period. This information can then be modified for graphical use by local and national media partners.

Finding 21: There can be a lack of consistency for graphics, text products, watches, warnings, and advisories when part of the state is in different County Warning Areas (CWAs).

Recommendation 21a: The NWS should investigate existing tools (e.g. GraphiDSS) to develop an enterprise solution for a customizable tool that automates the production of state-wide forecast graphics at state-supporting WFOs, RFCs, and National Centers.

Recommendation 21b: There should be agreement across WFOs and RFCs on a common format for text products that have different formats between local offices.

Finding 22: Partners send requests to local WFOs to generate graphics depicting observed conditions (e.g., peak wind gusts, rainfall) after an event for response and recovery purposes. These graphics can be difficult to generate given limited/inconsistent data sources, a limited range of software to produce the graphics, and a lack of GIS expertise in some WFOs. In addition, these graphics are usually requested immediately post-event when staffing at a WFO is being used for post storm assessments and other activities.

Recommendation 22a: NWS should investigate methods for local offices to efficiently create summary graphics documenting storm impacts on local and state level scales for dissemination to core partners. These graphics should be coordinated with NWS national centers to ensure consistent messaging.

Recommendation 22b: Consolidate and publicize where real-time data (e.g., surge, wind) are available (e.g., other NOAA line offices and core partners such as USGS) so that partners can better plan re-entry or recovery activities.

Finding 23: Per feedback from NWSH, creation of post-event graphics of observed conditions could put local offices in the position of violating the COASTAL Act. The COASTAL Act is not well understood at the regional and field office level.

Recommendation 23: The NWS should provide guidance to local offices on what type of post-event graphics can be allowed under the COASTAL Act, with the understanding that the graphics being created by local offices are considered “preliminary”, and are being created to meet the immediate needs of core partners.

Finding 24: The cone in the Tropical Cyclone Track Forecast Cone and Watch/Warning Graphic continues to be misinterpreted as a “cone of impact” by NWS core partners. Finding and Recommendation 3 from the *October 2016 Hurricane Matthew Service Assessment* and Finding and Recommendation 41 from the *Hurricane Irene, August 21-30, 2011 Service Assessment* are relevant to this point.

Recommendation 24: As noted in the *October 2016 Hurricane Matthew Service Assessment*, NOAA and NWS should continue their examination of how users make decisions based upon the Tropical Cyclone Track Forecast Cone and Watch/Warning Graphic. Furthermore, the organizations should support adequate resourcing for projects involving the Tropical Cyclone Track Forecast Cone and Watch/Warning Graphic through the Hurricane Forecast Improvement Program.

Finding 25: The NHC Tropical Cyclone Track Forecast Cone and Watch/Warning Graphic can misrepresent the placement of coastal tropical cyclone watches and warnings (**Figure 22**). Feedback indicates this is likely a function of how the software code draws the delineation line(s) and its pre-defined thickness for the line(s).

Recommendation 25: NHC should ensure its publicly disseminated Tropical Cyclone Track Forecast Cone and Watch/Warning Graphic includes correct placement of all tropical cyclone watches and warnings, including those for inland areas.

Finding 26: NHC, WFO Tallahassee, and WFO Raleigh made quick decisions to use Facebook Live during the hurricane(s), which greatly enhanced the reach of NWS messaging.

Recommendation 26: During a high-impact event, all offices should be able to use non-traditional platforms (e.g., Facebook Live) that reach the largest possible audience given the appropriate circumstances. Facebook Live and other similar platforms should move beyond experimental and be incorporated into the full suite of available tools a WFO or office can use to disseminate key communications.

Finding 27: One size does not fit all when it comes to virtual conferencing tools needed for NWS IDSS. Offices differ in the number of core partners they are briefing in high impact events.

Recommendation 27: NWS should incorporate scalable options for WFOs and RFCs to utilize during times of increased online briefing needs for core partners. Specifically, NWS should allow WFOs with a larger number of core partners to use more expansive licensing that allows for more participants based upon their IDSS needs.

Finding 28: NWS core partners expressed the need for a reliable visualization platform to display various parameters, such as radar data, watch/warning/advisory information, and current conditions. NWS core partners are utilizing GIS platforms such as EDD which are still considered experimental by the NWS after many years.

Recommendation 28: NWS should ensure NOAA and NWS data visualization platforms are robust, reliable, nationally-supported, and well advertised to partners. This will support partner data requirements to support a long term vision and pathway for NOAA data services and GIS capabilities.

Finding 29: The lack of dissemination capabilities at the NWC will impact the NWC's ability to provide effective IDSS in the future.

Recommendation 29: The Office of Dissemination should work with the Office of Water Prediction (OWP) to either leverage existing data services/portals or help the NWC create its own data service/web portal to allow partners to download raw data or output.

Finding 30: A collection of overlapping or similar GIS or Geospatial data services exist within the NWS and NOAA. Some of these platforms and services are not well known throughout the NWS or by its partners. Various platforms (both regionally and nationally developed within NOAA and the NWS) were used by many NWS partners and NWS offices to support their individual decision support services.

Recommendation 30a: NWS should develop a vision for consolidating all of those services under one capability that provide the data for partners who have the resources to pull the raw data and display it on their platforms, as well as a visualization capability for those that do not have that capability.

Recommendation 30b: NOAA, inclusive of the NWS, needs additional hardware to handle increased user demand during high-impact weather events. NOAA should also investigate and explore the feasibility of migrating legacy and future data services and visualization capabilities to a commercial cloud infrastructure using open source software, thus allowing scalable solutions to meet user load, particularly during high-traffic events like land-falling hurricanes.

Finding 31: The DAT is an essential tool for WFOs to document impacts from hazardous weather events and share these with NWS core partners.

Recommendation 31a: The DAT should become an official tool, with appropriate funding, that WFOs may use to document damage from hazardous weather events, and as such should receive national support.

Recommendation 31b: The DAT, and its associated editor and viewer platforms, should be expanded to document storm surge, flooding, and tropical wind damage.

Finding 32: Partners interpreted the language describing threat impacts differently.

Recommendation 32a: The NWS, in concert with core partners and social scientists, should develop standard language to describe the impacts of storms. This language should allow for a gradation, or a range of language, for storm impacts based on level of effect in warnings other than a blanket term category for the entire storm.

Recommendation 32b: WFOs should use existing communications resources, such as social media and NWSChat to core partners, to let them know what the term “flash flood emergency” means when it is included in a warning. WFOs can refer to NWS Directive 10-922 (sections 5.3.4 and 6.3.4) for the criteria for flash flood emergency.

Recommendation 32c: WFOs should include education regarding the use of flash flood emergency in partner training such as IWT meetings, tabletop exercises, etc.

Finding 33: The majority of the partners, including the media, did not use the HLS in their decision-making process.

Recommendation 33: The NWS should work in concert with social science partners to determine whether/how the HLS and the corollary TCV products are being used and whether they should be improved or terminated.

Finding 34: The Hurricane Florence team found that webinars, briefing packets, and emails were used most by EMs and media for decision making. Legacy NWS text products appeared to be secondary in use for decision making for many partners. Core partners noted that briefings started well ahead of landfall. EMs distributed briefing packets via their social media accounts.

Recommendation 34: NWS needs to reassess its suite of legacy text products and determine which products are still important and which should be discontinued. Identifying unnecessary products allows more time to focus on widely used and disseminated webinars, briefing packets, and e-mail.

