Service Assessment

The Historic South Carolina Floods of October 1–5, 2015

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

Cover Photograph:
Road Washout at Jackson Creek in Columbia, SC, 2015
Source: *WIS TV Columbia, SC*

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July 2016

National Weather Service
John D. Murphy
Chief Operating Officer

Preface

The combination of a surface low-pressure system located along a stationary frontal boundary off the U.S. Southeast coast, a slow moving upper low to the west, and a persistent plume of tropical moisture associated with Hurricane Joaquin resulted in record rainfall over portions of South Carolina, October 1–5, 2015. Some areas experienced more than 20 inches of rainfall over the 5-day period. Many locations recorded rainfall rates of 2 inches per hour. This rainfall occurred over urban areas where runoff rates are high and on grounds already wet from recent rains.

Widespread, heavy rainfall caused major flooding in areas from the central part of South Carolina to the coast. The historic rainfall resulted in moderate to major river flooding across South Carolina with at least 20 locations exceeding the established flood stages. Flooding from this event resulted in 19 fatalities. Nine of these fatalities occurred in Richland County, which includes the main urban center of Columbia. South Carolina State Officials said damage losses were $1.492 billion.

Because of the significant impacts of the event, the National Weather Service formed a service assessment team to evaluate its performance before and during the record flooding. The National Weather Service Mission Delivery Council will review and consider the findings and recommendations from this assessment. As appropriate, recommendations will then be integrated into the Annual Operating Plan to improve the quality of operational products and services and enhance the National Weather Service's ability to provide an increase in public education and awareness materials related to flooding. The ultimate goal of this report is to help the National Weather Service meet its mission to protect life and property and enhance the national economy.

John D. Murphy
Chief Operating Officer

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Executive Summary

The historic flooding across South Carolina, October 1–5, 2015, resulted from several hydrometeorological factors. A stalled surface frontal boundary off the coast, a slow moving upper low west of the Carolinas and ample Atlantic moisture helped set the stage for this historic event. These factors, combined with a persistent plume of tropical moisture associated with Hurricane Joaquin, produced more than 20 inches of rain in central and coastal sections of South Carolina. This widespread heavy rainfall caused major flooding within the Pee Dee, Santee, and Ashley-Cooper-Edisto Basins where at least 20 locations exceeded established flood stages.

Flooding from this event resulted in 19 fatalities according to the South Carolina Emergency Management Department, as can be seen in Appendix H. Nine of these were in Richland County, which includes the main urban center of Columbia. Several of the fatalities were individuals trapped in vehicles swept into high water. South Carolina State Officials said damage losses were $1.492 billion.

In addition to impacts to life and livelihood, the infrastructure impacts of this event were widespread across South Carolina. During the event, approximately 410 roads and bridges, including 74 miles of I-95 between I-26 and I-20, were closed due to high water, flood inundation, or safety (U.S. Department of Interior Office of Emergency Management, written communication, October 8, 2015). Other closures included I-20 at the Broad River Bridge in Columbia, I-126 near downtown Columbia, I-26 over the Saluda River, and I-95 between I-26 and I-20.

State emergency management officials reported more than 1,500 water rescues and significant urban flooding in the Columbia metro area. The State's Department of Health and Environmental Control (http://www.scdhec.gov/HomeAndEnvironment/DisasterPreparedness/FloodUpdates/FailedDamReports/) confirmed the failure of 36 regulated dams. Some of the failed dams under the Department of Health and Environmental Control's jurisdiction include Corbett Lake in Aiken County; Clyburn Dam in Lee County; Old Mill Pond, Gibson Pond, and Barr Lake in Lexington County; Upper Rocky Creek/North Lake, Cary's Lake, Beaver Dam, Boyd's Pond #2, Wildwood Pond #2 in Richland County; and Semmes Lake at Fort Jackson.

Major reservoirs, such as the Saluda Dam at Lake Murray, initiated flood control releases or emergency discharges. Saturated soils, along with moderate to strong winds, contributed to downed trees and power line poles across portions of South Carolina; about 50,000 residents lost power at the height of the storm. Fortunately, power was restored to all customers by October 6. The October 2015 floods severely impacted safety, life, and livelihood in South Carolina.

Service Assessment Report

1. Introduction

1.1. NWS Mission

The mission of the 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. The NWS disseminates centrally produced data, weather products, and guidance to 122 Weather Forecast Offices (WFO) and 13 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 NWS is organized into six regional and one national headquarters, which provide policy, guidance, and administrative support to WFOs and RFCs. The National Centers for Environmental Prediction (NCEP), consisting of nine prediction centers, provide central guidance, outlooks, and hazardous weather watches and warnings to the NWS organization and the public.

1.2. Purpose of Assessment Report

The NWS may conduct service assessments of significant weather-related events that result in one or more of the following: multiple fatalities, numerous injuries requiring hospitalization, significant impact on the economy of a large area or population, extensive national public interest or media coverage, or an unusual level of attention to NWS operations (performance of systems or adequacy of warnings, watches, and forecasts) by media, the EM community, or elected officials. Service assessments evaluate the NWS performance and ensure the effectiveness of NWS products and services in meeting the mission. The goal of service assessments is to better protect life and property by implementing recommendations and best practices that improve NWS products and services.

This document presents findings and recommendations from the evaluation of NWS performance prior to and over the course of the historic South Carolina flood of October 1–5, 2015. Heavy rains over several days produced major river flooding and widespread flash flooding across middle to lower parts of South Carolina. This event resulted in 19 fatalities, caused considerable property loss, and significantly affected transportation and commerce.

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

- Timeliness, quality, accuracy, and usefulness of NWS forecasts and warning services
- Situational awareness of the affected field offices prior to and during the event
- Effectiveness of current hydrologic and numerical weather prediction modeling capabilities for this event

- Effectiveness of coordination and decision support services (DSS) for federal partners and key stakeholders prior to and during the event
- Effectiveness of NWS continuity of operations in providing service backup during a communications failure

1.3. Methodology

The NWS formed an assessment team on October 23, 2015, consisting of employees from NWS field offices, NWS Headquarters (NWSH), Office of the Data Chief of the U.S. Geological Survey (USGS), social scientists, and a county EM Director. The team completed the following:

- Performed an on-scene evaluation from November 9–13, 2015
- Interviewed staff from WFOs Columbia, Charleston; Greenville-Spartanburg, SC; Wilmington, NC; and the Southeast RFC (SERFC). These offices had primary responsibility for providing forecasts, warnings, and DSS to the residents and EMs of the affected areas
- Interviewed EMs; the media; local, state/federal partners; and local citizens in the impacted areas
- Evaluated products and services issued by the NWS Weather Prediction Center (WPC), WFOs, and RFCs
- Developed a list of significant findings and recommendations to improve the effectiveness of NWS products and services

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

2. Hydrometeorology

2.1. Event Evolution

Several ingredients led to the historic flooding across South Carolina October 1–5, 2015. In particular, a surface frontal boundary was stalled just off the coast with an area of low pressure along the front. A slow moving upper low to the west and surface high pressure over eastern Canada helped to produce a strong easterly flow component off the Atlantic Ocean. Hurricane Joaquin to the east provided a persistent source of deep tropical moisture **(Figure 1).** Some areas experienced more than 20 inches of rainfall over the period October 1–5, 2015 **(Figure 2).** Widespread, heavy rainfall resulted in major flooding in areas from the central part of the state to the coast **(Figure 3).** Nineteen fatalities occurred due to floods. The South Carolina Emergency Management Department said damage losses were $1.492 billion.

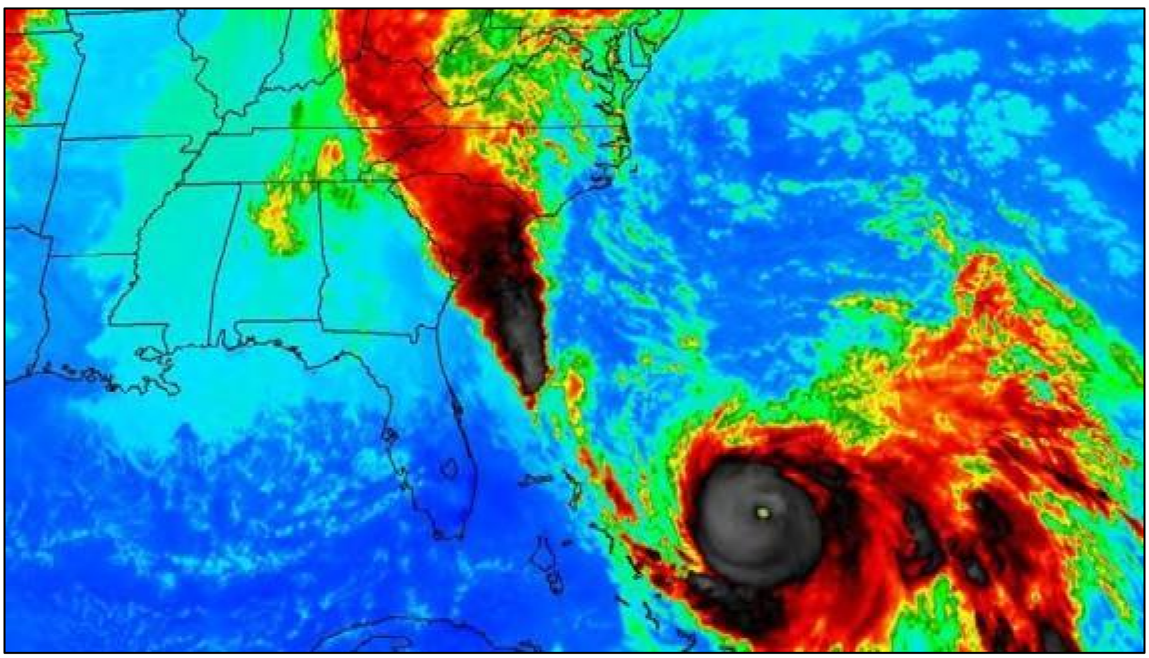


Figure 1: Infrared satellite image of the intense rainfall being funneled toward South Carolina during the morning of October 3, 2015. *Source: National Aeronautics and Space Administration (NASA)*

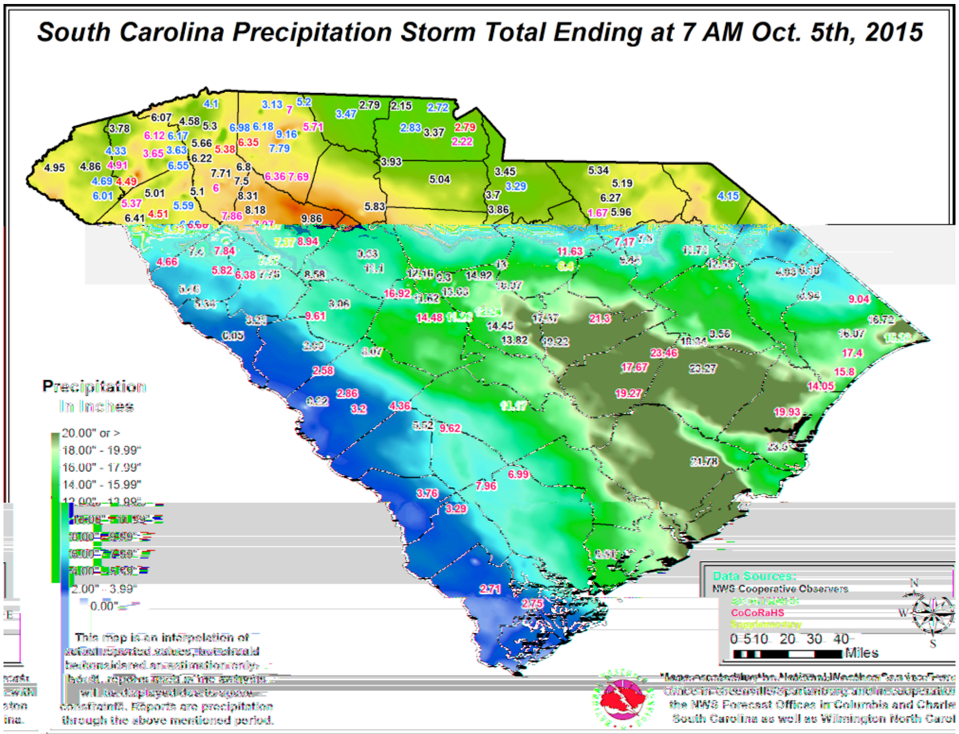


Figure 2: Preliminary NWS rainfall totals for October 1–5, 2015. *Source: NWS*

Figure 3: Aerial photograph of flooding in Columbia, SC, at the confluence of the Broad and Saluda Rivers (looking upstream). *Source: The South Carolina Army National Guard, October 5, 2015*

The historic rainfall resulted in moderate to major river flooding at selected NWS river forecast points across South Carolina. At 20 or more river locations, water spilled out of banks, exceeding established flood stages. **Table 1** provides Additional information about these peak stages relative to their gage history and historical ranking of annual peaks.

Table 1: Historic River Flooding in the WFO Charleston, Columbia, and Wilmington Service Areas

River Name and Location	River Basin	Ranking / Annual Peaks	Gage History	2015 Peak Stage/Flow/Date	Flood Stage
Black Creek near Quinby	Pee Dee	1/13	2002–2014	16.81 ft (6,530 cfs) 10/4/2015	10 ft
Lynches River at Effingham	Pee Dee	3/88	1908, 1928–2014	19.73 ft (17,000 cfs) 10/6/2015	14 ft
Black River at Kingstree	Pee Dee	1/87	1928–2014	22.65 ft (83,700 cfs) 10/6/2015	12 ft
Waccamaw River near Conway	Pee Dee	3/20	1995–2014	15.93 ft (14,500 cfs) 10/6/2015	11 ft
Santee River at Jamestown	Santee	2/27	1987–2000, 2002–2014	22.13 ft (96,600 cfs) 10/10/2015	10 ft
Congaree River at Columbia	Santee	8/123	1900–2014	31.81 ft (185,000 cfs) 10/4/2015	19 ft
Gills Creek at Columbia	Santee	1/50	1965–2014	19.60 ft (-) 10/4/2015	6.7 ft
Saluda River at Lake Murray	Santee	1/26	1989–2014	27.50 ft (-) 10/4/2015	---
Little River near Silverstreet	Santee	1/24	1991–2014	18.46 ft (14,800 cfs) 10/5/2015	11 ft
Bush River near Propensity	Santee	1/24	1991–2014	19.74 ft (10,000 cfs) 10/4/2015	11 ft
N. Fork Edisto River at Orangeburg	Edisto	3/77	1928, 1939–1988, 1990–2014	13.64 ft (8,640 cfs) 10/5/2015	8 ft
Edisto River at Givhans Ferry	Edisto	1/81	1925, 1928, 1939–2014	16.06 ft (25,600 cfs) 10/8/2015	10 ft

South Carolina has three major physiographic provinces: Blue Ridge, Piedmont, and Coastal Plain (Cooke, 1936). The Blue Ridge is a mountainous region of steep terrain. The Piedmont has rolling hills, elongated ridges, and moderately deep to shallow valleys. About two-thirds of the state is in the Coastal Plain region. The lower part of the Coastal Plain consists of low-elevation flat plains with many swamps, marshes, dunes, barrier islands, and beaches, which typically are lower, flatter, and more poorly drained than the upper part of the Coastal Plain (Omernik, 1987). Each area has issues that make it flood prone: The Blue Ridge (Upstate) is hilly terrain, upslope and prone to flash flooding. The Piedmont (Midlands) is a regulated basin. The Coastal Plain (Lowcountry) is slow draining. Annual rainfall averages are as follows:

- The Blue Ridge region: > 56 inches
- Upper portion of the Piedmont: 47 to 55 inches
- Lower portion of the Piedmont: 45 to 48 inches
- Upper portion of the Coastal Plain: 44 to 49 inches
- Lower portion of the Coastal Plain: 46 to 53 inches

This event produced rainfall amounts equaling one third of the average annual rainfall for many locations across the Midlands and Lowcountry in just over 4 days.

The heavy rainfall predominantly affected three major basins: the Santee, Pee Dee, and Ashley-Combahee-Edisto (ACE) **(Figure 4)**. The Santee Basin, the largest of the South Carolina River Basins, encompasses all three distinctive terrain induced flooding characteristics: Blue Ridge, Piedmont, and Coastal Plains. The slow draining coastal sections of South Carolina include the mainstem Santee River and the lower half of Pee Dee and ACE basins.

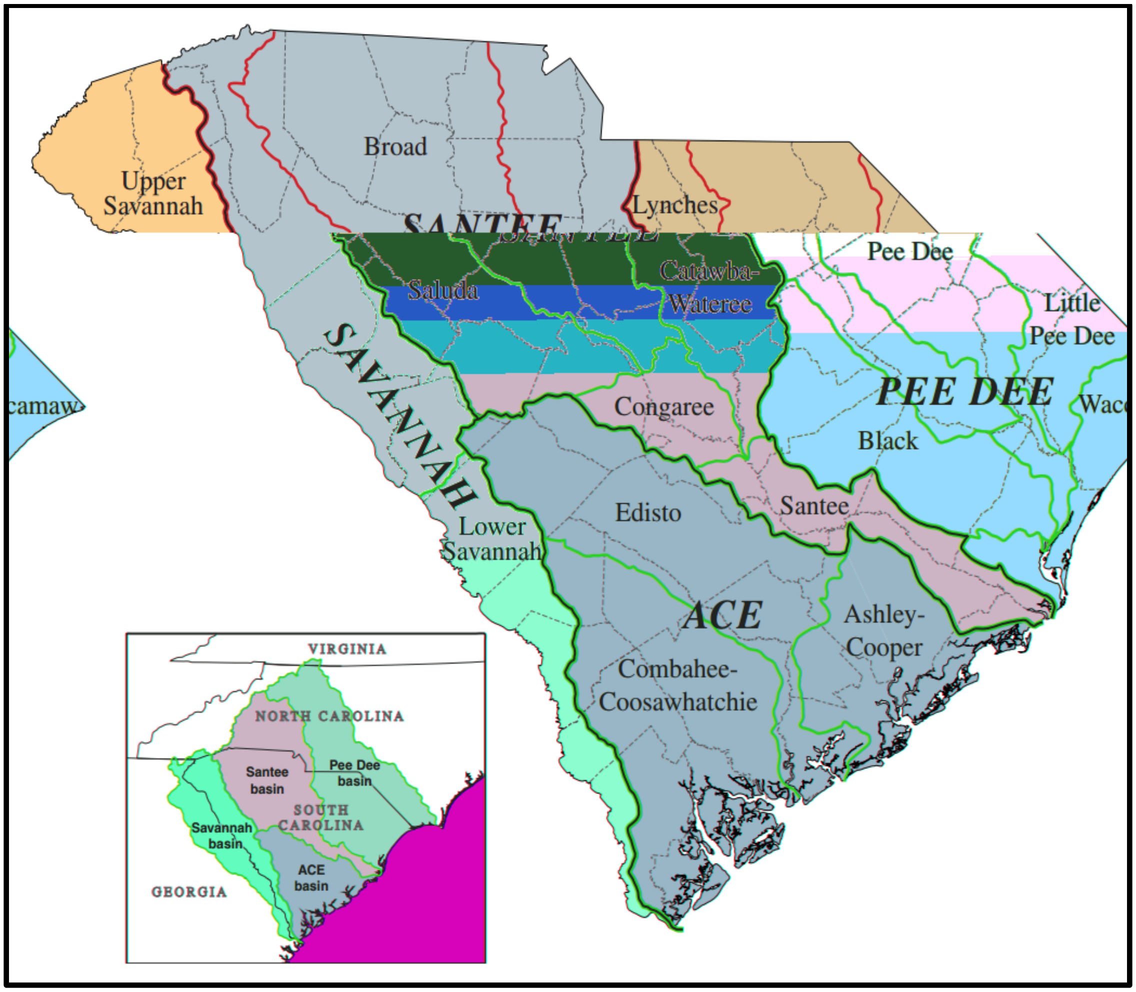


Figure 4: Major river basins and streams in South Carolina.
Source: South Carolina Department of Natural Resources

2.2. Impacts

The impacts to the infrastructure across South Carolina were widespread **(Figure 5)**. Approximately 410 roads and bridges, including 74 miles of I-95 between I-26 and I-20, were closed during the event (U.S. Department of Interior Office of Emergency Management, written communication, October 8, 2015). There were 36 dam failures. Some major reservoirs, such as the Saluda Dam at Lake Murray, initiated flood control releases.

Figure 5: Conditions at U.S. Geological Survey streamgaging station 02169570, Gills Creek at Columbia, SC, on October 5, 2015. *Source: USGS*

South Carolina EM officials reported more than 1,500 water rescues, including motorists and homeowners trapped by high water **(Figure 6)**. In addition to flooding, saturated soils, along with moderate to strong east/northeasterly winds, contributed to downed trees and power lines across portions of South Carolina. About 50,000 residents lost power during the storm. River channels were unable to convey the excessive river flow, spilling out of banks, causing stream bank erosion and inundating homes (**Figure 7).**

Figure 6: Water rescues. *Source: Brett Adair, Live Storms Media, LLC*

Figure 7: U.S. Geological Survey measures high water at flooded home in Lexington County, SC for the October 2015 flood. *Source: USGS*

The storm caused significant impacts across four service areas of the WFOs Charleston, Columbia, Greenville-Spartanburg, and Wilmington. The heaviest amounts of precipitation, between 15 and 25 inches, fell in the Midlands and Lowcountry, south of Greenville-Spartanburg, mainly from the I-26 corridor eastward into the South Carolina counties served by Wilmington, NC. Although, WFO Greenville-Spartanburg's service area experienced 5–8 inches of intense rainfall, which triggered flash flooding and caused numerous road closures.

2.2.1. Columbia, SC

In WFO Columbia's service area, storm total amounts of greater than 20 inches fell in Columbia and Sumter, SC. Record rainfall caused widespread flood damage to roadways, dams, businesses, residences and infrastructure in the Columbia area. The following rainfall records were broken at the Columbia Metro Airport (KCAE).

- Greatest 1-Day Rainfall: 6.71" on Oct 4, 2015
- Greatest 2-Day Rainfall: 10.28" on Oct 3–4, 2015

Over 12 inches of rain in 48 hours, overwhelmed dams with excess runoff. The floodgates of Lake Murray Dam on the Saluda River, which had not been opened since 1969, were operated to maintain lake levels below 360 feet, National Geodetic Vertical Datum of 1929. Multiple dam failures on the Twelve Mile Creek sent floodwaters into the town of Lexington and farther downstream into the Saluda River destroying homes, businesses, and community parks. Flows up to 73,000 cfs from the Broad River, as measured in Alston, combined with the waters of the Saluda River to create massive flooding on the Congaree River in Columbia. The Columbia Canal, which diverts water from the Congaree River to the Columbia's municipal water supply facilities, breached on October 3, 2015.

Figure 8: USGS webcam monitors flooding on Rocky Branch. *Source: USGS*

Rocky Branch at Whaley and Main Street in downtown Columbia rose 7 feet, moderate flood stage of 8 feet, in less than 90 minutes (**Figure 8**). Gills Creek at Columbia crested 10 feet above the previous record of 9.4 feet set in 1997, up to a stage of 19.6 feet on October 4. The Congaree River over-spilled its bank at multiple locations. The river rose 13 feet above flood stage in Columbia with an estimated flow of 185,000 cfs and peaked at a stage of 31.8 feet on October 4, 2015. Although the October 2015 peak ranked eighth in the site's 123 years of record, the last flood to exceed this peak occurred on April 8, 1936, when the river reached a stage of 33.3 feet. This community had not experienced this magnitude of flooding in over 75 years. A snapshot of the river conditions and trends on October 5 revealed that seven river locations monitored and/or forecast by NWS had already crested, four locations rising near crest, and five other locations forecast to crest in the next 1–2 weeks (**Figure 9**).

