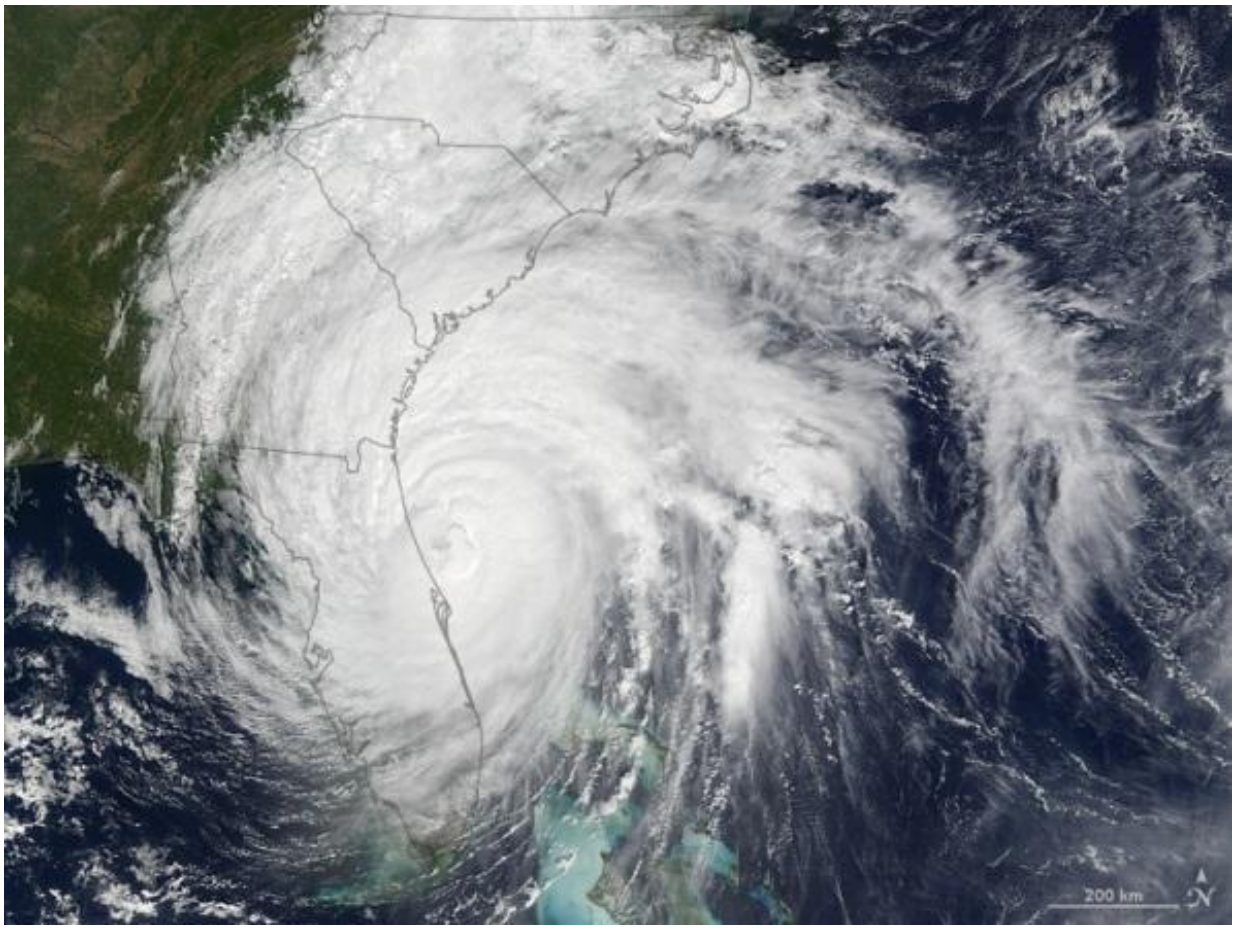
Service Assessment

October 2016 Hurricane Matthew



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

Cover Photograph: Moderate-resolution imaging spectroradiometer (MODIS) satellite view from the NASA Terra Satellite of Hurricane Matthew taken at 12 pm EDT, October 7, 2016.

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August 2017

National Weather Service
John D. Murphy
Chief Operating Officer

Preface

Hurricane Matthew left a trail of destruction from the Caribbean to Virginia from September 29 – October 9, 2016. High winds, pounding surf, storm surge, and historic flooding led to widespread, devastating impacts along the southeast U.S. coastline. Hurricane Matthew traveled northward nearly parallel to the coast before making landfall in South Carolina. The storm produced winds in excess of 100 mph, storm surge in excess of 7 feet, and up to 20 inches of rainfall. Weather-related fatalities occurred up and down the southeast U.S. coast. The majority of fatalities were the result of flooding, making inland flooding a primary focus for this assessment.

Because of the significant impacts of the event, the National Weather Service (NWS) formed a service assessment team to evaluate its performance before and during Hurricane Matthew's impacts. The NWS Mission Delivery Council will review and consider the findings and recommendations from this 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 NWS's public education and awareness materials related to flooding and other tropical cyclone hazards. The ultimate goal of this report is to help the NWS meet its mission to protect life and property and enhance the national economy.

John D. Murphy
Chief Operating Officer

August 2017

Table of Contents

Page

List of Figures

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Executive Summary

Hurricane Matthew laid a path of destruction from the Caribbean to the Mid-Atlantic coast of the United States. The powerful storm reached Category 5 strength–the first tropical system in the Atlantic Basin to attain that level since Hurricane Felix in 2007. Matthew brought strong winds, devastating flooding, and damaging storm surge to the southeastern United States from Florida to Virginia, making landfall on October 8 as a Category 1 storm with sustained winds of 85 mph near McClellanville, SC. The storm was long-lived, remaining at hurricane strength from September 29 to October 9, 2016.

Peak wind gusts observed in the NWS surface network reached 107 mph along Matthew's path. Winds in excess of 85 mph were measured from Florida to the outer banks of North Carolina. Full details regarding Matthew's winds, track and other details are in NHC's tropical cyclone report found at http://www.nhc.noaa.gov/data/tcr/AL142016_Matthew.pdf. These winds caused widespread power outages, infrastructure damage, and led to several fatalities due to falling trees and debris. Along the coast, storm surge set records from Florida to North Carolina. Seven tide gages set local records for the highest water level in this area, with surge causing widespread damage to coastal infrastructure.

Matthew's most deadly hazard was inland flooding. Deep moisture drawn north by the tropical cyclone interacted with a stationary boundary over the Carolinas to produce rainfall amounts between 10 and 20 inches over a broad area of eastern South and North Carolina. Wet conditions were in place prior to this extreme rainfall, leading to historic flooding. Swollen rivers and creeks led to deadly conditions claiming close to 50 lives. Flood impacts lingered for weeks after the storm moved east and dissipated. This was the first time since Hurricane Floyd in 1999 that impacts of this magnitude occurred in the Carolinas. In some cases, the highest river flows in recorded history occurred.

Communicating the extreme threat posed by Matthew was a monumental task for the National Weather Service. Matthew required close coordination among all levels of the organization: field offices, regional headquarters, national centers, and NWS national headquarters. Significant internal coordination occurred with information shared through a wide variety of impact-based decision support. NWS offices coordinated with partners at all levels and provided both remote and onsite support up and down the coast.

The service assessment team found that NWS staff members performed exceptionally and professionally throughout the event and provided tremendous service in the face of such a dangerous and historic situation.

Service Assessment Report

1. Introduction

1.1. NWS Mission

The mission of National Oceanic and Atmospheric Administration's (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 135 regional headquarters (HQ), local Weather Forecast Offices (WFO), and River Forecast Centers (RFC). The forecasters at the WFOs and RFCs issue local forecasts and warnings to the public and interface with local emergency managers (EM) and state and local government to promote community awareness and understanding of local climates, forecasts, and weather events. The National Hurricane Center (NHC) issues hurricane and tropical storm warnings for coastal locations.

The NWS has its National HQ in Silver Spring, Maryland and six regional HQ, which together provide policy and guidance to the WFOs and RFCs. The National Centers for Environmental Prediction (NCEP), consisting of nine prediction centers, provide central guidance, outlooks, forecasts and hazardous weather watches and warnings to NWS and the public.

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 the 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 domestic performance during Hurricane Matthew, October 6–9, 2016. This event affected areas from southern Florida to southeast Virginia. Hurricane Matthew brought strong winds, storm

surge, and extensive inland flooding that resulted in 49 fatalities, considerable property loss, and significantly affected transportation and commerce.

The objectives of this assessment were to identify significant findings and issue recommendations and best practices related to the following key areas:

- Timeliness, quality, accuracy, and usefulness of NWS forecasts and warnings
- Effectiveness of NWS decision support services before, during, and after the event
- Effectiveness of NWS external messaging of hazards, impacts and risk to partners and the public at large
- Evaluation of NWS event staffing and technological support
- Effectiveness of NWS internal communication, coordination, and collaboration

1.3. Methodology

NWS formed a service assessment team on October 21, 2016, consisting of employees from NWS field offices, NCEP, NWS HQ (NWSH), the US Geologic Survey (USGS), and the Federal Emergency Management Agency (FEMA).

The eight-member team completed the following:

- Performed on-scene evaluations from south Florida to North Carolina from October 31 to November 4, 2016
- Conducted in person interviews with staff from WFOs in Raleigh, Morehead City, and Wilmington, NC; Charleston, and Columbia, SC; Jacksonville, , Melbourne, and Miami, FL; the Southeast RFC (SERFC); the National Hurricane Center (NHC); and Southern Region Headquarters (SRH), including the Regional Operations Center (ROC)
- Conducted interviews remotely with the following NWS offices: Tallahassee, FL; Peachtree City, GA; Greer, SC; Wakefield, VA; Weather Prediction Center (WPC); Ocean Prediction Center (OPC); Environmental Modeling Center; HQ Marine, Tropical & Tsunami Services; HQ Office of Water Prediction; Eastern Region Headquarters (ERH); and the NWS Operations Center (NWSOC)
- Interviewed EM, the media, and the public as well as other government agency representatives
- Assessed the damaged areas
- Evaluated products and services issued by the WFOs, SRH, ERH, SERFC, and NCEP Centers
- Compiled a core list of common theme areas discovered during onsite and remote interviews
- Agreed on the 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, signed by the NOAA Assistant Administrator for Weather Services, and issued to the American public.

2. Event Summary

Hurricane Matthew was an extremely destructive and long-lived tropical cyclone that impacted areas from the Lesser Antilles to the southeast United States between September 28 and October 9, 2016 (**Figure 1**). Overall, the hurricane claimed more than 1,600 lives, created an estimated $10.5B in damages, and caused major flooding in the Carolinas that lasted through the month of October. Originating from a tropical wave off the African coast, Hurricane Matthew was the first Category 5 Atlantic Basin hurricane since Hurricane Felix in 2007. At Hurricane Matthew's strongest point, NWS estimated sustained surface winds of 165 mph with a barometric pressure of 934 millibars. Hurricane Matthew was the first hurricane on record to make landfall as a major hurricane in Haiti, Cuba, and the Bahamas.

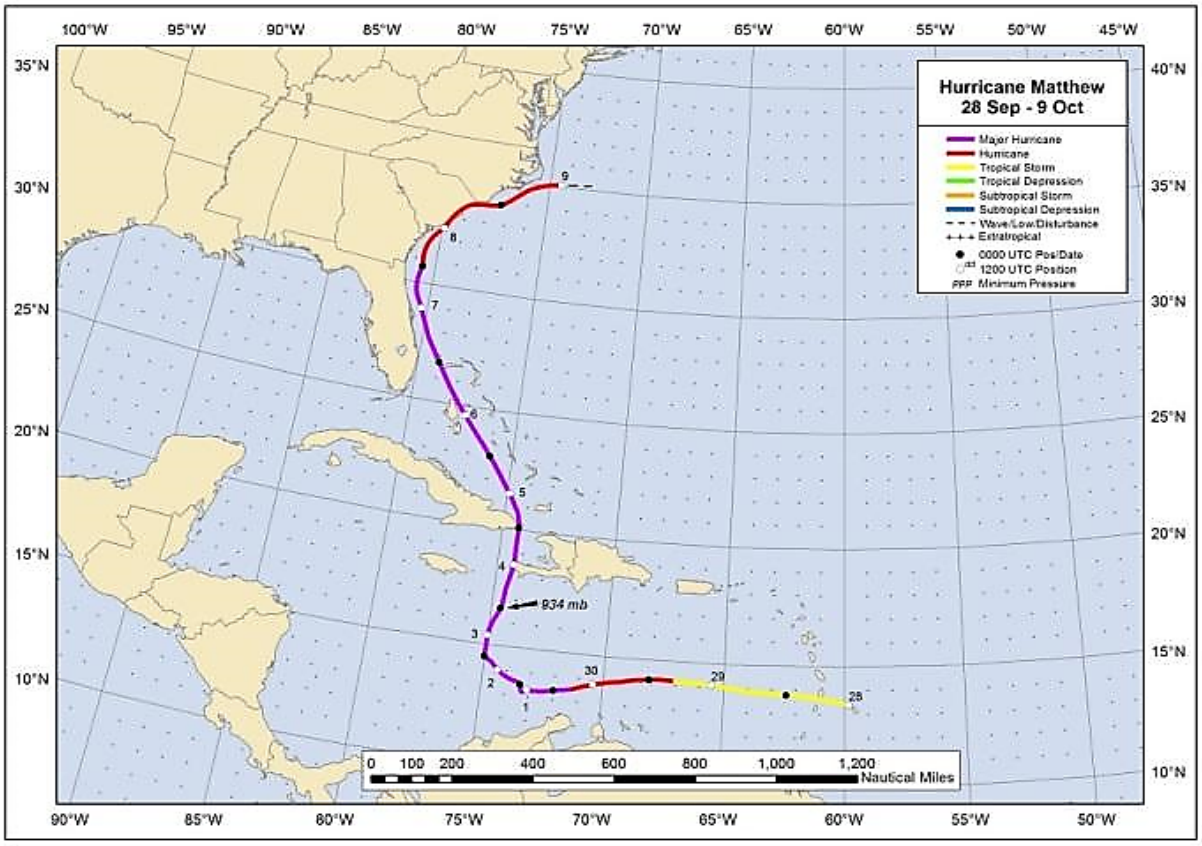

Figure 1: Matthew post-storm analysis of track & intensity (best track). *Source: NOAA*

Hurricane Matthew brought strong winds, devastating flooding, and damaging storm surge to the southeast from Florida to Virginia. The hurricane made landfall on October 8 as a Category 1, 85-mph hurricane, over the Cape Romain National Wildlife Refuge near McClellanville, SC. Hurricane Matthew triggered mass evacuations along the coast and 49 deaths in the United States. According to NOAA's National Centers for Environmental Information, the storm caused at least $10.1B in damage in the United States, making it tied for the third most expensive weather or climate disaster since Hurricane Sandy in 2012 (see https://www.ncdc.noaa.gov/billions/events/US/1980-2017).