Finding 35: Several officials stated the SSHWS negatively impacted the Hurricane Florence flood messaging when the storm was downgraded in wind intensity. Many partners also noted that the change in storm category likely impacted some people's decision not to evacuate.

Recommendation 35a: The NWS should establish a multi disciplinary working group of scientists to investigate the advantages and disadvantages of the SSHWS as it pertains to multi-threat impact-based decision support services to set a foundation for an organizational discussion on the use of intensity scales in hurricane messaging.

Recommendation 35b: Work with the tropical training program to emphasize messaging the impacts from each unique storm, and downplay the SSHWS.

Recommendation 35c: Develop an outreach effort that targets media, EMs, and the public to focus on the holistic hazard potential of tropical cyclones, and de-emphasize the SSHWS. This outreach effort should particularly focus upon news producers and directors, not just those tied to the production of weather segments.

Recommendation 35d: NWS needs to evaluate the impact of using descriptive terms for storm trends (e.g. weakening) that may lead to conflicting perceptions of risk due to the overall threat level.

Finding 36: Core partners requested more information regarding potential tropical cyclone intensity at landfall; they specifically requested an additional forecast point at landfall.

Recommendation 36: The NHC should explore developing probabilistic landfall intensity information.

Finding 37: The MAS team was underutilized in Hurricane Florence.

Recommendation 37a: The NWS should establish a Program Leader at NWSH to formalize and coordinate Spanish-language services. This Program Leader would coordinate Spanish translation services and other relevant services.

Recommendation 37b: The skills and services of the MAS team should be more thoroughly marketed throughout the NWS and regularly used by the agency, particularly for major events.

Finding 38: SAVI was utilized significantly during Hurricane Michael, but not during Hurricane Florence.

Recommendation 38: The SAVI program should be used by NWS WFOs during major events. The program should be more thoroughly marketed throughout the agency with the assistance of the NWS regional offices.

Finding 39: The USGS and core partners shared expertise and assisted the NWS in conducting post-event storm surge surveys following Hurricane Michael.

Recommendation 39a: The NWS should continue to leverage relationships with NWS core partners, other NOAA line offices such as NOS, USGS, and private entities who have expertise in surveying water levels, in conducting post-event storm surge surveys.

Recommendation 39b: The NWS should follow the guidance provided in the USGS report, *Identifying and Preserving High-Water Mark Data,* by Koenig and others (2016). This will help to ensure consistency in identifying high-water marks and assigning vertical accuracy.

Finding 40: The remote support provided by staff at OHRFC is a good example of how the NWS can best leverage expertise across NWS regions to better serve a local core partner and support major events.

Recommendation 40: OWP, collaboratively with NWS Regions and RFCs, should maintain a cadre of SMEs with modeling and interpretive expertise for dam break and levee breach situations. Adequate training and material resources should be allocated for the SMEs to maintain operational proficiency and deployment readiness status.

Finding 41: There were inconsistencies in the prioritization of the threats, recommended actions, and timelines for future impacts in the messaging from local, regional, and national offices as the storm gained strength in the southern Gulf of Mexico prior to the issuance of NHC advisories on the system. It was not until Sunday, October 7, that a Fully Integrated Field

Structure (FIFS) concept emerged with a consistent depiction of threats, impacts, and timeline for core partners. Some of this was due to the rapidly evolving nature of the threats.

Recommendation 41: When internal contingency planning occurs within the NWS in advance of a potential high impact event, an external message needs to be crafted and shared with core partners so they can begin their own contingency planning. As part of a FIFS, this message should be developed collaboratively and its dissemination coordinated between local, regional, and national offices even in advance of the issuance of tropical cyclone advisories. This coordination is particularly important when extenuating factors exist such as an upcoming holiday weekend or when recently impacted communities are potentially in play.

Finding 42: In the case of Florence, three days prior to expected impacts, NHC products conveyed a large amount of uncertainty in the forecast intensity. However, a WFO slide deck used in briefings for core partners issued around the time of the NHC product implied a false level of confidence in conveying that the maximum winds for Hurricane Florence would "reach up near a minimal Category 5." This wording triggered officials to put into place evacuation orders incurring significant activation costs. From a FIFS standpoint, this conflict in messaging provides one example of why better coordination of messaging is needed in the three to seven day time period at all levels of the agency.

Recommendation 42: The team recommends a larger collaboration role between the WFOs, ROCs, and National Centers on messaging to the public during the three to seven day time period that includes appropriate expressions of uncertainty. This would ensure a well collaborated message at the local, regional and national levels. As an example, the NWS should consider the use of the internal NHC/WPC Medium Range Conference Call on the hurricane hotline as an official conduit for coordination of messaging for a potential event in the medium range from NWS national, regional, and local offices. Extenuating circumstances such as an upcoming holiday weekend should be considered at all levels of the agency in consistent messaging of potential impacts to federal, state, and local core partners.

Finding 43: The NWS did a good job of messaging catastrophic flooding in its products during Florence, but some users felt it would have been useful to see something graphically to differentiate between a high risk of flash flooding and widespread catastrophic flooding on a regional or national scale.

Recommendation 43: OWP should look into a graphical way of messaging the threat of catastrophic flooding that goes above and beyond the standard high risk designation in the WPC Excessive Rainfall Outlook and the threat levels for present and future conditions depicted in the Significant River Flood Outlook.

Finding 44: The WPC Excessive Rainfall Outlook is depicted on a smaller storm-specific map scale (**Figure 35**), but is not available on state or FEMA region scales.

Recommendation 44: The WPC Excessive Rainfall Outlook should be available on customizable geographical scales.

Finding 45: Hydrologic hazards messaging, through the complexity of NWS products, remains a significant challenge for core partners.

Recommendation 45: Similar to winter hazards simplification, additional work should continue to be supported to simplify the products and messages issued regarding flood hazards.

Finding 46: The vertex limits in AWIPS Warngen can make it difficult for WFOs to issue the best warnings based on the science and potential impacts.

Recommendation 46: NWS needs to explore the possibility of increasing the vertex limit, as well as addressing the land/marine zone interface display issues.

Finding 47: During Hurricane Florence, North Carolina OEM meteorologists commented on inconsistencies with watches, warnings, and advisories between North Carolina WFOs and that the wind warnings did not match up with the forecasted winds.

Recommendation 47a: From a FIFS standpoint, the ROCs should help coordinate and alleviate watch, warning, advisory consistency issues between WFOs, especially in a tropical situation.

Recommendation 47b: WFOs should collaborate on state-level messaging and issue pertinent tropical products (e.g., Tropical Storm Warning) when a tropical cyclone impacts their area of responsibility.

Finding 48: The point-and-click forecast feature on weather.gov can serve to undermine key NWS IDSS messaging. By using this feature, users can receive forecasts that conflict with ongoing NWS hazards due to the combination of both deterministic and probabilistic information.

Recommendation 48: Revise the underlying computer code in the NWS point-and-click forecasts that merges deterministic forecasts with probabilistic forecasts. Only probabilistic information should be emphasized in the point-and-click forecast when expressions of uncertainty are triggered.

Finding 49: There is a larger, philosophical issue for the NWS on when the agency should use deterministic forecasts in messaging and when it is best to solely use probabilistic information.