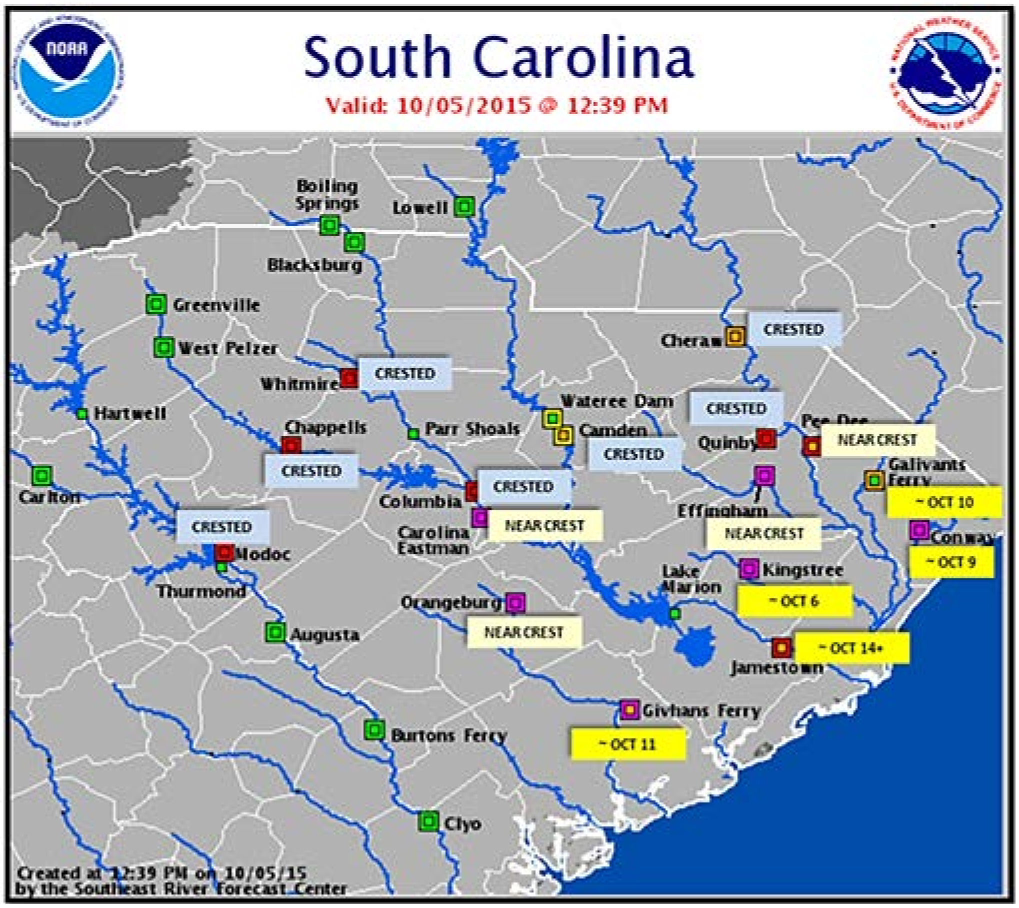


Figure 9: Map created by SERFC depicting river crest conditions on October 5, 2015. *Source: SERFC*

Additional information and timeline of the event is available at *NOAA ESRI Story Maps:* *http://noaa.maps.arcgis.com/apps/MapJournal/?appid=2d473e302db74c3799419d4b89f00d47*

2.2.2. Charleston, SC

Historic rainfall amounts averaging 15–20 inches caused widespread flooding across Colleton, Dorchester, Berkeley, and Charleston counties. Localized amounts in excess of 25 inches triggered flash floods and caused personal property damage, business losses, bridge collapses, road washouts, emergency evacuations, and travel disruptions. Mount Pleasant, SC recorded a storm total of 26.88 inches of rain. Numerous rainfall records were broken at the Charleston International Airport (KCHS).

- Greatest 1–Day Rainfall: 11.50" on Oct 3, 2015
- Greatest 2–Day Rainfall: 14.31" on Oct 3–4, 2015
- Greatest 3–Day Rainfall: 15.92" on Oct 2–4, 2015
- Greatest 4–Day Rainfall: 17.29" on Oct 1–4, 2015
- Greatest Monthly October Rainfall: 17.29" through Oct 4, 2015

In the WFO Charleston service area, the most significant flooding occurred near small creeks, streams, and tributaries feeding into the Edisto, Ashley, Cooper, and Santee Rivers. Because of significant inflows, the Santee River at Jamestown was expected to rise above major flood stage on October 10 **(Figure 10)**. Higher than normal tides due to the perigee spring tide and persistent onshore winds caused coastal flooding in downtown Charleston. More information on impacts is available at: *http://www.weather.gov/chs/HistoricFlooding-Oct2015*.

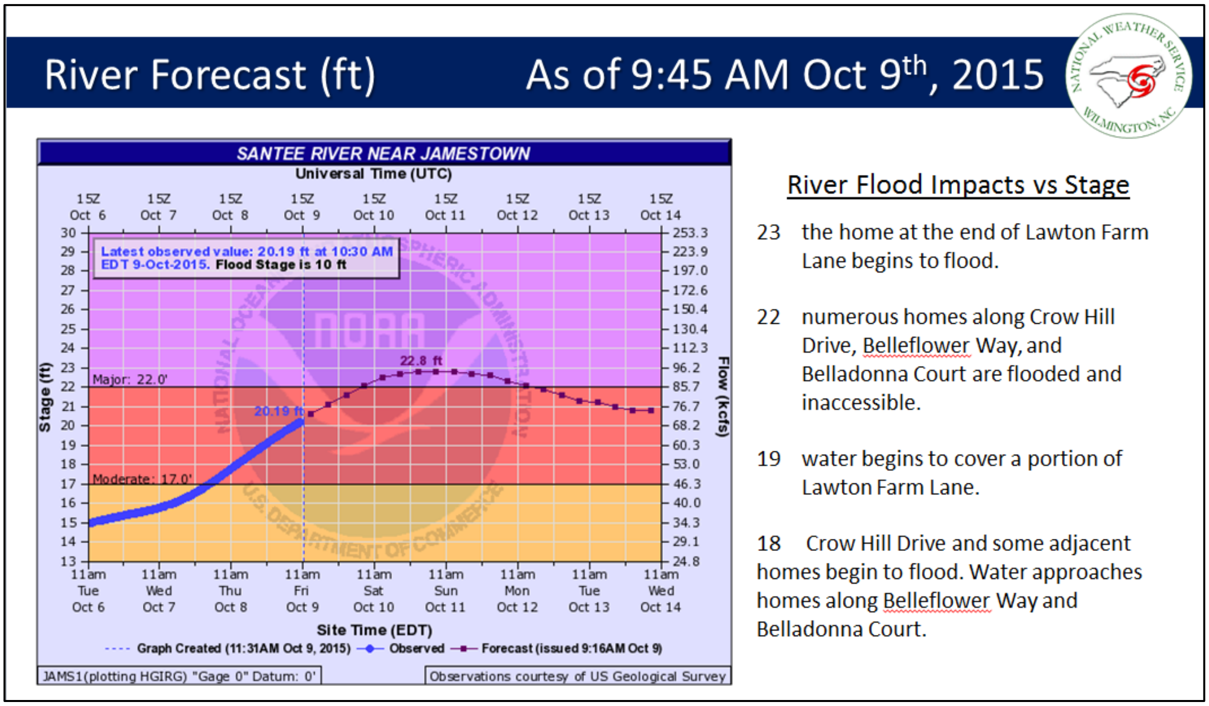


Figure 10: Advanced Hydrologic Prediction Service (AHPS) forecast of the Santee River near Jamestown used in DSS briefing package. *Source: WFO Wilmington, NC*

2.2.3. Wilmington, NC

A record storm total of 24.75 inches of rain fell in Kingstree, SC. Daily maximum rainfall amounts of 7.88 inches fell in North Myrtle Beach, SC, 6.94 inches in Darlington, SC, and 5.19 inches at the Wilmington International Airport, NC, October 2–4. Monthly October rainfall in Wilmington was 14.4 inches, the second highest total since 2005.

By October 5, most of the upper watersheds of the Pee Dee and Santee Basin had crested. By October 6, the Lynches River at Effingham, SC, which feeds into the Pee Dee River, rose within 1.5 feet of the maximum record set on September 22, 1945, to the third highest historic level. The Waccamaw River near Longs and at Conway had not risen over 15 feet since Hurricane Floyd in September 1999. The Black River at Kingstree reached an all-time record high stage of 22.65 feet on October 6, exceeding the previous maximum peak on June 14, 1973 **(Figure 11)**.

Figure 11: AHPS forecast of the Black River at Kingstree SC shown in NWS WFO Wilmington DSS briefing. *Source: WFO Wilmington, NC*

The towns of Georgetown and Kingstree, SC, sustained major flood damage during the event **(Figure 12)**. Georgetown, which is located in the confluence of the Sampit, Black, Great Pee Dee and Waccamaw Rivers (**Figure 13**), suffered an estimated $44.8 million in losses with 670 homes damaged. Because of relatively slow draining lowlands, the Black River and the lower tributaries of the Pee Dee, Santee, and Edisto Basin remained in flood stage for nearly 2 weeks in October.

Figure 12: Flooded homes in Georgetown, SC. *Source: USGS*

Figure 13: Waccamaw River Floods out Railroad Bridge Flooded in Conway, SC. *Source: USGS*

2.3. Flash Flood Verification

During this event, WFOs Charleston, Columbia, Greenville-Spartanburg, and Wilmington collectively issued 41 flash flood warnings.

The average False Alarm Ratio (FAR) for the four WFOs was 17 percent (**Table 2**) and Probability of Detection for this event was high at 98.7 percent **(Table 3)**. The average lead time for flash flood warnings was 97 minutes, above the national goal of 61 minutes (**Table 3**). **Appendix D** provides a summary of flash flood warnings and data to support Tables 2 and 3.

Table 2: Flash Flood Warning Statistics Including FAR

Forecast Office	Number of Warnings	Number of Warnings Verified	Number of Warnings Unverified	FAR
Charleston, SC	**8**	**8**	**0**	**0.00**
Columbia, SC	**12**	**9**	**3**	**0.25**
Greenville-Spartanburg, SC	**9**	**7**	**2**	**0.22**
Wilmington, NC	**12**	**10**	**2**	**0.17**
Total	**41**	**34**	**7**	**0.17**

Table 3: Flash Flood Event Statistics Including Average Lead Time and Probability of Detection

Forecast Office	Number of Events	Probability of Detection	Avg. Lead Time (mins.)
Charleston, SC	**140**	**0.99**	**114.0**
Columbia, SC	**41**	**0.97**	**93.3**
Greenville-Spartanburg, SC	**8**	**1.00**	**68.3**
Wilmington, NC	**70**	**0.97**	**111.0**
Total	**259**	**0.99**	**96.7**

WFO Columbia issued three flash flood warnings for potential dam breaks at the requests of Richland County officials. The dams did not break so the three flash flood warnings did not verify, resulting in a FAR of 0.25 for WFO Columbia. Though the dams did not fail, WFO Columbia provided good public service.

2.4. River Flood Verification

WFOs Charleston, Columbia, Greenville-Spartanburg, and Wilmington collectively issued 49 river flood warnings for the South Carolina 2015 flood event. The average weighted lead time for all river flood warnings was under 32 hours with an average FAR of 27 percent (**Table 4**).

Table 4: River Flood Warning Statistics Including FAR

Forecast Office	Number of Warnings	Number of Warnings Verified	Number of Warnings Unverified	FAR	Avg. Weighted Lead Time (hrs.)
Charleston, SC	**16**	**16**	**0**	**0.00**	**29.2**
Columbia, SC	**9**	**9**	**0**	**0.00**	**6.9**
Greenville-Spartanburg, SC	**13**	**1**	**12**	**0.92**	**46.6**
Wilmington, NC	**11**	**10**	**1**	**0.09**	**44.3**
Total	**49**	**36**	**13**	**0.27**	**31.7**

WFO Greenville-Spartanburg based its river flood warnings on SERFC's river model simulations, which were in turn driven by nationally consistent Quantitative Precipitation Forecast (QPF) values. Since the heaviest rainfall fell south of the Greenville-Spartanburg area, many of the rivers in its service area did not flood which led to the high FAR for the WFO.

During this event, WFOs overall provided ample lead time for their river warnings shown by comparing the last two columns in Table 4. WFO Columbia's average weighted lead time of 6.87 hours for this event is very close to lead times provided in prior floods. WFO Columbia routinely confirms rainfall and river trends before issuing river flood warnings. During high flow events, reservoir operations can quickly change from minimum flows, hydro-power cycling, to large spillway releases on the Saluda and Broad Rivers. Since the Congaree River is highly influenced by regulated flows from upstream reservoirs and dams, WFO Columbia works closely with dam operators to obtain pool information and confirm its daily operation schedules. Time spent on coordination and understanding the final decisions of reservoir operations resulted in shorter riverine flood warnings lead times for WFO Columbia Hydrologic Service Area.

3. Facts, Findings, Recommendations, and Best Practices

3.1. Operations

3.1.1. Weather Forecast Offices

The WFOs were well prepared for this historic flood event despite some staffing issues (see Finding/Recommendation 1), media attention to Hurricane Joaquin, and perceived conditions after a prolonged drought. The three common words consistently communicated by the WFOs prior to the Carolina Floods were “Regardless,” “Antecedent,” and “Historic.”

Over the course of the event, 3 key words were commonly used in discussions and briefings:

ANTECEDENT: The situation was particularly dangerous because it was preceded by an antecedent period of heavy rainfall that saturated the ground, which would make runoff more efficient, and flooding more likely and rapid.

REGARDLESS: Much effort was spent on the possible track of Hurricane Joaquin, with different models showing historic levels of disagreement on landfall. Some models had landfall in the Carolinas, while others had no land fall at all. However, models indicated the area would receive extreme rainfall regardless of the track of Joaquin.

HISTORIC: GFS and EC models at different times had up to 20” of rainfall over a wide area. This forecast was for an unprecedented event that greatly concerned, and even frightened forecasters.

Figure 14: October 2015 Extreme Rainfall Event In-Brief by WFO GSP. *Source: WFO Greenville-Spartanburg Briefing*

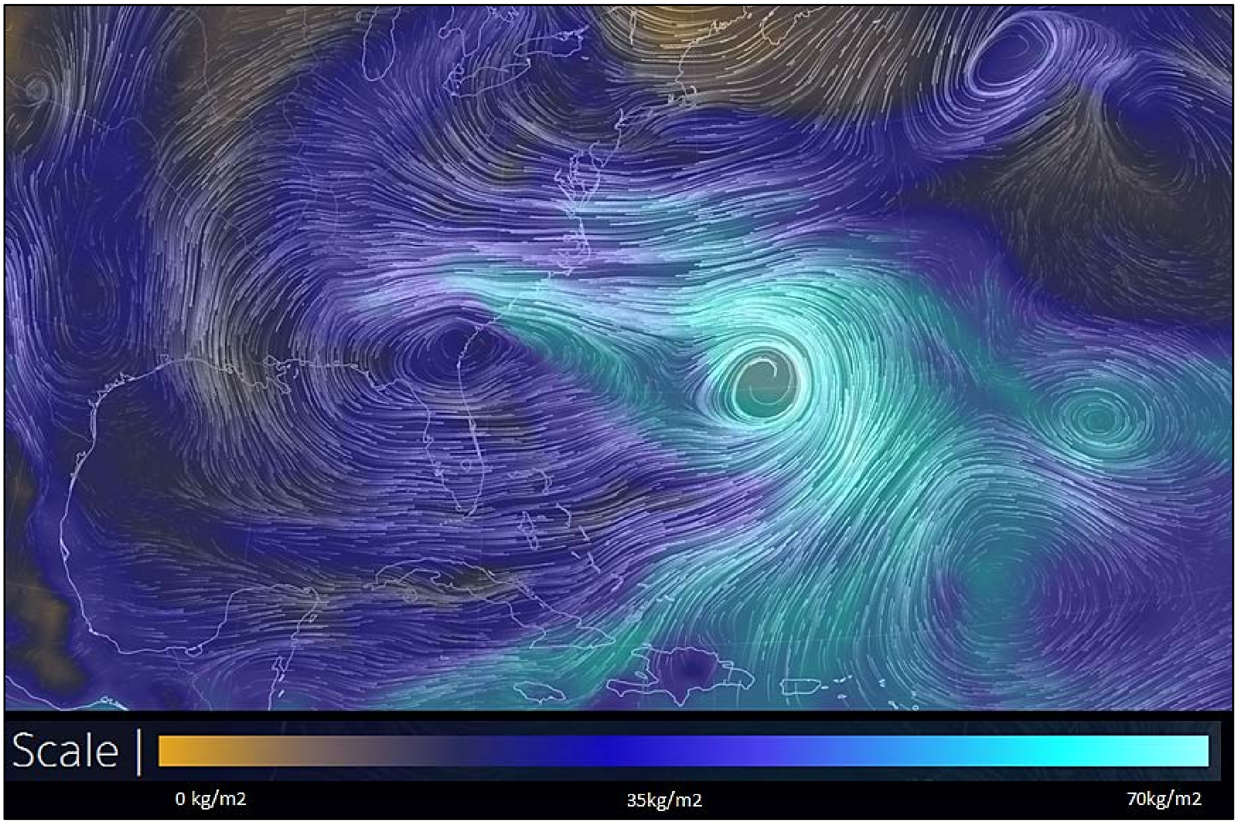


Figure 15: Earth wind map of GFS 850mb wind for 10/04/201512 UTC. *Source: WFO Greenville-Spartanburg Briefing*

WFOs Charleston, Greenville-Spartanburg, and Wilmington provided highly effective DSS briefing packages for stakeholders. The briefings provided stakeholders a better understanding of the moisture streaming from the Atlantic and the circulation patterns causing the significant rainfalls (**Figure 15**). WFO Columbia did not provide DSS briefing packages, although it did supply helpful graphics on its website. Some of these helpful graphics can be seen at the following URL: http://www.weather.gov/cae/HistoricFloodingOct2015.html

Best Practice: The WFOs DSS/PowerPoint and briefing packages (with proactive messaging on the hurricane threat transitioning to extreme flooding, summary of daily flood forecasts, and river flood assessments) were highly effective in communicating the severity of the floods.

WFOs used communication tools such as NWSChat, 12Planet, Skype, YouTube, Facebook, and Twitter effectively to share information with the public, media, and key partners. In general, the WFOs and the RFCs use of NWSChat was extremely effective for two-way communication.

WFO Charleston had a special media room to Skype its interviews with key media personnel. The public found these interviews very beneficial in raising awareness on the local and national severity of this weather event.

Best Practice: Use of Skype for national media interviews is highly effective.

To communicate the event's severity, WFOs Charleston, Columbia, and Greenville-Spartanburg had adapted the use of an informative situational awareness tool, *ESRI Story Maps*, for its forecasters and stakeholders. Story Maps was used to combine maps, images, and text into "storybooks" to describe the flood and convey the impacts on the community. The "storybooks" garnered extremely positive internal and external feedback. See example of the "storybook" using *ESRI Story Maps*: *http://noaa.maps.arcgis.com/apps/MapJournal/?appid=2d473e302db74c3799419d4b89f00d47* (**Figure 16).**

Figure 16: Carolina Flood event told via ESRI Story Maps. *Source: WFO Columbia*

Best Practice: WFOs developed a robust interactive "storybook" of the flood event to show the threats and impacts to the affected areas.

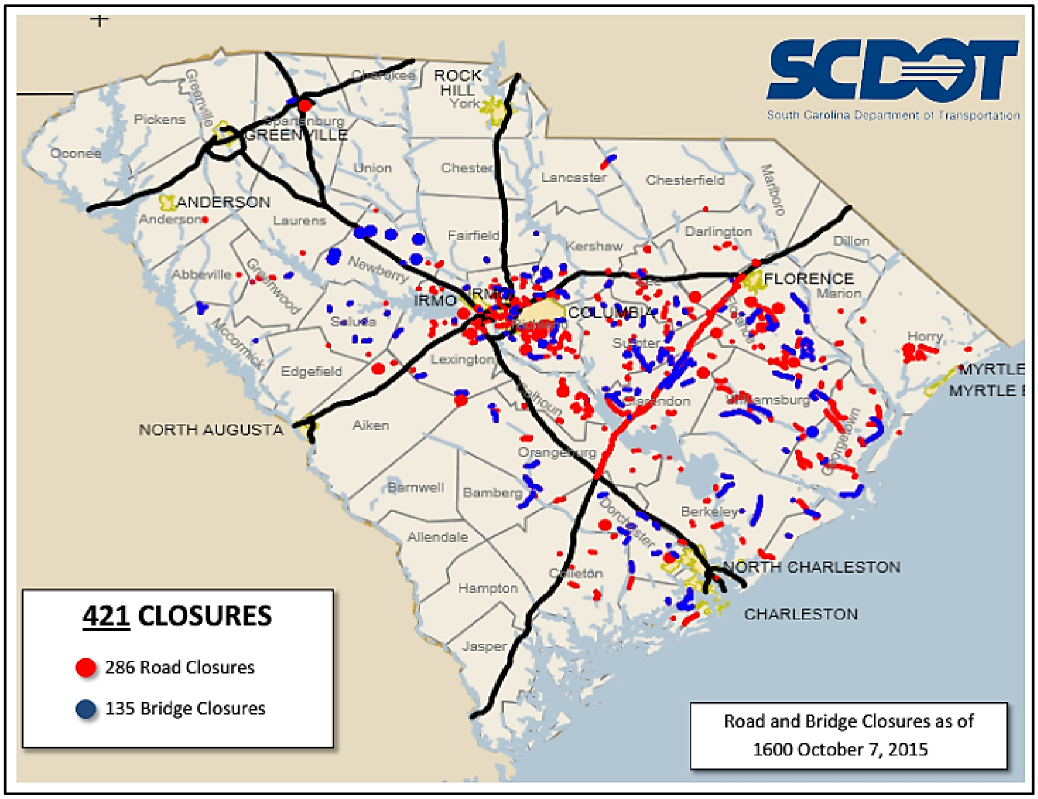


Figure 17: WFO Columbia continuously monitored numerous road and bridge closings. *Source: South Carolina Department of Transportation*

WFO Columbia, located in the state capitol, serves a vital role as the State Liaison. WFO Columbia is responsible for critical interactions with the State Department of Transportation (DOT) and Emergency Operations (**Figure 17),** who coordinate closely with the Governor's office. WFO Columbia had been short staffed for a prolonged period and had three critical vacancies during this event: the Service Hydrologist (SH), the Science and Operations Officer (SOO), and the WCM. Eastern Region Operations Center (ROC) had allocated three additional staff to WFO Columbia and one each to the other three neighboring WFOs to assist in specific operational and DSS needs. Neighboring WFOs Charleston, Greenville-Spartanburg, and Wilmington had more trained in-house staff to work the operational desks. These offices adjusted services depending on the stakeholder's situational needs. For example, WFO Charleston transferred its terminal aerodrome forecast responsibilities to WFO Wilmington to better serve its EMs and media on DSS-related tasks associated with two extra tidal concerns in its service area.

Finding 1: Staffing shortages at WFO Columbia caused extra challenges in the office's ability to deliver operational services and DSS.

Recommendation 1: The NWS needs to continue to work with WFMO/OPM to process and fill NWS vacancies expeditiously.

The biggest threats during this event were from severe river flooding and flash floods due to extreme rainfall and dam failures. WFO Charleston's use of "Historic and Life-Threatening

Flash Flooding" terminology and its issuance of flash flood emergencies were highly effective in garnering the attention of NWS partners, stakeholders, and public. WFO Columbia provided flash flood warnings for pending or imminent dam failures. One of the dams that failed in WFO Columbia's warning area was Gibson's Pond Dam (**Figure 18**). This dam is rated as class C2 by the South Carolina Department Home and Environment Control, defined as not likely to cause loss of life but may damage infrastructure. There were 17 class C2 dams that failed. Failure at Class C1 dams may cause loss of life or serious damage to infrastructure. All 7 class C1 dams and 16 of the 17 class C2 dams which failed were in the WFO Columbia county warning area. There was an opportunity to use the flash flood emergency notification (Flash Flood Emergency).

Finding 2: During the floods, there were 36 dam failures across South Carolina. Some of these failures had posed a threat to life and property.

Figure 18: Gibson Pond Dam on Twelve Mile Creek in Lexington, SC, fails.
Source: WFO Columbia, SC

Recommendation 2: If a dam break poses a severe threat to human life or catastrophic damage, the WFO, in coordination with the EM, should issue a flash flood emergency for more effective communication to the public.

During the event, the WFOs issued numerous watches, warnings, and advisories (**Figure 19**). The WFOs struggled with whether to issue areal flood or flash flood warnings. There was confusion in extending the warning times, allowing warnings to expire, transitioning from flash flood to areal flood warnings, and/or providing more specific impact statements about the floods.