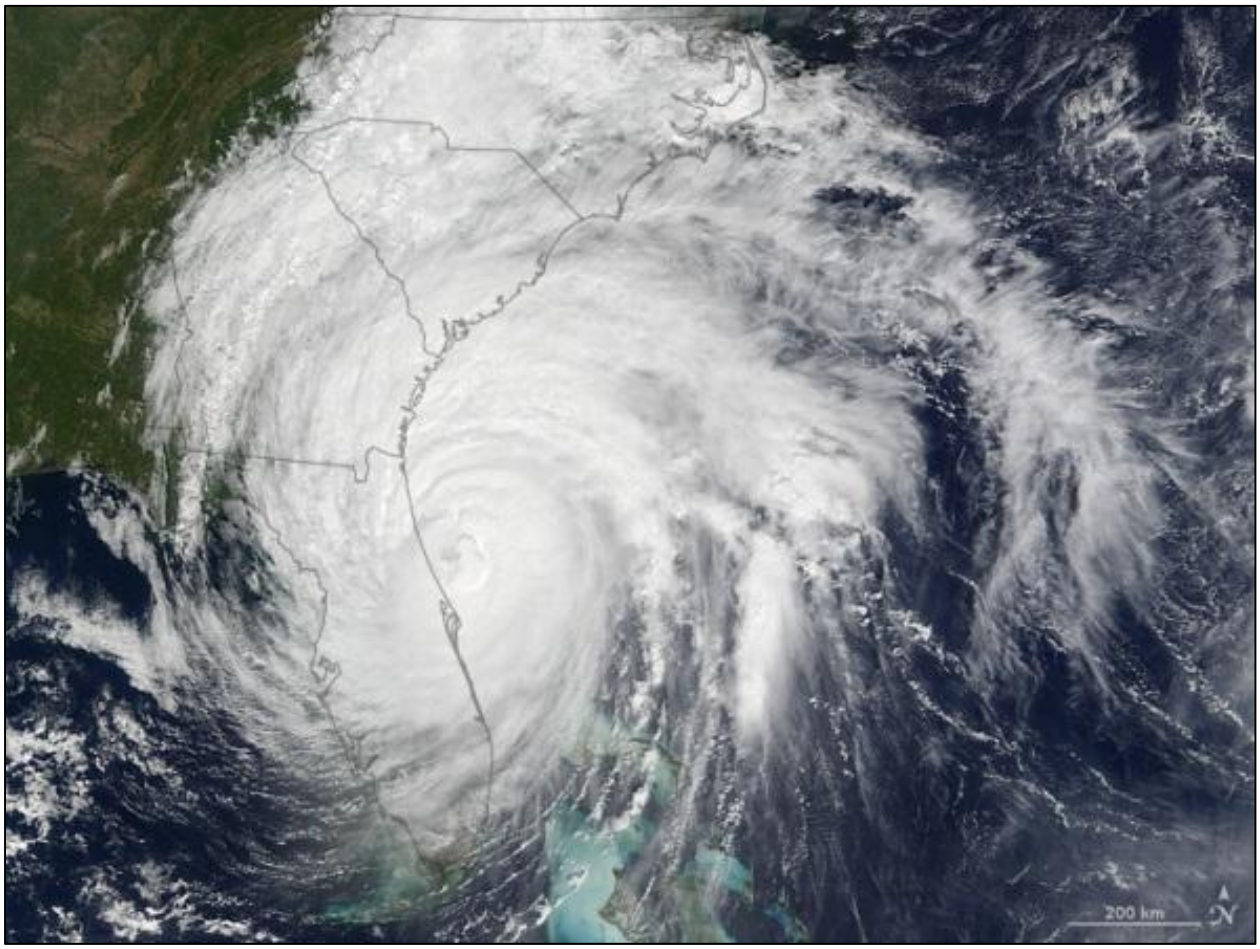

Figure 2: MODIS satellite image from the NASA Terra Satellite showing Hurricane Matthew at 12 pm EDT, October 7, 2016. At the time, Hurricane Matthew was a Category 3 storm with 120 mph winds. *Source: NASA*

2.1. Wind Impacts

The strongest observed winds near the United States were off the Florida coast as the storm moved parallel to the coastline (**Figure 2**). Sustained hurricane-force/Category 1 winds were confined mainly to the immediate coastal areas and barrier islands of east-central and northeastern Florida, and the barrier islands of Georgia, South Carolina and North Carolina, including the Outer Banks. Although the strongest winds remained just offshore, Port Canaveral, FL, recorded an observed wind gust of 107 mph, causing damage at the Kennedy Space Center and delaying the launch of NOAA's next generation satellite, GOES-R. Walt Disney World resort closed for only the fourth time in its history. Other notable peak wind gusts included Tybee Island, GA, (96 mph), Daytona Beach, FL, (91 mph), Jennette's Pier, NC, (91 mph), Hilton Head, SC, (88 mph) and the Jacksonville, FL, area (87 mph) **(Figure 3**).

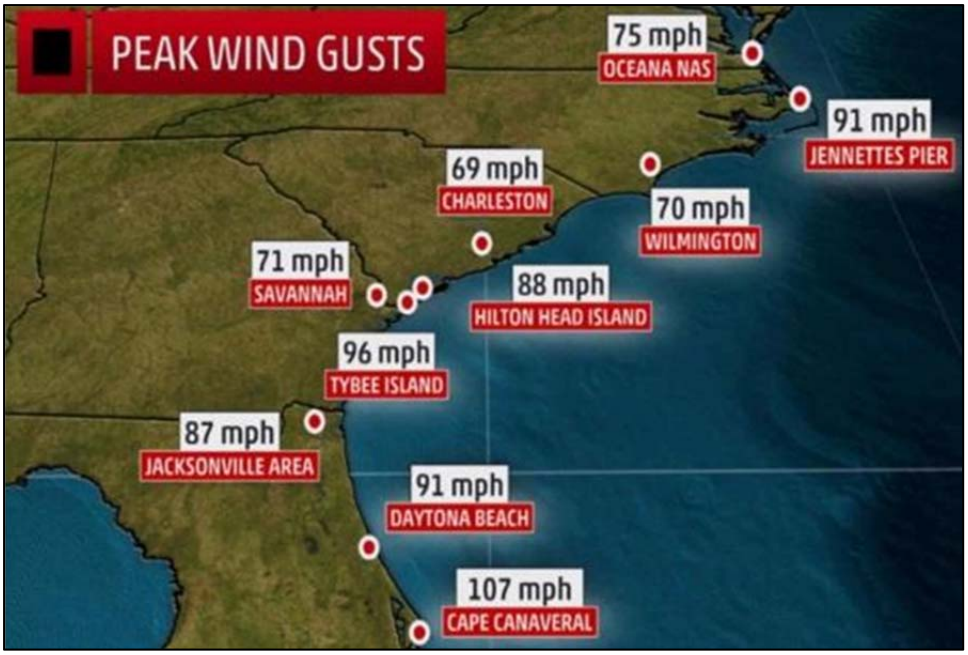

Figure 3: Peak wind gusts during Hurricane Matthew. *Source: The Weather Channel*

2.1.1. Heavy Rain & Flooding Impacts

While damage was primarily confined to the coast in Florida and Georgia, heavy rains spread inland in the Carolinas and Virginia, causing catastrophic flooding over the Coastal Plains of North Carolina and South Carolina. A swath of 10–20 inches of rain fell in the eastern sections of the Carolinas, with hourly rainfall estimates as high as 7 inches per hour (**Figure 4**). The maximum reported storm-total rainfall was near Evergreen, NC, where 18.95 inches was measured on 8–9 October. Other notable rainfall amounts measured were 17.48 inches at Hunter Army Air Field in Savannah, GA, 17.05 inches at Hope Mills in southeastern North Carolina, 17.01 inches at Cape Canaveral Air Station in east-central Florida, 16.90 inches on Edisto Island, SC, and 14.21 inches in extreme southeastern Virginia. The Annual Exceedance Probabilities graphic (**Figure 5**) shows that rainfall in many areas of the Carolina coastal plain reached or exceeded a 1 in 500-year event, or a 0.2 percent chance of occurrence in a given year.

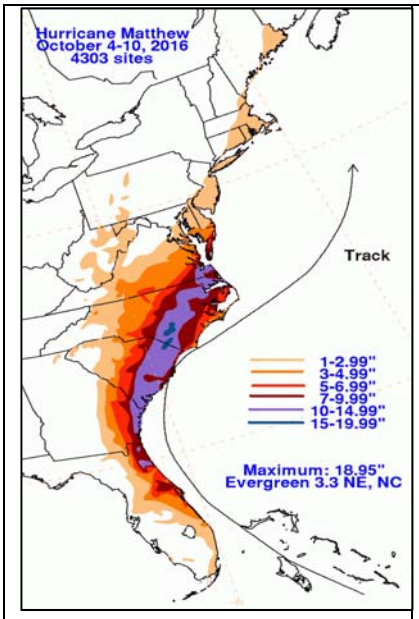

Figure 4: Precipitation totals for Matthew with black line indicating track of storm center. *Source: NOAA*

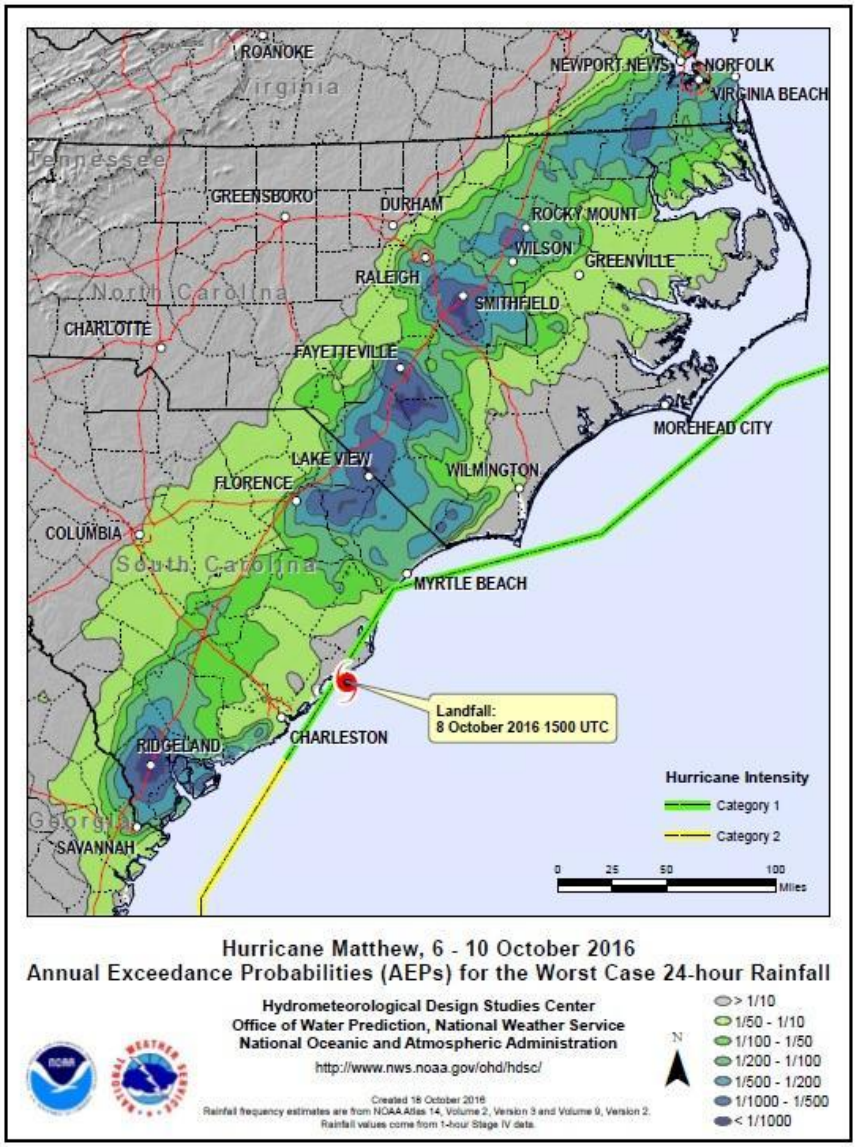

Figure 5: Annual Exceedance Probabilities for the worst case 24-Hour rainfall for Matthew. *Source: NOAA*

Heavy rainfall associated with Hurricane Matthew resulted in record river flooding not seen since Hurricane Floyd in 1999, causing millions of dollars of damage and 24 flood related fatalities across the eastern third of North Carolina. Buildings were flooded, roads were washed out (**Figure 6**), and sections of Interstates 95 and 40 were closed for days due to flooding.

Figure 6: Washed out road near Fayetteville, NC. *Source: Reuters*

According to the USGS report on Hurricane Matthew's flooding (found at https://pubs.er.usgs.gov/publication/ofr20161205), the heavy rainfall caused major flooding in parts of the eastern Piedmont of North Carolina and coastal regions of North and South Carolina. USGS stream gages recorded peak streamflows of record at 26 locations, including 11 sites with long-term records of 30 years or more. A total of 44 additional locations had peak streamflows that ranked in the top 5 for the period of record. A period of record is the timespan USGS has been measuring flows at those sites, also known as the gages' period of record. The USGS has been measuring streamflow data at some sites across the country since the 1890s.

Five additional stage-only sites (where streamflow is not calculated) also had new period-of-record peak stages. For example, on the Neuse River in North Carolina, USGS stream gage locations near Goldsboro and at Kinston recorded peak stages in excess of Hurricane Floyd flooding in 1999 (**Figure 7**). The Neuse River near the Goldsboro stream gage recorded a stage of 29.74 feet on October 12 and the stream gage on the Neuse River at Kinston recorded waters reaching a stage of approximately 28.31 feet on October 14.

WFOs Wilmington and Newport/Morehead City, NC, issued their first-ever Flash Flood Warnings that included flash flood emergency wording during the event. Areas impacted included the Myrtle Beach Grand Strand and Conway, SC. The WFOs issued flash flood warnings due to the combination of riverine and storm surge flooding. Flash flood emergency wording is used only during rare, exceptionally dangerous events. Flash flood emergencies were also issued by WFOs Raleigh, NC, and Wakefield, VA.

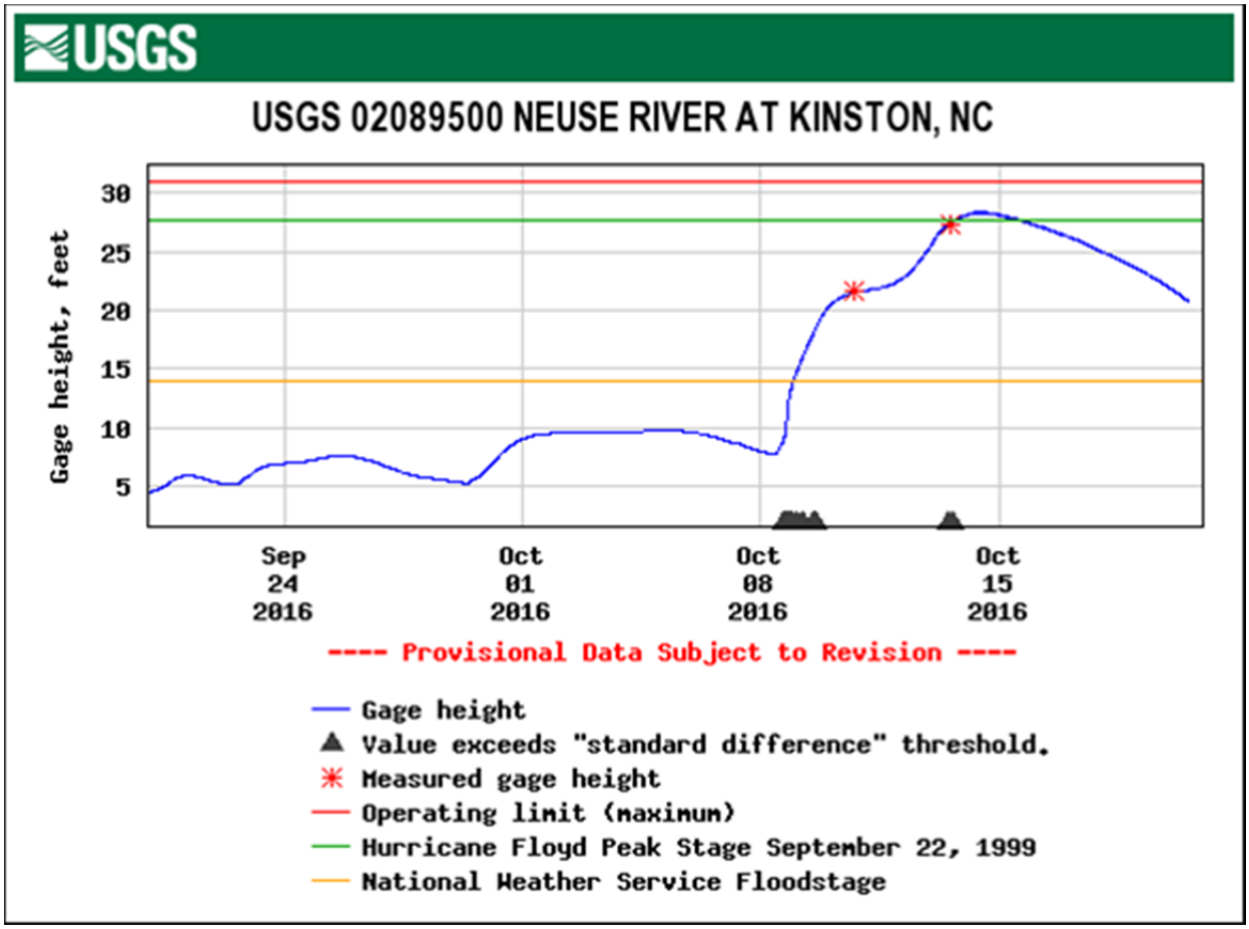

Figure 7: USGS graph of gage height or stage at stream gage 02089500 on the Neuse River at Kinston, NC, September 20 to October 20, 2016. *Source: USGS*

2.1.2. Storm Surge Impacts

Hurricane Matthew brought significant inundation from storm surge along and near the Southeast Coast, which flooded roads, homes, and businesses. The maximum storm surge measured by a tide gauge in the U.S. was 7.70 feet above normal tide levels at a National Ocean Service (NOS) gauge at Fort Pulaski, GA. Matthew also produced storm surges of 6.96 feet at Fernandina Beach, FL; 6.20 feet at Charleston, SC; and 6.06 feet at Hatteras, NC, as well as along the St. Johns River where the highest water levels on record were measured during Matthew (**Figure 8**).