Recommendation 49: NWS should form a team comprising social scientists and EMs to investigate how best to infuse probabilistic information with deterministic forecasts. This team should include representation from NHC, OCLO, and other major NWS program offices with

tropical program responsibilities. The team should evaluate what content is currently available from the NWS tropical training program which is currently leading this effort.

Finding 50: During tropical cyclone events, the NWS website (weather.gov) lacks a “one-stop shop” for national and local information.

Recommendation 50: NWS should hire or contract with web design experts and use state of the art technology and user experience research to develop a more intuitive, consistent, and user-friendly experience across all NWS online web based interfaces (including mobile devices) that effectively prioritizes communication of critical information. The information should be organized for total, storm specific information including NHC’s track and surge information with local impact information from the WFOs including flooding, rip currents, etc.

Finding 51: The WCM position at NHC is considered a full time hurricane specialist and must work a full shift load during hurricane season which detracts from the time this person spends focusing on and leading IDSS efforts.

Recommendation 51: The NWS should investigate staffing flexibilities for NHC to meet increasing IDSS needs during the tropical cyclone season.

Finding 52: Feedback from within the NWS is that the roles and capabilities of both OWP and the NWC are not well understood.

Recommendation 52a: The NWS needs to proactively engage with other parts of NOAA to clearly communicate NWC's roles and capabilities in a major tropical or hydrologic event. OWP inclusive of the NWC Operations Center needs to have their role defined prior to the onset of a tropical system rather than during the event.

Recommendation 52b: An explanation of NWC’s roles and responsibilities should be added to NWS tropical training curriculum such as EHM and Seasonal Readiness Training (SRT).

Finding 53: The timing of the QPF collaboration calls between the WFOs and WPC during Hurricane Florence was occurring late in the WFO forecast creation process. This made the timeline for collaborated forecast creation difficult for the WFOs.

Recommendation 53: WPC, NWS RHs, and WFOs should investigate ways prior to the tropical cyclone season to set the timing of the QPF collaboration calls to be earlier in the WFO forecast product creation process.

Finding 54: At the time of Hurricanes Florence and Michael, not all NWS ROCs were equally staffed.

Recommendation 54: NWS should define and implement ROC Final Operational Capability (FOC) staffing to address present and emerging IDSS demands during high impact events such as tropical cyclones.

Finding 55: There is a limited pool of volunteers with tropical experience to fulfill the role of IDSS coordinator and this presents a challenge to meet IDSS and internal messaging needs.

Recommendation 55a: The NWS should ensure, when possible, that there are at least two tropical experts deployed to NHC as IDSS coordinators to provide continuous coverage for each tropical cyclone event threatening the United States.

Recommendation 55b: The NWS should ensure there is a substantial pool of volunteers with tropical experience to fulfill these support roles. These volunteers should meet minimum training standards with required approval to be tropical deployment ready. These training standards are documented on the NWS Tropical DSS Coordinator Google Sites page.

Finding 56: The process for making emergency purchases in the NWS is complicated. The rules are unclear, they lack flexibility, and each purchase has a long approval process.

Recommendation 56a: The NWS should determine if NWS Directive NWSI 1-208 goes far enough in providing sufficient, flexible, and consistent guidance for emergency purchases and procurement of lodging for WFO employees during tropical events.

Recommendation 56b: The NWS should provide an annual review of administrative processes, guided by NWS Directive NWSI 1-208, that FMCs and WFO leadership should follow in emergencies.

Recommendation 56c: The Chief Financial Officer (CFO), in conjunction with appropriate finance offices, should develop a “deployment ready” team to promptly support the Financial Management Centers during emergency procurement and evacuation decisions, ensuring that senior officials can maintain employees’ safety during a high impact tropical event.

Recommendation 56d: The NWS should reach out to other federal agencies to gather best practices for handling administrative policies, practices, and procedures in emergencies.

Finding 57: There is inconsistency between office to office in shelter-in-place capabilities for major events.

Recommendation 57a: Where possible, NWS should investigate additional ways to incorporate shelter-in-place resources at WFO and RFC facilities, or use core partner locations. The team agrees with Finding 37 of *Hurricane Irene, August 21-30, 2011 Service Assessment* that before the tropical season, the NWS should investigate the potential to modify storage

areas and equipment room spaces to facilitate shelter-in-place needs for sleep and basic hygiene needs.

Recommendation 57b: There should be a consultation from NWS Operations with the Facilities Division Directors at HQ as well as the Regional HQ Facilities POCs to make the most informed decision regarding sheltering-in-place at the WFO, moving to another partner location, or going into service backup.

Finding 58: There is no formal procedure for getting information from NOS to NWS and vice versa at the line office level.

Recommendation 58: Formalize how NOAA line offices (e.g., NWS and NOS) work together in all phases of a tropical cyclone, including preparation and recovery (see **Appendix D** for further discussion of NOS roles). NOAA's Homeland Security Program Office, the NOS Incident Management Team, and the Tropical IDSS Coordinator could facilitate this line office coordination. In addition, the NOAA Regional Teams can work to help build relationships and establish protocols between NOAA line offices.

Finding 59: Creating the PSH within the required timeframe for a tropical cyclone is a long, complex process, particularly given the level of coordination required for events of this magnitude.

Recommendation 59a: The NWS should investigate methods to automate, where possible, the process of creating PSHs.

Recommendation 59b: The NWS should review Directive 10-601 and to ensure adequate time is provided for the completion of inter-agency storm surge surveys for inclusion in the PSH.

Finding 60: The issue with the SSWW incorrectly displaying on weather.gov pages was triggered by code changes for non-tropical program areas.

Recommendation 60: Changes to any code that may affect tropical product dissemination should be tested for a tropical scenario prior to implementation.

Finding 61: The SSWW was incorrectly displayed over too large an area in some GIS-based platforms such as NOAA NowCOAST due to an incorrect depiction of the SSWW in the National Hazards KMZ file.

Recommendation 61: DIS should fix the National Hazards KMZ file so that it shows the correct depiction of the gridded SSWW collaborated between WFOs and NHC. This should be made a high priority as it concerns a warning being improperly displayed during an event when critical decisions are being made to protect life and property.

Finding 62: The one-hour time lag for NDFD updates after forecast issuances impacted NWS' effective messaging of hazards on NWS websites, a primary communication tool.

Recommendation 62: NWS should conduct an external evaluation of the Integration Dissemination Program (IDP) that includes the system's configuration, configuration changes, latency in displaying information generated by NWS offices, and ability to withstand user load during high impact weather events. In the meantime, the NWS should include use of a disclaimer to alert users of delays in posting WFO grids during major events.

Finding 63: The failure to install a critical HTI patch prior to Florence is one example of the existing AWIPS Discrepancy Report review process not working effectively. In this specific case, the patch was not given the correct priority level to be implemented quickly which impacted watch/warning operations at multiple WFOs.

Recommendation 63: The Advanced Weather Interactive Processing System (AWIPS) Discrepancy Report review process should be evaluated to ensure that mission critical software patches and bug fixes are in place consistently.

Finding 64: The NWS does not have a formal testbed process for testing changes to tropical program software.

Recommendation 64: The NWS should use the NWS Operations Proving Ground to develop a tropical testbed for testing new or updated WFO tropical software. The testbed must have the ability to run parallel operations during an event, but with no risk of interfering with operations. This system could be the focal point for testing, validation, or modifications. If the tropical program had such an end-to-end system, training scenarios could easily be run on a local, regional, and national scale.