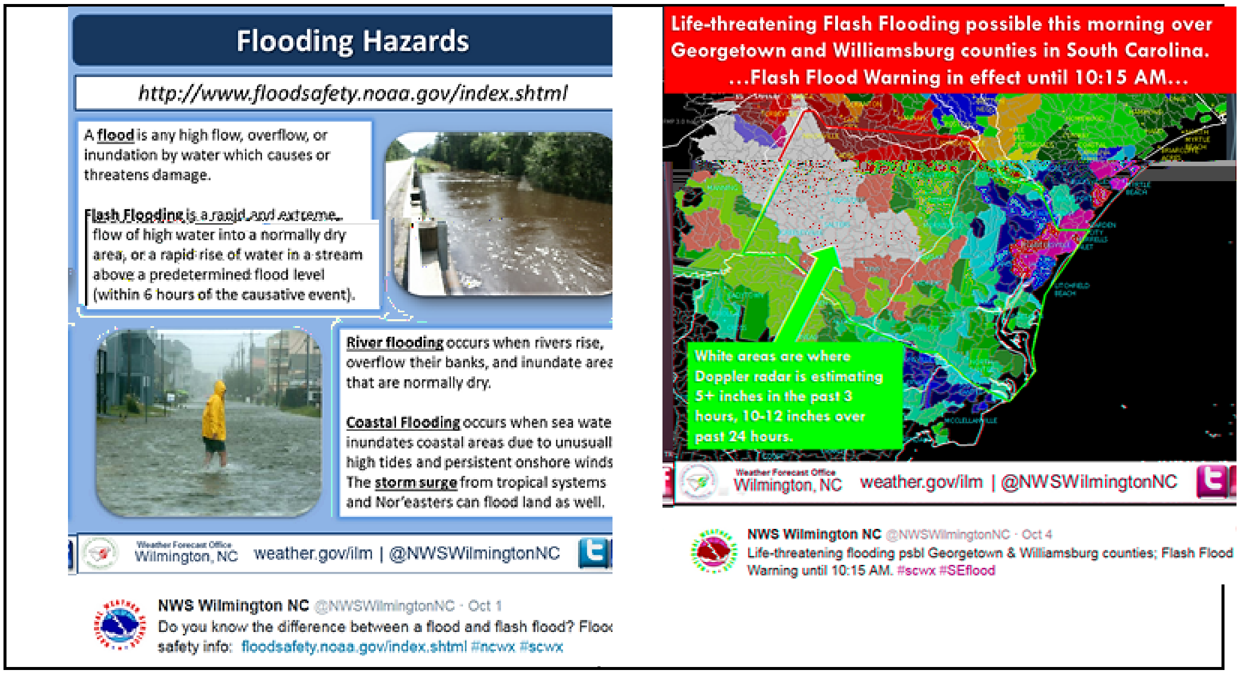


Figure 19: WFO Wilmington identified areas of potential life threatening flash flooding. *Source: WFO Wilmington, NC*

Finding 3: It was challenging for NWS forecasters to understand when to transition from one flood product to another (e.g., when to transition from a flash flood watch/warning to areal flood warning—especially for this magnitude of a storm).

Recommendation 3: With the help of social scientists, the NWS should revise NWS Instruction 10-922 to provide simplified criteria for issuing a flash flood warning, areal flood warning, and urban small stream flood advisory. Additionally, forecasters should be trained on these revised products, as well as best practices for transitioning between products.

WFOs Wilmington and Greenville-Spartanburg used the SERFC Meteorological Models Ensemble Forecast System (MMEFS) (**Figure 20**), in their briefings to convey the probability of their forecast points reaching flood stage, moderate flood stage, and major flood stage. EMs and dam operators found these briefings helpful and convey additional information beyond the deterministic forecasts.

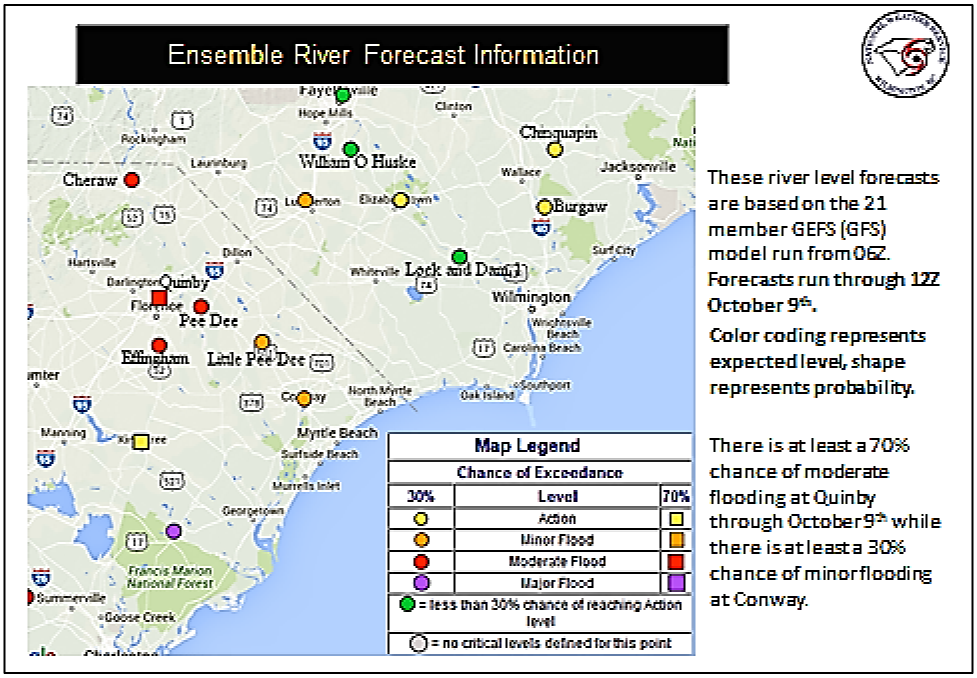


Figure 20: Graphic depicting SERFC MMEFS river forecast information.
Source: WFO Wilmington, NC

Finding 4: EMs and dam operators commented that additional hydrologic forecasts beyond the deterministic river forecasts would have helped determine the range of severity for the pending event.

Recommendation 4: RFCs should provide additional probabilistic information to complement the deterministic forecasts routinely for all forecast points.

EMs asked WFOs Wilmington and Charleston to provide additional decision support information at flooded areas upstream and downstream of AHPS river forecast locations. Such locations were the Black River between Blacktree and Georgetown, SC; the Santee River upstream and downstream of Jamestown, SC; and at impacted locations not forecast by SERFC or modeled by WFO with Site Specific Models, such as Cooper River and its tributaries, Ashley River, and Waccamaw River upstream of Conway, SC.

These WFOs were not able to provide critical information to NWS stakeholders on when rivers were expected to crest or when water levels would drop below flood stage for some of these areas. The SERFC will continue to work with the WFOs on closing gaps in streamflow-water level forecasts by improving model capabilities for non-RFC forecast locations, increasing forecast capacities, and providing new services for previously unforecast locations.

The WFOs pointed EMs and community officials to the AHPS webpages with embedded Federal Emergency Management Agency (FEMA) flood maps. Some of the AHPS webpages for South Carolina, especially for the Pee Dee Basin, did not have embedded FEMA maps because FEMA flood studies supporting the development of these maps were either outdated or non-existent.

Finding 5: Some FEMA flood maps, which would have been useful to understand the extent and magnitude of flooding, were unavailable on AHPS, due to outdated or non-existent FEMA studies.

Recommendation 5: The NWS should work with respective state National Flood Insurance Program coordinators to identify flood map deficiencies or areas needing new FEMA Flood Studies.

WFO Wilmington's SH had Digital Elevation Model data, basic hydraulic understanding, and Geographic Information System skills required to create vital inundation maps on the fly for various river levels.

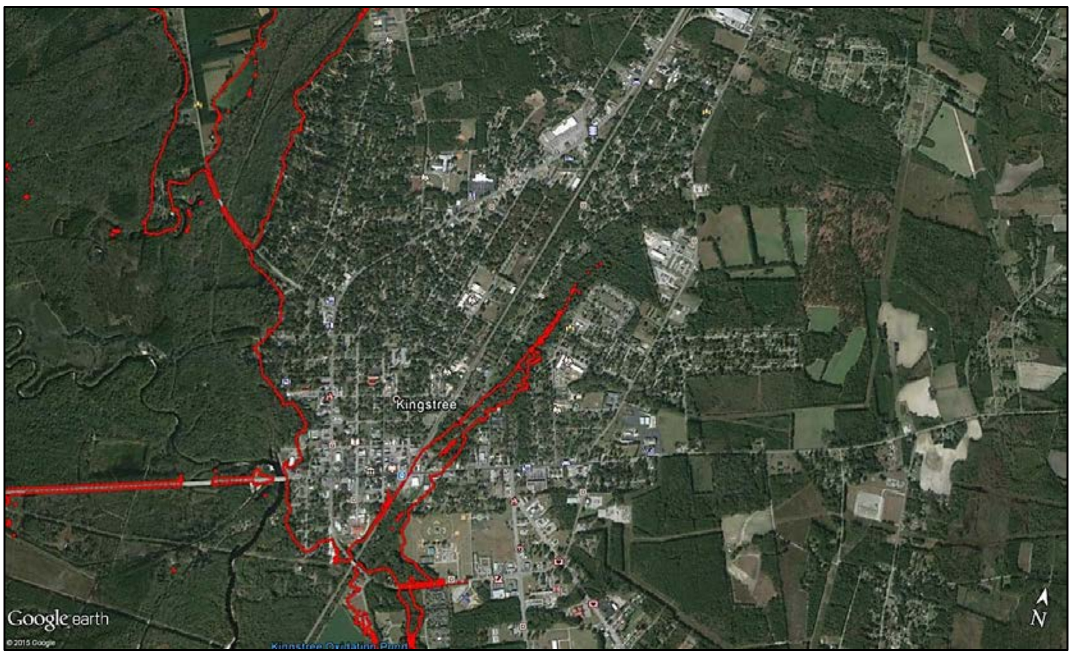


Figure 21: The extent of flooding when Black River Gage in Kingstree, SC, is at 20 feet (see red line traced on the Google Map). *Source: WFO Wilmington, NC*

As long as the forecast maps are explained, EMs appreciate rudimentary flood maps showing the extent of predicted flooding even if these maps are less accurate, lower in precision, and contain some level of uncertainty.

Fact: In the absence of static or dynamic inundation maps, real-time mapping tools are useful to generate on-the-fly maps for enhanced decision support at the neighborhood scale.

The public requested the WFOs provide additional products for water level in the Intra-Coastal Waterways (ICW) and tidal rivers. Currently, there are a lack of tidal observations and forecasts on AHPS for sites in the ICW. There are also observational gaps in the NOAA tide gages for North and South Carolina. See NOAA Tides and Currents links below.

- Tidal Observations: *https://tidesandcurrents.noaa.gov/stations.html?type=Water+Levels*
- Predictions: *http://tidesandcurrents.noaa.gov/noaacurrents/Regions*

Finding 6: During the event, WFOs Wilmington and Charleston identified the need for more tide gages and associated forecasts to assess coastal flood conditions.

Recommendation 6: The NWS should work with the National Ocean Service to identify opportunities for installing new tide gages for observations and predictions.

Figure 22: WFO Briefing showing road washouts along the Ashley River.
Source: WFO Charleston

Many streams and creeks had overflowed and washed out roads and bridges (**Figure 22**). If more of these streams were gaged, WFOs would be able to improve their situational awareness and more effectively communicate when and where river flooding would affect roads.

Finding 7: WFOs lacked streamgage observations for key areas in their Hydrologic Service Area (HSA) that had experienced severe flooding.

Recommendation 7: WFOs, with the support of the RFCs, should work with their local USGS office, local officials, and community to identify where additional streamgages are needed.

USGS installed rapid deployment gages to provide crucial information on rising and falling water levels for some of the highly impacted streams that did not have existing streamflow monitoring stations. This action was important to help identify whether flooding would persist or had already crested on ungaged streams.

Finding 8: While WFOs, EMs, and other stakeholders found the USGS Rapid Deployment Gages helpful for providing river level trends during the storm, they could have been more useful if they were tied to a datum to determine the water surface elevation.

Recommendation 8: WFOs should work with their RFCs and USGS to define critical locations to deploy future Rapid Deployment Gages so that they can be pre-surveyed and integrated into NWS operations.

The NWS found the Damage Assessment toolkit to be useful for flood surveys, but had to adapt the tool due to lack of specific flood attribute fields. During the post-event assessments, the WFOs used the toolkit's weather attributes to document the flood event.

Finding 9: The NWS Damage Assessment toolkit does not have flood attribute fields.

Recommendation 9: The NWS should identify and implement flood attributes within the Damage Assessment toolkit.

Overall, the WFOs operational performance was exceptional during the Carolina Floods. The relationships and rapport WFOs Columbia, Charleston, Greenville-Spartanburg, and Wilmington have established with the media, government officials, municipalities, and private sector users were outstanding. This team's opinion is supported by feedback documented in Sections 3, 4, and 5. To foster and maintain this relationship, the WFOs routinely meet with stakeholders at their respective offices and continually engaged with partners to refine the messages, enhance service needs, and deliver required products. WFO stakeholders stated that annual workshops had helped media and EM partners to better understand the available NWS services and products.

Best Practice: Holding annual media and EM workshops at respective WFOs has proven to be an exceptional way to build relationships and rapport with the media, government officials, municipalities, and the private sector.

3.1.2. Southeast River Forecast Center

The SERFC recognized the potential for an extreme precipitation event associated with Hurricane Joaquin during the last week of September and began sending Hydrologic Vulnerability Assessments that highlighted the flood potential to EMs, dam operators, WFOs, and other DSS outlets in South Carolina, North Carolina, southern Virginia, and Georgia. EMs, WFOs and other stakeholders reported that RFC products were concise and provided more than adequate event lead time.

On October 1, 2015, the SERFC assigned a staff member to serve as an Event Manager within its office to coordinate DSS, optimize staffing for 24-hour operations, and oversee RFC product quality control. The SERFC also began issuing Daily Operational Support Messages to over 80 entities. At this time, the WPC QPF forecast grids indicated 15–20 inches of precipitation over areas of South Carolina for October 2–3. The SERFC continued to operate 24-hour shifts through the first week of October.

The SERFC deployed a staff hydrologist to FEMA Region IV headquarters in Atlanta and conducted numerous interviews and briefings during the event. The deployed SERFC forecaster also relayed dam break notifications to affected WFOs and SERFC as the notifications were received from FEMA, and flash flood warnings and dam break forecasts to FEMA from the NWS when these products became available. The SERFC employee also coordinated talking points between the Regional and National Operation Centers and the National NOAA FEMA Liaison.

Best Practice: The SERFC deployed a staff hydrologist to FEMA Region IV Headquarters, which provided a variety of relevant information to FEMA and other federal agencies, such as the U.S. Coast Guard and the U.S. DOT. FEMA and other partner agency personnel reported the NWS deployment was beneficial to their operations during the event.

At the time of the event, the SERFC had a Journey Hydrologist vacancy that had gone unfilled for 2.5 years and an unfilled Hydrometeorological Analysis and Support (HAS) forecaster vacancy for 3 years. If the event would have lasted much longer, the SERFC would have had to pull out the on-site support to FEMA IV and request an additional HAS forecaster and hydrologist to maintain its high quality forecast and DSS. To mitigate these staffing shortages in the short term, the SERFC used innovative shift durations and rotations; however, modifying shift rotations and their duration is not a long-term solution.

Finding 10: During the event, SERFC had two critical vacancies, a HAS forecaster and a Journeyman Hydrologist. These two vacancies added to the complexity of delivering operational services and DSS. Long-term staff shortages had reduced SERFC's ability to develop and implement cutting-edge hydraulic modeling, inundation mapping, and enhance decision support services.

Recommendation 10: The NWS needs to continue to work with WFMO/OPM to process and fill NWS vacancies as expeditiously as possible.

Numerous neighborhood lakes/retention ponds broke during the flood event. Because of the small scale of many of the projects, information about these failures were either not available in the AWIPS dam catalog, outdated, or incorrect. This gap made it difficult to get meaningful results from the Simplified Dam Break Model.

Finding 11: The SERFC was not able to provide downstream guidance because many dams were not in the dam catalog or the information was incorrect.

Recommendation 11: The NWS should develop a means to query information accurately for all dams to ascertain information needed for running NWS dam break tools.

It was also found that the Simplified Dam Break Model program is significantly out of date. In addition, the Geo Simplified Dam Break Model uses an unsupported version (i.e., no more updates available) of ArcGIS. This outdated software forced offices to rely on local information technology expertise and ingenuity to keep the software operational.

Finding 12: NWS does not provide national Dam Break programmatic or software support to RFCs. RFCs have relied on their own expertise and ingenuity to keep the Simplified Dam Break Model software operational.

Recommendation 12: NWS should develop national program and technical support for the Dam Break flood program. Part of this support should involve modernizing the NWS Dam Break Program and associated software.

The SERFC recently hosted the Santee Cooper Utility for a familiarization visit. It was mutually felt this gave Santee Cooper a greater level of understanding of SERFC operations and, in turn, increased its confidence in SERFC forecast capabilities. Because of this improved confidence and interpersonal relationships, Santee Cooper was more comfortable providing its release plans to the NWS.

SERFC coordination with the South Carolina (SCANA) energy holding utility helped reduce flood impacts on the Congaree River when a canal broke. Because of SERFC collaboration, SCANA cut its discharges from Lake Murray to lessen the flood impact. If the open line of communication and trust was not there, flood levels could have been much worse.

Best Practice: The SERFC's dedication to building enduring partnerships and its commitment to routine collaboration with multiple operators resulted in improved forecast service.

The SERFC routinely collaborates with 12 different operators for some 80 projects in its river forecast model. The SERFC had smooth and effective coordination with its dam operators (Duke Energy, SCANA, Santee Cooper, USACE, etc.) during the event. As a result of this collaboration, the SERFC was able to manually override NWS reservoir model releases with amounts from the reservoir operators. This data improved river forecast accuracy.

Best Practice: Partner confidence in SERFC forecast capabilities allowed increased information exchange between agencies, improving river forecasts downstream of reservoir regulation.

There were numerous forecast service requests for tidally influenced rivers, such as the Waccamaw River. The SERFC does not forecast tidally affected rivers because it cannot account for the numerous complexities in its hydrologic modeling schemes. This need for improved modeling of the riverine-ocean interface was also identified in the assessment of Hurricane/Post-Tropical Cyclone Sandy, October 22–29, 2012, in Finding 16. As can be seen in Appendix G (Referenced Findings and Recommendations from Previous Service Assessments), to address that Finding, the Storm Surge Roadmap team assembled a roadmap in FY15. The roadmap lays the groundwork to build on actions related to tropical storm surge (storm surge watch/warning) and apply that knowledge to extratropical and riverine flooding from storm surge. The NWS is now forming a team to address extratropical storm surge flooding; riverine storm surge related-flooding is a longer-term effort.

3.1.3. Eastern Regional Operations Center (ER-ROC)

On September 21, the ER-ROC began focusing its attention on the possibility of Hurricane Joaquin affecting the East Coast. It later became clear that the threat was transitioning from a hurricane to historic flooding across the Carolinas. By September 29, the ROC had elevated its staff to 16-hour per day operations and maintained that level through October 5, 2015.

During the event, ER-ROC supplemented staffing at WFOs Columbia, Charleston, Wilmington, and Greenville-Spartanburg by redeploying nine people from other offices. The ER-ROC took proactive measures by ramping up collaboration calls to ensure local, regional, and national consistency and common understanding of the potential impacts due to this unprecedented storm.

The ER-ROC conducted and participated in numerous conference calls with the National Hurricane Center (NHC), WPC, the National Operations Center (NOC), Southern Region ROC (SR-ROC), the RFCs (Southeast, Lower-Mississippi, and Mid-Atlantic RFCs), WFOs, FEMA Regions (II, III, and IV), state emergency operations centers, state EMAs, and many others.

During this event, ER-ROC was physically staffed for 16 hours and had staff on-call via cellphone for the overnight hours. ER-ROC normally goes to a 24-hour physically staffed operations only when a tropical watch or warning is issued. Some of the WFOs assumed that ER-ROC had ramped up to a fully staffed 24-hour operations given the magnitude of the event. As a result, the WFOs were expecting feedback from ER-ROC on NWSChat/12Planet during the overnight hours.

Finding 13: Some of the WFOs were not clear whether the ER-ROC was physically being staffed around the clock or not, thus causing some confusion, especially during the overnight hours on NWSChat and 12Planet.

Recommendation 13: ERH should inform the WFOs and corresponding RFCs of the ER-ROC staffing plans on both NWSChat and 12Planet and indicate if/when it is going offline on the NWSChat/12Planet.

The ER-ROC's main role is to coordinate regional support activities, such as information technology support for the WFOs. The ER-ROC also prepares situational event reports and provides the information to the NOC and others as and when needed. WFOs noted different practices of the ER and SR ROCs and would like a better understanding of the similarities and differences of the regional ROCs.

Finding 14: Some of the staff at the WFOs and RFCs was unaware of the roles and responsibilities of the Regional ROCs.

Recommendation 14: The Regional ROCs should ensure their role and responsibility is understood by WFOs and RFCs.

3.1.4. National Centers

National Weather Service Weather Prediction Center

The WPC first highlighted the heavy rain threat on September 30, 2015. On October 1, WPC provided the 72-hour forecast QPF graphic **(Figure 23)** to indicate the potential for catastrophic rainfall with over 10 inches of rain forecast for parts of the Carolinas. On October 2, WPC provided the 72-hour forecast QPF graphic that indicated an expanded area expected to measure over 15 inches of rain for the same period from 12 UTC October 2 to 12 UTC October 5, 2015 **(Figure 24)**.

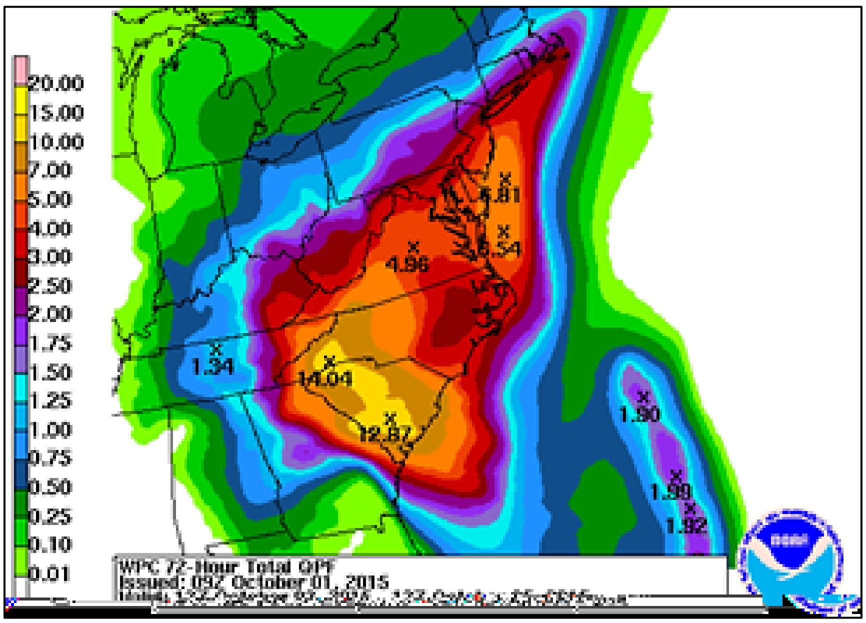


Figure 23: WPC 72-Hour QPF issued at 0900 UTC on October 1.
Source: Weather Prediction Center

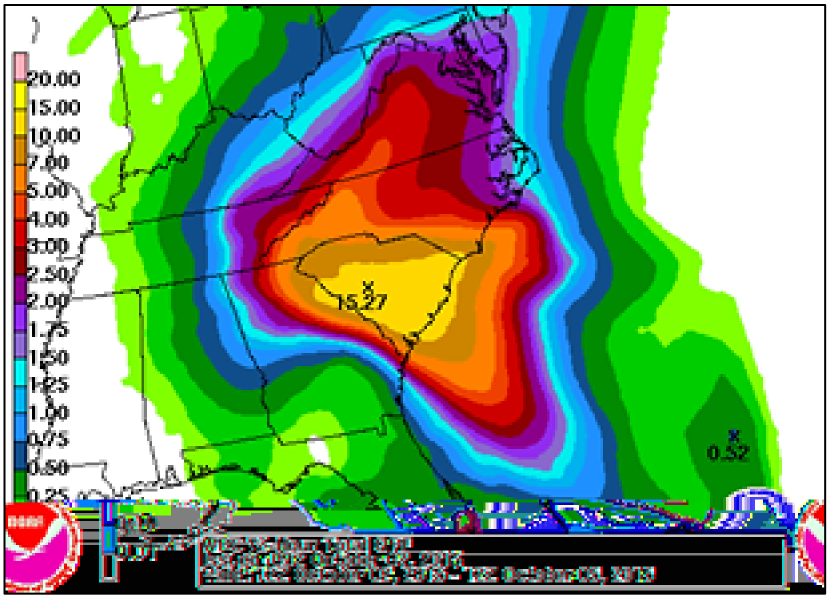


Figure 24: WPC 72-Hour QPF issued at 0900 UTC on October 2. *Source: Weather Prediction Center*

WPC did not waiver in calling for heavy rainfall in South Carolina despite discrepancies in some of the Numerical Weather Prediction (NWP) model fields and recommendations from WFOs to lower QPF amounts for October 1. On October 1, the NWP models were nearly unanimous in forecasting maximum amounts in excess of 10 inches over upstate South Carolina.

At 0900 UTC on October 1, WPC issued a 72-hr QPF with 10+ inches of expected rainfall, but did not pre-coordinate these rather unusual numbers with the affected WFOs. WPC should host a pre-coordination call for extremely impactful QPF in its guidance package when it expects big events of 10+ inches of rainfall or more. (The Record Front Range and Eastern Colorado Floods of September 11–17, 2013, Finding 1 addresses the issue of conducting WPC coordination calls with WFOs and RFCs when the potential exists for widespread heavy rain and flash flooding.)