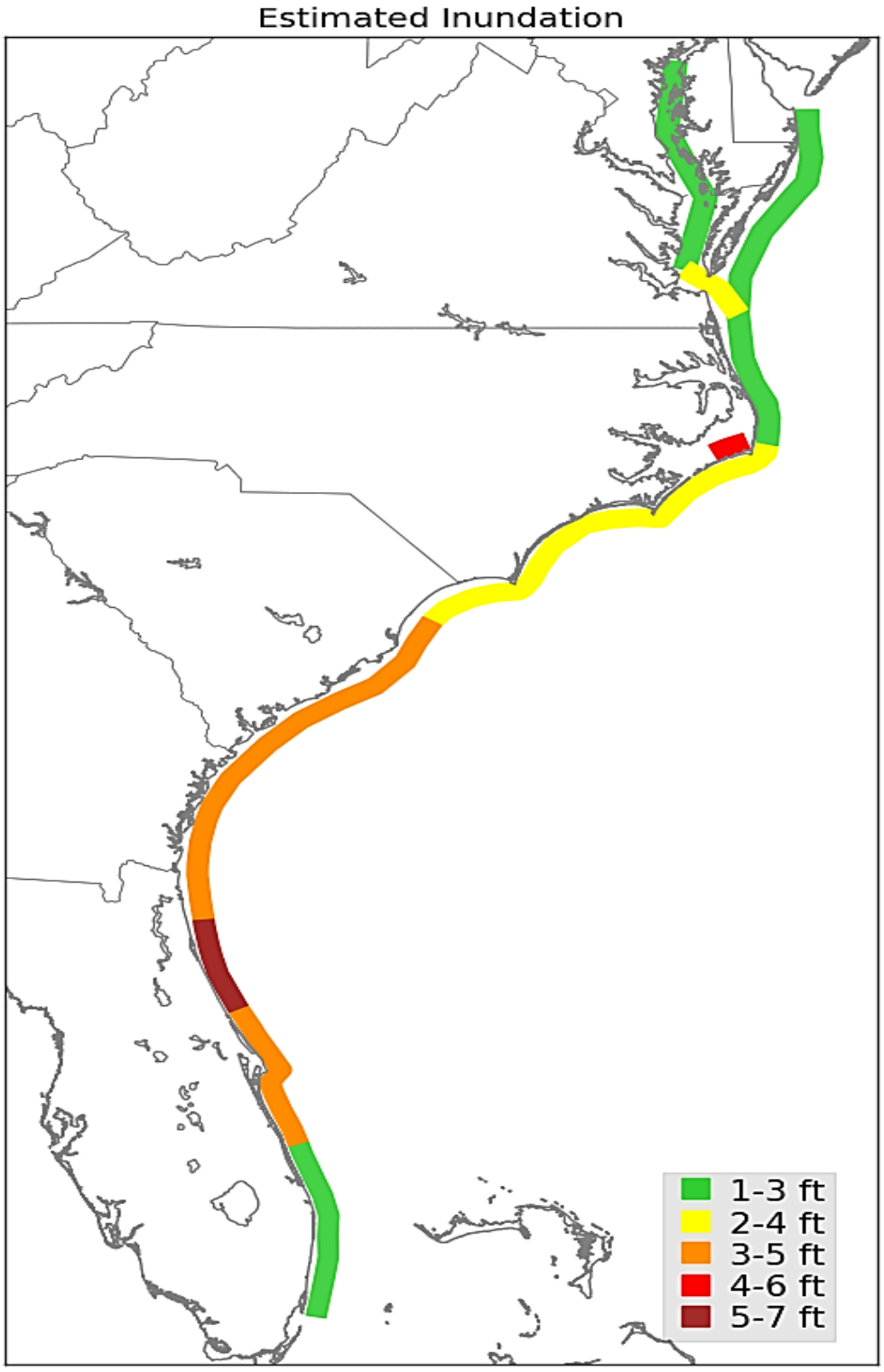

Figure 8: Estimated maximum storm surge inundation levels (ft. above ground level) on Atlantic coast due to Hurricane Matthew based on USGS and NWS high water mark observations, NOS tide station observations and USGS storm tide pressure sensors: *Source: NHC*

NHC's Potential Storm Surge Flooding Map (**Figure 9**) and Prototype Storm Surge Watch/Warning graphic (**Figure 10**) were widely used in communicating the storm surge threat to NWS partners and the public up and down the coast. After the event, NHC experts traveled to areas in Florida, Georgia, and South Carolina that were hardest hit by Hurricane Matthew's storm surge. This was the second time NHC personnel were able to truth-test their operational potential storm surge flooding maps and see how EM and the public used the experimental storm surge watch and warning graphics. USGS also documented the magnitude of the surge as part of its storm tide network. Water level and barometric pressure sensors at 288 locations along the Atlantic Coast from Florida to North Carolina recorded the timing, areal extent, and magnitude of the storm tide and coastal flooding generated by Hurricane Matthew.

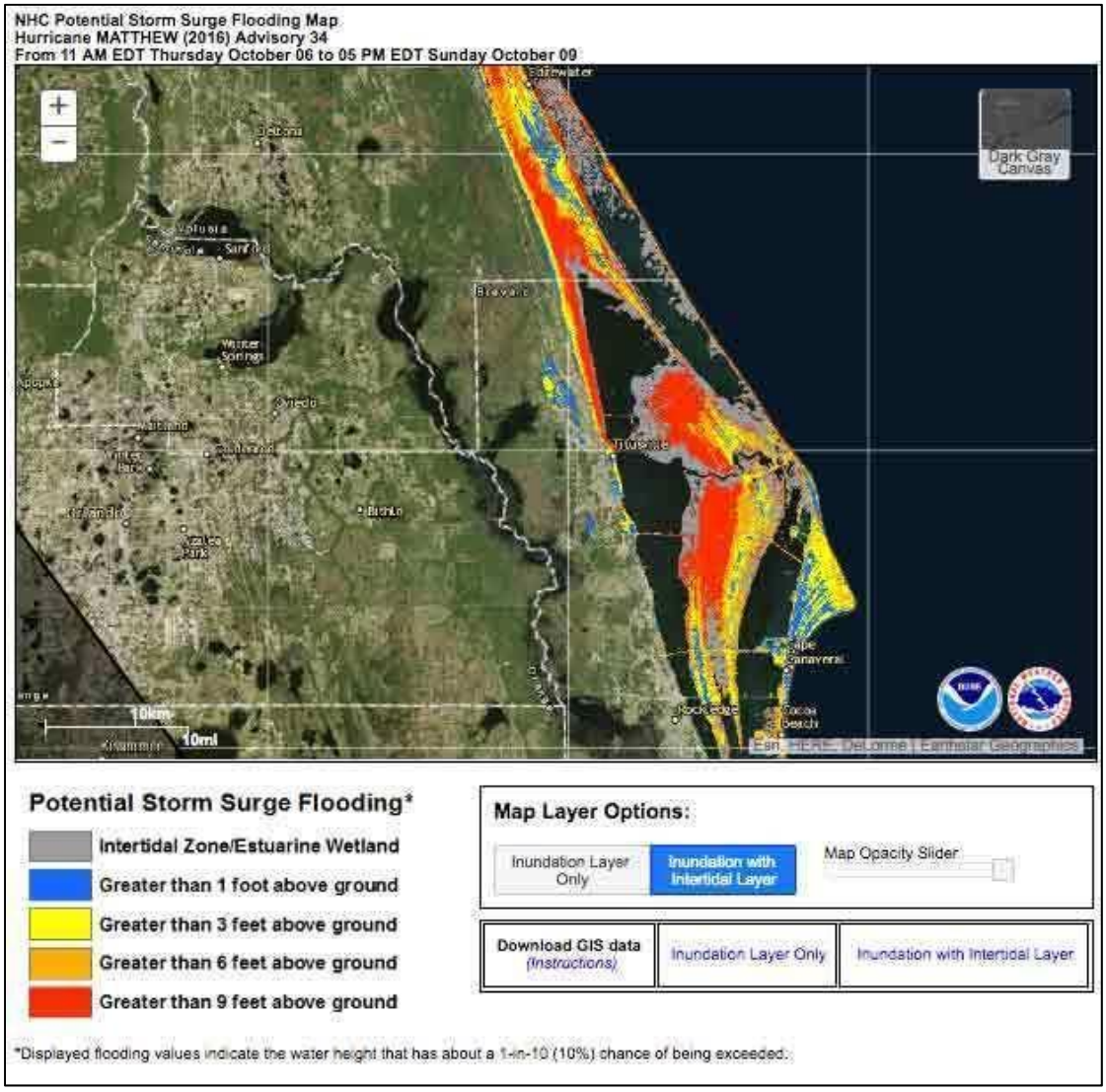

Figure 9: NHC Potential Storm Surge Flooding map issued October 6, 2016. *Source: NOAA*

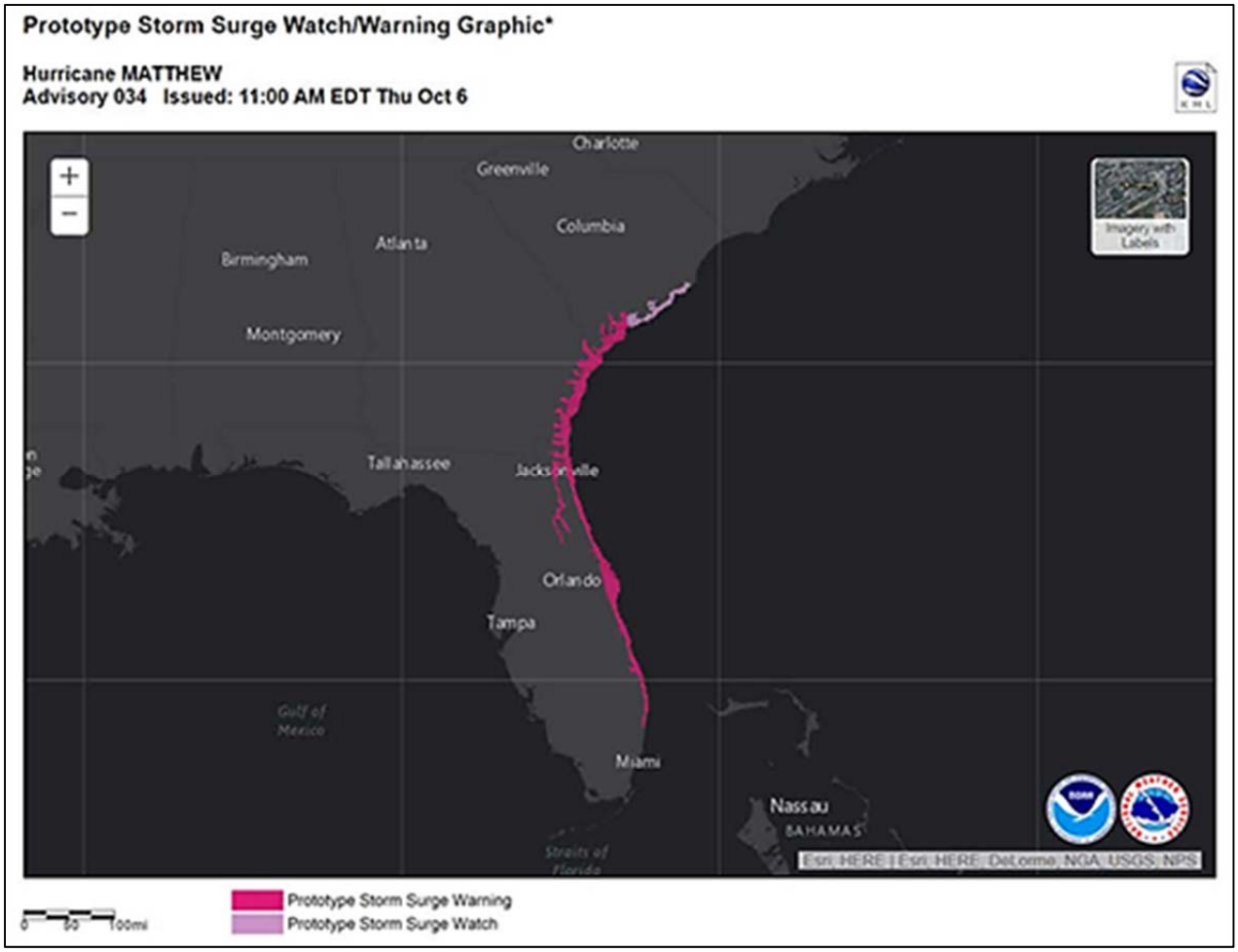

Figure 10: NHC Prototype Storm Surge Watch/Warning Product issued on October 6, 2016.

According to USGS, Hurricane Matthew's storm surge and waves overwashed 177 miles of beach dunes in four states. This total included about 11 percent of the sand dunes on Florida's Atlantic coast, 30 percent along Georgia's coastline, 58 percent of dunes on South Carolina's beaches, and 9 percent of North Carolina's dunes. Sand dunes are important to maintain because they play a vital role in protecting beaches, coastline, and coastal developments from hazards such as erosion, coastal flooding, storm surge, and large waves.

South of St. Augustine, FL, the storm surge opened up a new inlet between the Atlantic Ocean and the Matanzas River, stripping away a 12-foot dune and carrying most of its sand into the estuary (**Figure 11**). An estimated 7 feet of inundation was recorded in this area. Farther south in the town of Flagler Beach, FL, powerful waves washed away a portion of Highway A1A, closing the beachfront highway indefinitely, and obliterating a 17-foot dune (**Figure 12**).

Figure 11: Low-altitude oblique photos taken before Hurricane Matthew (September 6, 2014) and after (October 13, 2016) showing where the storm cut a new inlet between the Atlantic Ocean and the Matanzas River, stripping away 12-foot dune and carrying sand into the estuary. S*ource: USGS*

Figure 12: Beach erosion and road damage on Highway A1A left by Hurricane Matthew in Flagler Beach, FL. *Source: NBC News*

3. Findings, Recommendations, and Best Practices

3.1. NWS Forecasts, Products, Warnings—Inland Flooding

Inland flooding was devastating across portions of North Carolina, South Carolina, and southern Virginia. The NWS uses a variety of products and services to communicate the threats and impacts associated with tropical cyclones, including inland flooding. During Hurricane Matthew, inland flooding was emphasized in products including NHC's public forecast, WPC rainfall graphics, RFC forecasts and briefings, model forecast data, WFO partner/media briefings, Hurricane Local Statements (HLS), and others. WFOs, RFCs, and national centers provided extensive information regarding the threat both remotely and onsite with the public, media, and EM officials. The shear scope of the advanced warning information was tremendous, spanning hundreds of official products, Impact-Based Decision Support Services (IDSS), phone calls, emails, etc. EM officials and media interviewed shared exuberant praise for these efforts.

Despite these extraordinary efforts, partners stated repeatedly that while they understood inland flooding was expected, the impacts/magnitude of the flooding caught them by surprise. Part of the surprise may have been the fact that many of the areas most significantly flooded experienced flooding at levels not previously recorded. According to the USGS, some locations received rainfall totals that exceeded NOAA Atlas 14 return periods of 1,000 years. Twenty-six USGS river gauges, in North Carolina alone, recorded new peaks in river height, including one gauge that has been utilized since 1896. Difficulty in communicating the inland flooding threat is not a new issue and has appeared repeatedly in previous service assessments.