Finding 65: The NWS needs to allow for a sufficient period of operational testing and experimental use before new software is declared operational.

Recommendation 65a: The NWS needs to follow the AWIPS code "check in" process for implementation of new or experimental software releases. Any new or experimental software should be tested in parallel to the operational system before it is implemented or approved for operational use.

Recommendation 65b: NWS should use the following best practice, as outlined in the 2011 guidance on www.testbeds.noaa.gov and currently used by several of the NOAA Testbeds and NWS Operations Proving Ground to follow a deliberate, repeatable process for developing, testing, and transitioning to operations. Similarly, the process described in NWS Directive 10-102 outlines the dissemination and evaluation process, along with a defined mechanism for customer feedback.

Finding 66: The national test conducted each spring involving national centers, regions, and local offices for the tropical program falls short of the needed true end-to-end testing technique as it does not include the testing of AWIPS product generation and NWS dissemination.

Recommendation 66: The NWS should conduct a collaborative national end-to-end test of a tropical cyclone scenario pre-season, which includes all relevant national, regional, and local offices, and includes NWS dissemination and AWIPS product generation to ensure agency readiness. There is precedent for conducting end-to-end tests; this has proven to be a valuable component of the tsunami warning program's system readiness.

Finding 67: The forecasts generated in the TCV and Zone Forecast Product (ZFP) use a 15% moderated maximum wind which means the highest 15% of values are thrown out. Especially in a tropical event, those 15% represent the highest forecast wind speeds. Thus, the software program artificially lowers the produced forecast wind values.

Recommendation 67: The issue of the AWIPS software throwing out the highest forecast wind speeds in the TCV and ZFP text products needs to be addressed.

Finding 68: At the end of the multi-week CWD period, due to the extended period of inland flooding in Hurricane Florence, the overall operational pace had slowed as other threats waned. The multi-week CWD designation blocked implementation of bug fixes for critical software such as that used to create HTI graphics.

Recommendation 68a: The process to prioritize urgent software patches needs to be revisited to capitalize on these short-term opportunities in cases of multi-day or even multi-week CWD declarations to allow implementation of bug fixes to improve services.

Recommendation 68b: The NWS should develop an efficient, repeatable software and system testing and implementation process. This should limit the need for CWD waiver requests to perform software fixes or modifications.

Finding 69: The NCF showed limitations in its ability to troubleshoot and diagnose issues with the tropical software within the AWIPS baseline software structure; therefore, WFO tropical operations are effectively being supported by a small number of key NWS field experts who provide this support as a voluntary collateral duty.

Recommendation 69a: The NWS should implement a robust reporting system to gather occurrences of where NCF is not fulfilling its obligation to fully support 24x7 operations for baselined tropical software in AWIPS. Based upon findings from these investigations, the NWS should implement enhanced monitoring and responsiveness of the contractor and, if necessary, apply curative actions to ensure NWS field operations are fully supported 24x7.

Recommendation 69b: As part of a rigorous testing scheme, NCF staff should be required to take training for any software changes deployed as part of the NWS tropical program.

Finding 70: Feedback from WFO Jacksonville said that providing service backup on the day of Hurricane Michael's landfall pushed both forecast staff and the AWIPS system to its limits. WFO Jacksonville continued to provide service backup for WFO Tallahassee for a week or more after the storm. Per WFO Jacksonville feedback, once the storm had exited north Florida the service backup was no longer an issue for staffing or systems.

Recommendation 70: NWS should use non-adjacent WFOs, and those that are not being directly impacted by the tropical cyclone, to provide backup during high impact tropical cyclone events. Other options should be considered as well. For example, a pre-configured fully functional COOP site, perhaps the ROC, could be used.

Finding 71: In a tertiary backup configuration, there are known configuration limits with certain parts of the AWIPS software (e.g., RiverPro, climate) running at the backup site. This prevents the tertiary backup site from providing full backup support.

Recommendation 71: The NWS should accelerate its phased approach work to fully integrate all forecast and watch/warning/advisory production into a standardized configuration setup to facilitate continuity of operations.

Finding 72: Despite the OneNWSNet outage, WFO Tallahassee diligently ensured IDSS continuity (e.g., social media, email briefings to core partners, etc.), by using the Florida State University wireless network.

Recommendation 72: The NWS must ensure that a chosen upgrade to the network backup system (e.g., newer, enhanced VSAT system) meets field requirements for IDSS functionality when the primary NWS network goes down during major events.

Finding 73: Staff at WFO Tallahassee experienced significant issues using government-issued laptops once the OneNWSNet failed. To get around these issues, they used their personal equipment to access and work through the Florida State University network.

Recommendation 73: NWS should develop secure configurations that permit easier access to office desktop computers and laptops using wireless networks (when available) during emergencies.

Finding 74: The hardware NWS staff are required to use limits their ability to perform effective IDSS during low bandwidth situations that often occur during tropical cyclone events and when they are deployed.

Recommendation 74a: WFOs should have procedures to check all systems, including mobile hotspots, that a deployment-ready forecaster will use before each event if not more often. NWS should develop a deployment-ready checklist for each office before each event. This checklist could be best used by the Information Technology Officer and Electronic Systems Analyst for each WFO. Each ROC can help develop checklists.

Recommendation 74b: The NWS needs a cohesive plan to meet the remote IT needs for dedicated onsite IDSS during tropical events. This plan could leverage the best practices from the IMET program.

Finding 75: Only one WSR-88D provided adequate sampling of the core of Hurricane Michael at landfall.

Recommendation 75: The NWS should examine more resilient communication and network alternatives to provide backups during high impact events like Hurricane Michael; providing these resilient backups also supports the relevant goals and objectives outlined in the 2018 - 2022 Department of Commerce (DOC) Strategic Plan:

> Strategic Objective 2.3: Strengthen Domestic Commerce and the U.S. Industrial Base. Specifically, to "deliver data services, thus improving the public's ability to visualize and leverage our data."
>
> Strategic Goal 3: Strengthen U.S. Economic and National Security references states that we "share accurate weather information" along with Strategic Objective 3.3: Reduce Extreme Weather Impacts that will "enhance our long-term observation capabilities and infrastructure that directly inform understanding of weather variability, extreme events, and ecosystem processes."

Finding 76: The solutions laid out in the NEXRAD Radar Operations Center study for the issue of tree blockage along radials at the KLTX WSR-88D site have not been implemented.

Recommendation 76: The NWS should implement the solutions provided in the NEXRAD Radar Operations Center's report to resolve the KLTX blockage issue.

Finding 77: Data from non-NWS observational networks (e.g., the University of Georgia Automated Environmental Monitoring Network and the previously mentioned private company) were consistently recorded under tropical cyclone conditions.

Recommendation 77: The NWS should continue working through the NWS National Mesonet Program to expand partnerships with the broader weather enterprise and further expand observational networks (including data for both wind and water level), which can remain operational during tropical cyclones.

Finding 78: There is no standard reference point for collecting wind observations.

Recommendation 78: The NWS should develop a standardized and automated method to normalize wind observations to 10-meter AGL elevation height.

Finding 79: There were multiple NWR communications issues throughout both hurricanes such as transmitters being unable to broadcast warnings and not having a robust backup in place for the transmitters. These issues persist primarily due to the analog point-to-point connection that is present at the site.