As the storm began to take shape over the Carolinas on October 2, WPC continued to highlight the high risk of excessive rainfall from October 3–5, 2015, with an emphasis of the potentially historic and catastrophic nature of the event. WPC posted DSS “Briefings,” highlighting rainfall amounts, excessive rainfall outlooks (including high risk), and expected impacts and provided flood safety information.

Despite WPC’s forceful messaging of a historic rainfall event, WFO Columbia was intentionally conservative relative to WPC QPF and introduced a significant discontinuity at WFO service boundaries **(Figure 25)** for QPF forecast on October 1, 2015.

Finding 15: WFO Columbia QPF grids were inconsistent with surrounding offices and the WPC until October 2, 2015.

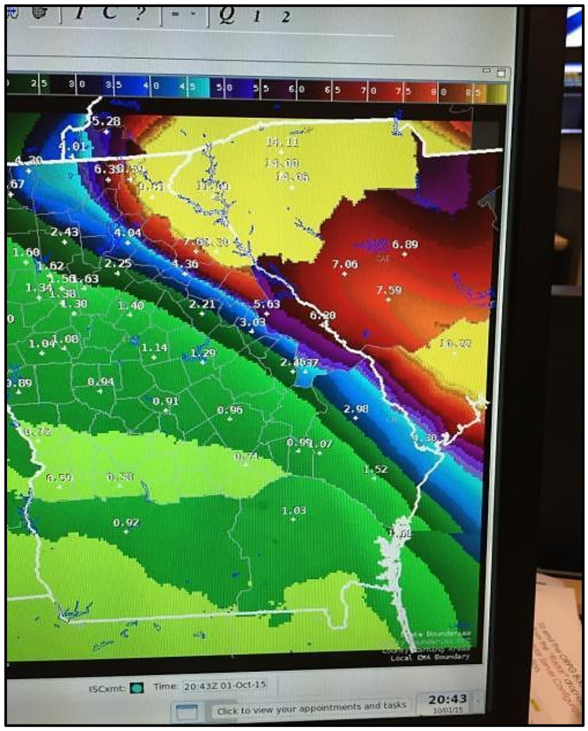


Figure 25: QPF grid inconsistencies in the 10–15 inch bullseye. *Source: WFO Peachtree City*

Recommendation 15: The NWS should track and accelerate the development of a visual grid collaboration tool for use between WPC, WFOs, and RFCs to make collaboration more effective and help address spatial inconsistencies.

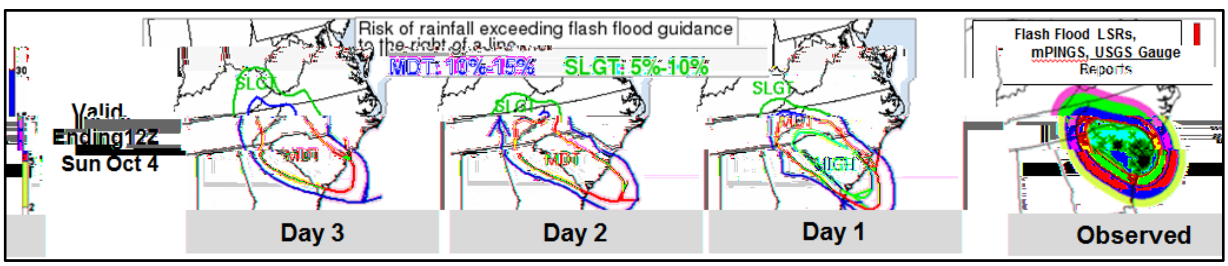


Figure 26: WPC Excessive Rainfall Outlooks. *Source: NWS Weather Prediction Center*

Finding 16: WFOs would like WPC policy to allow for "High Risk for flash flooding" to be indicated on the Day 2 and 3 Excessive Rainfall Outlooks when there is high certainty (**Figure 26**).

Recommendation 16: WPC should re-examine the WPC Excessive Rainfall Outlooks to determine whether High Risk for Flash Flooding should be noted on Day 2 and/or Day 3 products when there is high certainty.

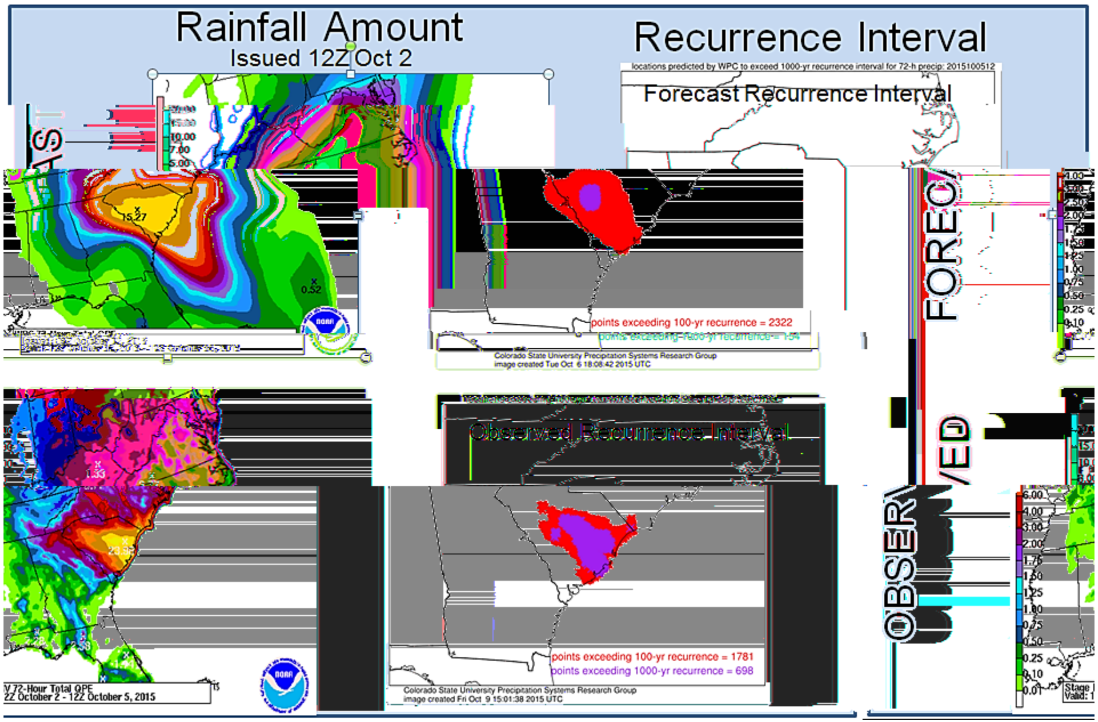


Figure 27: WPC comparison of forecast and observed rainfalls with recurrence intervals. *Source: NWS Weather Prediction Center*

The WPC precipitation verification from October 1–5, 2015, showed the event was forecast very well (**Figure 27**). FEMA Region IV and the media recognized this was a significant and historic event. The media outlets described this event as a 1 in 100 to 1 in 1,000-year flood based on observed rainfall recurrence intervals. Although the media and public are gaining more knowledge in understanding confidence and probabilities, there is still misunderstanding as to whether a 1 in 1,000-year rainfall causes a 1 in 1,000-year flood. In fact, floods are highly dependent on the antecedent conditions, runoff characteristics, and effectiveness of dams to attenuate the flooding.

Finding 17: Some of the media and public officials incorrectly called this a 1,000-year flood.

Recommendation 17: The NWS should work closely with USGS and behavioral scientists to help the public better understand the recurrence intervals for precipitation and floods.

Need to Better Define Roles of NWS Offices

The service assessment team thinks NWS should better define the appropriate interactions, roles, and responsibilities among WFOs, RFCs, regional ROCs, the NOC, the NWS Communications Office, and the National Centers for providing impact-based decision support (IDSS). In particular, NWS needs to clarify where each office's role begins and ends **(Figure 28)**. NOAA NWS Operations and Service Assessment during Hurricane Irene in August 2011, Finding 12 is directly related to this need. The NWS should ensure the IDSS directive covers standard operating procedures for communication and defines roles in high visibility high-impact events.

Figure 28: WFO Charleston personnel providing media interview on historic floods. *Source: WFO Charleston, SC*

The headlines from several media sources supported an overarching finding that the extreme precipitation event was well forecast. *The Washington Post* on October 7 stated, "*Meteorologists pegged the epic South Carolina flood forecast days in advance*" **(Figure 29)**. Other comments included "*But as unusual and extreme as this event was, meteorologists identified and communicated the threat with plenty of lead time. It was an extraordinarily well-forecast flood.*" These comments are supported by the NWS Products and Services from WPC, RFCs, and WFOs.

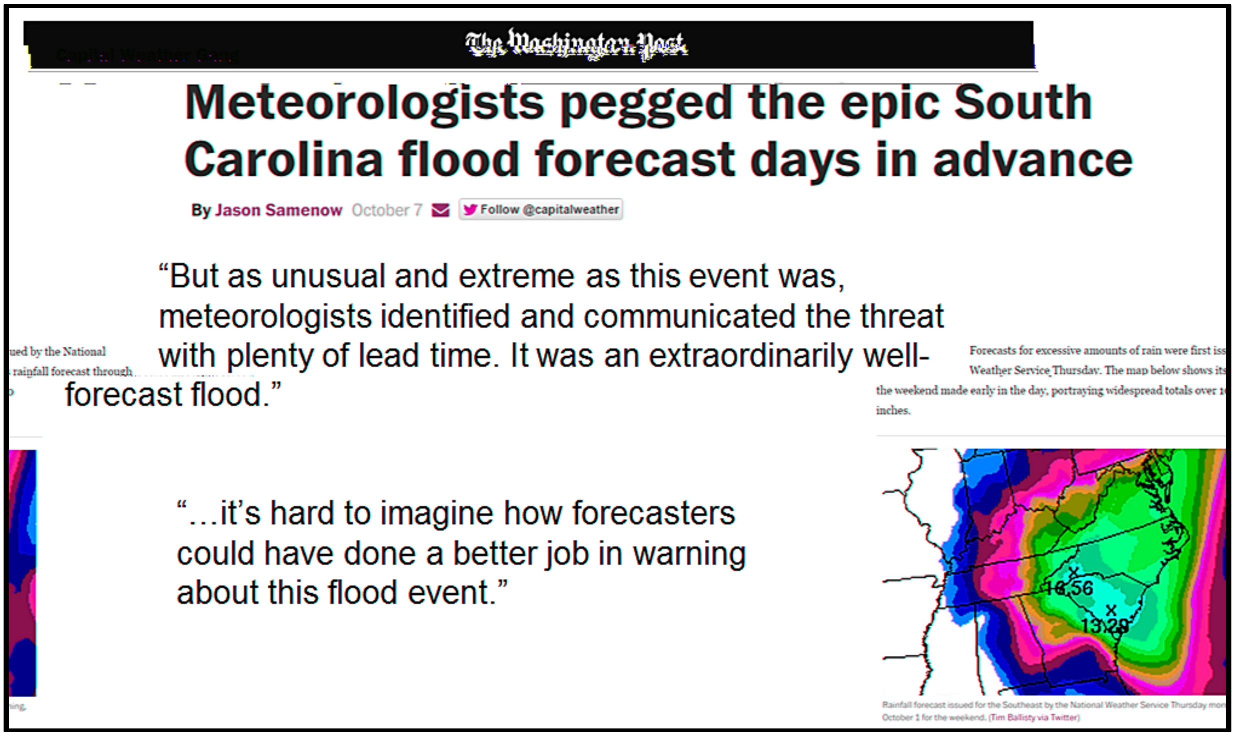


Figure 29: Captions from national media. *Source: The Washington Post*

National Hurricane Center

NHC stated that the South Carolina Storm and Hurricane Joaquin occurred in regional proximity to each other, but largely developed independently; however, NHC did note the easterly and southeasterly low-level onshore winds, overrunning the front near the South Carolina coast, contributed to the rain, but were not a part of the tropical cyclone's circulation. NHC operations were evaluated separately from this Service Assessment. The evaluation of weather model performance for Hurricane Joaquin was conducted by NCEP Environmental Modeling Center (See **Appendix I**).

3.2. Decision Support Services and Products

The Service Assessment Team interviewed stakeholders served by WFOs Columbia, Charleston, Greenville-Spartanburg, and Wilmington. Stakeholders included the state, county, and city EMs, the South Carolina governor's office, dam operators, the media, and the public. The WFOs and RFC provided a variety of DSS and product suite provided before, during, and after the event. Most partners were familiar with the basic product suite provided during the event, but some lacked knowledge of the additional support services available.

3.2.1. Services and Products for Local Partners Prior to Event (outreach and preparedness)

County EM Agency (EMA) directors value the partnership with WFO staff in promoting education and preparedness activities such as severe weather, winter weather, hurricane, or flood safety awareness campaigns. Some EM directors indicated that certain segments of the general population do not understand the intent of the awareness campaign messaging. These population segments included, for example, generational or socio-economic.

Finding 18: NWS educational materials are not understood by a diverse population (i.e., specific age ranges and education levels).

Recommendation 18: NWS educational materials need to be in a format that can be understood by a diverse population.

WFOs should continue to identify and enhance partnership opportunities to help educate the public on weather hazards. These include preparedness partnership events, NOAA Weather Radio promotion events, etc.

3.2.2. Services and Products for Local Partners During the Event

Overall, partners stated they were satisfied with the NWS forecasts and warnings during the event. Many partners said they relied on the hydrographs for river levels though they were less familiar with the AHPS webpage than the local WFO webpage. These partners had the hydrographs bookmarked or had received links in an email blast that went directly to the specific hydrographs.

County EMA directors valued email blasts from the WFOs and felt the frequency and format during the flood event was appropriate. These communications occurred multiple times each day and contained easy-to-understand graphics of the impending weather threats. They appreciated receiving a wealth of information without having to make a formal request for it. These blasts helped the EM directors facilitate effective communication with other government officials within their respective county.

Best Practice: WFOs provided rapid and consistent delivery of email blasts to core partners (e.g., EMs), providing them with up-to-date information to use in local operations.

NWS conference calls were a critical resource for EMs. The information was timely and highly relevant to making EM decisions. There was a high degree of awareness on how to participate in the calls and EMs felt the frequency of the calls was appropriate. EMs participated on an as needed basis.

Best Practice: WFOs provided consistently scheduled conference calls to core partners (e.g., EMs) for the duration of the event.

The South Carolina Emergency Management Divsion (SCEMD) would routinely have to assess the event situation by looking at the individual WFO graphics. At times, this hampered efforts to process a large volume of information. Since most of the state was expected to be impacted by heavy rainfall, having a state scale map presentation would have help planners at the state Emergency Operations Center (EOC).

Finding 19: The SCEMD requested state-scaled products (i.e., forecast precipitation maps). These products would help provide a broad-based picture to facilitate more effective operations.

Recommendation 19: Explore capabilities of standardized and baseline tools to create standardized state level maps depicting various parameters such as precipitation forecasts. These maps potentially could be generated by an automated process that pulls from the gridded forecast.

Nineteen people lost their lives during the flood event. Eleven of the fatalities were drownings, eight of which were auto related. Most EM directors were frustrated that drowning fatalities by people driving through flooded roadways remains a long-standing issue. EMs and broadcast partners thought there were limitations in their ability to warn/educate the public on the dangers of driving through flooded roadways.

Finding 20: A majority of the county EM directors were not aware of the "Turn Around Don't Drown" DOT signs for use in their county.

Recommendation 20: WFOs should communicate to EM directors the availability of the DOT signs as another tool to alert the public during high water events.

Social media was an effective tool for sharing of information between the NWS and core partners during the flood event. Social media helped ensure the flow of communication between conference calls and email blasts issued from the WFOs or information coming into the state EOC or county EMs. Social media played a significant role in communicating to the public. It was noted that various demographic groups (e.g., age specific) use of different social media outlets should be accounted for in message delivery.

The Service Assessment Team believes that WFOs should become better aware of the content that partners find most useful in the social media context. It is also important to gain an understanding of each demographic group to reach as diverse an audience as possible. The team thinks WFOs should then provide content that EMs can quickly pass along via social media without modifying. There are three social media-related findings currently being addressed from these service assessments:

- Hurricane and Post-Tropical Cyclone Sandy, October 22–29, 2012, Finding 12
- May 2013 Oklahoma Tornadoes and Flash Flooding, Finding 25
- Colorado Flooding of September 11–17, 2013, Finding 12

3.2.3. Southeast River Forecast Center Services

The SERFC issued a Daily Operational Support Message and Hydrologic Vulnerability Assessment. These were PowerPoint presentations containing Quantitative Precipitation Estimates (QPE), QPF, current river levels, forecast river levels, and probabilistic forecasts relative to minor, moderate and major flood stages. These briefings were emailed to over 80 SERFC stakeholders and referenced by SERFC staff for situation awareness throughout the event.

Best Practice: The SERFC Decision Support Services (DSS) briefing packages proved informative and useful to dam operators, WFOs and other entities because they covered the entire event domain and were concise.

The SERFC began to provide short-term hydrologic ensemble forecasts to its partners in 2011 through the Meteorological Model-based Ensemble Forecasting System (MMEFS). This service gave partners a better feel for the current hydrologic situation with its sensitivity to varying precipitation scenarios. Although the individual graphs can be confusing for all but high-end users, the summary graphics were a useful way to help tell the current flood situation and story.

Best Practice: The SERFC probabilistic river forecast services proved useful to express hydrologic forecast model sensitivities, hydrologic uncertainties and provided situational awareness to WFOs and partner agencies concerning the various precipitation scenarios during the event.

The SERFC participated in the South Carolina EM river forecast technical call for EMs across the state and with the governor of South Carolina. There were four calls each day, two of which included the governor, and two solely with EMs. At the request of the county EMs, WFO Wilmington coordinated a separate call for 4 days to address specific questions about the forecasts. SERFC offered this option to all affected WFOs as a possible service.

Best Practice: The SERFC offered to collaborate with WFOs and participated as required in WFO-hosted river forecast technical calls for EMs in affected areas.

3.2.4. WPC IDSS

WPC provided DSS at the national level preceding and during the event. As early as September 29, WPC was involved in collaboration calls with the WFOs and SERFC increasing from once a day to twice a day through October 2. WPC also provided three live FEMA video teleconference calls on October 1–2, three briefing to the NOC on October 1–2, and one Congressional briefing on October 2. An effective practice was established for this event through a single talking point sheet that consolidated the efforts of WPC, NHC, Communications, and the ROCs. WPC used these talking points in their briefings.

3.2.5. INWS

Some EMs, but not all, relied on the Interactive NWS (iNWS) as a key alert function for NWS watches and warnings. Those partners cited iNWS alerts as their first notification of an event affecting their area. This system provided timely text messages and/or emails, extracting the information relevant for the partners' geographic areas.

Finding 21: Not all EMs readily used iNWS to receive automatic notification when NWS issued products.

Recommendation 21: WFOs should provide outreach and education on the benefits of iNWS, emphasizing it as a key tool for notifications, watches, and warnings.

3.2.6. Flash Flood Emergency

In exceedingly rare situations, when human life is threatened and/or catastrophic damage is imminent or ongoing from a flash flood, WFOs can issue a "flash flood emergency" by adding the phrase, **"THIS IS A FLASH FLOOD EMERGENCY"** to the third bullet of a flash flood warning.

The intent of the use of the "Emergency" wording in a flash flood product is to provide immediate attention to the public, media partners, EMs, and first responders. The term is meant to create a sense of urgency to the people living and serving in the flood area. The emergency message also informs EMs and first responders to prepare for a very serious flood event that could include search and rescue, evacuation, emergency sheltering, and numerous deaths, etc. There were four flash flood emergencies issued during the South Carolina flood event, all issued by the WFO Charleston. WFO Columbia opted not to use the "Flash Flood Emergency" language in its flash flood warning products, although some criteria events occurred in their County Warning Area.

NWS Directive 10-922 provides the following example criteria for when NWS Meteorologists may include the use of flash flood emergency language in flash flood warnings, but are not limited to the following:

- EM(s) of the affected county(s) or the state emergency management association declare a state of emergency and have confirmed that rapidly rising floodwaters are placing or will place people in life-threatening situations. The state of emergency for the affected areas may have been previously relayed by the EM(s) or the state emergency management association through the WFO in a non-weather emergency message. These might include a CEM, evacuate immediate, or local area emergency.
- Water has rapidly risen or will rapidly rise to levels where people who are ordinarily in safe locations during previous flash flood events are now placed in life-threatening situations. For example, people in homes that might see waters rapidly rise up to their front yards or steps during typical flash flood situations would experience waters that are several feet above floor level such that rescue is necessary and/or their entire home is threatened.
- Multiple swift water rescue teams have been or are being deployed in response to flash flooding of an exceptional magnitude.
- Streamgages, where available, indicate floodwaters have risen rapidly to at least major levels or if gages are not available, floodwaters have risen to levels rarely if ever seen.
- Total failure of a major high hazard dam that would have a catastrophic impact on the downstream communities.

One of the county EM directors in the WFO Greenville-Spartanburg area stated he was confused by the number of flash flood watches/warnings and areal flood warnings. He suggested it would have been more effective to issue one flash flood emergency for his area of responsibility.

Finding 22: The public, media partners, and EMs were confused by the many types and the quantity of watches/warnings WFOs issued.

Recommendation 22: The NWS should review hydrologic products described in 10-922 and determine if the suite of flood products can be condensed, revise this directive, and provide training to forecasters on the revised 10-922, especially concerning when and how to use specific hydrologic warning products.

3.2.7. Civil Emergency Message

NWS Directive 10-518, *Non-Weather Related Emergency Products Specification*, states that a civil emergency message (CEM) is an emergency message regarding an in-progress or imminent significant threat to public safety and/or property. These messages, along with other non-weather related messages, are normally issued under agreements with local and state EMs. The CEM is disseminated by WFOs usually at the request of local or state EMs. WFOs will develop and institute authentication procedures with state, tribal, and local government officials to minimize the possibility of a false or inappropriate release of a non-weather emergency message.

During the South Carolina flood event, WFOs disseminated eight CEMs. WFO Columbia issued four CEMs (one was for a correction deleting counties in Georgia), WFO Charleston disseminated one, WFO Greenville-Spartanburg disseminated one, and WFO Wilmington, two. Most of the CEMs were disseminated at the request of the SCEMD. The CEM covered citizens sheltering in place and using 911 for life threatening emergencies only. Two of the CEMs disseminated by WFO Columbia pertained to mandatory evacuations due to a dam breach in Richland County. The public expressed some confusion or misunderstanding about the meaning of CEMs received on their cell phones via Wireless Emergency Alerts (WEA) (**Figure 30**). The belief of the Service Assessment Team is that CEMs need to be more informative. The CEMs should either contain improved text and/or be enhanced by some other method (e.g., the inclusion of a web link to obtain further explanation of the CEM's text).

Finding 23: The public expressed some confusion or misunderstanding about the meaning of CEMs received on cell phones via WEA.

Recommendation 23: CEMs and other cell phone automated government dissemination products should have a link directing the user to further text explanation of the product alert.

Public #1: "Just received top alert but I can't open to read. Anybody know what it is?"

Public #2: "I was wondering the same thing."

Public #3: "It does not say anything about it on their website either. Thoroughly confused."

Like · **Reply** · **October 4 at 6:03am**

US National Weather Service Columbia South Carolina The message should be a CEM from South Carolina Emergency Management asking all residents of South Carolina to stay in a safe place today and only use 911 for life threatening emergencies. A copy of the text has been posted on Facebook.

Public #1: "Thank You."

Figure 30: Discussion of WEA alert via Facebook after CEM disseminated by WFO Columbia . *Source: WFO Columbia, SC, Facebook*

3.3. Social Media

NWS provided a substantial amount of content via social media throughout the event. This content includes contributions from the four affected WFOs, SERFC, and the WPC. By comparison, all four of the WFOs shared more information via Twitter, even though they had a stronger social media presence on Facebook. WFO Charleston was the only office who had more followers on Twitter than Facebook. None of the four WFOs have Instagram accounts to disseminate hazard related information.

Even though all WFOs made adequate use of social media during this event, they all agreed that staffing levels have to be used more effectively to make social media a high priority in operations during high-impact events such as this historic flood.

While a large number of individuals followed NWS content on social media, a majority of respondents in the public interviews have never visited NWS web pages or NWS social media outlets as discussed in the Societal Impacts Section 5.2. It is critical that NWS continue to raise public awareness of NWS social media products to maximize its communication reach. Social media continues to trend higher in the number of users and the importance relied upon these information resources. One broadcast meteorologist stated that 70 percent of her reach is through social media, versus television broadcast. Viewers are relying more on social media than traditional news sources, which is causing broadcast meteorologists to rely increasingly on social media to disseminate their messages. Social media users are also engaging in transactional communication between the WFO and other users. Transactional communication was demonstrated through the use of Facebook, where users asked specific questions to the WFOs in the comment section of the posts and the WFOs responded to the users' questions. Users provided information on storm damage through posts and WFO staff had to retype the information into the official local storm report product. WFOs found this process duplicative and tedious.