The service assessment team found that NWS partners and the public viewed the available products used to describe the flooding threat, but several still felt surprised at the outcome. NWS partners, including the media, made reference to HLSs issued by WFOs. Most felt that recent improvements to make the product more concise and more focused on impacts have helped. That said, many interviewees indicated that the product could be even more focused and less wordy. Some referenced the HLS as invaluable, while others indicated that they reviewed the product only to see the portion that describes the latest changes to the forecast relevant to their local area. There was universal perception among the partners that the HLS is designed to describe local conditions and provide specific impact information for local impacts.

NWS partners indicated that flash and river flood watches and warnings were helpful during the event. These watches and warnings were featured prominently during media broadcasts and relayed via social media. All those interviewed indicated that the products were well understood.

In North Carolina, WFOs in coordination with SERFC, used a two-tiered flood product paradigm during the event. The WFOs issues Flood Advisories for non-life threatening situations and flood warnings for life threatening situations. SERFC hydrologists produced guidance products, and provided the interpretation thereof, indicating anticipated responses on area rivers. WFOs and SERFC identified the inland flood threat; however, WFOs chose to delay issuing river flood warnings even though official river forecast guidance (**Figure 13**) and Meteorological Model Ensemble River Forecasts (MMEFS) from SERFC (**Figure 14**) indicated

the possibility of major river flooding. The decision to delay issuing the river flood warnings was based primarily on past experience and low confidence in Quantitative Precipitation Forecasts (QPF) in the 24 to 48 hour time frame prior to the arrival of heavy rain. QPF from WPC highlighted the significant rainfall totals expected with a lead time of 72 to 96 hours and were accurate to within 100 miles of the heavy rain maxima.

Fact: NWS representatives interviewed during the assessment indicated the QPF information produced by WPC was crucial to raising their situational awareness.

Finding 1: Partners indicated that despite the excellent service and information provided by the NWS they were surprised at the magnitude of flooding they experienced and did not feel that the threat was communicated adequately.

Recommendation 1: The NWS needs to take a comprehensive look at communication related to inland flood threats for both river and flash flooding. This may include confidence-based forecasts, inundation maps, increased educational efforts, pursuing a social science analysis of flood related messaging, and links to WPC's Excessive Rainfall graphics on NHC's web page.

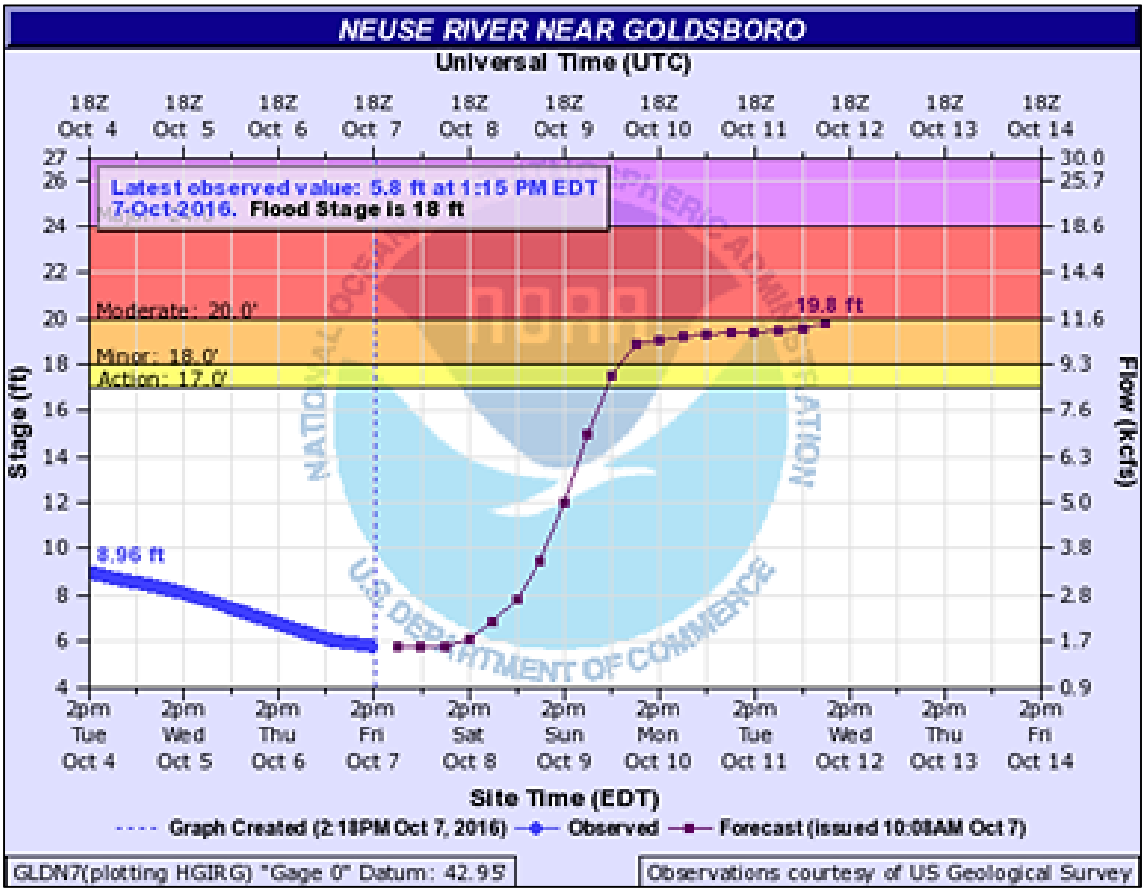

Figure 13: Advanced Hydrologic Prediction Service River Forecast, WFO Raleigh, NC, Friday, October 7, 2016 about 24 hours before heavy rainfall arrived. *Source: NOAA*

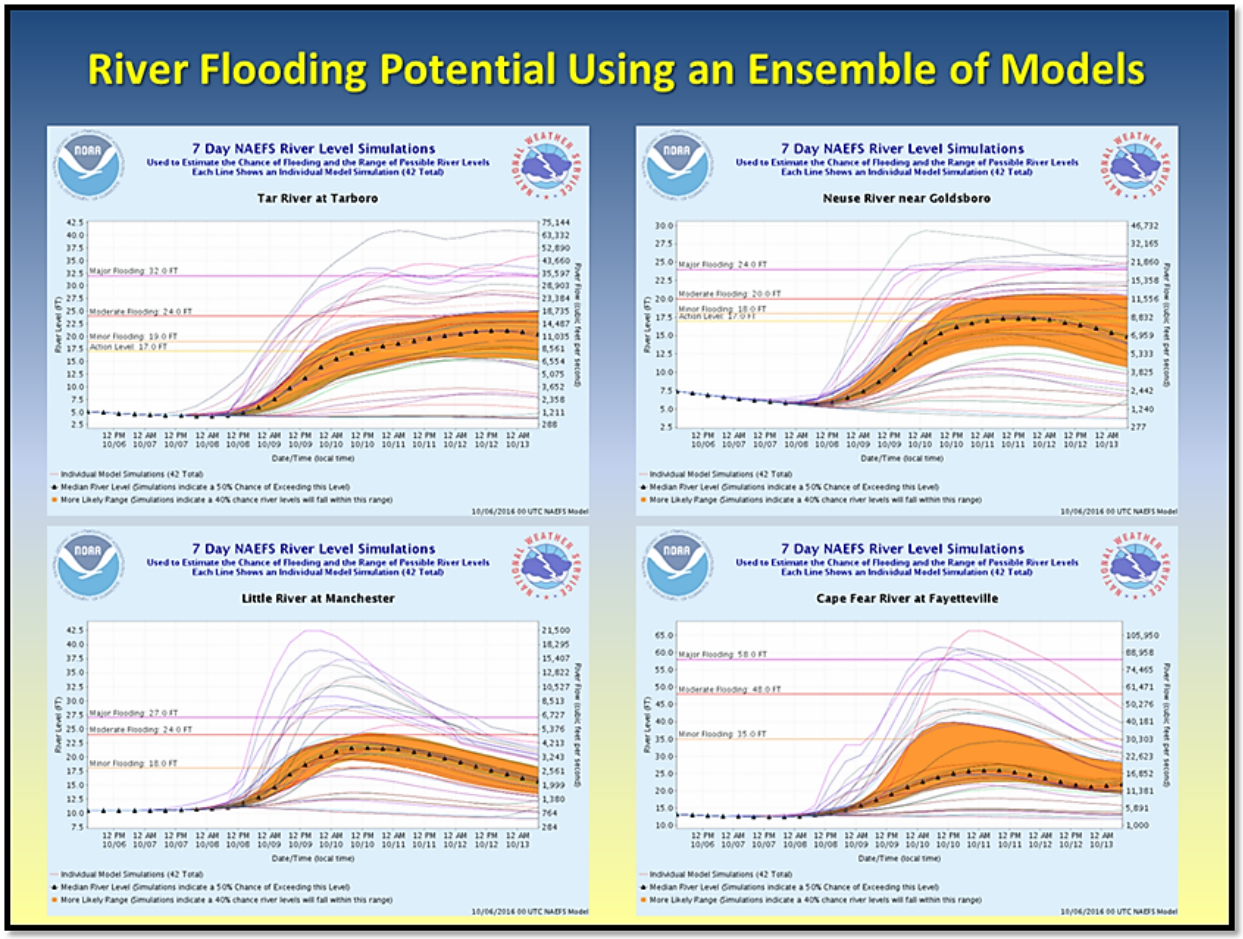

Figure 14: Meteorological Model Ensemble River Forecast (MMEFS) from SERFC for WFO Raleigh, NC, Thursday, October 6, 2016. *Source: NOAA*

Standards for specific hydrologic products follow a multi-tiered "Ready, Set, Go" concept as outlined in the NWS Instruction 10-922. This is used to convey severity and timing of a forecast along with forecaster confidence. Flash flood warnings are listed under the flood statement identifier "Go" and are intended to provide advance notification of dangerous, short-fused flood events. In rare situations, flash flood emergency language may be added to the warning if there is confirmatory evidence of rapidly rising flood waters that pose severe and/or immediate threat to human life and property. The addition of flash flood emergency wording to the product does not change the product title or associated coding, only the text included in the warning.

Finding 2: WFOs Wilmington, Raleigh, Wakefield and, Newport/Morehead City issued flash flood warnings with flash flood emergency wording for the first time during Hurricane Matthew. Media partners indicated that they had a hard time identifying how the product differed from the standard flash flood warning. The result was an impact on NWS media partners' ability to communicate the proper threat level and recommended protective actions to the public.

Recommendation 2: Prior to the issuance of newly- or rarely-used NWS products, adequate outreach to NWS partners and the public should be completed. Information should be shared

that addresses product definitions, their purpose, and context for its use. If the newly- or rarely-used product is similar to other products the differences should be communicated clearly.

Per NHC's official advisory at 0900Z on October 9, Hurricane Matthew transitioned from a tropical system to a post-tropical cyclone. The service assessment team found that universally NWS officials interviewed indicated that Post-Sandy tropical transition rules were followed successfully during Hurricane Matthew. Officials from NCEP (NHC/OPC) and WFOs all shared that they felt coordination surrounding the post-tropical transition of Hurricane Matthew was well coordinated through the established conference call procedure. It was apparent that NHC operational and management staff made this an area of emphasis during the event and listened closely to the requests of SRH and ERH and WFOs during the decision making process. During interviews with NWS partners and the media, there were no indications of confusion regarding the transition process or wording within the products themselves. Based on interviews conducted and feedback received, it appears that the Post-Sandy tropical transition rules were well coordinated and understood.

NWS partners indicated the current array of stream/river gages is not adequate for decision making and there is a need for additional forecast points at existing river gages as well as additional gages farther downstream of existing forecast points and at key tributaries. NWS partners indicated that Rapid Deployment Gages provided good information at un-gaged sites. The locations to deploy future Rapid Deployment Gages is being addressed by the *Historic South Carolina Floods of October 15, 2015* service assessment, Action Item 8.

3.2. NWS Forecasts, Products and Warnings—National Hurricane Center Products and Forecasts

Statistics available in the Hurricane Matthew Tropical Cyclone Report produced by NHC indicated that the official NHC forecast did quite well overall. In fact, official track errors were below the running 5-year mean at each forecast period. While the mean errors reflect generally outstanding forecasts, coastal WFOs and agency partners indicated that the forecast issued 48 hours prior to the storms closest approach to both South and North Carolina led to an unfortunate drop in perceptions of the severity of the storm. This forecast indicated that the storm would move eastward and away from the coast, therefore partners in North Carolina said that they "took our feet off the gas." As the forecast then shifted back toward the coast and further north over the next several communication packages, partners indicated they felt they needed to rush preparation of their communications to match the adjusting conditions.

Partners expressed confusion regarding the most likely track of Hurricane Matthew beyond the 72-hour forecast point due to longer interpolation between forecast points between 72 and 120 hours. Currently, forecast points are issued every 12 hours out through 72 hours and every 24 hours between 72 and 120 hours (**Figure 15**). Partners indicated that the longer interpolation between forecast points affected their planning especially while the forecast track remained close to the coast because of uncertainty in the track of the storm's center. It was apparent to the service assessment team that in most cases EM and the public continued to focus on the forecast storm track. They also felt the forecast track during the longer interpolation between the 72- and

120-hour points did not represent the most likely scenario. Despite NHC's effort to remove the forecast track from their default graphics, NWS partners and the public alike continue to focus on the "skinny black line and many view the uncertainty cone as an impact area/zone. The service assessment team found that this leads to potential confusion regarding the true hazards and probability of impacts.

Finding 3: Significant confusion continues regarding the official NHC tropical cyclone track forecast. NWS partners and the public alike continue to focus on the "skinny black line" and many of them view the uncertainty cone as an impact area/zone.

Recommendation 3: NHC, WFOs, RFCs, Social Scientists, and NWS partners should collaborate on the most effective way to display the official NHC tropical cyclone track and impact information.

Finding 4: NWS partners and the media indicated the lack of intermediate forecast points during the 48- to 120-hour window of the official forecast track gave the impression that the forecast track did not represent the most likely scenario.

Recommendation 4: NHC should include intermediate forecast points beyond 48 hours in the official forecast.

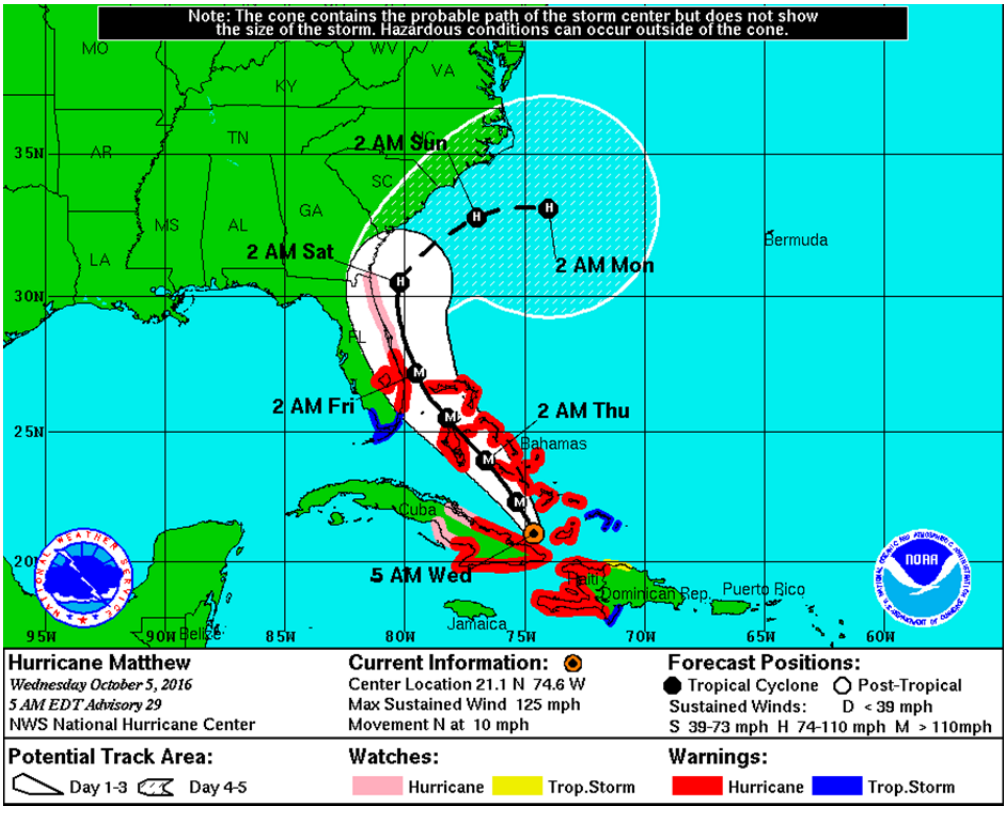

Figure 15: NHC official forecast graphic, with track included, from 5 am on Wednesday, October 5, 2016. *Source: NOAA*

A few partners, including one local and state level EM and a regional television news media outlet, expressed their concern that late night issuances of hurricane watches caused them communications and public relations problems. These NWS partners are often not in a 24-hour operational mode when a hurricane watch is issued. By the time these NWS partners return to their respective offices in the morning, the hurricane watch has been issued hours earlier and the NWS partners were informing their constituents/viewers late. These NWS partners would prefer the hurricane watch be issued (around 5 pm ET). For EM, these late night issuances also result in political issues for their agencies, such as late night calls from county commissioners, political leadership, and local media.