Recommendation 79: The NWS needs to investigate and invest in acceptable backup technologies for NWR. A robust backup system for NWR (including for backup offices) must be developed, which includes the priority of service response time, if the agency wants to continue using NWR as a primary communication tool.

Finding 80: Small changes in the NHC probabilities of tropical storm or hurricane conditions can result in significant changes to impact wording in the WFO text products, even when wind or wave forecasts remain unchanged. These changes can result in significant post production editing of text forecasts at the WFO level to maintain consistent messaging.

Recommendation 80: The NWS needs to employ a multi-disciplinary approach to identify the possible causes (e.g., grid formatter) that result in wording being removed or changed from “tropical storm conditions are possible” to “hurricane conditions are possible” in order to identify a path forward to resolve this inconsistency between forecast packages.

Finding 81: NWS is not putting enough resources toward tropical operations training development.

Recommendation 81a: The NWS should add additional resources, specifically a dedicated position, that is dedicated to aid and enhance tropical training development.

Recommendation 81b: NWS meteorologists should receive pertinent, simulation-based training that can be executed within the limitations of the operational shift work schedule for each tropical season, recognizing they will not receive on-the-job proficiency due to the sporadic nature of tropical cyclones. A similar approach to the RAC should be employed for tropical hazards, where pertinent, based on the employee’s mission requirements.

Finding 82: Some local NWS offices develop GFE operations training for forecasters using the test cases available on the NOAA VLab; however, this practice is inconsistent across offices.

Recommendation 82: More robust tropical operational (test case) training needs to be developed for AWIPS II. The NWS should examine the existing library of test cases to determine their effectiveness in delivering effective simulation based training.

Finding 83: NWS does not have a testbed to conduct testing and evaluation of tropical procedures, products and training which focuses on local office tropical operations.

Recommendation 83: The NWS needs to follow the model of severe weather training and convective warning operations to develop a similar enterprise solution for NWS tropical training and software testing. This structure would include National Centers, NWS Regions training personnel, as well as WFO and RFC experts as members of the team who jointly develop the training program, meet on a regular schedule, and follow a codified and structured process for developing tropical training. The planning and training should be repeated annually and available for use before the start of the tropical season.

Finding 84: The EHM has proven effective at providing tropical messaging training to a subset of NWS meteorologists and hydrologists, however resources remain limited.

Recommendation 84a: The NWS should maintain the EHM Course, and continue to prioritize attendance based on the attendees' roles in the tropical program (e.g., those responsible for messaging such as new managers and focal points with a role in the tropical program and deployment-ready staff) with the understanding that not every meteorologist or hydrologist that works in an office with tropical program responsibilities will be able to attend due to limited resources. EHM Course attendance should also be prioritized for those meteorologists working at National Centers, and for non-NWS state meteorologists where possible.

Recommendation 84b: The NWS should look into an additional, short, virtual version of the EHM course to serve as refresher training for staff that have attended the course and to capture larger portions of the staff at local offices that are unable to attend the course. This virtual class would supplement but not replace the classroom portion.

Finding 85: There are significant differences in philosophies and future goals for the tropical training program within NWS program areas charged with forecaster training and development programs.

Recommendation 85: The NWS should evaluate the current portfolio of tropical program training to identify strengths and weaknesses or gaps in the existing program inclusive of in person evaluation of existing courses, desktop exercises, and applicability of NWS training to forecaster readiness in real events.

Finding 86: NWS and core partnering agencies find the discussed coursework offered by FEMA and NHC instrumental in preparing for the tropical cyclone season. Some state meteorologists and media partners in tropical cyclone impacted areas have not received any formal training on how to use or message NHC forecast and products.

Recommendation 86: NWS should work with FEMA to explore expansion of the residence or "roadshow" type simulation based training for tropical messaging to deep core partners such as broadcast meteorologists. The course should be a hybrid that fills the gap between the FEMA hurricane training that is more emergency management focused, and the NWS EHM Course that is more NWS meteorologist focused.

Finding 87: Feedback gathered from members of the national broadcast media indicated that they appreciate NWS participation in virtual media interviews (e.g. Skype) and feel it has been beneficial to have the local perspective that the WFO can provide. However, they also report that some NWS meteorologists are still not coming across as prepared and trained for these types of interviews. These partners suggested additional training for NWS operational personnel to effectively deliver key messages to a television audience.

Recommendation 87: The NWS should leverage existing OLCO and Regional Headquarters resources to achieve consistent quality in effectively communicating during media interviews. In addition to the IDSS Professional Competency Units (PCUs) provided in the Commerce Learning Center, WFOs and RFCs should establish local training initiatives to re-train annually on how to provide effective interviews with the media. This should include the effective use of digital platforms such as Skype and Facebook Live, where appropriate.

Best Practices

Best Practice: WFO Tallahassee deployed staff members to three different locations: Bay County Emergency Operations Center (EOC), Leon County EOC, and the Florida State University (FSU) EOC. Staff at WFO Tallahassee worked with deployed meteorologists and emergency managers to facilitate a last minute "push" of messaging the night before landfall (**Figure 14**); Hurricane Michael was rapidly intensifying and emergency managers wanted to strongly encourage those that were still left behind to evacuate. This included a combination of a WFO-hosted midnight webinar, Wireless Emergency Alert (WEA) messages, and Facebook Live broadcasts. Law enforcement did a door-to-door search in Mexico Beach, FL the night before landfall. The end result is that the number of people remaining on Mexico Beach went from 250 the evening before landfall to 50 the morning of landfall. These deployments were highly beneficial during Hurricane Michael. All EMs with deployed staff said the deployments made a big difference regarding decision-making during the event.

Best Practice: The WFO Atlanta Meteorologist In Charge (MIC) called the emergency managers in 15 of their inland Georgia counties on the morning of October 10, just prior to WFO Atlanta's issuance of Hurricane Warnings for these counties. These calls were to ensure that their core partners understood the meaning of a Hurricane Warning and predicted impacts given the expected winds. The MIC discussed the potential scenarios with partners in non-technical terms (trees will be down) and emphasized the timing of those impacts (outside daylight hours) and potential complications (trees down on homes and first responders' inability to access locations). Having a senior member of the WFO staff contact EMs increased the emphasis of the messaging.

Best Practice: The NHC Storm Surge Unit (SSU) coordinated extensively with local WFOs, as well as with NWS core partners such as the state emergency management offices in North Carolina, South Carolina, and Virginia, and Bay County, FL, Emergency Management Division to help interpret storm surge guidance and aid in their broader decision-making process.

Best Practice: The FEMA Hurricane Liaison Team (HLT), embedded at NHC, provided calls and briefings for the states of South Carolina, North Carolina, and Virginia; FEMA Headquarters, FEMA Region 4, and FEMA Region 3; and participated in numerous federal and state video-teleconferences for Hurricane Florence. During Hurricane Michael, the HLT provided support via teleconferences to the state of Florida, which reached its peak the day before and into the overnight hours that preceded Michael's landfall on October 10. NHC-led federal and state video-teleconference briefings continued through landfall and into October 11 as Hurricane Michael moved through the eastern U.S.

Best Practice: The Ocean Prediction Center (OPC) and the Tropical Analysis and Forecast Branch (TAFB) coordinated closely with the U.S. Coast Guard (USCG) during both Hurricanes Michael and Florence. Per leadership at OPC, this coordination began in 2018 as an informal

pilot project, following the El Faro incident in 2015. This coordination is now a routine practice to improve coordination efforts and provide better situational awareness for the USCG and mariners. This was lauded by staff following Hurricanes Florence and Michael at NWSH and NHC as highly beneficial for both the agencies.