Finding 24: WFO staff said local storm reports were a lot of work and very hard to keep up with but helped support the office's social media presence.

Recommendation 24: The NWS should create a tool to transfer social media posts to local storm reports.

It is important to remember that individuals process information differently depending on their age, education, ethnicity, gender and socioeconomic status. These dimensions not only influence how users seek hazardous weather information, but also influence how this information is processed.

Finding 25: The Service Assessment Team determined different demographic groups (e.g., age specific) use different social media resources (e.g., Twitter, Facebook).

Recommendation 25: Social Scientists need to examine demographic groups and translate this understanding into accessible information in order to reach diverse audiences.

NWS social media content was not as useful as it could have been to disseminate information easily from the EMs to the public. NWS should become better aware of the content that partners find most useful in social media. As stated earlier in Section 3.2.2, NWS should provide content that EMs can quickly pass along via social media without modification.

The social media directive has been written to address these findings. At the time of this assessment, the directive was in the review process.

The following trends were evident in regards to information disseminated through social media from the four WFOs.

On Facebook, the following content was shared from WFOs respective pages:

- Radar loops
- Coast guard rescue videos
- Videos of flooding
- Radar images
- Maps showing the hazardous weather outlook
- Images of staff being interviewed by the weather channel
- Satellite image with a radar overlay looping
- CEMs from South Carolina EM.

On Twitter, the following content was shared from WFOs respective pages:

- Images from the floods via drones
- River forecast information
- Storm total rainfall
- Civil emergencies
- Dam and flash flood warning information
- Storm graphics
- Rainfall forecast for the state
- List of road closures
- Information regarding river gauges
- Flash flood warnings
- Images of the floods
- River flooding records
- Local storm reports
- Locations of flash flooding
- Water rescues
- Areas of major flooding
- Travel advisories
- Urban and small stream flood advisories
- Images of conditions in users areas
- Rainfall records

Table 5 illustrates the breakdown of followers for each WFO's Facebook and Twitter account. Additionally, WPC social media reach was over 1 million people, roughly 60 percent from Facebook and 40 percent from Twitter.

Table 5: WFO Social Media Reach

	Facebook Followers	Twitter Followers	Total Reach
WFO Columbia	17,003	4,863	21,866
WFO Charleston	10,340	12,500	22,840
WFO Greenville-Spartanburg	17,683	5,607	23,290
WFO Wilmington	10,168	5,945	16,113
WPC	645,867	395,752	1,041,619

** Estimated totals as of December 8, 2015*
** For WPC, numbers indicate total reach of each social media network (not amount of followers)*

WFOs Social Media Usage: October 1–5 2015

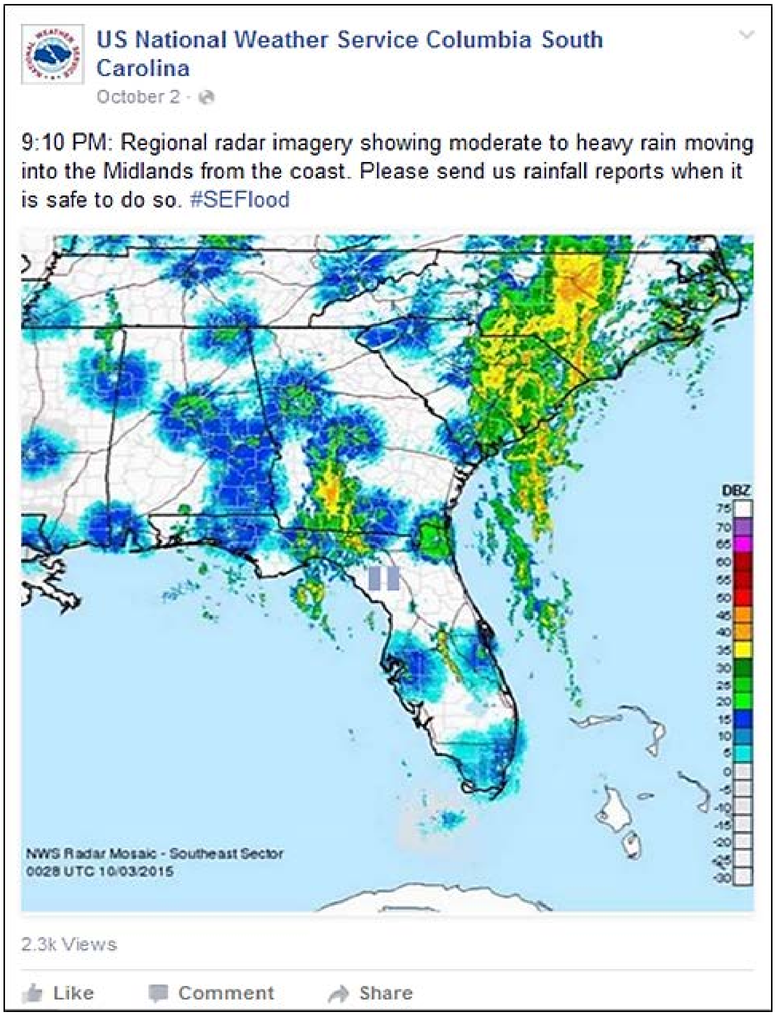
The following is a summary of the social media outreach by each WFO within the area of interest during the flooding event.

WFO Columbia: Facebook

- Two posts during the event (32 and 37 likes respectively, with 25 and 99 shares, and 2,300 and 16,000 views).
- Both posts were radar animations/videos.
- Most comments on their posts were from users who were sharing current conditions in their viewing area and users providing local rainfall totals.

User Engagement

- There were some users who doubted the severity of the storm on the WFO's Facebook page based on current conditions. One user posted that the storm was "not exactly historic."
- WFO Columbia also engaged in limited user engagement with its users during the event.
- **Figure 31** highlights an example of WFO Columbia's user engagement.



Facebook User Commentary:

Person 1: Not exactly Historic. 2 Likes (posted on 10/3/2015 @ 1:15 PM.)
Person 2: Do you know around what time this evening we can expect the rain back? (posted on 10/3/15 @ 1:15 PM).
Response from WFO Columbia: We expect the rain to come back into the Columbia area later this afternoon. A couple of hours (posted on 10/3/15 @ 2:23 PM).

Figure 31: An example of user engagement from WFO Columbia. *Source: WFO Columbia, SC, Facebook page*

WFO Columbia: Twitter

- WFO Columbia posted 85 total tweets during the event.
- Most tweets were original tweets from the WFO providing updates on the hazardous weather.
- There were also tweets that WFO Columbia re-tweeted from NWS and other organizations such as:
  - o South Carolina EM Division
  - o NWS Hanford

- Broadcast Meteorologist
- Midlands Wx
- Public users
- Local news stations

- User engagement was limited between Twitter users and the WFO.
- The WFOs most popular tweet had 448 re-tweets and 216 likes.
- The WFOs most popular re-tweet was from NWS Eastern Region with 293 re-tweets and 124 likes.

WFO Charleston: Facebook

- WFO Charleston posted four posts during the event.
- Its most popular post received 118 likes, 188 shares, and 18,000 views.
- Three of its posts were videos.
- One was an image.

User Engagement

- User engagement included users expressing concern for other users, comments urging users to stay safe, and users offering support to those who were adversely impacted.
- Majority of the comments were users discussing conditions at their home and sharing personal pictures demonstrating how they are being impacted.
- There were also debates occurring between users in the comments sections of the posts. One specific comment was a user doubting the impact of the flooding and heavy rainfall in the affected area. These comments were deleted and other users engaged in conversation dispelling this Internet troll.

WFO Charleston: Twitter

- WFO Charleston posted 174 tweets during the event.
- Most tweets were original tweets from the WFO providing updates on the weather situation.
- Charleston also re-tweeted tweets from NWS and other organizations such as:
    - NHC
    - NWS
    - Ready.gov
    - Broadcast meteorologists
    - Public users
    - Print media organizations
    - FEMA
    - South Carolina Electric and Gas
    - Charleston County
    - South Carolina EM Division
    - Local police departments
    - Storm chasers
    - NWS Eastern Region

- Private weather companies
- USGS
- Broadcast journalists
- Charleston Airport
- Local counties
- South Carolina DOT

- There was limited user engagement between Twitter users and the WFO.
- The WFO’s most popular tweet had 178 re-tweets and 43 likes.
- The WFO’s most popular re-tweet was from FEMA with 390 re-tweets and 175 likes.

WFO Greenville-Spartanburg (GSP): Facebook

- WFO GSP posted two photos during the event: 11 and 9 likes respectively, with 1 and 3 shares respectively.
- Both were photos uploaded to the album titled “Hazardous Weather.”
- Both were images of the hazardous weather outlook.

Figures 32 and 33 demonstrate how these images appeared in users’ news feeds.

Finding 26: WFO GSP posted images into a photo album on its Facebook page instead of directly to its wall. This resulted in users seeing comments that were not directly related to the event.

Recommendation 26: WFOs should post images directly to their Facebook wall and not in photo albums on their page.

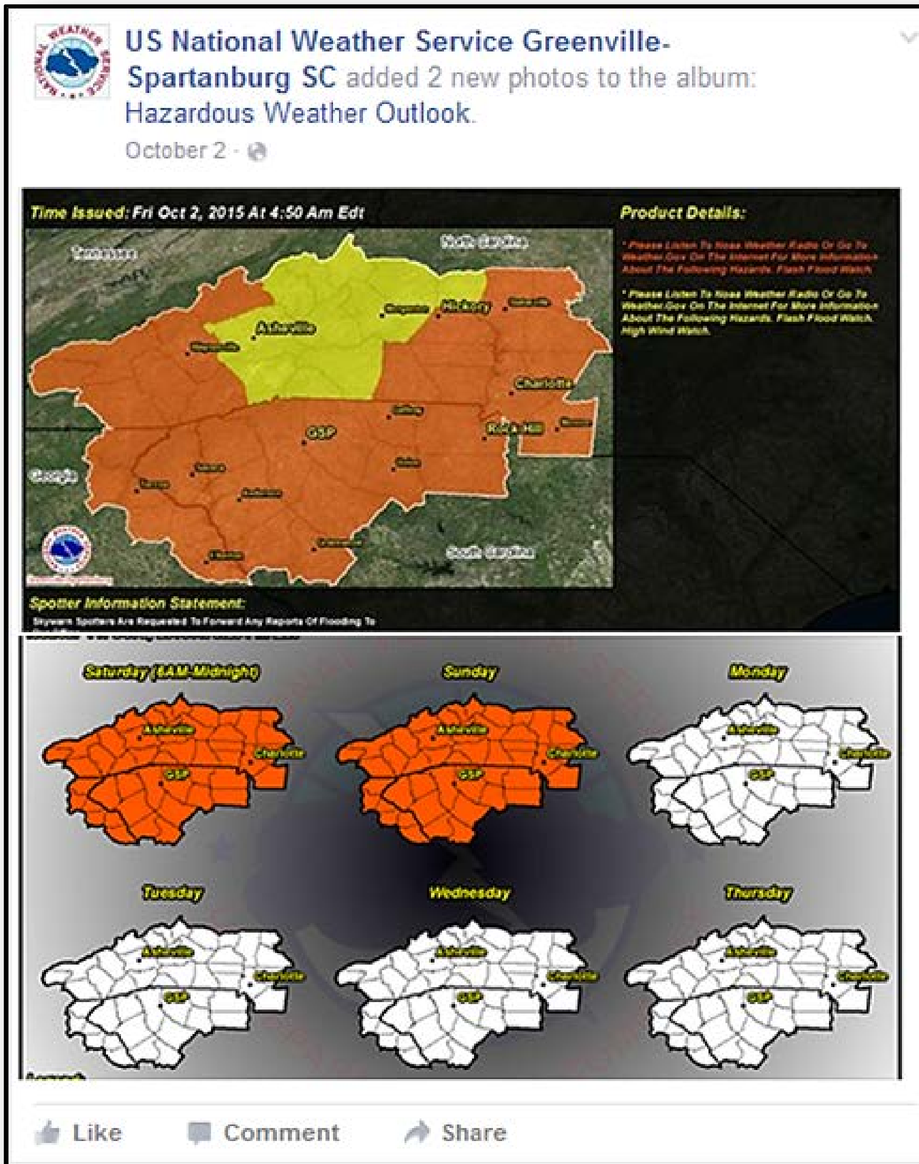


Figure 32: Confusion surrounding location of Facebook posts. *Source: WFO Greenville-Spartanburg, SC, Facebook page.*

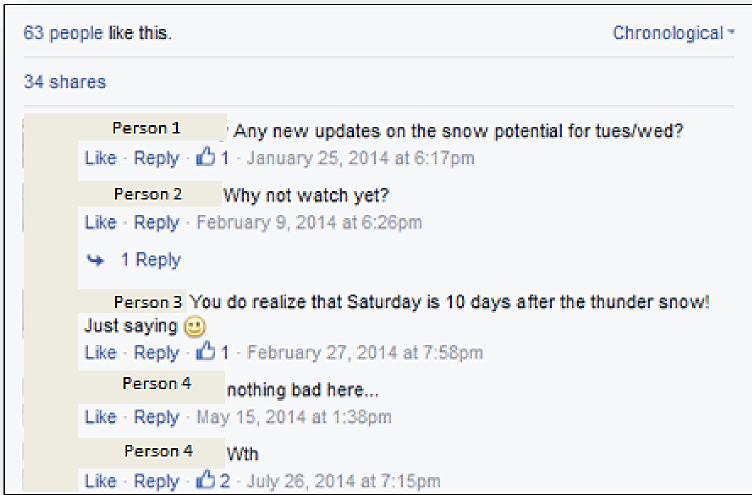


Figure 33: Confusion surrounding location of Facebook posts. *Source: WFO Greenville-Spartanburg, SC, Facebook page*

WFO Greenville/Spartanburg: Twitter

- GSP posted 89 tweets during the event.
- Most tweets were original tweets from the WFO providing updates on the hazardous weather and directing users to more sources of information and additional resources.
- There were also re-tweets from other Twitter users such as:
  - SCEMD
  - Broadcast meteorologists
  - Anderson County EMA
  - Anderson Sheriff
  - FEMA
  - NWS
  - WFO Columbia
  - WFO Charleston
- There was limited user engagement between Twitter users and the WFO.
- The WFO’s most popular tweet had 165 re-tweets and 59 likes.
- Its most popular re-tweet from another organization was from SCEMD with 124 re-tweets and 36 likes.

WFO Wilmington: Facebook

- Four posts during the event.
- Posts consisted of radar loops and CEMs.

User Feedback:

- Visitor wall posts consisted of users questioning the accuracy of forecast information and asking questions of what to expect with the storm.
- There are also a few comments associated with the dangers of driving/travel.
- October 4 and 5, WFO Wilmington wall posts primarily focused on users sharing rainfall amounts and posting videos of flooded yards and neighborhoods.
- October 5, Facebook comments offer kudos to WCM Steve Pfaff and the WFO staff for a job well done.

WFO Wilmington: Twitter

- WFO Wilmington had 30 posts during the event.
- Twitter posts focus primarily on rainfall amounts, river flood levels, and the dangers of driving through flooded roadways.
- All associated watch, warning, and advisory language was posted.
- The WFO only re-tweeted two items during the event. One was a post from SCEMD, and the other was from a Myrtle Beach-based broadcast meteorologist.

3.4. Systems

3.4.1. AWIPS

On September 28, the NWS Network Control Facility (NCF) installed an AWIPS security patch at the SERFC. Although this patch was coordinated 2 days prior, the SERFC was busy with flood operations and expressed concerns about the potential risk of adverse impacts from the installation of the patch. On the day of the patch install, the SERFC had the impression a further delay was not an option. As a result, the patch was installed and the SERFC spent many hours verifying data transfer scripts remained operational. This distracted the staff from river forecasting duties. It was noted that a Critical Weather Day had not been declared on September 28.

Finding 27: SERFC employees need to know how to request a Critical Weather Day declaration to protect mission essential operations from non-essential software updates.

Recommendation 27: Procedures from Directive 10-2203, *Critical Weather Day*, with regard to the Critical Weather Day purpose, coordination, communication, requisition, and its declaration should be re-emphasized to the field.

Precipitation accumulation products with a default maximum of 15 inches were quickly exceeded in the event. When these values were subsequently raised to 25 inches (the max allowable) by the WFOs, the changes did not take effect in AWIPS. During the event, the ER ROC had instructed NCF to look into this problem.

Finding 28: The precipitation accumulation products did not properly display the accumulated rainfall amounts in AWIPS.

Recommendation 28: Precipitation accumulation products scales, which are defaulted to 15 inches, should be configurable to show at least 25 inches.

3.4.2. Bandwidth

3.4.3. WSR-88D (Weather Surveillance Radar 88 Doppler)

WFO Columbia's radar suffers from beam blockages which may be a combination of both trees and man made obstructions. The NWS may need to consider a more costly structural upgrade such as relocating or raising the radome.

WFO Greenville-Spartanburg's radar also suffers beam blockage, with the most likely contribution from surrounding terrain. This impediment is addressed by the office working extensively to identify and bring rainfall data from the various cooperative observers in its HSA.

The connection to the WFO Charleston radar was briefly lost, but the connectivity was restored using the recently installed high-speed backup connection to the radar. The communications back up capability that was delivered is automated such that it was "transparent" to operations resulting in virtually no loss in data. This valuable installation resulted from the implementation of Finding 4 of the NOAA NWS Operations and Services during Historic Tornado Outbreaks of April 2011. Finding 4 stated NWS should ensure alternative methods of data delivery to the WFOs from all remote radars.

WFO Wilmington's radar is significantly blocked by trees along many radials, most extremely along the heavily populated Grand Strand Myrtle Beach area **(Figure 34)**. A contract has been awarded for a site survey of the Wilmington radar to help determine appropriate tree blockage mitigation options.

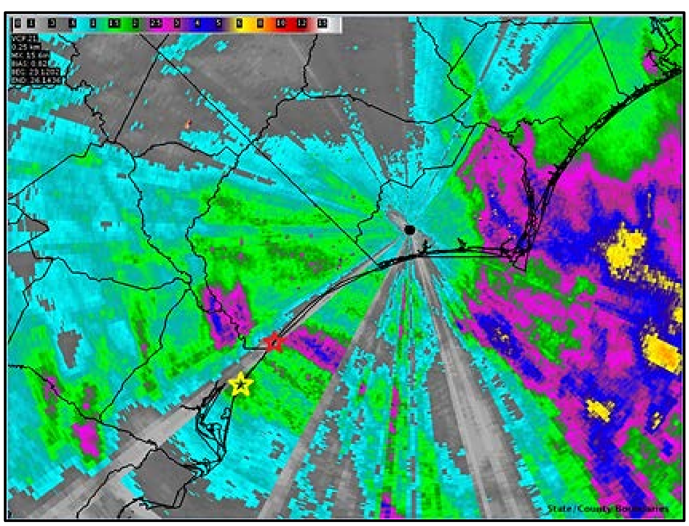


Figure 34: WFO Wilmington radar: red star: Myrtle Beach, SC; yellow star: Georgetown, SC. *Source: WFO Wilmington, NC*

In the case of Columbia and Greenville-Spartanburg offices, the ROC is currently working on an engineering assessment to determine appropriate mitigation options.

Finding 29: WFOs Columbia, Greenville-Spartanburg, and Wilmington all suffer from beam blockage due to nearby obstructions. This blockage resulted in degradation of radar precipitation estimates during the flood event. The beam blockage issue was mentioned by many broadcast partners as a hindrance to analysis and to their situational awareness of flooding in certain areas.

Recommendation 29: The Radar Operations Center needs to expedite a solution to the significant radar beam blockage issues.

3.4.4. Other Bandwidth

While NWS Internet accessibility and reliability has improved over the years, services periodically went down at the SERFC during the event. In one particular outage, SERFC lost Internet connectivity 10 minutes prior to a DSS webinar briefing.

Finding 30: Internet service outages occurred that negatively impacted and limited NWS DSS capabilities at the SERFC.

Recommendation 30: Internet accessibility and reliability continues to need enhancement at WFOs.

3.4.5. Communications Outages

There were Verizon issues at WFOs Charleston and Columbia during the event. At WFO Charleston, voice over Internet Protocol phones (VoIP) stopped working when the T1 line went down during the height of the event Saturday night. Verizon staff had accidentally cut a line and the network became oversaturated on the available service lines. The WFO Charleston staff communicated using AWIPS administrative messages (ADM), office cell phones, personal cell phones, chat rooms and social media. WFO Columbia phone lines were also impacted by down lines, cutting off incoming phone calls for a number of hours. Although some of the services were restored, the phone service continued to be degraded until the WFO Columbia Electronic Systems Analyst (ESA) worked with Verizon to restore the office's service to full/unlimited access circuitry. The ESA found Verizon had incorrectly put WFO Columbia onto a limited access line during the VoIP upgrade and learned this mistake was being repeated at other WFOs undergoing similar upgrades.

Finding 31: Because Verizon placed the WFOs into a VoIP plan with a limited access line, calls to and from the office can be dropped when available Verizon service lines are oversaturated.

Recommendation 31: After VoIP upgrades, ESAs should check to ensure their respective WFOs are on the correct VoIP plan.

3.5. Training

The SERFC staff hydrologist deployed to FEMA Region IV headquarters in Atlanta conducted numerous interviews and briefings during the event. The deployed SERFC forecaster also passed on dam break notifications to affected WFOs and SERFC as the notifications were received from FEMA, and flash flood warnings to FEMA from the NWS as they became available. The SERFC employee coordinated talking points between the Regional and National Operation Centers and the National NOAA FEMA Liaison.

Finding 32: Because the SERFC staff member deployed to FEMA Region IV Center did not have prior Incident Command System (ICS) Training specific to Region IV, this person initially had difficulty understanding the NWS role and how to integrate into the ICS in that setting.

Recommendation 32: The NWS should expedite the existing goal of ICS training for meteorologists and hydrologists. Likewise, the NWS should expedite the development of a cadre of Emergency Response Specialists (ERS) experienced in various disciplines such as hydrologic and water resources issues, who have taken appropriate FEMA preparatory coursework and ERS training.

WFOs emphasized the effectiveness of training related to extreme weather. Staff found the Advanced Warning Operations Course (AWOC) flash flood training to be particularly effective. At the time of the South Carolina floods, completions of AWOC flash flood training included a WES-1 simulation of a flash flood case. As a result, staff members felt they were better prepared for operations during riverine and flash floods.

Best Practice: WFO managers identified a need for AWOC flash flood and river flood training. This training helped prepare staff for flash flooding operations.

WFOs stated they would like more NWS flash and river flood training incorporated into Weather Event Simulator (WES) cases. This need was also identified in The Front Range and Eastern Colorado Floods of September 11–17, 2013, Service Assessment Finding 24. The Warning Decision Training Division has developed two simulation packages that meet these requests, based on one event that exhibited both flash and riverine flooding. The full, five-day simulation package focuses on how to effectively use AWIPS-2 Hydro Applications for improved decision-making during river flooding. The flash flood portion of the event was highlighted as part of the FY16 Warning Operations Course flash flood training, focusing on applying the learning objectives from the CLC course material to operational practices. Taking these two simulations in tandem covers the spectrum of flash to river flooding. Simulation materials have been made available to all offices with a WES-2 Bridge machine.
The SA team thinks WFO managers and training officers should have their staff practice riverine and flash flood operations routinely using WES-2 Bridge simulations, including events that allow forecasters to practice both skill sets.