Fact: Numerical models were good at showing the potential threat of Hurricane Matthew more than a week in advance. The largest errors occurred during the rapid intensification of Hurricane Matthew as it crossed the Bahamas and approached the U.S. Southeast Coast. A full review of model performance during Matthew has been produced by the Environmental Modeling Center (EMC) and will be available on their website.

Storm surge products remain highly valuable for NWS partners; however, many NWS partners felt the 48-hour window for the products does not provide sufficient lead time to incorporate into their evacuation planning. NWS partner's decisions are typically made earlier than 48 hours. To date, partners have been trained to use probabilistic surge data referred to as Maximum of Maximums (MOM) and Maximum Envelope of Water (MEOW) that are outputs of NHC's Sea, Lake, and Overland Surge from Hurricane (SLOSH) model for long-range planning. These products are used to define their local floodplain, determine evacuation zones, and can be used in real-time to obtain a reasonable assessment of risk.

NWS partners indicated confusion regarding the meaning of "above ground" and "inundation" wording in the storm surge products. NWS partners also indicated the 3-foot threshold on the probabilistic storm surge product is not universally effective in representing true storm surge threat.

Finding 5: NHC's storm surge products were not universally understood by NWS forecasters, EMs, media, and the general public. Many users did not understand the potential storm surge flooding map represented the most probable worst-case scenario and instead interpreted the product as the official forecast. Some EMs indicated that this graphic should not be made public because it creates confusion and affects their ability to convey evacuation information. They stated that differences between the graphic and their evacuation zones led to public misinterpretation of the risk. Furthermore, they indicated they are very interested in graphics representing the actual forecasted surge.

Recommendation 5: Probabilistic storm surge graphics conveying the worst and most-likely case should be developed for EMs. Once developed, the storm surge values for the most-likely case should remain included in the NHC public advisory product; however, the graphics should primarily be an internal coordination tool for the EM community. NWS educational materials should be updated accordingly.

3.3. NWS Forecasts, Products and Warnings—Policy and WFOs and RFCs

During events like Hurricane Matthew, National Centers, WFOs, RFCs, and regional HQ are required to follow a series of local, regional, and national policies. These policies assist offices in creating consistent products and services. The service assessment team found that the offices interviewed provided excellent products and services in accordance with these policies; however, the team learned that some policies could be improved to help the offices provide even better services. Additionally, the team identified local products and services that deserved a highlight.

It is a daunting responsibility to manage local, regional, and national tropical cyclone programs. The service assessment team found that, in most cases, WFOs accomplished this process utilizing staff members assigned as the Tropical Focal Point. These individuals are tasked with completing routine and emergency duties as well as overseeing the integration of national and regional tropical cyclone policies into local operations. Additionally, many times these individuals are local leaders of training and education programs. WFO tropical focal points indicated that they have challenges aligning local programs with regional and national initiatives. This is due to the large scope of the program, annual changes, integration of training materials and policies, and is compounded by having to balance routine duties at the same time.

Finding 6: WFO personnel said managing their office's tropical program and aligning it with the national program is a significant effort made difficult by other routine duties and programmatic expectations. This balancing of duties was found to make it difficult to allow for the focus that is needed on the tropical program at several local offices.

Recommendation 6: In the spirit of the NWS's Evolve initiative the NWS should adjust the tropical cyclone program so there is at least one dedicated individual with tropical cyclone expertise at all coastal WFOs. These individuals would serve as the local expert for all things tropical and manage the WFO's local tropical program. During tropical cyclone season they would serve as a key IDSS resource in WFO operations overseeing activities and working shifts as necessary. Outside of tropical cyclone season they would take the lead of office tropical cyclone outreach, collaborate on office training with the Science and Operations Officer, and work on methods to improve local tropical operations. They would not routinely work shifts during the offseason. As an example, many NWS Western Region WFOs have dedicated forecasters for the fire weather program.

Policies regarding the ability for inland WFOs to issue tropical cyclone products during tropical events differs among NWS regions. This leads to abrupt changes in product suites across county warning area boundaries, leading to considerable confusion among external NWS partners and confusion by the public. Coastal states served by several WFOs and/or NWS regions are forced to describe the situation in multiple ways using the various products.

Finding 7: Current ERH policy does not allow inland WFOs to issue tropical cyclone products, while SRH policy encourages inland WFOs to issue tropical cyclone products during events. This practice is inconsistent and leads to varying levels of service and mixed messages.

Recommendation 7: The NWS Tropical Program, in coordination with regional HQs, and the Office of Water Prediction, should establish a common baseline, based on national directives, for messaging tropical cyclone events for both coastal and inland WFOs.

During tropical events, NHC is viewed as the authority on all tropical weather forecasts. NHC web pages include forecasts from other National Centers, such as QPF from WPC and tornado watches from the Storm Prediction Center. Inland flooding forecasts/information is not included on the NHC web pages. Many NWS partners interviewed commented that the public goes to the NHC web page for all tropical cyclone hazard information and they suggested that the site should be upgraded to include information of flooding potential. The service assessment team found that this is an active requirement currently being pursued through the Annual Operating Plan process.

The service assessment team found that the Hurricane Threats and Impact product (HTI) was an important source of information by EM and media reps. The HTI (**Figure 16**) includes a threat index graphic for wind potential and can serve as a mechanism for communicating tropical cyclone threats both inside and outside the agency. The product allows for crafted messages regarding the threats and NWS partners use the graphics in various forms. This product is not universally available across NWS Eastern Region (ER) and Southern Region (SR), resulting in inconsistent service.

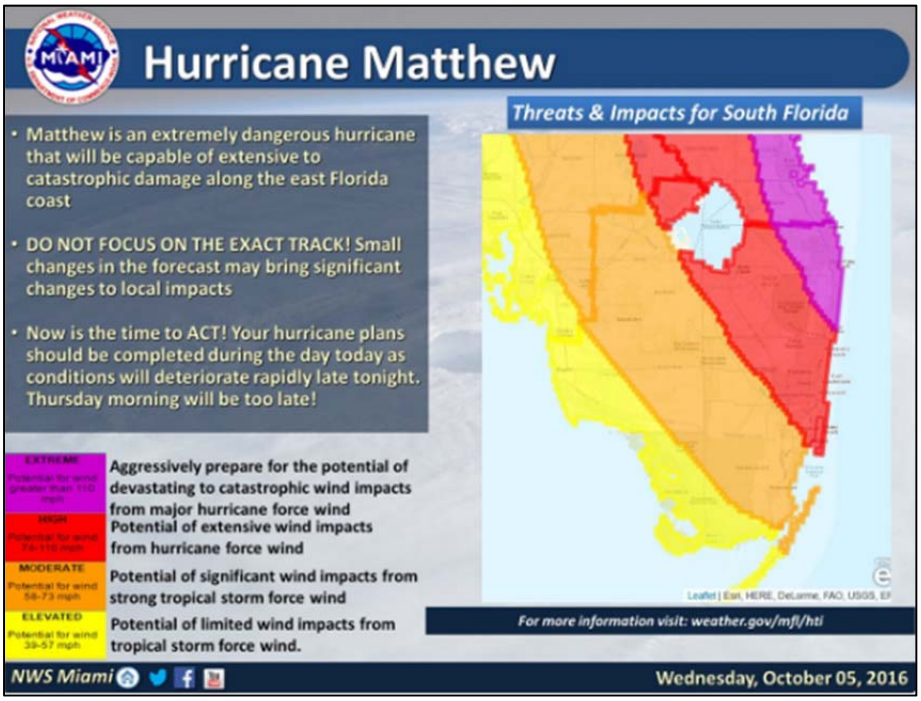

Figure 16: HTI information from WFO Miami, FL, issued via social media on October 5, 2016. S*ource: NOAA*

Fact: EM and media indicated to the service assessment team that the large number of concurrent watches, warnings, and advisories during the event made it difficult to identify the most important information from the colors on WWA maps. One media outlet limited its

relaying of product information to crawling only warnings. The service assessment team is encouraged that the NWS Hazard Simplification Project is already working to improve how WWA maps convey information

3.4. IDSS and External Communications Services

Overall, the service assessment team found a common theme of partner appreciation for the many forms of IDSS received during the event. This included services provided by NCEP, RFCs, and the WFOs before, during, and after the event. Many NWS partners expressed that they could not have carried out their mission as effectively without the support received from the NWS, both at the local and national levels. NWS offices faced several challenges during the event, including staff shortages, deployment fatigue, the need to integrate a large variety of weather and hydrology data into consolidated briefings and messages.

Figure 17: SC Emergency Operations Center during Hurricane Matthew. *Source: WFO Columbia, SC*

The WFOs provided a varying array of specific forms of IDSS. Each WFO or state grouping of WFOs created their IDSS services and NWS partner communications products from scratch, many times in the form of a graphic or briefing product (text or PowerPoint). The types of IDSS provided widely varied from WFO-to-WFO based on resources available at the local WFO, as well as the service level needs of NWS partners. NWS partners were universal in praising the IDSS efforts of WFOs. Those who received onsite support, such as the South Carolina Emergency Management Division (SCEMD), indicated that the support they received was instrumental to their success (**Figure 17**). Other agencies, such as the state of North Carolina, preferred remote support and felt well served through online and phone briefings, calls, and discussions. The service assessment team found that flexibility was a key component to meeting the various partner needs and expectations during Hurricane Matthew.

WPC and NHC briefings to FEMA and State Emergency Management officials helped amplify the IDSS messaging. The Hurricane Liaison Team (HLT) played a critical role in supporting hurricane response operations through the rapid exchange of information between the NHC, WPC, RFCs, and the EM community. The HLT is composed of EM and NWS meteorologists and hydrologists who maintain open lines of communication about the progress and threat level of the storm with appropriate federal, state, and local officials.

As with the findings of previous NWS service assessments, social media played a critical and essential external communications role for getting the word out on expected impacts from the storm.

Even though many WFOs were understaffed during Hurricane Matthew, EM at the state and local levels resoundingly praised the WFOs. EM indicated that their strong relationship with the WFOs and forecasters led to an increase in confidence and better decision making overall. It was apparent that the local WFOs in the impacted areas had built strong working relationships with their partners through extensive educational campaigns and outreach.

While WFOs were praised for their efforts, staff shortages did have an impact on the level of IDSS that could be provided ahead of, during, and after the event. WFO management told the service assessment team that staff shortages were a key consideration as to how they would staff shifts and the level of onsite and offsite decision support services they could provide.

Staffing shortages at the local and national levels within NWS were identified previously as a key finding in the *Hurricane/Post Tropical Cyclone Sandy* service assessment from 2012 with Recommendations 21a and 21b outlined in that service assessment being pertinent to what this service assessment has found, as well. Staff shortages were also referenced in Recommendation 1 of the *Historic South Carolina Floods of October 1–5, 2015* service assessment.

The service assessment team found that innovation at the local levels in providing IDSS to NWS partners was key to the success of NWS IDSS efforts. Many WFOs had unique ways of displaying forecast and impact information to raise the situational awareness of decision makers and the public. This included some WFOs adjusting the colors and themes of their briefings to emphasize the changing threats and hazards as the storm evolved. These changes caught the attention of several users and helped highlight the dangerous flooding event.

Best Practice: WFO Newport/Morehead City changed slide colors in their briefings to highlight increased confidence and the magnitude of the flood threat.

Best Practice: WFO Wakefield created a one-stop-shop event web page with links to forecast, hazard, and impact information weather.gov/akq/matthew.

Best Practice: WFO Jacksonville used the same web page URL for every briefing package release to NWS partners to avoid confusion on where to find latest briefings.

Best Practice: The WFOs serving South Carolina produced one-page briefings and provided them to SCEMD to ensure consistent messaging. This was very well received and praised by NWS partners. Additionally, support for SCEMD was administered through one office, the Columbia, SC WFO (**Figure 18**). This provided a singular consistent voice for the state, enhancing message clarity and decision making.

Figure 18: WFO Columbia WCM John Quagliariello speaking in a South Carolina Governor's press conference on Hurricane Matthew's expected impacts. *Source: South Carolina Emergency Management Division*

Best Practice: WFO Melbourne provided blog-like graphicasts every 1-to-3 hours during the event via social media. These graphics provided nowcast-like information regarding the latest event updates. They were widely viewed by the public and NWS partners.

Best Practice: WFO Melbourne used IDSS briefings and NWSChat to shape the EM and media communities message regarding a potential extreme wind warning issuance. Forecasters recognized the potential for the first issuance of the product and took the opportunity to proactively provide information to ensure NWS partners relayed the proper message if the product was issued. NWS partners, especially the media, indicated that this proactive approach provided them with a seamless transition when the product was eventually issued.

Best Practice: Pre-event meetings, weekly briefing outlooks, webinars, and participation by WFO staff and management in EM exercises helped WFO Columbia, SC, build a better working relationship with the SCEMD.

Best Practice: SERFC created a table with hydrological forecasts, comparing hydrologic model runs with and without United States Army Corps of Engineer (USACE) releases, to help show the impacts of proposed releases to the official forecast. This table was color coded, matching

conventional Advanced Hydrologic Prediction System (AHPS) color schemes, to highlight forecast points in minor, moderate, and major/record flooding.

Some WFOs utilized hydrology-specific briefings as the event transitioned to more of an inland flooding event; these briefings were well received. Also, NWS partners indicated that National Center guidance (e.g., NHC, WPC) was most useful for providing situational awareness and setting the stage for the event. They were unanimous in saying that they relied on the expertise from their local WFO for impact and short-range forecast conditions. NWS media partners indicated that discussion of the impending extreme wind warning in NWSChat by WFO Melbourne was critical to their station's planning. The early discussion allowed them to align their station resources and plan their broadcast cycle.

WFOs that deployed meteorologists to local and state emergency operations centers (EOC) found that the deployment resulted in some staff working very long hours (in some cases nearly 18 hours per day) with little rest or relief. In one case, a deployed Meteorologist in Charge (MIC) stated that a lack of adequate IDSS training limited the number of personnel available for deployment. Findings 4 and 14 of the *Historic Nor'easter of January 2016* service assessment also addresses staffing and IDSS. Two of the meteorologists deployed to state and local EOCs described the experience as exhausting. In some cases, the meteorologists deployed said the experience became overwhelming at times due to the lack of clearly defined roles and expectations by both EM and NWS.

The service assessment team agrees with Finding 8 from *The Record Front Range and Eastern Colorado Floods of September 11–17, 2013* service assessment and Finding 21 from the *Hurricane Irene, August 21–30, 2011* service assessment, which recommend that a baseline set of skills, expectations, and training should be established for the IDSS program within the NWS. The ongoing effort to evolve the NWS will likely address this issue. However, the service assessment team recommends a strong emphasis to include input from internal and external NWS partners as the IDSS program is refined.

SRH deployed an IDSS coordinator to NHC during the event. This individual worked to gather WFO briefing materials and to share their common messages between WFOs, RFCs, Regional Operation Centers (ROC), and NCEP centers. The positive influence of this position was referenced by all NWS parties interviewed during this service assessment. This position is a significant step in the right direction to ensure that NWS speaks with one voice during hazardous hydrometeorological events.

Finding 8: SRH deployed an IDSS coordinator to NHC. This individual attempted to facilitate a consistent message among all NWS entities and partners. The presence of the coordinator was widely lauded by all parts of the NWS. The concept of a deployed IDSS coordinator into a National Center is not in practice at all regional HQ.

Recommendation 8: Regional HQ should consider a model of field support that includes onsite IDSS coordinators at the appropriate National Center(s) during significant events.