Best Practice: WFO Columbia held pre-storm meetings with the South Carolina EMD, SC governor, and the governor's senior staff prior to the primary executive briefing with full leadership during an actual event. This meeting was considered to be real-time support, not an exercise or training.

Best Practice: All of the WFOs in the affected area hosted Integrated Warning Team (IWT) workshops, participated in table top exercises, and other key planning events throughout the year. NHC provided support for some of these exercises, including a hurricane scenario that was used for local exercises with WFO Tallahassee core partners in spring 2018. This process helped streamline the process to build relationships ahead of significant weather events, bolstering the knowledge and use of local WFO expertise to assist local decision-makers.

Best Practice: WFO Morehead City conducted a pre-hurricane season tabletop exercise with Onslow County, NC. This exercise helped county EMs feel comfortable with not requesting WFO Morehead City deployments to the EOC. The pre-season tabletop exercise enabled Onslow County, NC, EMs to specifically request the appropriate tropical products.

Best Practice: In addition to webinars, partners used one-pagers and briefings. Partners were able to cut and paste diagrams and charts and appreciated that they were able to share accurate and credible information.

Best Practice: NHC also issued key message talking points in graphics distributed via social media and the NHC webpage, and forecast discussions.

Best Practice: WFOs (even those with SHs) are adapting their staff resources to address core partner needs for increased hydrologic forecasting and water level IDSS.

Best Practice: WFO Raleigh developed a "River Flood Table" briefing tool, which garnered positive feedback from core partners. This tool was adapted from the Meteorological Model Ensemble Forecast System (MMEFS) ensemble table that RFCs produce, and displayed via a local webpage for briefings (**Figure 15**).

Best Practice: SERFC adjusted its typical operating procedures to ensure it conveyed the true nature of the forecast hazard. In this case, the RFC moved from its typical operating procedure of using 48-hr QPF to using 72-hr QPF closer to the onset of impacts from Hurricane Florence. This adjustment was necessary for AHPS to display at least major river flooding as the storm neared landfall.

Best Practice: The NHC media pool was used during both Hurricanes Florence and Michael to quickly amplify the messaging for both storms to a wide range of media partners.

Best Practice: NHC wind probability, time of arrival, and storm surge inundation forecast graphics were widely used by partners to make critical decisions.

Best Practice: WFO Atlanta created a website to create state-wide forecast graphics. This website allowed forecasters to see inconsistencies between offices for watches, warnings, and advisories across northern Georgia. Any inconsistencies were adjudicated by coordination with WFO Greenville/Spartanburg, SC, which resulted in consistency within WWA products and forecasts for Hurricane Michael (**Figure 22**).

Best Practice: NWSChat was reported as a primary means for EMs and the media to receive timely information from the NWS. Local offices used NWSChat to request that partners emphasize certain critical messages about the storm.

Best Practice: DAT was used by WFOs to expediently provide storm impacts and summaries following Hurricane Michael's impact, which were in turn further used by partners (e.g., GFC and Federal Emergency Management Agency (FEMA) Region 4) to calculate damages and losses, and to deploy assets appropriately.

Best Practice: There are several examples where NHC and local forecast offices focused messaging on storm hazards and expected impacts. This messaging was evident in several IDSS deliverables and HLS headlines from local offices, WPC social media, and with NHC's "Key Messages" which were prominently displayed on its website and integrated into messaging at all levels of the agency (**Figures 28** and **29**).

Best Practice: The NWS MAS team proved vital in aiding the NWS with Spanish language social media translations and media interviews during Hurricanes Florence and Michael.

Best Practice: The NWS SAVI team proved vital in aiding WFO Tallahassee with social media efforts during Hurricane Michael.

Best Practice: The NHC SSU provides a "hindcast" of storm surge impacts to aid NWS core partners with post-event surveys and recovery activities.

Best Practice: Deploying hydrology subject matter experts to either local NWS WFOs or to core partners in potential hurricane flooding areas is very useful.

Best Practice: SRH works to develop a deployment pool that covers multiple regions to leverage resources nationwide. Per SRH feedback: "Incident Command System (ICS) principles are being followed in Southern Region regarding deployment of resources to offices for mutual aid or IDSS. Local office assesses their support needs and resources. In particular,

a key component is the role to be fulfilled - in-office product generation (grid editing, etc) or deployment to provide IDSS. If offices exceed their local capability to support, then they contact region (either through a defined email address, the ROC, or call someone on the phone) to request assistance. SRH evaluates all requests and prioritizes following the RD's or Incident Commanders guidelines. Note - the RD has the ultimate responsibility to authorize expenditures. We search within the region for people to deploy. We will reach outside of the region (i.e. go national) for resources if necessary. This includes financial approval from AFS or qualified personnel from other regions."

Best Practice: The use of NWSChat by both the HSU and SSU streamlines the coordination process for storm surge levels, watches, and warnings between NHC and the WFOs.

Best Practice: SRH and local leadership proactively made the decision to secure lodging prior to the event; this is not the standard practice. The WFO Tallahassee MIC found one of only a few hotels that had emergency backup power before reserving rooms. The hotel was within a short drive or walkable if necessary.

Best Practice: WFO Wilmington, NC used the total office concept by empowering non-meteorological staff to provide additional logistical support throughout the entire tropical event.

Best Practice: ERH deployed FETs to WFOs during Hurricane Florence. SRH deployed the FET to WFO Tallahassee in advance of Hurricane Michael to aid with preparation and recovery issues.

Best Practice: SRH worked with WFO Tallahassee management to purchase bedding and towels pre-season, and emergency food and supplies such as paper towels and toilet paper leading up to the event.

Best Practice: NOS/CO-OPS participated in NWSOC daily briefings during Hurricane Florence to provide information on significant water level observations.

Best Practice: NOS/CO-OPS and NHC kept lines of communication open and SSU regularly engaged with NOS leadership during Florence and Michael. The SSU sent CO-OPS requests for water level validation for transforming datums at non-NOAA gauges. NOS/CO-OPS participated in storm surge surveys following Hurricane Michael at the request of WFO Tallahassee.

Best Practice: WFO Mobile worked closely with OCS by participating in Port Coordination Team meetings. OCS was also included in NWS briefings. The information provided by the WFO was critical to decisions on port openings/closures from Mobile, AL eastward to Panama City, FL.

Best Practice: SRH provided two forecasters to WFO Jacksonville prior to the onset of Hurricane Michael to assist with service backup operations.

Best Practice: A number of ER and SR WFOs performed backups after the storm; this backup allowed staff to recover, check on family, conduct storm surveys, etc.

Best Practice: WFO Tallahassee held a series of internal, local office, tropical operational workshops, with the last one held only a few weeks before Hurricane Michael, largely due to an influx of new employees at the office. The WFO had seven new employees at the time of Hurricane Michael. These workshops were cited as essential in getting employees prepared for the storm.

Best Practice: WFO Columbia held an IWT in the spring prior to Florence focusing on understanding terminology with hydrology and flooding.

Best Practice: Local WFOs in the region heavily impacted by Hurricane Michael including WFOs Mobile, Tallahassee, and Jacksonville, conducted extensive training and interaction with their core partners in the spring and summer prior to Hurricane Michael. This training included tropical workshops, IWT meetings, and hands on exercises. NWS core partners provided positive feedback that the training and interaction helped them prepare for the storm.