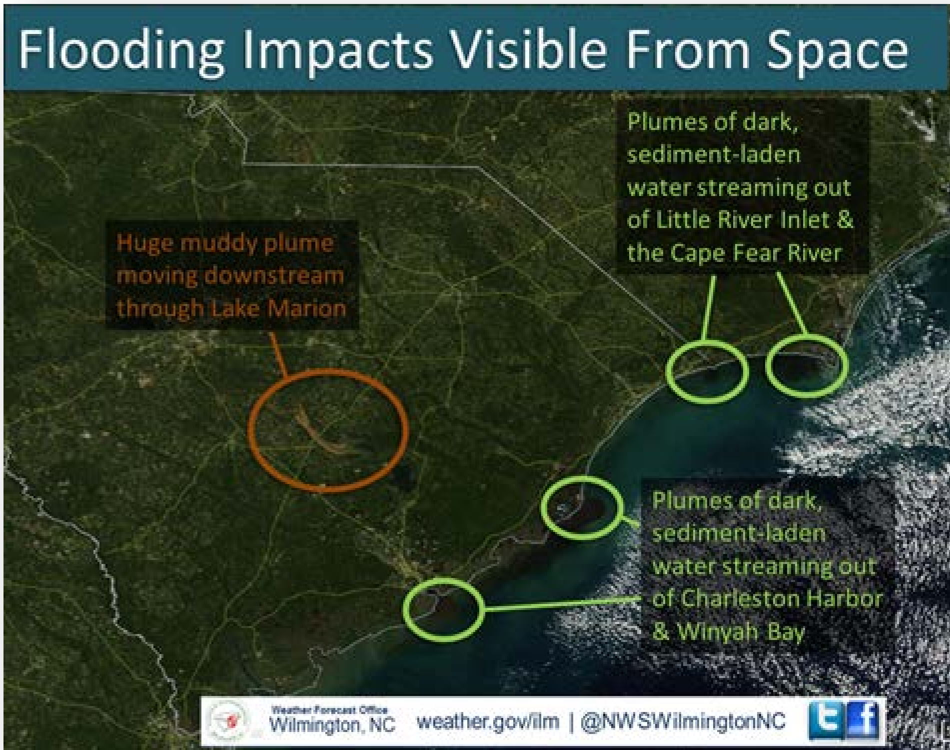


Figure 35: Sediment plumes visible from space. *Sources: NASA, with annotations by WFO Wilmington, NC*

Some of the WFOs were aware of satellite products and imagery that could be useful for impact decision support, but most WFOs have not integrated that information into their DSS briefing and outreach. During its outreach, WFO Wilmington provided an imagery of rivers laden by sediment (**Figure 35**). EMs found this information helpful to identify not only where the river plume is but also to understand the potential of water quality issues, but also where rivers are being choked by sediment flow and its riverbanks have eroded.

Finding 33: Local EMs would like to know when streams have eroded, become clogged with debris, and quality degraded.

Recommendation 33: Provide training on how this NASA product could enhance NWS operations in identifying sediment plumes observable via NASA satellite.

4. Societal Impacts: Facts, Findings, and Recommendations

The social science analysis provides a 3-part guide to understand responses to NWS activities before, during, and after the flooding.

- Part 1: The significant issue of residents continuing to drive through flooded roadways, not only risking their lives, but also the lives of emergency responders.
- Part 2: The significant issue of residents not understanding the impact of hazardous weather through NWS products and services.
- Part 3: Communication Plans: Full range of the communication process (risk and crisis).

The role of the NWS and the implications for societal impacts are critical. EMs, media representatives such as broadcast meteorologists, local law enforcement, community leaders, and the public and other officials all play a vital role. The relationships between the NWS and end users are also highlighted.

4.1. Societal Impacts: Driving through Flooded Roadways

Flooded roadways are a continual challenge associated with areal and flash flooding events. A majority of flood-related fatalities occur because people drive through floodwaters rather than avoiding them. The public has little to no awareness of the power of moving water and its ability to overtake motor vehicles easily. A significant number of fatalities related to this event were related to vehicles swept away by flood waters. Of the 19 deaths, 8 occurred because someone drove a motor vehicle through flooded roadways.

As referenced in the EM section of this report, EMs are at a loss on how to mediate the issue of fatalities attributed to people driving through floodwaters. Barricades erected by EMs to prevent access to flooded roadways are frequently ignored. There were reports of motorists driving through barricades even though there was an official directing traffic away from a flooded area. Such behavior creates a challenging public safety threat. EMs try to educate the public on the dangers of this practice. The average automobile can be swept off the road in 12 inches of moving water, and roads covered by water are prone to collapse. Attempting to drive through water may also stall the engine, which could lead to further risk of life. Most EMs did not know the U.S. DOT will provide "Turn Around Don't Drown" road signs to enhance safety messaging.

Many EMs feel a media outreach campaign, including a Public Service Announcement (PSA), would be helpful to educate the public on this hazard. Suggestions for the content of a PSA were diverse. Some EMs felt that a more grim and shocking message on the risk of life is warranted to scare people into making a sound decision. Other EMs felt that a more positive message, such as a family encountering a flooded roadway and driving away (i.e., a happy ending) would have a more positive impact. Overall, EMs felt a significant segment of the population will continue this dangerous practice regardless of the level of outreach and messaging.

Finding 34: Social scientific research is needed to determine an effective outreach strategy with effective Public Service Announcement (PSA) content designed to minimize the dangerous practice of motorists driving through flooded roadways.

Recommendation 34: NWS should work with social scientists to provide behavior-based statements and videos to demonstrate the results of not following the "Turn Around Don't Drown" slogan.

4.2. Societal Impacts: Misunderstanding of NWS Products and Services

A majority of the interviewed public felt aware of the critical elements that made up the storm. There was a realization that Hurricane Joaquin was only part of the overall meteorological picture. On nearly all accounts, the public reported that they felt prepared for the storm. While there was little reported awareness or use of NWS products, citizens were able to obtain information they felt was meaningful and appropriate to survive the storm event. There were clear instances of NWS products in use but lack of awareness of the information source. Interviewees indicated they received phone/text alerts and they understood the content contained within these alerts. Facebook was another critical resource to individuals and communities. Families within discrete neighborhoods used Facebook as a communication platform to share weather information before, during, and after the event.

Despite multiple means of communication, many citizens were not prepared. Many people did not know what 20 inches of rain looked like in their area. A majority of those interviewed knew the area would have a historic flood, but most did not understand the impacts of the flood. WFO Wilmington specifically mentioned there is a need to work with social scientists on simplifying flooding products for the public. Local SHs should work with WCMs, social scientists, local EMs, and Service Coordination Hydrologists to create impact-based graphics and statements demonstrating the effect of specific flood hazards in reference to specific U.S. geographic regions. This need was also stated in the Record Front Range and Eastern Colorado Floods of September 11–17, 2013, Service Assessment Finding #9.

Finding 35: Most public respondents interviewed had never visited NWS web pages or NWS social media outlets.

Recommendation 35a: The NWS should work with marketing specialists to bring more awareness to NWS web pages and NWS social media outlets.

Recommendation 35b: The NWS should work with social media outlets to push life-threatening alerts to social media users via zip codes in the threatened areas.

4.3. Communication Plans: Full range of the communication process

Even though the WFOs did an excellent job forecasting this event, the WFOs were unable to convey to the public the full extent of the risk. When the forecast called for 20 plus inches of rain, residents could not comprehend what this meant specifically to them because they lacked a point of reference to compare with this event or a way to visualize it. For effective communication to occur among the NWS, its partners, and the public, transactional two-way communication must be deployed as a means not only for developing messages but also in disseminating these messages. This process involves incorporating the principles of effective risk and crisis communication before or early in the event of hazardous weather.

Finding 36: Information shared from WFOs directly to the public did not convey the full extent of risk.

Recommendation 36: Expedite the publication of risk communication guidance and mitigation information from NOAA social scientists.

It is important to note that not all users receive information from digital information sources. Low-tech forms of communications are still a critical component to communicating risk to the broader public. While the public heavily relies on social and broadcast media sources, there is still a need for simpler methods of communication. For example, in one rural South Carolina community, the EM Director put up flyers in neighborhoods to build awareness that a major storm event was pending. NWS can aid in this process by ensuring communications are clear and succinct, using plain language, allowing EMs to repurpose content for such purposes with minimally modification.

Fact: Portions of the American public do not have access to cell phones and broadcast media (television, radio) for weather-related information.

5. Interagency Coordination/Collaboration

5.1. USGS

There are streams/rivers in the southern part of South Carolina that are not monitored by USGS streamflow monitoring stations. Because of these gaps in the streamflow monitoring network, USGS deployed Rapid Deployment Gages (RDG) as part of a FEMA Mission Assignment, October 9–10, to provide additional, short-term monitoring. The SERFC helped USGS identify optimal locations for deploying the gages, which helped with timing of the flood wave as it progressed downstream. The NWS should work with USGS to identify and secure potential funding sources to expand the streamflow monitoring network (i.e., the USGS National Streamflow Information Program) to address these observational gaps, as noted in other service assessments.

Throughout the event, the USGS South Atlantic Water Science Center-South Carolina closely collaborated with the NWS by sending critical river measurements at key locations. The USGS used the latest NWS forecasts to help schedule crew deployments to verify these measurements **(Figure 36)**. The USGS was also asked to adjust and extended the stage-discharge rating curves for this event as soon as the high-flow measurements were made. USGS used Acoustic Doppler Current Profilers to measure streamflow, profile velocities and establish stage-discharge relationships for the rating curves.

Best Practice: There was open communication between the WFOs and the USGS during the event. USGS staff promptly answered streamflow monitoring station questions or requests from the WFOs, enabling them to more accurately and efficiently provide critical products to the public and EMs.

Figure 36: USGS personnel measuring streamflow in Conway, SC. *Source: USGS*

5.2. FEMA Region IV

FEMA requested NWS on-site IDSS for this event. The main mission was to provide situational awareness briefings for FEMA Region IV so its staff could make informed decisions about flood response efforts. Secondary to the main mission, was to keep FEMA senior leadership situationally aware as the flood progressed. FEMA noted there were inconsistencies between WFOs with regard to hydrologic products used to communicate the flood threat, related to IDSS services and their formats. These inconsistencies made it challenging to maintain situation awareness throughout the event.

Finding 37: FEMA Region IV was appreciative of on-site IDSS, but noted hydrologic service and product inconsistencies amongst the WFOs.

Recommendation 37: The NWS should expedite the progress toward a baseline for IDSS services and define those hydrologic products required by FEMA through Hazard Simplification.

Due to the initial focus on Hurricane Joaquin, FEMA Region IV did not initially request hydrology support. As the event focus transferred from a hurricane to a flood threat, the SR-ROC advocated sending a hydrologist for support. As a result, a SERFC hydrologist was deployed to FEMA Region IV. FEMA affirmed deploying a hydrologist to FEMA Region IV for this historic flood event was a good decision.

Best Practice: From the FEMA perspective, the most beneficial DSS were the weather and flood conference calls, and briefings to state EM agencies. On-site DSS ensured there was a unified voice from the national FEMA and the NWS perspective.

Because of initial NWS briefings, FEMA was able to redirect its efforts from hurricane to flood response early in the event. FEMA personnel confirmed that the NWS should have a cadre of qualified personnel for this on-site DSS. FEMA affirmed the deployment cadre needs to be trained and have strong interpersonal and communication skills. FEMA recognizes that exercises, meetings, and preparedness efforts are important in developing and refining these personal relationships and interactions.

FEMA noted there were too many hydrologic products (i.e., coastal, flash flood, or river flooding) to keep track off and that these products should be streamlined to one flood product focused on impacts. Finding 22 in Section 3.2.5 (Flash Flood Emergency) of this document addresses the need for the NWS to investigate streamlining its hydrologic products via hazard simplification.

FEMA stated that its stakeholders did not know the significance of what minor, moderate, or major flood means. For its stakeholders-to take appropriate action, they would need to know specific impacts (i.e., How many houses are going to be impacted? What roads are going to be closed?). In addition, its stakeholders do not understand "*whether 15 inches of rain would mean 15 inches of flood water on their property (door step*)." This need was also stated in the Record

Front Range and Eastern Colorado Floods of September 11–17, 2013, Service Assessment Finding #9.

Finding 38: FEMA and other response officials need NWS services to be impact-based to take appropriate action.

Recommendation 38a: The NWS should continue to move its services towards being impact-driven and based through the development of the Impacts Catalog.

Recommendation 38b: NWS should expedite the development of an Impacts Catalog and increase impact information contained in the WFO Hydrologic Forecast System and associated services.

Finding 39: Flood inundation maps were generally not used because they weren't available. FEMA Region IV stated that inundation maps for every gaged river would be useful.

Recommendation 39: NWS should expedite the development of additional AHPS flood maps cooperatively with FEMA.

5.3. SCEMD

The SCEMD indicated before the event they did not need a NWS liaison at the state EOC but if offered this option they would have accepted. In retrospect, they thought a liaison would have been beneficial. An example was the scheduling of the different WFO driven conference calls. Having a liaison at the state EOC might have helped with this effort. WFOs should work with the EM community to become fully integrated in the nomenclature and structure. This knowledge ultimately helps to facilitate more effectively the flow of communication with respect to conference call/webinars, etc. NOAA NWS Operations and Service Assessment during Hurricane Irene in August 2011's Finding 12, states *"...NOAA/NWS should develop a protocol for building, sustaining, and evaluating working relationships among embedded meteorologists/NWS liaisons, WFOs, and RFCs."*

5.4. South Carolina Local EMA

The EM community thought the strong working relationship with WFOs helped the flow of information. The NWS was viewed as the authority and source of information. One EM referred to messaging from the WFO as "gospel."

Best Practice: NWS should continue to foster strong relationships with its stakeholders through regular engagement and communications. This contact could include educational outreach, drill exercises, Local Emergency Planning Committee meetings, and other partnership opportunities.

Some EMs were looking at river conditions outside their county to determine conditions of their ungaged river because of the lack of river gages in their county. They did not know the USGS could deploy RDGs in real time.

As stated in Section 6.1 (USGS), WFOs should examine river gage needs in partnership with the SERFC and USGS to facilitate more effective river forecasting for communities impacted by river flooding.

A growing trend in the NWS is to establish Integrated Warning Teams (IWT) to strengthen the existing relationships between NWS, EMs, media and other government agencies. Coordination, communication, and service issues can be addressed in this model to formulate and align common goals.

Finding 40: Several EM county directors indicated they were not aware of the IWT concept.

Recommendation 40: The NWS should increase awareness of the IWT concept with core partners and conduct IWT workshops to strategically harness the existing relationships.

Inundation maps generated by WFO Wilmington were useful to Williamsburg County EMA for mitigation planning purposes related to the Black and Santee rivers. This information allowed the EM and county officials to strategically evacuate citizens impacted by the expected river levels. While this capability to produce real-time inundation maps is limited, these maps proved to be critically helpful for the EMA to target areas for evacuation. A representative of FEMA Region IV expressed the need for inundation mapping services. This need is also stated in Section 3.1.1 (Weather Forecast Offices) Finding 5, of this document.

5.5. Media

Working with the Media

The team interviewed 11 broadcast meteorologists from four media market areas: Greenville-Spartanburg, Columbia, Charleston, and Myrtle Beach. The interviews focused on communication with NWS, the NWS products, and suggestions for improvement.

The Charleston media commented that its WFO provides workshops to media and EMs every year to discuss and demonstrate new products and available services. These workshops helped media and EMs understand the NWS services and products available during the flood and assisted these users in their decision-making processes. WFOs Greenville-Spartanburg and Charleston have an outreach team approach to building relationships with media partners so it is not just a WCM duty. Media partners knew forecast staff members on a first name basis and were in frequent communication, demonstrating an excellent relationship between the WFOs and the media.

All four media markets mentioned there was no confusion due to messaging over Joaquin in their media markets. One broadcast meteorologist mentioned this was an issue in the national media, not the local media.

Impact emails issued by WFO Greenville-Spartanburg garnered multiple communications of praise from media partners. One broadcast meteorologist emphasized that these emails were “FANTASTIC.”

A media partner stated that the information provided by the SH for non-AHPS river locations via the NWS chat room was very useful. This partner felt it would have been more beneficial if this non-routine forecast was distributed more broadly to other partners outside the NWS chat room.

NWSChat is a tool consistently used by NWS partners. WFOs provided constant communication and information via NWSChat, which was invaluable and highly regarded by the partners.

Appendix A: Acronyms

ACE	Ashley-Combahee-Edisto (estuarine basin)
ADM	AWIPS Administrative Message
AFS	Analyze, Forecast and Support Office
AHPS	Advanced Hydrologic Prediction System
AWIPS	Advanced Weather Interactive Processing System
AWOC	Advanced Warning Operations Course
CMC	Canadian Meteorological Centre
CEM	Civil Emergency Message
CWA	County Warning Area
DOH	Development and Operations Hydrologist
DOT	Department of Transportation
DSS	Decision Support Services
ECM	European Centre models
ECMWF	European Centre for Medium Range Forecasting (model)
EM	Emergency Manager (or Management)
EMA	Emergency Management Agency
EMD	Emergency Management Division
EPS	European Centre Ensemble Prediction System
ERH	Eastern Region Headquarters
ER-ROC	Eastern Region Operations Center
ERS	Emergency Response Specialists
FAR	False Alarm Ratio
FEMA	Federal Emergency Management Agency
GEFS	Global Ensemble Forecast System
GFDL	Geophysical Fluid Dynamics Laboratory
GFS	Global Forecast Systems model
GFSX	Global Forecast System parallel model
HAS	Hydrometeorological Analysis and Support
HSA	Hydrologic Service Area
HWRF	Hurricane Weather Research and Forecasting model
ICS	Incident Command System
ICW	Intra-Coastal Waterways
iNWS	Interactive NWS, mobile weather service delivery
JMA	Japan Meteorological Agency
KCAE	Columbia Metro Airport
KCHS	Charleston International Airport
LST	Local Standard Time
MIC	Meteorologist in Charge
MMEFS	Meteorological Models Ensemble Forecast System
NAM	North American Mesoscale Forecast System
NASA	National Aeronautics and Space Administration
NAVGEM	Naval Research Laboratory Monterey
NCEP	National Centers for Environmental Prediction

NCF	Network Control Facility
NHC	National Hurricane Center
NOAA	National Oceanic and Atmospheric Administration
NWP	Numerical Weather Prediction
NWR	NOAA Weather Radio All Hazards
NWS	National Weather Service
NWSH	National Weather Service Headquarters
QPE	Quantitative Precipitation Estimate
QPF	Quantitative Precipitation Forecast
RDG	Rapid Deployment Streamflow Gages
RFC	River Forecast Center
ROC	Regional Operations Center
SCEMD	South Caroline Emergency Management Division
SERFC	Southeast River Forecast Center
SH	Service Hydrologist
SR-ROC	Southern Region (Regional) Operations Center
SOO	Science and Operations Officer
UKMET	United Kingdom Meteorological (weather forecast model/office)
USGS	United States Geological Survey
UTC	Coordinated Universal Time
VoIP	Voice Over Internet Protocol
WCM	Warning Coordination Meteorologist
WEA	Wireless Emergency Alerts
WES	Weather Event Simulator
WFO	Weather Forecast Office
WPC	Weather Prediction Center
WRF	Weather Research and Forecasting model
WSR-88D	Weather Surveillance Radar 88 Doppler

Appendix B: Findings, Recommendations, & Best Practices

Definitions

Best Practice: An activity or procedure that 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.

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 on an associated finding. Not all recommendations may be achievable but they are important to document. If the affected office(s) and AFS determine a recommendation will likely improve NWS operations and services, and it is achievable, the recommendation will likely become an action. Recommendations should be clear, specific, and measurable.

Findings, Recommendations

Finding 1: Staffing shortages at WFO Columbia caused extra challenges in the office's ability to deliver operational services and DSS.

Recommendation 1: The NWS needs to continue to work with WFMO/OPM to process and fill NWS vacancies expeditiously.

Finding 2: During the floods, there were 36 dam failures across South Carolina. Some of these failures had posed a threat to life and property.

Recommendation 2: If a dam break poses a severe threat to human life or catastrophic damage, the WFO, in coordination with the EM, should issue a flash flood emergency for more effective communication to the public.

Finding 3: It was challenging for NWS forecasters to understand when to transition from one flood product to another (e.g., when to transition from a flash flood watch/warning to areal flood warning—especially for this magnitude of a storm).

Recommendation 3: With the help of social scientists, the NWS should revise NWS Instruction 10-922 to provide simplified criteria for issuing a flash flood warning, areal flood warning, and urban small stream flood advisory. Additionally, forecasters should be trained on these revised products, as well as best practices for transitioning between products.

Finding 4: EMs and dam operators commented that additional hydrologic forecasts beyond the deterministic river forecasts would have helped determine the range of severity for the pending event.

Recommendation 4: RFCs should provide additional probabilistic information to complement the deterministic forecasts routinely for all forecast points.

Finding 5: Some FEMA flood maps, which would have been useful to understand the extent and magnitude of flooding, were unavailable on AHPS, due to outdated or non-existent FEMA studies.

Recommendation 5: The NWS should work with respective state National Flood Insurance Program coordinators to identify flood map deficiencies or areas needing new FEMA Flood Studies.

Finding 6: During the event, WFOs Wilmington and Charleston identified the need for more tide gages and associated forecasts to assess coastal flood conditions.

Recommendation 6: The NWS should work with the National Ocean Service to identify opportunities for installing new tide gages for observations and predictions.

Finding 7: WFOs lacked streamgage observations for key areas in their Hydrologic Service Area (HSA) that had experienced severe flooding.

Recommendation 7: WFOs, with the support of the RFCs, should work with their local USGS office, local officials, and community to identify where additional streamgages are needed.

Finding 8: While WFOs, EMs, and other stakeholders found the USGS Rapid Deployment Gages helpful for providing river level trends during the storm, they could have been more useful if they were tied to a datum to determine the water surface elevation.

Recommendation 8: WFOs should work with their RFCs and USGS to define critical locations to deploy future Rapid Deployment Gages so that they can be pre-surveyed and integrated into NWS operations.

Finding 9: The NWS Damage Assessment toolkit does not have flood attribute fields.

Recommendation 9: The NWS should identify and implement flood attributes within the Damage Assessment toolkit.

Finding 10: During the event, SERFC had two critical vacancies, a HAS forecaster and a Journeyman Hydrologist. These two vacancies added to the complexity of delivering operational services and DSS. Long-term staff shortages had reduced SERFC's ability to develop and implement cutting-edge hydraulic modeling, inundation mapping, and enhance decision support services.

Recommendation 10: The NWS needs to continue to work with WFMO/OPM to process and fill NWS vacancies as expeditiously as possible.

Finding 11: The SERFC was not able to provide downstream guidance because many dams were not in the dam catalog or the information was incorrect.

Recommendation 11: The NWS should develop a means to query information accurately for all dams to ascertain information needed for running NWS dam break tools.

Finding 12: NWS does not provide national Dam Break programmatic or software support to RFCs. RFCs have relied on their own expertise and ingenuity to keep the Simplified Dam Break Model software operational.

Recommendation 12: NWS should develop national program and technical support for the Dam Break flood program. Part of this support should involve modernizing the NWS Dam Break Program and associated software.

Finding 13: Some of the WFOs were not clear whether the ER-ROC was physically being staffed around the clock or not, thus causing some confusion, especially during the overnight hours on NWSChat and 12Planet.

Recommendation 13: ERH should inform the WFOs and corresponding RFCs of the ER-ROC staffing plans on both NWSChat and 12Planet and indicate if/when it is going offline on the NWSChat/12Planet.

Finding 14: Some of the staff at the WFOs and RFCs was unaware of the roles and responsibilities of the Regional ROCs.

Recommendation 14: The Regional ROCs should ensure their role and responsibility is understood by WFOs and RFCs.

Finding 15: WFO Columbia QPF grids were inconsistent with surrounding offices and the WPC until October 2, 2015.

Recommendation 15: The NWS should track and accelerate the development of a visual grid collaboration tool for use between WPC, WFOs, and RFCs to make collaboration more effective and help address spatial inconsistencies.

Finding 16: WFOs would like WPC policy to allow for "High Risk for flash flooding" to be indicated on the Day 2 and 3 Excessive Rainfall Outlooks when there is high certainty.

Recommendation 16: WPC should re-examine the WPC Excessive Rainfall Outlooks to determine whether High Risk for Flash Flooding should be noted on Day 2 and/or Day 3 products when there is high certainty.

Finding 17: Some of the media and public officials incorrectly called this a 1,000-year flood.

Recommendation 17: The NWS should work closely with USGS and behavioral scientists to help the public better understand the recurrence intervals for precipitation and floods.

Finding 18: NWS educational materials are not understood by a diverse population (i.e., specific age ranges and education levels).

Recommendation 18: NWS educational materials need to be in a format that can be understood by a diverse population.

Finding 19: The SCEMD requested state-scaled products (i.e., forecast precipitation maps). These products would help provide a broad-based picture to facilitate more effective operations.

Recommendation 19: Explore capabilities of standardized and baseline tools to create standardized state level maps depicting various parameters such as precipitation forecasts. These maps potentially could be generated by an automated process that pulls from the gridded forecast.

Finding 20: A majority of the county EM directors were not aware of the “Turn Around Don’t Drown” DOT signs for use in their county.

Recommendation 20: WFOs should communicate to EM directors the availability of the DOT signs as another tool to alert the public during high water events.

Finding 21: Not all EMs readily used iNWS to receive automatic notification when NWS issued products.

Recommendation 21: WFOs should provide outreach and education on the benefits of iNWS, emphasizing it as a key tool for notifications, watches, and warnings.

Finding 22: The public, media partners, and EMs were confused by the many types and the quantity of watches/warnings WFOs issued.

Recommendation 22: The NWS should review hydrologic products described in 10-922 and determine if the suite of flood products can be condensed, revise this directive, and provide training to forecasters on the revised 10-922, especially concerning when and how to use specific hydrologic warning products.