NWS officials at all levels of the organization used various techniques for sharing briefing

information with their partners. This included electronic briefings, phone calls, email messages, graphics, text, and in-person coordination. This variety of IDSS techniques was universally well received by NWS partners. Despite this, it was apparent to the assessment team that the level and type of service was not consistent from WFO to WFO. While differences in partner needs and types necessitates variation in IDSS delivery, a baseline level of service is needed. The service assessment team agrees with the sentiments expressed in Recommendation 5 in the *Historic Nor'easter of January 2016* service assessment that the NWS should create a baseline set of available IDSS templates, products and techniques for use and incorporation by WFOs. While each WFO may not utilize the same types of IDSS, they would start from a common set of options with a consistent approach.

During Hurricane Matthew, a variety of river and precipitation forecast information was available for use by NWS forecasters. This included AHPS hydrographs, briefings by the SERFC discussing the official river forecasts and MMEFS output. MMEFS output began indicating the potential for significant flooding as early as October 6 (**Figure 14**), while official forecasts lagged behind. The service assessment team found that because the SERFC official forecasts only incorporate 48 hours of deterministic QPF information they were slower to pick up on the potential flooding. This made the earlier indications of flooding potential by the MMEFS exceptionally important to forecast and warning decisions. Additionally, the team received feedback that the briefing template used by the SERFC did not convey indications of enhanced risk because it was unchanged from the normal routine briefing template.

Finding 9: Ensemble forecast information produced by SERFC served as an early predictor of flood risk for the Carolinas. The service assessment team found that this model output was not emphasized to forecasters during internal briefings nor during external briefings with partners. This in part led to partners feeling that the event was more routine in nature and that the threat was reduced.

Recommendation 9: RFCs and WFOs should collaborate on the development of high-impact hydrologic event briefing templates to adequately highlight the enhanced hazard, threat, and risk of flooding. These templates should make it clear to participants that the content of these briefings differ from routine- and lower-impact events.

3.5. IDSS and External Communications—Communication Process

The service assessment team found that throughout the event the NWS maintained continuous communications with its partners to ensure sufficient public notification of impending impacts from Hurricane Matthew. This was accomplished through a variety of efforts including NWSChat, webinars, conference calls, and web content. As found in previous service assessments, social media continues to play an increasing role in notifying the public and partners of potential hazards and impacts. While the majority of efforts made during Hurricane Matthew were successful, the service assessment team found areas for improvement.

NWSChat was used extensively and well regarded during the event by both EM and NWS media partners. NWS media partners referred to NWSChat as a "lifeline" and used the service to

receive storm updates, official products, and briefings. However, media partners shared concerns about the range in response times from forecasters at the WFOs. Some forecasters respond to inquiries and requests in a very timely fashion, while others did not at all. Media representatives and EM also shared that chatrooms became flooded with participants and links to NWS products during the peak of the event. Currently, the NWSChat system automatically posts links to products into the chat room. During Hurricane Matthew, the system populated the room with so many links that it was difficult to find NWS partner requests and NWS partners said some of their requests did not garner responses. This quantity of information made it difficult to navigate the chat window and increased the likelihood that the WFO would miss partner questions and comments.

Fact: NWSChat information is exchanged in real-time with the media and EM, who in turn play a key role in communicating NWS's hazardous weather messages to the public.

Finding 10: Crowding of NWSChat rooms with numerous participants and automated links to NWS products during the peak of the event made it difficult to navigate the chat window for both NWS forecasters and partners.

Recommendation 10: WFOs should ensure an unimpeded flow of information to NWS partners, including limiting the number of products automatically displayed in the NWSChat window, and ensuring the NWSChat rooms do not get overwhelmed with participants.

Official websites are one of the most critical ways the NWS shares forecasts, products, and services. During Hurricane Matthew, local-, regional-, and national-level websites shared important forecast information. While much of the configuration of NWS web pages remains static, a few areas of the web pages can be updated dynamically to share updated information. This includes the "News Headlines" section of the web page (**Figure 19**), where information and web links can be shared. Updating this content is at the discretion of the NWS local office and requires some knowledge of local IT systems and procedures.

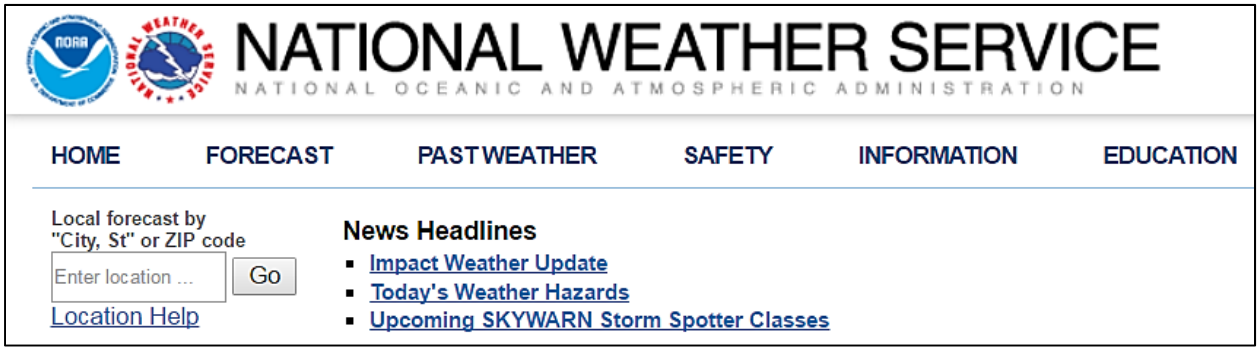

Figure 19: Example of News Headlines section of NWS web pages. *Source: NOAA NWS*

Finding 11: Some WFO staff members noted there were inconsistencies among local WFO web pages. Some WFO web pages were updated in a dynamic fashion, while others lagged behind updating content and headlines. From the WFOs' perspective, there were not enough individuals trained to make web page content and headline changes.

Recommendation 11: NWS should provide standardized training material to field personnel on how to change the top News Headlines and other necessary supporting web page content.

NHC leadership indicated they successfully used their mass media distribution system or "media pool" during the event. They would open the media pool at several coordinated times during the day and even scheduled impromptu interview periods as the hurricane approached the U.S. East Coast, emphasizing the inland flooding threat. NHC leadership shared concern that local television affiliates may not have been aware of the opportunity to join the media pool. Additionally, as concerns shifted to rainfall and flooding, the service assessment team believes that having a hydrology expert and/or WPC representative available to assist in messaging the event would have been valuable. NHC leadership further indicated they have difficulty creating media friendly graphics to use with their interviews and other outreach during events. Overall, the media pool was successful in helping NHC spread critical messages across the country to a variety of NWS media partners. At this time, the media pool is only available to NHC personnel.

As the event unfolded and the focus of the forecast began to shift toward inland flooding concerns, a wide array of official products were created by RFCs and WPC to highlight the excessive rainfall and flooding threat. In particular, WPC issued the second-ever Day 2 High Risk Excessive Rainfall Area highlighting the threat in the Carolinas. This information was communicated to NHC whose messaging to the media focused increasingly on flooding. The service assessment team recognized this effort as an example of the NWS being an excellent consumer of its own information. It was apparent to the team, however, that there is a need for a single, national voice for inland flooding events.

Finding 12: While WPC medium-range products highlighted the heavy rain and inland flood threat 96 hours prior to the event, the lack of an integrated, coordinated message at the national level made it difficult to communicate the threat in a holistic manner.

Recommendation 12a: NWS should establish a national plan for communication during inland flooding events that includes clarity on the roles for all internal organizational units.

Recommendation 12b: NWS should explore having a WCM and/or Public Affairs Officer function at the National Center for Weather and Climate Prediction to help with coordination and messaging during events.

WFOs, RFCs, NCEP, SRH, and ERH offices relied on various sources for graphics during the event. These sources included locally-produced images, official product images, geographic information system renderings of official data, and others. This diversity of sources led to inconsistent visual delivery of information to NWS partners and the public. Because local imagery was not available universally, some entities within the NWS lacked the opportunity to use improved graphics.

Finding 13: NHC and some WFOs indicated they have difficulty creating graphics to use with their interviews, IDSS efforts, and other outreach during events. Inconsistent visual delivery of information to NWS partners and the public was a result of local imagery not being available to

all WFOs universally. Some entities within the NWS had limited opportunities to use improved graphics.

Recommendation 13: NWS should provide a modernized, robust, and consistent graphics generation system for NHC, WFOs, National Centers, and ROCs to better meet IDSS and communications needs.

WFO Miami staff provided extensive Spanish media support for surrounding WFOs during the event. Their staff coordinated interviews with several media markets and provided translation for mission critical messaging regarding Hurricane Matthew's hazards. This ability to provide Spanish translation for media was not consistently available at each affected WFO, and is currently not covered by a national directive. For example, WFO San Antonio reported they were overwhelmed with requests from Spanish-speaking media.

Finding 14: An organized process for accommodating non-English media interviews and public inquiries does not currently exist.

Recommendation 14: The NWS should create and maintain a resource list of bi-and/or multilingual staff to provide forecast support both remotely and onsite during major events. Additionally, Recommendations 24 a and b from the *May 2013 Oklahoma Tornadoes* service assessment regarding the need for multilingual communication and support should continue to be pursued.

3.6. Facts, Findings, Recommendations, and Best Practices – Staffing

As indicated in past service assessments (e.g., Finding/Recommendation 1 of the *South Carolina Historic Flooding of October 2–5, 2015* service assessment and Finding/Recommendation 8 of the *Historic Nor'easter of January 2016 service assessment*), staffing shortages remain an ongoing issue for WFOs, and this event was no different. WFOs reported an average shortage of two (2) to four (4) staff members. This reduction of staff did not permit flexing of personnel to meet operational needs and completion of pre-season training and outreach. It has been recommended that WFOs employ a pre-event, 'high-impact staffing model.' This type of staffing calls for identification and configuration of staffing profiles and skill sets to meet operational requirements, maintain high awareness, anticipate off-site deployment, and fully execute IDSS. However, gaps in staffing levels and required expertise, made this model unsupportable in some WFOs. For example, it was impossible for WFOs, such as those in North Carolina, to deploy personnel. WFOs indicated that the staffing shortfall severely affected their ability to not only provide service and to meet operational needs, but also affected their staff's ability to adequately prepare and secure themselves and their family for the storm. Concern was expressed about continuous long work hours, leading to unreasonable workloads, extreme fatigue, and health issues within the WFOs.

The NWS National Operations Center (NWSOC) is one example where staffing issues affected services and operational needs. The NWSOC is currently staffed by four (4) permanent FTEs and four (4) NWSH staff members with other positions covered by volunteers to assist the

NWSOC staff during high profile events. These staffing levels make it difficult for the NWSOC to drive integration across NWS regions (ROCs/WFOs), National Centers, RFCs, and the National Water Center, which leads to inconsistent communication and messaging. To overcome staffing shortages during Hurricane Matthew, personnel from the FEMA Incident Management Assistance Team and the NOAA Rotational Assignment Program helped cover shifts at the FEMA National Response Coordination Center on behalf of NWSOC staff.

The service assessment team found confusion arose in the potential decision to close at least one WFO due to the impacts of Hurricane Matthew. NWS local and regional management followed regionally defined procedures to review the situation and make the best decision possible. Based on the forecast and office preparations, the regional HQ made the decision to keep the WFO open and operational. Less than 24 hours from the storm's arrival NWSH contacted the region to discuss potentially closing the office, leading to several hours of discussion and coordination. This resulted in Management team members stopping IDSS coordination to focus on the office closure discussion.

Finding 15: Staffing shortages and confusion concerning the potential decision to close at least one WFO during Hurricane Matthew resulted in the ineffective use of WFO's management time.

Recommendation 15: NWSH should coordinate with regional HQ to ensure that their WFOs' closure procedures are well understood by all parties prior to events. Recommendation 8 in the *Historic Nor'easter of January 2016* is similar to this recommendation.

During Hurricane Matthew, regional HQ coordinated the deployment of additional personnel to ease staff shortages at several WFOs. ERH deployed 13 staff members and SRH deployed 7. Regional HQ closely coordinated these deployments with local WFO management officials and in part, based decisions on the perceived need expressed by the WFO. At one WFO, deployed meteorologists to EOCs reported 18-hour workdays that led to significant fatigue. One MIC of an affected WFO reported that having more meteorologists to help backfill positions and split up workdays more effectively would have better supported WFO IDSS needs.

Finding 16: Even though significant effort was made to deploy additional personnel to WFOs, the service assessment team found that these deployments fell short of meeting operational needs. Lack of available staffing led to potentially dangerous forecaster fatigue and limitations to WFO IDSS efforts.

Recommendation 16: NWSH and regional HQ should develop a national pool of trained personnel with tropical cyclone experience and IDSS specialists who would be available for deployment to assist WFOs, regardless of NWS region. Special emphasis should be placed on including personnel with prior experience in the affected area, IDSS expertise, and multi-lingual skills.

Best Practice: Regional HQ made every effort to deploy individuals with prior knowledge of a WFO to facilitate their integration. Bringing in people who are already familiar with the area

makes it easier for everyone to focus on the weather event rather than spending time familiarizing the new person with the local situation.

Fact: SRH currently maintains a "tropical pool" of forecasters, hydrologists, and specialists who are available for deployment.

The evolution of NWS is reliant on cutting-edge advanced technologies that improve forecasting, warning, and distribution of weather information. Therefore, it is imperative that adequate, well-trained IT expertise is readily available and accessible throughout NWSH and the NWS field to operate and maintain a solid infrastructure. Information Technology Officers (ITO) played a critical role within WFOs leading up to and during the event. WFOs are required to complete a series of preparations ahead of a hurricane season, many of which include technical upgrades. During events, the ITO is the WFO's primary resource when technical issues arise. WFOs were unanimous in their support of having a local ITO present to address issues before, during, and after hurricane season.

Adding to the staffing and workload issues, the limited number of AWIPS 2 workstations (4-5 workstations per WFO) made it difficult to meet operational work requirements, including routine products, IDSS and situational awareness, and the increased tropical product workload. Forecasters had a limited number of workstations to produce products and view critical observations in some cases. The lack of available workstations in combination with staff shortages led to the perception of an unreasonable workload by several staff members. Dedicated AWIPS 2 enhancements are in progress (at the time of this report) and will deliver 8 workstations to each WFO, thus partially easing the technical restrictions from lack of work stations.

3.7. Facts, Findings, Recommendations, and Best Practices—Technology

The service assessment team found WFO technical operations performed successfully throughout the event. There were, however, some hardware and software challenges that impacted the efficiency and effectiveness of WFO performance.

3.7.1. System Upgrades

SR WFOs were required to complete a system upgrade to a new Content Management System (CMS) by the end of September 2016.

Best Practice: ITOs provided critical support to their WFOs during the event to mitigate website issues associated with the CMS change.

Significant format and design changes led to the loss of web page functionality, including posting headlines. This resulted in a degradation of service to NWS partners and the public during Hurricane Matthew. For example, SR WFOs reported difficulty in making the HTI available via their web pages during the event due to the mandatory website change. They reported NWS partners wanted to view the HTI product, but in some cases, NWS personnel were

unable to make the product available to them. The short timeframe between when this upgrade was mandated and the onset of hurricane season made it difficult for WFOs to realign their pages to fit with IDSS needs of the local user. Some WFOs reported this also caused issues with IDSS briefings. NWS partners commented that changing link locations made it difficult for them to find forecast information during Hurricane Matthew which occurred less than a week after the system upgrade.

Finding 17: Several WFOs impacted by Hurricane Matthew were only able to make the required conversion to CMS at the end of September 2016. This limited access to HTI and the ability to post web headlines also led to inadequate notification to NWS partners of impending changes and confusion when services were not available.

Recommendation 17: Significant changes to NWS web page services (outside of needed emergency fixes) should be made well in advance of the onset of tropical season to ensure sufficient time is available for WFOs to align their IDSS needs with web page resources. Additionally, NWS partners should be notified of changes to NWS decision support web functions prior to upgrade time.

3.7.2. Phone and Internet Connection Challenges

NWS forecasters from WFO Jacksonville, who were deployed to the Duval County Florida EOC, reported that there were significant issues with mobile WIFI (my Wi-Fi or MIFI) connections as supplied by the NWS. They found the supplied device was inadequate for the informational and IDSS needs for their mission. More specifically, the provider of MIFI service to WFOs meters (slows down significantly) the bandwidth speeds of the MIFI connection when a pre-determined ceiling in used data is reached. This can occur in only a few hours of on-site support given the larger data downloads and uploads required. Similar findings were also reported by staff at WFO Columbia, SC, where they had several days of on-site support at the SCEMD. In the words of the WFO Jacksonville staff, "*the MIFI quickly became useless.*"

Finding 18: Meteorologists deployed to state and local EOCs reported that the mobile WIFI devices (my Wi-Fi or MIFI) supplied to the WFOs did not provide sufficient Internet bandwidth and reliable service to support IDSS needs. Additionally, in some cases the WIFI device was the only Internet access that deployed personnel had without alternative backup options.