Best Practice: Interactive, IDSS-oriented, exercise-based "roadshow" type training programs were given positive feedback by meteorologists in preparing them to work Hurricane Michael. Many employees cited hands-on training opportunities such as the NWS SR IDSS Roadshow as instrumental in preparing them for the event. One meteorologist at WFO Tallahassee who was deployed to Bay County Emergency Management stated that the SR IDSS Roadshow greatly helped him prepare for his on-site deployment.

Best Practice: Remote video conferencing interviewing tools (including, Skype or Facebook Live) have proven beneficial for both broadcast networks and NWS in conducting interviews. Such tools provide a valuable and less intrusive way for both entities to deliver a common message to the public. The NWS has incorporated media training into some of its formal training including the EHM Course and the IDSS Deployment Boot Camp. The EHM Course participants have the opportunity to gain on-air interview experience through a partnership with the Weather Channel that conducts mock interviews during the final course exercise.

Appendix C: Messaging for Hurricane Florence in the Medium to Long Range

Five days prior to NHC's first mention in their Discussion 36 that Hurricane Florence might affect the east coast of the U.S., the Climate Prediction Center's (CPC) Medium Range Discussion (PMDMRD) and the U.S. Hazards Outlook Product (PMDTHR) presented the scenario that Hurricane Florence might approach the U.S. east coast. These were the first NWS products to state this risk. In CPC's 9-10 day forecast period, the products presented two scenarios. One scenario noted the 00 UTC September 3 European Center for Medium-Range Weather Forecasts model (ECMWF), and the 00 UTC and 12 UTC September 3 Canadian models had Hurricane Florence approaching the east coast 9 to 10 days out (Wednesday, September 12 and Thursday, September 13). The second scenario, using the track forecast by the 6 UTC September 3 GFS and ensemble members, would keep the storm off the east coast. The CPC PMDTHR, issued 24 hours later on September 4, continued to note the possibility that Hurricane Florence might affect the east coast. The PMDMRD only mentioned Hurricane Florence would track west northwest across the tropical Atlantic and the future track would have to be closely monitored.

At 151 a.m. EDT on September 4, WFO Columbia was the first WFO to mention Hurricane Florence, other than in WFO Area Forecast Discussion (AFD) marine sections, where the only impacts associated with Florence would be ocean swells. This was four days prior to NHC Discussion 36. In the long term section for Friday, September 7 to Sunday, September 9, the WFO Columbia AFD stated the official forecast kept Hurricane Florence out to sea through Sunday with the caveat that there was still too much model spread after Sunday to speculate what Florence might do beyond the weekend.

On September 5, the NHC legacy cone graphic, issued with the 11 p.m. AST/EDT Advisory 27 package for Hurricane Florence, showed the beginning of a westward shift of the cone of uncertainty. Discussion 36, issued at 5 a.m. AST/EDT September 8 (six days prior to the eventual landfall), was the first NHC product that stated Hurricane Florence might affect the U.S. east coast. The five day Tropical Cyclone Track Forecast Cone and Watch/Warning Graphic, issued with Discussion 36, showed the eastern edge of the Tropical Cyclone Track Forecast Cone and Watch/Warning Graphic, was just offshore the U.S. Atlantic coast extending from Florida to North Carolina.

On September 6, the WPC Extended Forecast Discussion (PMDEPD) which discusses the day 3-7 forecast, noted "As for Florence's track, confidence in any solution is rather low as model/ensemble members have been diverging considerably after about Sun. By day 7, Thu 18Z GFS/12Z ECMWF runs that bring Florence to or near the East Coast are in the western part of the overall ensemble spread. The new 00Z GFS has returned a bit to the east."

The next day on September 7, WFO Wilmington, NC increased the specificity of the track of Hurricane Florence. The 520 a.m. EDT WFO Wilmington, NC HWO stated a chance that Hurricane Florence could move through a portion of the Carolinas between Wednesday and Friday of the following week. This was the only WFO with this much specificity on the track. This wording was removed in subsequent WFO Wilmington, NC HWOs issued on September 7. These locally produced HWOs expanded upon the broad/more general wording used by CPC Center in its September 7 products that the storm was moving in the direction of the east coast.

On the same day (Sept 7), the WPC PMDEPD stated "...the forecast track of Hurricane Florence remains highly volatile beyond Day 5/Wednesday. Potential landfall could be anywhere from the eastern Florida Panhandle up to the Mid-Atlantic late next week while other scenarios turn the circulation north and east before reaching the coast. While the focus is on the individual cyclone track, impacts far away from the center are likely given the expected increase in strength over the next few days. Please visit the National Hurricane Center website for more information on Florence."

Appendix D: National Ocean Service (NOS) Roles and Offices

NOS participates in the Working Group For Coastal Act Support (WG/CAS) supported by the Office of the Federal Coordinator for Meteorology Services and Supporting Research (OFCM). The WG/CAS provides a forum for interagency coordination and collaboration on the development of capabilities and provision of services in support of COASTAL Act requirements. The WG/CAS was established by the Interdepartmental Committee for Meteorological Services and Supporting Research (ICMSSR) and is aligned under the Working Group for Disaster Impact Assessment Plan (WG/DIAP). The WG/CAS intiatiates coordination calls before significant storm events to coordinate the deployment of water level observations, coastal imagery, and reporting on the initiation of operational water level products like Storm QuickLook.

In 2016 NOS released its first post-storm synopsis of peak water-level observations and now provides these for every major landfalling tropical storm. Although a step towards better post-storm communication of peak water-levels, gaps still remain around cross coordination on communicating changing water-levels during events.

In particular, NHC has desired greater cross-coordination with NOS regarding risk communication and messaging on elevated water-levels due to the interplay between storm surge and peak river stage well after a storm has dissipated in the area as occurred in Hurricane Harvey in 2017.

Office of Response & Restoration (OR&R)

- OR&R is the lead office for the NOS Incident Management Team (IMT), a group of staff across NOS who are trained to fill key coordination roles during significant events and who maintain situational awareness through daily meetings and an online Disaster Coordination Dashboard. The IMT is a potential connection point for NWS pre- and post-disasters.
- OR&R has the responsibility for pollution threats and marine debris. Their scientific support coordinators work closely with USCG and local WFOs for spill assessment and mitigation.

Center for Operational Oceanographic Products & Services (CO-OPS)

- CO-OPS provides water-level, meteorological, and current data along the nation's coasts, as well as tidal datum information. CO-OPS provided input on significant water-level observations at the NWSOC daily stand up briefings during Hurricane Florence.
- CO-OPS and NHC have a partnership memo that includes reciprocal 24x7 points of contact during the tropical storm season to support the NHC SSU, WFOs, and CO-OPS QuickLook Team Operations. As a result, CO-OPS and NHC have an open line of communication, and the NHC SSU regularly engages with this office. NHC SSU periodically sends CO-OPS requests for the background water level anomaly (stearic

anomaly) for water level validation and for transforming datums at non-NOAA gauges. CO-OPS and AFSO have also started a new formalized memo outlining storm surge support.