Finding 23: The public expressed some confusion or misunderstanding about the meaning of CEMs received on cell phones via WEA.

Recommendation 23: CEMs and other cell phone automated government dissemination products should have a link directing the user to further text explanation of the product alert.

Finding 24: WFO staff said local storm reports were a lot of work and very hard to keep up with but helped support the office’s social media presence.

Recommendation 24: The NWS should create a tool to transfer social media posts to local storm reports.

Finding 25: The Service Assessment Team determined different demographic groups (e.g., age specific) use different social media resources (e.g., Twitter, Facebook).

Recommendation 25: Social Scientists need to examine demographic groups and translate this understanding into accessible information in order to reach diverse audiences.

Finding 26: WFO GSP posted images into a photo album on its Facebook page instead of directly to its wall. This resulted in users seeing comments that were not directly related to the event.

Recommendation 26: WFOs should post images directly to their Facebook wall and not in photo albums on their page.

Finding 27: SERFC employees need to know how to request a Critical Weather Day declaration to protect mission essential operations from non-essential software updates.

Recommendation 27: Procedures from Directive 10-2203, *Critical Weather Day*, with regard to the Critical Weather Day purpose, coordination, communication, requisition, and its declaration should be re-emphasized to the field.

Finding 28: The precipitation accumulation products did not properly display the accumulated rainfall amounts in AWIPS.

Recommendation 28: Precipitation accumulation products scales, which are defaulted to 15 inches, should be configurable to show at least 25 inches.

Finding 29: WFOs Columbia, Greenville-Spartanburg, and Wilmington all suffer from beam blockage due to nearby obstructions. This blockage resulted in degradation of radar precipitation estimates during the flood event. The beam blockage issue was mentioned by many broadcast partners as a hindrance to analysis and to their situational awareness of flooding in certain areas.

Recommendation 29: The Radar Operations Center needs to expedite a solution to the significant radar beam blockage issues.

Finding 30: Internet service outages occurred that negatively impacted and limited NWS DSS capabilities at the SERFC.

Recommendation 30: Internet accessibility and reliability continues to need enhancement at WFOs.

Finding 31: Because Verizon placed the WFOs into a VoIP plan with a limited access line, calls to and from the office can be dropped when available Verizon service lines are oversaturated.

Recommendation 31: After VoIP upgrades, ESAs should check to ensure their respective WFOs are on the correct VoIP plan.

Finding 32: Because the SERFC staff member deployed to FEMA Region IV Center did not have prior Incident Command System (ICS) Training specific to Region IV, this person initially had difficulty understanding the NWS role and how to integrate into the ICS in that setting.

Recommendation 32: The NWS should expedite the existing goal of ICS training for meteorologists and hydrologists. Likewise, the NWS should expedite the development of a cadre of Emergency Response Specialists (ERS) experienced in various disciplines such as hydrologic and water resources issues, who have taken appropriate FEMA preparatory coursework and ERS training.

Finding 33: Local EMs would like to know when streams have eroded, become clogged with debris, and quality degraded.

Recommendation 33: Provide training on how this NASA product could enhance NWS operations in identifying sediment plumes observable via NASA satellite.

Finding 34: Social scientific research is needed to determine an effective outreach strategy with effective Public Service Announcement (PSA) content designed to minimize the dangerous practice of motorists driving through flooded roadways.

Recommendation 34: NWS should work with social scientists to provide behavior-based statements and videos to demonstrate the results of not following the "Turn Around Don't Drown" slogan.

Finding 35: Most public respondents interviewed had never visited NWS web pages or NWS social media outlets.

Recommendation 35a: The NWS should work with marketing specialists to bring more awareness to NWS web pages and NWS social media outlets.

Recommendation 35b: The NWS should work with social media outlets to push life-threatening alerts to social media users via zip codes in the threatened areas.

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Recommendation 37: The NWS should expedite the progress toward a baseline for IDSS services and define those hydrologic products required by FEMA through Hazard Simplification.

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Recommendation 39: NWS should expedite the development of additional AHPS flood maps cooperatively with FEMA.

Finding 40: Several EM county directors indicated they were not aware of the IWT concept.

Recommendation 40: The NWS should increase awareness of the IWT concept with core partners and conduct IWT workshops to strategically harness the existing relationships.

Best Practices

Best Practice: The WFOs DSS/PowerPoint and briefing packages (with proactive messaging on the hurricane threat transitioning to extreme flooding, summary of daily flood forecasts, and river flood assessments) were highly effective in communicating the severity of the floods.

Best Practice: Use of Skype for national media interviews is highly effective.

Best Practice: WFOs developed a robust interactive "storybook" of the flood event to show the threats and impacts to the affected areas.

Best Practice: Holding annual media and EM workshops at respective WFOs has proven to be an exceptional way to build relationships and rapport with the media, government officials, municipalities, and the private sector.

Best Practice: The SERFC deployed a staff hydrologist to FEMA Region IV Headquarters, which provided a variety of relevant information to FEMA and other federal agencies, such as the U.S. Coast Guard and the U.S. DOT. FEMA and other partner agency personnel reported the NWS deployment was beneficial to their operations during the event.

Best Practice: The SERFC's dedication to building enduring partnerships and its commitment to routine collaboration with multiple operators resulted in improved forecast service.

Best Practice: Partner confidence in SERFC forecast capabilities allowed increased information exchange between agencies, improving river forecasts downstream of reservoir regulation.

Best Practice: WFOs provided rapid and consistent delivery of email blasts to core partners (e.g., EMs), providing them with up-to-date information to use in local operations.

Best Practice: WFOs provided consistently scheduled conference calls to core partners (e.g., EMs) for the duration of the event.

Best Practice: The SERFC Decision Support Services (DSS) briefing packages proved informative and useful to dam operators, WFOs and other entities because they covered the entire event domain and were concise.

Best Practice: The SERFC probabilistic river forecast services proved useful to express hydrologic forecast model sensitivities, hydrologic uncertainties and provided situational awareness to WFOs and partner agencies concerning the various precipitation scenarios during the event.

Best Practice: The SERFC offered to collaborate with WFOs and participated as required in WFO-hosted river forecast technical calls for EMs in affected areas.

Best Practice: WFO managers identified a need for AWOC flash flood and river flood training. This training helped prepare staff for flash flooding operations.

Best Practice: There was open communication between the WFOs and the USGS during the event. USGS staff promptly answered streamflow monitoring station questions or requests from the WFOs, enabling them to more accurately and efficiently provide critical products to the public and EMs.

Best Practice: From the FEMA perspective, the most beneficial DSS were the weather and flood conference calls, and briefings to state EM agencies. On-site DSS ensured there was a unified voice from the national FEMA and the NWS perspective.

Best Practice: NWS should continue to foster strong relationships with its stakeholders through regular engagement and communications. This contact could include educational outreach, drill exercises, Local Emergency Planning Committee meetings, and other partnership opportunities.

Appendix C: Methodology

The NWS formed an assessment team on October 23, 2015. Team efforts included conducting:

- In person interviews of staff and management at WFO Columbia, SC; Charleston, SC; Greenville-Spartanburg, SC; SERFC Peachtree City, GA; and WFO Wilmington, NC, the offices with primary responsibility for providing forecasts, warnings and decision support to critical partners and the general public for the most impacted areas
- In person and telephone interviews with county level EM directors and South Carolina state EM officials
- In person interviews with TV broadcast partners in Columbia, Greenville-Spartanburg, Charleston, and Myrtle Beach, SC
- Phone interviews with the ER-ROC and ERH
- In person interview with the WPC
- Interview with the NHC
- In-person interview with the South Carolina governor's office
- In-person interview with a dam operator from South Carolina Electric
- Phone interview with a FEMA Region IV representative
- In-person interviews with the public in Columbia, Charleston, and Myrtle Beach, SC
- A separate team investigated the hurricane track model performance

Appendix D: Summary of Flash Flood Warnings

WFO Charleston

- Issued 13 Areal Flood Warnings
- Issued 8 Flash Flood Warnings (140 Events)
- Extended 13 Flash Flood Warnings in time.
- Issued 3 River Flood Warnings for two river forecast points. (one was for an upgrade to major flooding at Jamestown)
- Issued 8 Flood Advisories
- Follow-up Statements: 46 for river flood, 6 for areal flood

WFO Columbia

- Issued 6 Urban and Small Stream Flood Advisories
- Issued 2 Flood Advisories
- Issued 12 Flash Flood Warnings (41 Events)
- Issued River Flood Warning for 9 of 10 river forecast points.
- Follow-up Statements: 51 (River Flooding through all of October) and 17 Flood Statements, which are follow up statements for Flood Warnings

WFO Greenville-Spartanburg

- Issued 20 Areal Flood Warnings
- Issued 9 Flash Flood Warnings (eight Events in seven Verified Warnings)
- Issued 13 River Flood Warnings for 12 of 15 river forecast points
- Flood Advisories: 31
- Follow-up Statements: 62

WFO Wilmington

- Issued 18 Areal Flood Warnings
- Issued 12 Flash Flood Warnings (70 Events)
- Issued River Flood Warnings for 10 of 11 river forecast points.
- Flood Advisories - 8
- Follow-up Statements - 40

Appendix E: Summary of River Flood Guidance Verification for SERFC

Below is an alphabetical listing of forecast locations by response times. A response time in hydrologic terms is the amount of time it will take a watershed to react to a given rainfall event. Response times are broken down into three categories, Fast response times are those less than 24 hours. Medium response times are those greater or equal to 24 hours and less than 60 hours. Slow response times are greater or equal than 60 hours.

NWS Handbook 5 ID	Gage Location	Response Time
	SERFC	
ALTV2	Roanoke River at Altavista	Fast
BROV2	Roanoke River at Brookneal	Fast
CARG1	Broad River near Carlton	Fast
CEAS1	Congaree River at Carolina Eastman	Fast
GSLS1	Saluda River near Greenville north of Old Easley Rd	Fast
HAWN7	Haw River at Haw River	Fast
LAWV2	Meherrin River near Lawrenceville	Fast
MODS1	Stevens Creek near Modoc	Fast
NRWN7	Rocky River near Norwood	Fast
RONV2	Roanoke River at Walnut Avenue	Fast
BBGS1	Broad River near Blacksburg	Medium
BCRS1	Black Creek near Quinby	Medium
BSPN7	Broad River near Boiling Springs	Medium
BYNN7	Haw River near Bynum	Medium
CHAS1	Saluda River at Chappells	Medium
CHES1	Pee Dee River at Cheraw	Medium
CLYN7	Neuse River near Clayton	Medium
CMDS1	Wateree River near Camden	Medium
COLS1	Congaree River at Columbia	Medium
DVLV2	Dan River at Danville	Medium
LBRN7	Lumber River at Lumberton	Medium
LOWN7	South Fork Catawba River at Lowell	Medium
MANN7	Lower Little River at Manchester	Medium
ORBS1	North Fork Edisto River at Orangeburg	Medium
PCEV2	Dan River at Paces	Medium
RNDV2	Roanoke River at Randolph	Medium
SBNV2	Dan River at South Boston	Medium
SMFN7	Neuse River at Smithfield	Medium
WEPS1	Saluda River at West Pelzer	Medium
WHMS1	Enoree River at Whitmire	Medium
YADN7	Yadkin River at Yadkin College	Medium
BGWN7	N.E. Cape Fear River near Burgaw	Slow
CHIN7	N.E. Cape Fear River near Chinquapin	Slow
CNWS1	Waccamaw River near Conway	Slow
EFFS1	Lynches River at Effingham	Slow
GALS1	Little Pee Dee River near Galivants Ferry	Slow
GIVS1	Edisto River near Givhans Ferry	Slow
JAMS1	Santee River near Jamestown	Slow
KINS1	Black River at Kingstree	Slow
PDES1	Pee Dee River at Pee Dee	Slow
STPN7	Cape Fear River at W.O. Huske Lock	Slow

SERFC Forecast Lead Times to Minor Flood Stage for Fast Response Locations

Location	Flood Stage (FS) in feet	1st RVF fcst issued with value >= FS	1st time observed value >= FS	Lead Time
ALTV2	18.0	10/1/15 13:32		False Alarm
BROV2	23.0	10/1/15 13:32		False Alarm
CARG1	15.0	10/2/15 14:17		False Alarm
CEAS1	115.0	10/1/15 14:04	10/3/15 16:15	2 day 2 hrs 11 min
GSLS1	12.0	10/2/15 1:49		False Alarm
HAWN7	18.0	10/1/15 13:58	10/3/15 12:30	1 day 22 hrs 32 min
LAWV2	15.0	10/1/15 1:15	10/3/15 22:30	2 day 21 hrs 15 min
MODS1	19.0	10/2/15 1:29	10/4/15 14:00	2 day 12 hrs 31 min
NRWN7	20.0	10/1/15 14:24	10/3/15 11:30	1 day 21 hrs 6 min
RONV2	10.0	10/1/15 13:32		False Alarm

SERFC Forecast Lead Times to Moderate Flood Stage for Fast Response Locations

Location	Moderate flood stage (FS) in feet	1st RVF fcst issued with value >= Moderate FS	1st time observed value >= Moderate FS	Lead Time
CEAS1	119.0	10/1/15 14:04	10/4/15 7:30	2 day 17 hrs 26 min
HAWN7	23.0	10/1/15 13:58		False Alarm
MODS1	29.0	10/2/15 14:17	10/5/15 8:45	2 day 18 hrs 28 min
RONV2	12.0	10/1/15 13:32		False Alarm

SERFC Forecast Lead Times to Major Flood Stage for Fast Response Locations

Location	Major flood stage (FS) in feet	1st RVF fcst issued with value >= Major FS	1st time observed value >= Major FS	Lead Time
CEAS1	126.0	10/3/15 14:58	10/4/15 21:30	1 day 6 hrs 32 min
HAWN7	27.0	10/1/15 13:58		False Alarm
MODS1	35.0	10/2/15 14:17		False Alarm

SERFC Forecast Lead Times to Stage of Record for Fast Response Locations

Location	Stage of Record (FS) in feet	1st RVF fcst issued with value >= Record FS	1st time observed value >= Record FS	Lead time
CEAS1	126.95 (10/12/1976)	10/3/15 21:46		False Alarm

SERFC Forecast Lead Times to Minor Flood Stage for Medium Response Locations

Location	Minor flood stage (FS) in feet	1st RVF fcst issued with value >= Minor FS	1st time observed value >= Minor FS	Lead time
BBGS1	16.0	10/2/15 1:49		False Alarm
BCRS1	10.0	10/1/15 14:24	10/3/15 8:15	1 day 17 hrs 51 min
BSPN7	12.0	10/1/15 1:32		False Alarm
BYNN7	11.0	10/1/15 13:58	10/3/15 13:45	1 day 23 hrs 47 min
CHAS1	14.0	10/2/15 13:09	10/4/15 8:45	1 day 19 hrs 36 min
CHES1	30.0	10/1/15 14:24	10/4/15 1:00	2 day 10 hrs 36 min
CLYN7	9.0	10/1/15 13:58		False Alarm
CMDS1	27.0	10/2/15 13:09	10/4/15 23:00	2 day 9 hrs 51 min
COLS1	19.0	10/2/15 1:49	10/4/15 11:15	2 day 9 hrs 26 min
DVLV2	17.0	10/1/15 13:32	10/3/15 14:15	2 day 0 hrs 43 min
LBRN7	13.0	10/6/15 0:51	10/8/15 11:00	2 day 10 hrs 9 min
LOWN7	10.0	10/1/15 14:04		False Alarm
MANN7	18.0	10/3/15 7:40	10/3/15 9:00	0 day 1 hrs 20 min
ORBS1	8.0	10/2/15 1:49	10/4/15 10:00	2 day 8 hrs 11 min
PCEV2	20.0	10/1/15 13:32	10/4/15 0:30	2 day 10 hrs 58 min
RNDV2	21.0	10/1/15 13:32	10/2/15 13:00	0 day 23 hrs 28 min
SBNV2	19.0	10/1/15 13:32	10/3/15 11:00	1 day 21 hrs 28 min
SMFN7	15.0	10/1/15 13:58	10/4/15 5:15	2 day 15 hrs 17 min
WEPS1	12.0	10/2/15 1:49		False Alarm
WHMS1	25.0	10/2/15 1:49	10/4/15 15:00	2 day 13 hrs 11 min
YADN7	18.0	10/1/15 14:24		False Alarm

SERFC Forecast Lead Times to Moderate Flood Stage for Medium Response Locations

Location	Moderate flood stage (FS) in feet	1st RVF fcst issued with value >= Moderate FS	1st time observed value >= Moderate FS	Lead Time
BCRS1	15.0	10/3/15 8:03	10/4/15 1:45	0 day 17 hrs 42 min
BSPN7	14.0	10/2/15 1:49		False Alarm
BYNN7	15.0	10/1/15 13:58		False Alarm
CHAS1	20.0	10/4/15 13:03	10/4/15 19:00	0 day 5 hrs 57 min
CHES1	36.0	10/3/15 15:31		False Alarm
CMDS1	29.0	10/3/15 14:58	10/5/15 3:15	1 day 12 hrs 17 min
COLS1	24.0	10/2/15 13:09	10/4/15 12:00	1 day 22 hrs 51 min
DVLV2	20.5	10/1/15 13:32	10/3/15 21:00	2 day 7 hrs 28 min
ORBS1	10.0	10/3/15 14:58	10/4/15 21:00	1 day 6 hrs 2 min
PCEV2	24.0	10/1/15 13:32	10/5/15 1:45	3 day 12 hrs 13 min
RNDV2	24.0	10/1/15 13:32		False Alarm
SBNV2	25.0	10/1/15 13:32	10/5/15 8:30	3 day 18 hrs 58 min
WHMS1	28.0	10/2/15 13:09	10/5/15 6:00	2 day 16 hrs 51 min

SERFC Forecast Lead Times to Major Flood Stage for Medium Response Locations

Location	Major flood stage (FS) in feet	1st RVF fcst issued with value >= Major FS	1st time observed value >= Major FS	Lead Time
CHAS1	26.0	10/5/15 7:30	10/5/15 5:30	0 day -1 hrs 55 min
COLS1	30.0	10/4/15 17:20	10/4/15 17:30	0 day 0 hrs 10 min
DVLV2	25.5	10/5/15 10:57		False Alarm
ORBS1	11.5	10/5/15 0:38	10/5/15 3:00	0 day 2 hrs 22 min
PCEV2	27.0	10/1/15 13:32		False Alarm

SERFC Forecast Lead Times to Stage of Record for Medium Response Locations

Location	Stage of Record(FS) in feet	1st RVF fcst issued with value >= Record FS	1st time observed value >= Record FS	Lead Time
BCRS1	16.80 /10/2004	10/3/15 8:03	10/4/15 23:45	1 day 15 hrs 42 min

SERFC forecast lead times to Minor Flood Stage for Slow Response Locations

Location	flood stage (FS) in feet	1st RVF fcst issued with value >= FS	1st time observed value >= FS	Lead time
BGWN7	10.0	10/1/15 13:58	10/5/15 17:30	4 day 3 hrs 32 min
CHIN7	13.0	10/1/15 13:58	10/3/15 23:15	2 day 9 hrs 17 min
CNWS1	11.0	10/3/15 15:31	10/4/15 16:15	1 day 0 hrs 44 min

EFFS1	14.0	10/3/15 15:31	10/4/15 20:00	1 day 4 hrs 29 min
GALS1	9.0	10/3/15 15:31	10/11/15 0:00	7 day 8 hrs 29 min
GIVS1	10.0	10/2/15 13:09	10/5/15 4:00	2 day 14 hrs 51 min
JAMS1	10.0	10/2/15 13:09	10/4/15 14:45	2 day 1 hrs 36 min
KINS1	12.0	10/3/15 15:31	10/4/15 14:15	0 day 22 hrs 44 min
PDES1	19.0	10/1/15 14:24	10/4/15 20:00	3 day 5 hrs 36 min
STPN7	42.0	10/1/15 13:58	10/4/15 5:00	2 day 15 hrs 2 min

SERFC forecast lead times to Moderate Flood Stage for Slow Response Locations

Location	Moderate flood stage (FS) in feet	1st RVF fcst issued with value >= Moderate FS	1st time observed value >= Moderate FS	Lead Time
BGWN7	12.0	10/6/15 14:10	10/7/15 5:45	0 day 15 hrs 35 min
CNWS1	12.0	10/3/15 15:31	10/4/15 20:30	1 day 4 hrs 59 min
EFFS1	16.0	10/3/15 15:31	10/5/15 1:00	1 day 9 hrs 29 min
GIVS1	12.0	10/2/15 13:09	10/5/15 18:00	3 day 4 hrs 51 min
JAMS1	17.0	10/3/15 14:58	10/8/15 8:15	4 day 17 hrs 17 min
KINS1	14.0	10/4/15 12:41	10/4/15 22:45	0 day 10 hrs 4 min
PDES1	23.0	10/3/15 15:31		False Alarm

SERFC forecast lead times to Major Flood Stage for Slow Response Locations

Location	Major flood stage (FS) in feet	1st RVF fcst issued with value >= Major FS	1st time observed value >= Major FS	Lead Time
CNWS1	14.0	10/4/15 18:52	10/5/15 13:30	0 day 18 hrs 38 min
EFFS1	18.0		10/5/15 15:00	No Forecast Issued
GIVS1	15.0	10/3/15 14:58	10/7/15 5:00	3 day 14 hrs 2 min
JAMS1	22.0	10/7/15 0:27	10/10/15 19:15	3 day 18 hrs 48 min
KINS1	16.0	10/4/15 18:52	10/5/15 7:45	0 day 12 hrs 53 min

SERFC forecast lead times to Stage of Record for Slow Response Locations

Location	Stage of Record (FS) in feet	1st RVF fcst issued with value >= Record FS	1st time observed value >= Record FS	Lead Time
KINS1	19.77 6/14/1973	10/5/15 15:18	10/5/15 19:00	0 day 3 hrs 42 min

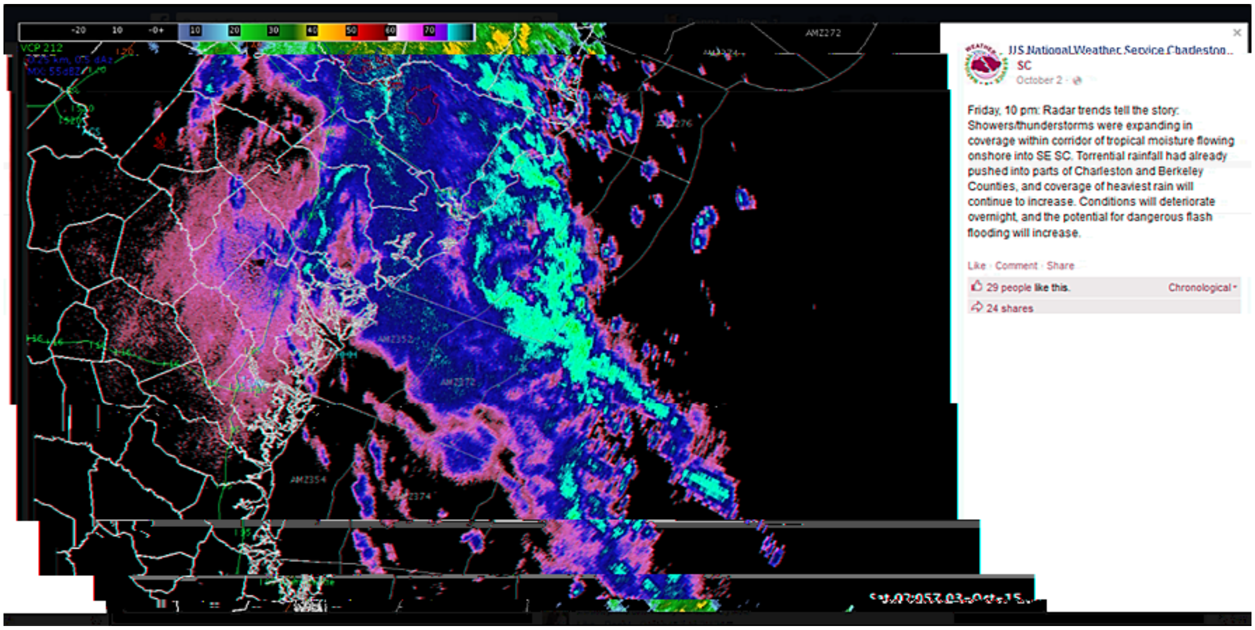
Appendix F: Summary of WFO Social Media Usage