Recommendation 18: Data plans for mobile WIFI devices should be investigated to ensure adequate data speed and coverage areas. In addition, backup mobile communication devices should be explored and made available to mitigate interruptions to WFO operations.

Finding 19: Several WFOs reported problems with a limited number of phone lines for WFO/partner briefings, restricting partner participation.

Recommendation 19: NWS regions should ensure WFOs understand the protocols and procedures for requesting additional conference phone lines for major event briefings.

3.7.3. Website Issues

NHC's web page received approximately two billion hits during Hurricane Matthew. Due to the high web traffic, NHC's website was redistributed through its web farm of servers; however, this proved to be only partially effective because there was only one Domain Name System. Because of this limitation, reportedly one-third of users were unable to access the website for a limited time. The majority of issues were resolved in approximately 4 hours.

There were several cases where the latest available content on NWS and NHC websites did not reflect the latest forecast information NWS was relaying via social media. Specifically, NWS social media messaging referred to the issuance of a tropical storm or hurricane warning, but NHC and NWS web pages did not reflect this information for several minutes. This gap created significant messaging issues for NWS partners attempting to obtain graphics to disseminate beyond what was posted on social media. The role of social media, in many of these cases, was to point the public to specific locations on the NWS web pages for more detailed information.

Finding 20: Latency and reliability issues with NWS web pages resulted in inconsistency in web services.

Recommendation 20: NWS Internet Dissemination Service, also known as NIDS, should work towards ensuring there is no delay between the issuance of official products and their appearance on official web pages.

3.8. Internal Communication, Collaboration & Coordination

The service assessment team found that internal communication, collaboration, and coordination were monumental tasks for all portions of the NWS during Hurricane Matthew. The varied threats associated with the storm and the sheer number of entities involved made coordination of a consolidated message difficult at best. NWS staff members worked tirelessly to share information throughout all parts of the NWS and other parts of NOAA. Numerous excellent examples of coordination along with areas of improvement were identified.

WFO staff were in a difficult position when it came to providing information to partners. Several numerical models indicated that Hurricane Matthew would form and potentially impact coastal areas of the southeastern and eastern United States more than a week in advance. WFOs began receiving inquiries from media, the public, and NWS partners who noticed the numerical model forecasts and wanted additional details. These requests placed coastal WFO staff in a difficult position without official input from NHC.

There were also issues with aligning NHC forecasts with WFO models. Coastal WFO forecasters used numerical model guidance to indicate the potential threat of the tropical cyclone in their extended gridded forecasts. This process became a coordination nightmare for many WFOs due to the variety of model data and their inability to use tools, such as the TCM Wind Tool, that only function when NHC has issued an official forecast.

Finding 21: The numerical model depicting Hurricane Matthew beyond the Day 5 forecast period created several issues for WFOs from the Gulf of Mexico to the Eastern Seaboard. Leading up to the event, there were several operational periods where numerical model guidance indicated Hurricane Matthew would be near the coast, but the timeframe was beyond the official forecast from NHC. This limitation meant WFOs needed to incorporate model wind forecasts that included tropical cyclone signatures without having an official NHC forecast on which to rely. The presence of the hurricane in the numerical guidance led to a significant amount of inquiries from the media, EM, and the public.

Recommendation 21: NHC and WPC should begin coordinating with NWS regional HQ and coastal WFOs earlier to create a common message and product representation of events that are forecast beyond the timeframe of the official forecast track.

NHC's Storm Surge Unit (SSU) employed a successful coordination process using the Graphical Forecast Editor. SSU's coordination process made it possible for impacted WFOs to provide direct input on where storm surge watches and warnings should be issued. WFOs were unanimous in their appreciation of this process and felt engaged and valued. Officials within the NHC SSU indicated they were pleased with the collaboration and have plans for further improvements. During Hurricane Matthew this coordination process was only possible through facilitation by the NHC SSU. The service assessment team notes that full back-up capability between OPC and NHC is already in place in preparation for the 2017 hurricane season.

During Hurricane Matthew, information was shared using a variety of methods across the organization. WFOs, RFCs, NCEP centers, SRH, and ERH were called upon to provide frequent updates to NWS and NOAA senior leadership regarding the forecast, local IDSS, staffing, and other decisions. Sharing information successfully required the coordination of many entities intimately involved in the forecast process and created a significant workload for NWS offices at all levels of the organization.

In particular, SERFC indicated it had to spend significant amounts of time preparing for and briefing the flooding situation to other NWS key staff. The lack of a national-level format for hydrological briefings made preparation more difficult. SERFC spent a significant amount of time determining what to share in their briefings and deciding how to present the information. In essence, they had to create the template and format for sharing their forecasts and internal messages from scratch without guidance or a sure knowledge of what was expected. Without a standard available, the SERFC and others created briefing materials that varied in context, content, and formatting potentially making assimilation into a common message difficult. Several entities, including SERFC and NWSOC, commented there were instances of duplication of effort and inconsistencies found in briefing materials and presentations.

Finding 22: The size and scope of NWS requires that a variety of offices work in unison to gather and share information within the organization. The service assessment team found that there were no consistent standards for the type and amount of information required for each level of the organization. This inconsistency led to confusion regarding requirements and

expectations. This finding is similar to Finding 19 in the *Historic Nor'easter of January 2016* service assessment, and is also referenced in the *Historic South Carolina Floods of October 1-5, 2015* service assessment.

Recommendation 22: NWSH, in coordination with regional HQ, the NWSOC, and officials within NOAA should establish and coordinate stringent requirements for information sharing up and down the organization during high-impact events. These requirements should incorporate specificity for each part of the organization, including which entity will serve as event messaging coordinator. This process will ensure local-, regional-, and national-level offices understand their service expectations and lead to a more efficient, consistent, and better-informed agency. The service assessment team recognizes that work is underway within the NWS to begin addressing this issue through revision of NWSI 10-1603, *Significant Event Reporting*.

Internal coordination of core event messaging during the event was handled in a variety of ways. This included onsite coordination through the SR IDSS Coordinator at NHC, email messages, briefings that included text and graphics, official forecasts, conference calls, and the Hurricane Hotline. As Hurricane Matthew evolved, the focus of hazard communication shifted from wind and surge impacts to inland flooding.

Approximately 96 hours before the flooding experienced in the Carolinas, WPC management sent an email to event participants such as NHC, NWSOC, FEMA HQ, SERFC, and ERH that the NWS should shift messaging to focus on flooding potential. The email was successful in adjusting the internal core message. Several NWS representatives stated this WPC effort was critical to internal decision making and helped reframe the event hazards.

WPC, NHC, ERH, and SRH followed a stringent coordination call schedule ahead of and during the event. This schedule provided NCEP the opportunity to share core forecast and hazard information. Most WFOs involved in the event indicated they appreciated the calls, but felt that critical decisions were made prior to the call and that they were involved too late in the process to add any significant input to the forecast discussion. This outcome led to the feeling that the WFOs had no true channel to add their concerns and forecast thoughts.

Similarly, WFOs reported confusion regarding how they can better coordinate and collaborate with NHC's Hurricane Specialist Unit. Forecasters and office management teams reported they felt there was no well-established method for discussing forecast details with members of the Hurricane Specialist Unit ahead of routine conference calls, and that coordination that took place during the call was not consistent. Additionally, WFOs indicated confusion regarding the use of the Hurricane Hotline, and whether they should use the Hurricane Hotline to contact NHC specialists. During the event, the Hurricane Hotline malfunctioned several times, creating communication difficulties. Hurricane Hotline issues should be mitigated with the planned system replacement before to the 2017 hurricane season.

Finding 23: There was no well-established methodology for sharing core event messaging during Hurricane Matthew. Forecast information was shared consistently during conference calls; however, there were strong indications found by the service assessment team that key

messages about event hazards and impacts were not understood by all parties involved in the coordination. This confusion led to WFOs, regions, and national centers not speaking with one consolidated voice during the event and may have led to NWS partner and public confusion.

Recommendation 23: NWS should develop a series of Incident Action Plans outlining the internal messaging process and expectations during events. ROCs and the NWSOC should act as the facilitators of the playbook. Emphasis should be placed on creating the common message(s) to be shared by the group.

3.9. Pre-Season Training and Education

The NWS Office of the Chief Learning Officer has one Tropical Training Instructor dedicated to overseeing the NWS Tropical Training Program. Due to new products and various changes, there are "on-going" training requirements for WFO staff and EM. Currently, it is recommended strongly that required courses are completed before the hurricane season begins, but a variety of challenges sometimes hinder course completion. For this event, staffing shortages and a high number of new products, particularly for storm surge, were among the most noted challenges. There is consensus amongst those interviewed that the training program needs improvements to the instructional design component, which would greatly enhance the user experience and increase training completion numbers.

Routine, seasonal tropical training is critical to the overall success and operational readiness of coastal WFOs and a robust tracking and monitoring of the training at the national and regional levels should occur annually. The service assessment team agrees with Finding and Recommendation 21 of the *Hurricane Irene* service assessment which states that the NWS should develop a comprehensive tropical training program. In addition, the training should be delivered annually, well before the start of hurricane season, and in coordination with the Office of the Chief Learning Officer to ensure operational readiness.

Finding 24: The service assessment team noted there are few technical personnel dedicated to the NWS Tropical Cyclone Program. Staff members, most of whom have other primary duties, are tasked with developing software, procedures, and educational materials. In general, insufficient amounts of NWS resources are dedicated to such a high-impact program.

Recommendation 24: In addition to realigning resources to fully support a robust tropical cyclone program, including investing in personnel, adequate product testing capability, and professional training, the NWS tropical program should leverage and strengthen the Tropical National Service Program team to ensure corporate expertise and resources are applied in a holistic manner. This group would collaborate on common issues and leverage a broader set of resources to promote more consistent services.

Finding 25: The service assessment team found that not all the WFOs were prepared adequately by the time of the event.

Recommendation 25: Regional HQ should ensure tropical training is integrated into their staffs' tropical seasonal readiness training at all relevant WFOs and RFCs and should establish a robust tracking and monitoring system to ensure consistent operational readiness across the agency.

WPC medium-range products highlighted the inland flood threat 96 hours prior to the event. Rainfall forecasts were quite accurate 48 hours in advance. Twice daily precipitation collaboration calls, begun 96 hours prior to the event, between WPC, NWS regions, and the ROCs were informative and effective. Although WPC issued its first ever Day 2 High Risk Excessive Rainfall Area, every internal and external group interviewed (media, EM, NWS, and public) was surprised by the severity of the inland flood threat. The magnitude of the potential flooding was not well explained, not well understood, or not communicated to the affected areas.

Finding 26: EM, the media, the public, and some NWS forecasters said they were not aware of the potential magnitude of flooding even though there was significant lead time in forecasts for heavy rainfall, shifts in product wording to emphasize the increasing flooding threat, and many media interviews. Additionally, several fatalities were related to inland flooding during this event across North and South Carolina. NWS staff and EM suggested an increase in public education regarding the threat posed by inland flooding during tropical cyclone events.

Recommendation 26: NHC, WPC, RFCs, and coastal WFOs should partner on projects emphasizing the creation of a long-term inland flooding education program with entities such as NOAA Sea Grant, which have well-established, local partnerships and collaborations. The education program should incorporate current courses such as Hurricane Readiness for Coastal Communities (L311) and Hurricane Readiness for Inland Communities (L310), while expanding education opportunities for the public, NWS partners, and within NWS.

Best Practice: The annual Hurricane Awareness Tour held by NHC typically visits inland and coastal locations in hurricane prone areas each year. During inland visits, discussion emphasizes the threat from excessive rainfall. In 2017 the WPC Director attended to help emphasize the hazards posed by tropical cyclone rainfall.

The services assessment team heard repeatedly that one of NWS' successes is its commitment to stakeholder outreach and education during the off season. For example, NWSOC and FEMA representatives said FEMA's Hurricane Preparedness for Decision Makers Course was critical and should be more available, perhaps online. This annual course is taught at both NHC and the Central Pacific Hurricane Center. Attendees come from EM, media, disaster support agencies (e.g., Red Cross), as well as other public safety entities. During the course, participants learn about core tropical cyclone products, messaging techniques, and the science behind tropical cyclones. These key educational interactions offer a great opportunity for NWS to prepare everyone for upcoming seasonal weather events.

Best Practice: The service assessment team believes the IDSS Boot Camp and the Effective Hurricane Messaging course provide excellent training for IDSS during high-impact events. The service assessment team thinks that this training should be expanded to include more operational

NWS forecasters, WCMs, Service Coordination Hydrologists, Science and Operations Officers, and Development and Operations Hydrologists.

Best Practice: Throughout the year, WFO Jacksonville staff hosts and participates in numerous workshops with community decision makers on the operational use of NWS tropical cyclone products. In addition, they work with EM to identify which storm surge values will inundate critical evacuation routes. Part of their educational plan each year is to familiarize decision makers with NWS tropical cyclone probabilistic messaging so there are no misinterpretations when a storm threatens. This whole-year approach to preparing for the next tropical season allows NWS staff members and community decision makers to build a culture of trust and familiarity.

Best Practice: WFO Miami worked with local EM to create public service announcements on safety and short live and/or recorded segments on local TV networks. These messages shared tropical cyclone impact and safety information.

The service assessment team found that while these excellent outreach and educational opportunities exist, there remains significant demand for additional training.

Finding 27: NHC and WFOs identified challenges sharing tropical cyclone education information properly due to limited travel budgets, requests for extensive partner and public outreach, and time constraints. Media officials said they would like more opportunities to participate in conferences and NHC training courses.

Recommendation 27: NWS should create a Train-the-Trainer program, based out of NHC and in partnership with coastal WFOs, to coordinate the sharing of tropical cyclone training and outreach materials across the country.

Finding 28: Many forecasters exhibited a lack of comfort with hydrology concepts and products during Hurricane Matthew. In particular, the assessment team found deficiencies in the understanding of lag in water transit times in river basins as well as the impacts of water releases by the USACE. This lack of understanding made WFO briefings and interpretation of SERFC products difficult and led to confusion among local EM resulting in increased workload and coordination by USACE and SERFC personnel.

Recommendation 28: All forecast staff should receive formal hydrology training. Training should be completed and tracked annually at the national level. Special emphasis on inland flooding associated with tropical cyclones should be included.

Appendix A: Acronyms

AHPS	Advanced Hydrologic Prediction System
AWIPS	Advanced Weather Interactive Processing System
CMS	Content Management System
EM	Emergency Manager(s)/Emergency Management
EOC	Emergency Operations Center
ER	NWS Eastern Region
ERH	NWS Eastern Region Headquarters
FEMA	Federal Emergency Management Agency
HQ	Headquarters
HTI	Hurricane Threat Index
IDSS	Impact-based Decision Support Services
IT	Information Technology
ITO	Information Technology Officer
MEOW	Maximum Envelope of Water
MIC	Meteorologist in Charge
MIFI	Mobile WIFI
MMEFS	Meteorological Model Ensemble River Forecasts
MOM	Maximum of Maximums
NCEP	National Centers for Environmental Prediction
NHC	National Hurricane Center
NOAA	National Oceanic and Atmospheric Administration
NOS	National Ocean Service
NWSOC	National Weather Service Operations Center
NWM	National Water Model
NWS	National Weather Service
NWSH	National Weather Service Headquarters
OPC	Ocean Prediction Center
QPF	Quantitative Precipitation Forecast
RFC	River Forecast Center
ROC	Regional Operations Center
SCEMD	South Carolina Emergency Management Division
SERFC	Southeast River Forecast Center
SLOSH	Sea, Lake, & Overland Surge from Hurricanes
SR	NWS Southern Region
SRH	NWS Southern Region Headquarters
SSU	Storm Surge Unit
USACE	United States Army Corps of Engineers
USGS	United States Geological Survey
WCM	Warning Coordination Meteorologist
WFO	Weather Forecast Office
WPC	Weather Prediction Center

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 OCWWS will compose an action item for each recommendation.