- The QuickLook product (**Figure 40**) is activated when a tropical storm or hurricane warning is issued and is updated every six hours. The product highlights water-level and meteorological observations at locations impacted by tropical cyclones. Using storm information downloaded from HURREVAC, updated maps were generated highlighting coastal water-level stations relative to the latest storm track. Florence was stood up slightly sooner (once coastal watches were issued) due to the high visibility of the storm. Beginning with the 2019 hurricane season, QuickLook is now issued through the Coastal Inundation Dashboard which retrieves the latest storm information and coastal watches and warnings automatically through nowCOAST map services. Given the drastic reduction in resources to generate the product in this new format, CO-OPS now stands up a new QuickLook at the onset of the first tropical storm or hurricane watch for the U.S. coast. For non-tropical systems (nor'easters), NOS will continue to wait for a NWS request to issue the product.

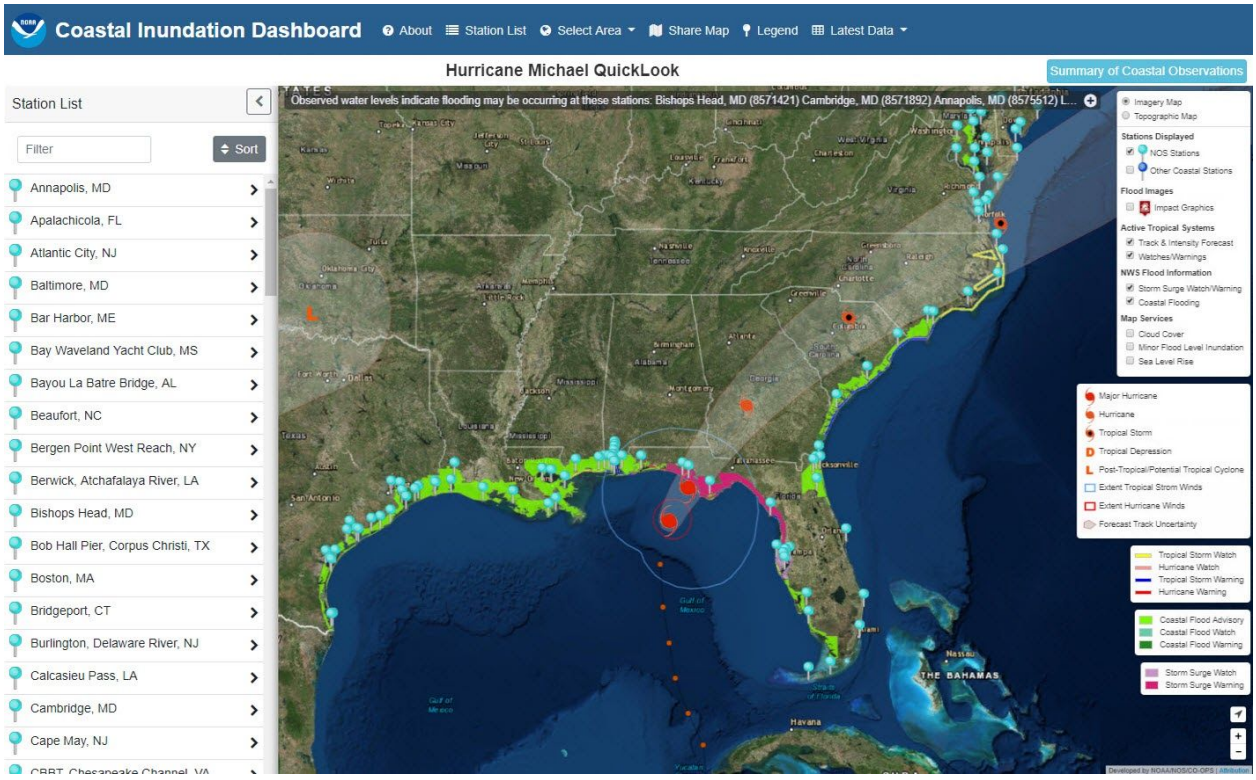

Figure 40: NOAA QuickLook graphic depiction for Hurricane Michael. *Source: NOAA/NOS Center for Operational Oceanographic Products and Services.*

Office for Coastal Management (OCM)

- In addition to delivering a wide variety of coastal data and tools, OCM offers training and other opportunities for coastal communities to define common goals and become more

resilient. OCM initiatives run the gamut from helping coastal communities become more resilient to coastal flooding, to generating better building codes for storm-resistant buildings.

- Deployment of OCM staff to WFO Charleston, SC was beneficial for utilizing NOS products to better understand total inundation and estimate potential storm surge impacts. For Hurricane Florence, OCM provided support to WFO Charleston, SC by assisting the marine focal point with surge guidance and interpretation of the potential surge inundation graphics as well as NOS products such as the QL and the new Inundation Dashboard. Existing NOAA mapping products were shared to look at potential impacts in NC and SC. WFO Charleston, SC found the various mapping products very useful to get a sense of overall inundation, and staff used them to estimate potential surge impacts.

Office of Coast Survey (OCS)

- OCS collects, manages, and compiles the data and information necessary to maintain the national suite of more than 1,000 nautical charts. OCS Navigation Response Teams (NRTs) remain on call to respond to emergencies, conducting hydrographic surveys in small vessels to help open ports and identify underwater dangers to navigation. They provide this critical information to port personnel, USCG and USACE.
- This office tasks the NOAA hydrographic survey vessels operated by the NOAA Office of Marine and Aviation Operations, and they have good communications with NHC and WFOs. They rely on the NWS storm surge forecast and when winds are forecast to drop below tropical storm force.
- OCS originally developed and hosted the nowCoast website. They continue to be involved in monitoring and supporting the product with NWS/NCEP.

National Geodetic Survey (NGS)

- The mission of NGS is to define, maintain and provide access to the National Spatial Reference System (NSRS). The NSRS provides a consistent coordinate system that defines latitude, longitude, height, scale, gravity, and orientation and shoreline throughout the United States and its territories.
- In order to support NOAA's homeland security and emergency response requirements, NGS has the capability to acquire and rapidly disseminate high resolution digital photography. During times of natural or human induced disasters, these capabilities are available for the collection and delivery of high resolution datasets, to a variety of users including federal, state, and local government agencies, as well as the general public.
- After Hurricane Florence, NGS collected 28,838 aerial images over a total area of 8,575 square kilometers using two of NOAA's aircraft from September 15-22, 2018. The imagery supported search and rescue efforts, logistics and supply efforts, transportation corridor assessments, and FEMA individual assistance efforts.
- For Hurricane Michael, NGS began response efforts on October 11, one day after landfall. NOAA's King Air aircraft, operating from Mobile, AL, collected 9,580 images covering 10,756 square kilometers of the most heavily affected areas. The imagery

supported search and rescue efforts, logistics, and supply efforts, transportation corridor assessments, and FEMA individual assistance efforts.

NOTES REGARDING CORRECTIONS:

1.) The original wording on page 38 was changed from:
"With existing vacancies, surge staffing only brought WFO Morehead City to standard staffing and WFO Wilmington, NC up to one below standard staffing."
to reflect the following phrase:
"With existing vacancies, surge staffing brought WFOs Morehead City and Wilmington, NC up to one below their standard staffing."

2.) The original wording on page 110 was changed from:
"Secondary backup between WFO Wakefield and WFO Morehead City was tested for the first time since 2018."
to reflect the following phrase:
"Secondary backup between WFO Wakefield and WFO Morehead City was enacted for the first time since 2018."