Findings and Recommendations

Finding 1: Partners indicated that despite the excellent service and information provided by the NWS they were surprised at the magnitude of flooding they experienced and did not feel that the threat was communicated adequately.

Recommendation 1: The NWS needs to take a comprehensive look at communication related to inland flood threats for both river and flash flooding. This may include confidence-based forecasts, inundation maps, increased educational efforts, pursuing a social science analysis of flood related messaging, and links to WPC's Excessive Rainfall graphics on NHC's web page.

Finding 2: WFOs Wilmington, Raleigh, Wakefield and, Newport/Morehead City issued flash flood warnings with flash flood emergency wording for the first time during Hurricane Matthew. Media partners indicated that they had a hard time identifying how the product differed from the standard flash flood warning. The result was an impact on NWS media partners' ability to communicate the proper threat level and recommended protective actions to the public.

Recommendation 2: Prior to the issuance of newly- or rarely-used NWS products, adequate outreach to NWS partners and the public should be completed. Information should be shared that addresses product definitions, their purpose, and context for its use. If the newly- or rarely-used product is similar to other products the differences should be communicated clearly.

Finding 3: Significant confusion continues regarding the official NHC tropical cyclone track forecast. NWS partners and the public alike continue to focus on the "skinny black line" and many of them view the uncertainty cone as an impact area/zone.

Recommendation 3: NHC, WFOs, RFCs, Social Scientists, and NWS partners should collaborate on the most effective way to display the official NHC tropical cyclone track and impact information.

Finding 4: NWS partners and the media indicated the lack of intermediate forecast points during the 48- to 120-hour window of the official forecast track gave the impression that the forecast track did not represent the most likely scenario.

Recommendation 4: NHC should include intermediate forecast points beyond 48 hours in the official forecast.

Finding 5: NHC's storm surge products were not universally understood by NWS forecasters, EM, media, and the general public. Many users did not understand the potential storm surge flooding map represented the most probable worst-case scenario and instead interpreted the product as the official forecast. Some EMs indicated that this graphic should not be made public because it creates confusion and affects their ability to convey evacuation information. They stated that differences between the graphic and their evacuation zones led to public misinterpretation of the risk. Furthermore, they indicated they are very interested in graphics representing the actual forecasted surge.

Recommendation 5: Probabilistic storm surge graphics conveying the worst and most-likely case should be developed for EMs. Once developed, the storm surge values for the most-likely case should remain included in the NHC public advisory product; however, the graphics should primarily be an internal coordination tool for the EM community. NWS educational materials should be updated accordingly.

Finding 6: WFO personnel said managing their office's tropical program and aligning it with the national program is a significant effort made difficult by other routine duties and programmatic expectations. This balancing of duties was found to make it difficult to allow for the focus that is needed on the tropical program at several local offices.

Recommendation 6: In the spirit of the NWS's Evolve initiative the NWS should adjust the tropical cyclone program so there is at least one dedicated individual with tropical cyclone expertise at all coastal WFOs. These individuals would serve as the local expert for all things tropical and manage the WFO's local tropical program. During tropical cyclone season they would serve as a key IDSS resource in WFO operations overseeing activities and working shifts as necessary. Outside of tropical cyclone season they would take the lead of office tropical cyclone outreach, collaborate on office training with the Science and Operations Officer, and work on methods to improve local tropical operations. They would not routinely work shifts during the offseason. As an example, many NWS Western Region WFOs have dedicated forecasters for the fire weather program.

Finding 7: Current ERH policy does not allow inland WFOs to issue tropical cyclone products, while SRH policy encourages inland WFOs to issue tropical cyclone products during events. This practice is inconsistent and leads to varying levels of service and mixed messages.

Recommendation 7: The NWS Tropical Program, in coordination with regional HQs, and the Water Resources national service program, should establish a common baseline, based on national directives, for messaging tropical cyclone events for both coastal and inland WFOs.

Finding 8: SRH deployed an IDSS coordinator to NHC. This individual attempted to facilitate a consistent message among all NWS entities and partners. The presence of the coordinator was widely lauded by all parts of the NWS. The concept of a deployed IDSS coordinator into a National Center is not in practice at all regional HQ.

Recommendation 8: Regional HQ should consider a model of field support that includes onsite IDSS coordinators at the appropriate National Center(s) during significant events.

Finding 9: Ensemble forecast information produced by SERFC served as an early predictor of flood risk for the Carolinas. The service assessment team found that this model output was not emphasized to forecasters during internal briefings nor during external briefings with partners. This in part led to partners feeling that the event was more routine in nature and that the threat was reduced.

Recommendation 9: RFCs and WFOs should collaborate on the development of high-impact hydrologic event briefing templates to adequately highlight the enhanced hazard, threat, and risk of flooding. These templates should make it clear to participants that the content of these briefings differ from routine- and lower-impact events.

Finding 10: Crowding of NWSChat rooms with numerous participants and automated links to NWS products during the peak of the event made it difficult to navigate the chat window for both NWS forecasters and partners.

Recommendation 10: WFOs should ensure an unimpeded flow of information to NWS partners, including limiting the number of products automatically displayed in the NWSChat window, and ensuring the NWSChat rooms do not get overwhelmed with participants.

Finding 11: Some WFO staff members noted that there were inconsistencies among local WFO web pages. Some WFO web pages were updated in a dynamic fashion, while others lagged behind updating content and headlines. From the WFO's perspective, there were not enough individuals trained to make web page content and headline changes.

Recommendation 11: NWS should provide standardized training material to field personnel on how to change the top News Headlines and other necessary supporting web page content.

Finding 12: While WPC medium-range products highlighted the heavy rain and inland flood threat 96 hours prior to the event, the lack of an integrated, coordinated message at the national level made it difficult to communicate the threat in a holistic manner.

Recommendation 12a: NWS should establish a national plan for communication during inland flooding events that includes clarity on the roles for all internal organizational units.

Recommendation 12b: NWS should explore having a WCM and/or Public Affairs Officer function at the National Center for Weather and Climate Prediction to help with coordination and messaging during events.

Finding 13: NHC and some WFOs indicated they have difficulty creating graphics to use with their interviews, IDSS efforts, and other outreach during events. Inconsistent visual delivery of information to NWS partners and the public was a result of local imagery not being available to all WFOs universally. Some entities within the NWS had limited opportunities to use improved graphics.

Recommendation 13: NWS should provide a modernized, robust, and consistent graphics generation system for NHC, WFOs, National Centers, and ROCs to better meet IDSS and communications needs.

Finding 14: An organized process for accommodating non-English media interviews and public inquiries does not currently exist.

Recommendation 14: The NWS should create and maintain a resource list of bi-and/or multilingual staff to provide forecast support both remotely and onsite during major events. Additionally, Recommendations 24 a and b from the *May 2013 Oklahoma Tornadoes* service assessment regarding the need for multilingual communication and support should continue to be pursued.

Finding 15: Staffing shortages and confusion concerning the potential decision to close at least one WFO during Hurricane Matthew resulted in the ineffective use of WFO's management time.

Recommendation 15: NWSH should coordinate with regional HQ to ensure that their WFOs' closure procedures are well understood by all parties prior to events. Recommendation 8 in the *Historic Nor'easter of January 2016* is similar to this recommendation.

Finding 16: Even though significant effort was made to deploy additional personnel to WFOs, the service assessment team found that these deployments fell short of meeting operational needs. Lack of available staffing led to potentially dangerous forecaster fatigue and limitations to WFO IDSS efforts.

Recommendation 16: NWSH and regional HQ should develop a national pool of trained personnel. with tropical cyclone experience and IDSS specialists who would be available for

deployment to assist WFOs, regardless of NWS region. Special emphasis should be placed on including prior experience in the affected area, IDSS expertise, and multi-lingual language skills.

Finding 17: Several WFOs impacted by Hurricane Matthew were only able to make the required conversion to CMS at the end of September 2016. This limited access to HTI and the ability to post web headlines also led to inadequate notification to NWS partners of impending changes and confusion when services were not available.

Recommendation 17: Significant changes to NWS web page services (outside of needed emergency fixes) should be made well in advance of the onset of tropical season to ensure sufficient time is available for WFOs to align their IDSS needs with web page resources. Additionally, NWS partners should be notified of changes to NWS decision support web functions prior to upgrade time.

Finding 18: Meteorologists deployed to state and local EOCs reported that the mobile WIFI devices (my Wi-Fi or MIFI) supplied to the WFOs did not provide sufficient Internet bandwidth and reliable service to support IDSS needs. Additionally, in some cases the WIFI device was the only Internet access that deployed personnel had without alternative backup options.

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Finding 27: NHC and WFOs identified challenges sharing tropical cyclone education information properly due to limited travel budgets, requests for extensive partner and public outreach, and time constraints. Media officials said they would like more opportunities to participate in conferences and NHC training courses.

Recommendation 27: NWS should create a Train-the-Trainer program, based out of NHC and in partnership with coastal WFOs, to coordinate the sharing of tropical cyclone training and outreach materials across the country.

Finding 28: Many forecasters exhibited a lack of comfort with hydrology concepts and products during Hurricane Matthew. In particular, the assessment team found deficiencies in the understanding of lag in water transit times in river basins as well as the impacts of water releases by the USACE. This lack of understanding made WFO briefings and interpretation of SERFC products difficult and led to confusion among local EM resulting in increased workload and coordination by USACE and SERFC personnel.

Recommendation 28: All forecast staff should receive formal hydrology training. Training should be completed and tracked annually at the national level. Special emphasis on inland flooding associated with tropical cyclones should be included.

Best Practices

Best Practice: WFO Newport/Morehead City changed slide colors in their briefings to highlight increased confidence and the magnitude of the flood threat.

Best Practice: WFO Wakefield created a one-stop-shop event web page with links to forecast, hazard, and impact information weather.gov/akq/matthew.

Best Practice: WFO Jacksonville used the same web page URL for every briefing package release to NWS partners to avoid confusion on where to find latest briefings.

Best Practice: The WFOs serving South Carolina produced one-page briefings and provided them to SCEMD to ensure consistent messaging. This was very well received and praised by NWS partners. Additionally, support for SCEMD was administered through one office, the Columbia, SC WFO. This allowed for a singular consistent voice for the state, enhancing message clarity and decision making.

Best Practice: WFO Melbourne provided blog-like graphicasts every 1-to-3 hours during the event via social media. These graphics provided nowcast-like information regarding the latest event updates. They were widely viewed by the public and NWS partners.

Best Practice: WFO Melbourne used IDSS briefings and NWSChat to shape the EM and media communities message regarding a potential extreme wind warning issuance. Forecasters recognized the potential for the first issuance of the product and took the opportunity to proactively provide information to ensure NWS partners relayed the proper message if the product was issued. NWS partners, especially the media, indicated that this proactive approach provided them with a seamless transition when the product was eventually issued.

Best Practice: Pre-event meetings, weekly briefing outlooks, webinars, and participation by WFO staff and management in EM exercises helped WFO Columbia, SC, build a better working relationship with the SCEMD.

Best Practice: SERFC created a table with hydrological forecasts, comparing hydrologic model runs with and without U.S. Army Corps of Engineer (USACE) releases, to help show the impacts of proposed releases to the official forecast. This table was color coded, matching conventional Advanced Hydrologic Prediction System (AHPS) color schemes, to highlight forecast points in minor, moderate, and major/record flooding.

Best Practice: WFO Melbourne used IDSS briefings and NWSChat to shape the EM and media communities message regarding a potential extreme wind warning issuance. Forecasters recognized the potential for the first issuance of the product and took the opportunity to proactively provide information to ensure NWS partners relayed the proper message if the product was issued. NWS partners, especially the media, indicated that this proactive approach provided them with a seamless transition when the product was eventually issued.

Best Practice: Pre-event meetings, weekly briefing outlooks, webinars, and participation by WFO staff and management in EM exercises helped WFO Columbia, SC build a better working relationship with the SCEMD.

Best Practice: Regional HQ made every effort to deploy individuals with prior knowledge of a WFO to facilitate their integration. Bringing in people who are already familiar with the area makes it easier for everyone to focus on the weather event rather than spending time familiarizing the new person.

Best Practice: ITOs provided critical support to their WFOs during the event to mitigate website issues associated with the CMS change.

Best Practice: The annual Hurricane Awareness Tour held by NHC typically visits inland and coastal locations in hurricane prone areas each year. During inland visits, discussion emphasizes the threat from excessive rainfall. In 2017 the WPC Director attended to help emphasize the hazards posed by tropical cyclone rainfall.

Best Practice: The service assessment team believes the IDSS Boot Camp and the Effective Hurricane Messaging course provide excellent training for IDSS during high-impact events. The service assessment team thinks that this training should be expanded to include more operational NWS forecasters, WCMs, Service Coordination Hydrologists, Science and Operations Officers, and Development and Operations Hydrologists.

Best Practice: Throughout the year, WFO Jacksonville staff hosts and participates in numerous workshops with community decision-makers on the operational use of NWS tropical cyclone products. In addition, they work with EM in identifying which storm surge values will inundate critical evacuation routes. Part of their educational plan each year is to familiarize decision-makers with NWS tropical cyclone probabilistic messaging so that there are no misinterpretations when a storm threatens. This whole-year approach of preparing for the next tropical season allows NWS staff members and community decision makers to build a culture of trust and familiarity.

Best Practice: The annual Hurricane Awareness Tour held by NHC typically visits inland and coastal locations in hurricane prone areas each year. During inland visits discussion emphasizes the threat from excessive rainfall. In 2017 the Director of NWS' Weather Prediction Center attended to help emphasize the hazards posed by tropical cyclone rainfall.

Best Practice: WFO Miami worked with local EM to create public service announcements on safety and short live and/or recorded segments on local TV networks. These messages shared tropical cyclone impact and safety information.

Appendix C: Hurricane Matthew Fatalities by State

Florida: 12		
County	**Direct (Y/N)**	**Cause**
Orange	N	Failed Medical Device
Putnam	Y	Fallen Tree on Trailer
Seminole	Y	Windblown Door Trauma
St. Lucie	Y	Heart Attack – No Medical Available During Storm
St. Lucie	Y	Stroke – No Medical Available During Storm
St. Lucie	N	Carbon Monoxide Poisoning
St. Lucie	N	Carbon Monoxide Poisoning
Volusia	Y	Fallen Tree
Volusia	N	Electrocution Due to Downed Powerline
Volusia	N	Carbon Monoxide Poisoning
Volusia	N	Rolling Tree During Clean-up
Volusia	N	Electrocution During Clean-up

Georgia: 3		
County	**Direct (Y/N)**	**Cause**
Bulloch	Y	Fallen Tree on Car
Bulloch	Y	Fallen Tree on Home
Chatham	Y	Fallen Tree on Trailer

North Carolina: 27		
County	**Direct (Y/N)**	**Cause**
Bladen	Y	Flood – in Vehicle
Bladen	Y	Flood – in Vehicle
Columbus	Y	Flood – in Vehicle
Cumberland	Y	Flood Related
Cumberland	N	Medical Event at Home
Cumberland	Y	Flood – in Vehicle
Gates	Y	Flood Related
Harnett	Y	Flood – in Vehicle
Johnston	Y	Flood – on Foot
Johnston	Y	Flood – in Vehicle
Johnston	Y	Flood – in Vehicle
Johnston	Y	Flood – in Vehicle
Lenoir	Y	Unknown
Lenoir	Y	Flood – in Vehicle
Lenoir	Y	Flood – in Vehicle
Lenoir	Y	Flood – on Horse
Pitt	Y	Flood – in Vehicle
Robeson	Y	Flood – in Vehicle
Robeson	Y	Flood – in Vehicle
Robeson	Y	Fall
Rowan	Y	House Fire
Sampson	Y	Car Accident – Hydroplaning Vehicle

Wake	Y	Fallen Tree on Car
Wayne	Y	Flood – in Vehicle
Wayne	Y	Flood – in Vehicle
Wilson	Y	Flood – in Vehicle
Wilson	Y	Flood – in Vehicle

South Carolina: 5

County	Direct (Y/N)	Cause
Dillon	N	Tree clearing accident
Florence	Y	Flood - in Vehicle
Florence	Y	Flood - in Vehicle
Marion	Y	Flood - in Residence
Richland	Y	Flood

Virginia: 2

County	Direct (Y/N)	Cause
Suffolk	Y	Flood
Chesapeake	Y	Vehicle Accident