WFO Facebook Usage

WFO Columbia

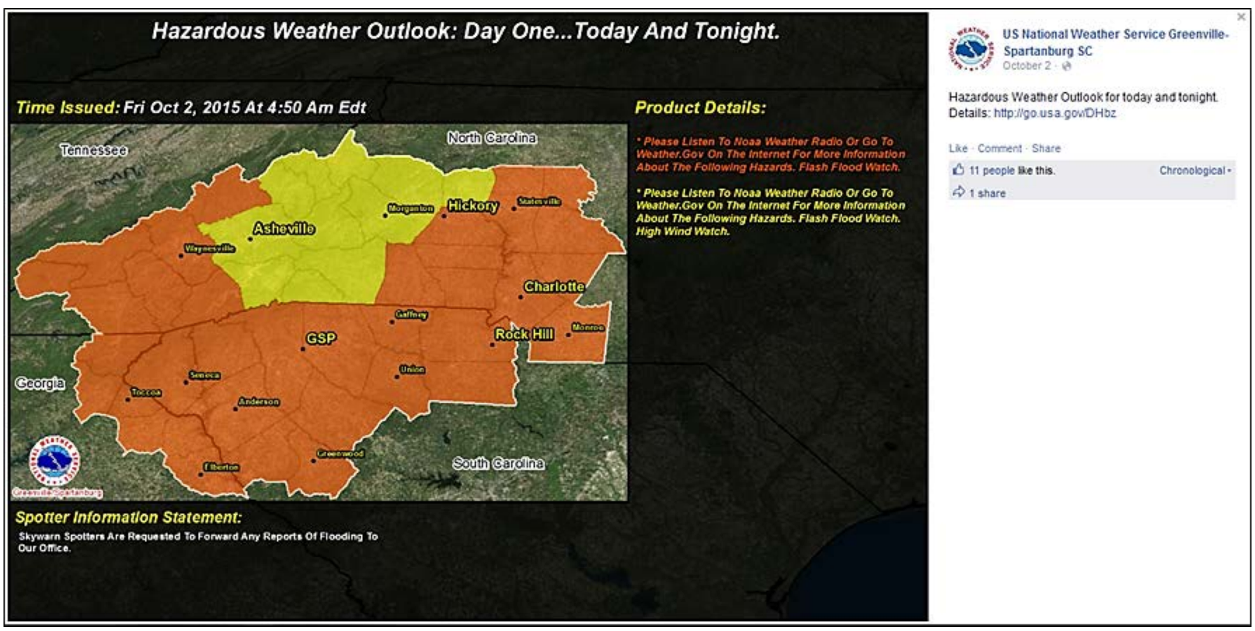
CSRA in the caption refers to the Central Savannah River Area.
Source: WFO Columbia Facebook Page

WFO Charleston

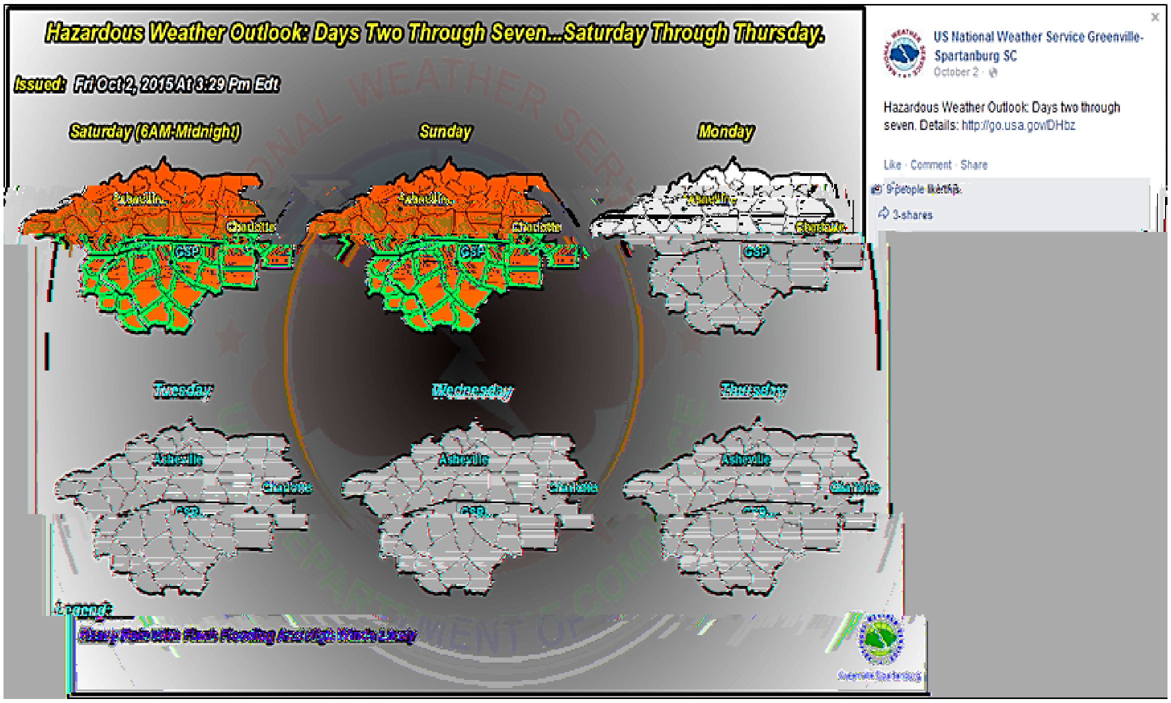


Source: WFO Charleston Facebook Page

WFO Greenville-Spartanburg



Source: WFO Greenville-Spartanburg Facebook Page

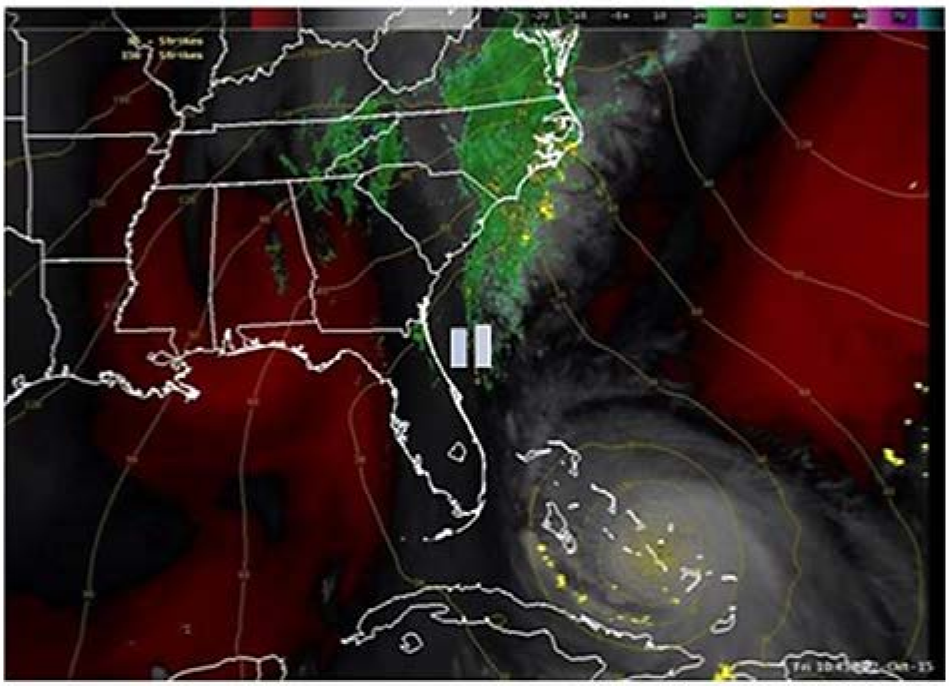


Source: WFO Greenville-Spartanburg Facebook Page

WFO Wilmington

US National Weather Service Wilmington NC
October 2 ·

Heavy rain and flooding over the Cape Fear region this morning is part of a stream of moisture extending down the Gulf Stream to the periphery of Hurricane Joaquin. This heavy rain should shift inland into South Carolina tonight and Saturday, then return to the coast and into southeastern North Carolina Sunday and Monday. A Flood Watch remains in effect for the potential of 8 to 12 inches of rain in parts of the eastern Carolinas over the next few days.



3.4k Views

Like Comment Share

36 people like this.

54 shares

Source: WFO Wilmington, NC Facebook Page

US National Weather Service Wilmington NC

October 5 ·

NWS Wilmington, NC Warning Coordination Meteorologist Steve Pfaff conducted an interview with The Weather Channel this morning, concerning the ongoing historic flood event. Widespread rainfall amounts of 12" to as much as 25" have fallen over the last few days. Although the rain will taper off today, flooding hazards will continue for the next few days.

Like Comment Share

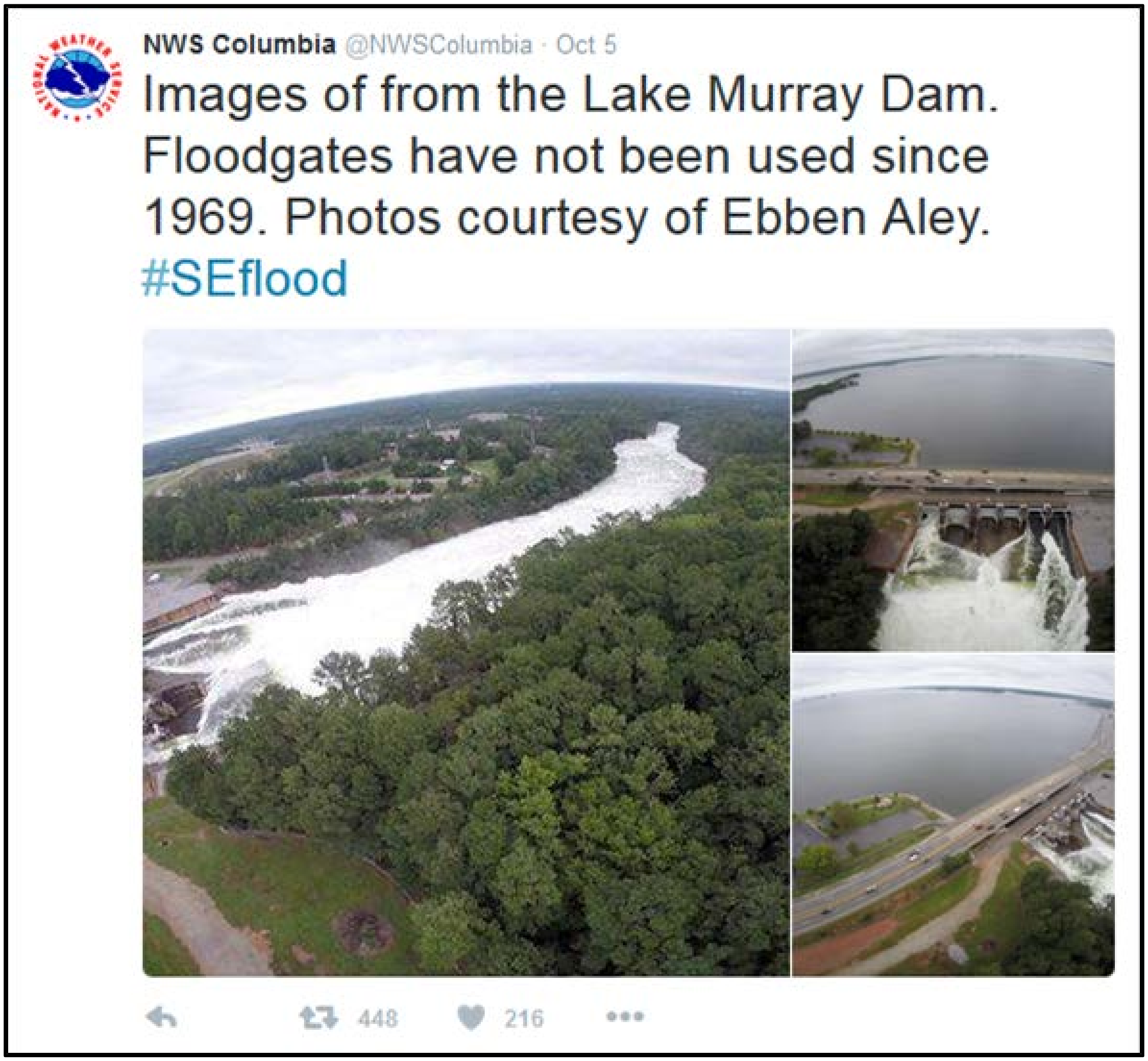
61 people like this. Top Comments ▾

16 shares

Source: WFO Wilmington, NC Facebook Page

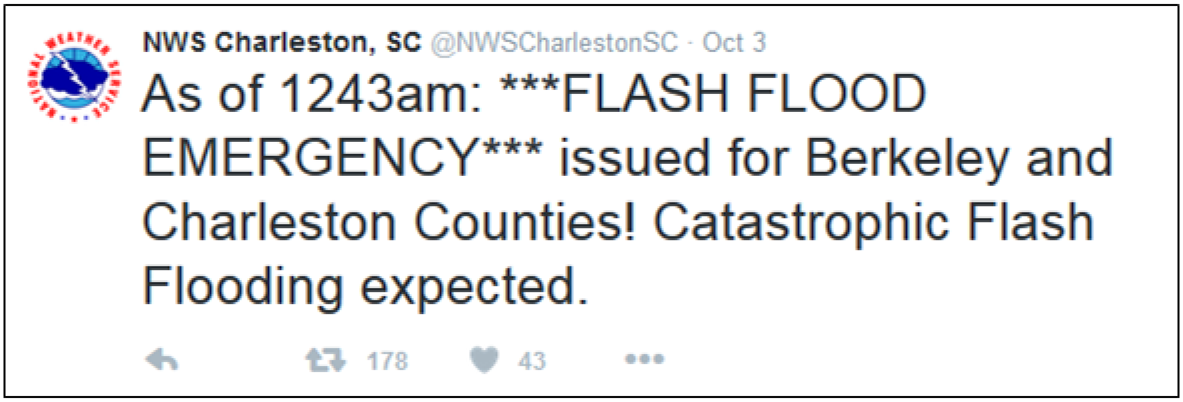
WFO Twitter Usage: Tweets with the most "re-tweets"

WFO Columbia



Source: WFO Columbia Twitter Page

WFO Charleston



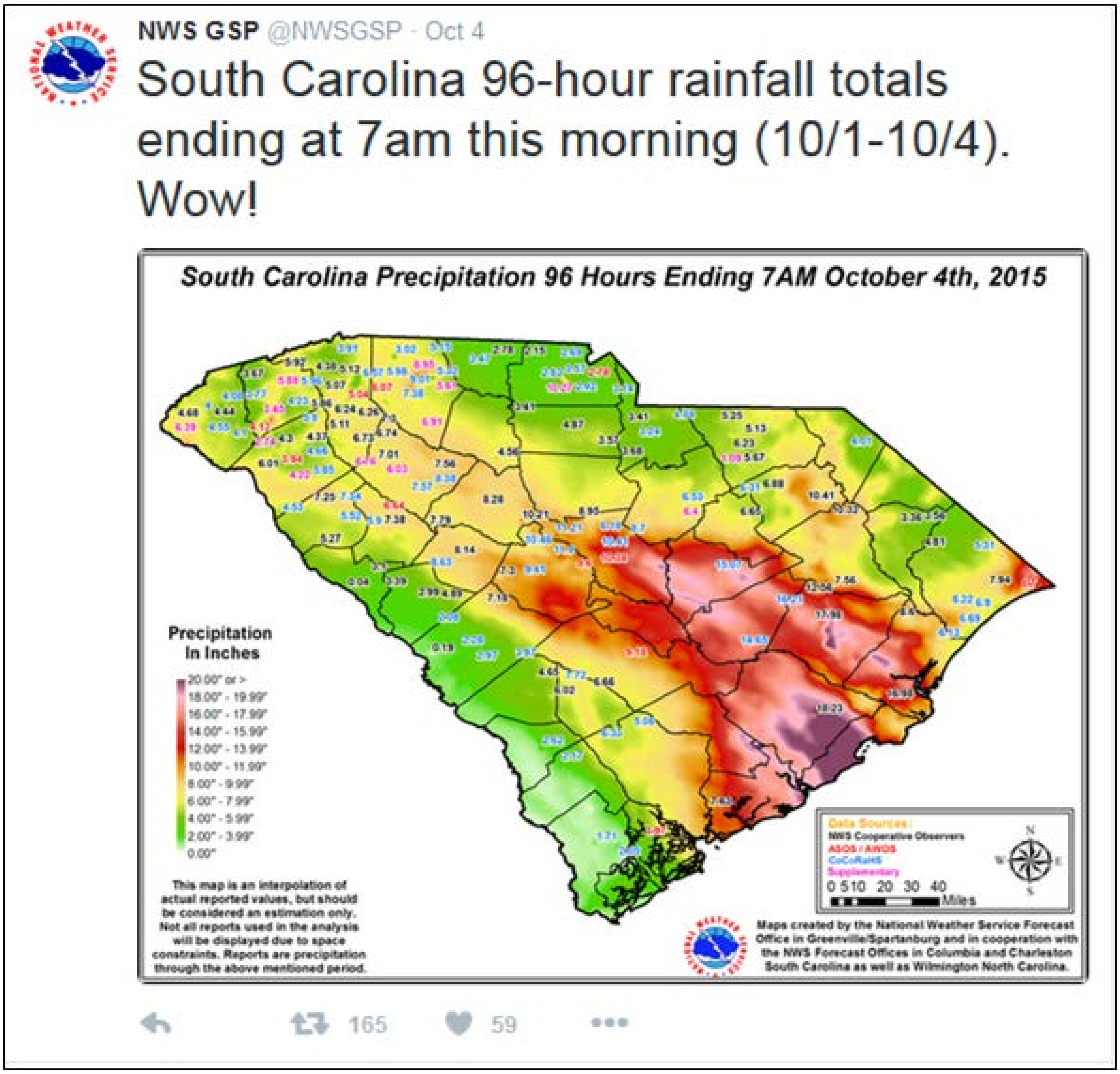
NWS Charleston, SC @NWSCharlestonSC · Oct 3

As of 1243am: ***FLASH FLOOD EMERGENCY*** issued for Berkeley and Charleston Counties! Catastrophic Flash Flooding expected.

178 43

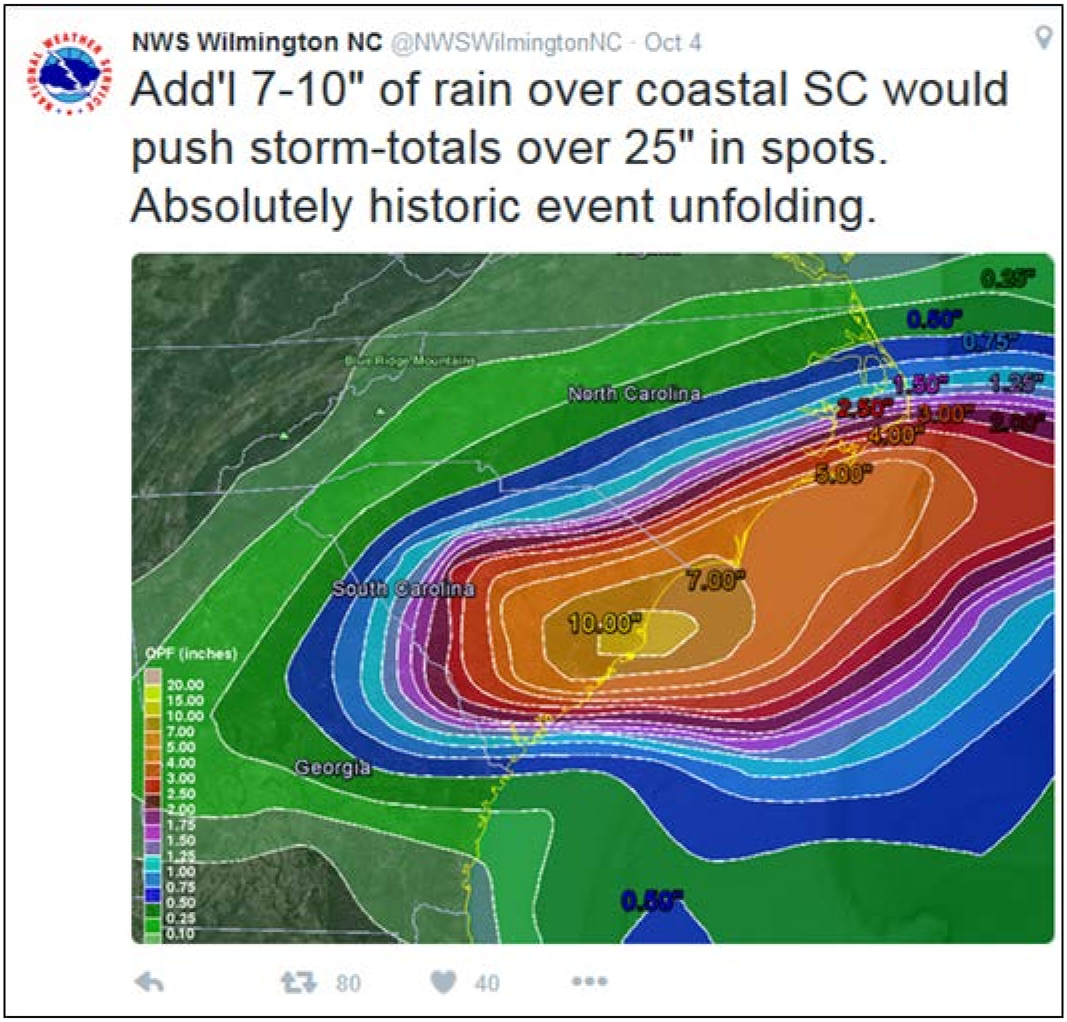
Source: WFO Charleston Twitter Page

WFO Greenville-Spartanburg



Source: WFO Greenville-Spartanburg Twitter Page

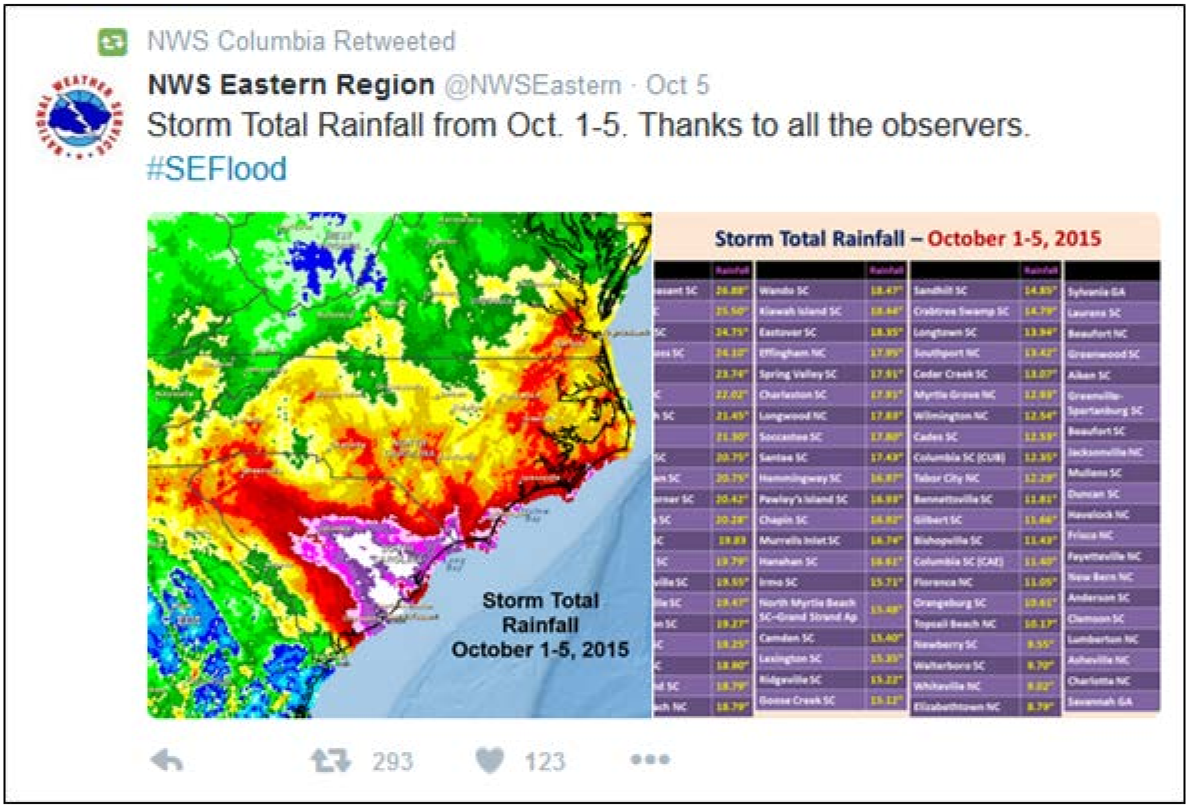
WFO Wilmington



Source: WFO Wilmington, NC Twitter Page

<u>WFO Twitter Usage: Most Popular "re-tweets" from other Organizations</u>

WFO Columbia


NWS Columbia Retweeted

NWS Eastern Region @NWSEastern · Oct 5

Storm Total Rainfall from Oct. 1-5. Thanks to all the observers. #SEFlood

Source: WFO Columbia Twitter Page


Twitter Alert from SCEMD

SCEMD @SCEMD · Oct 4

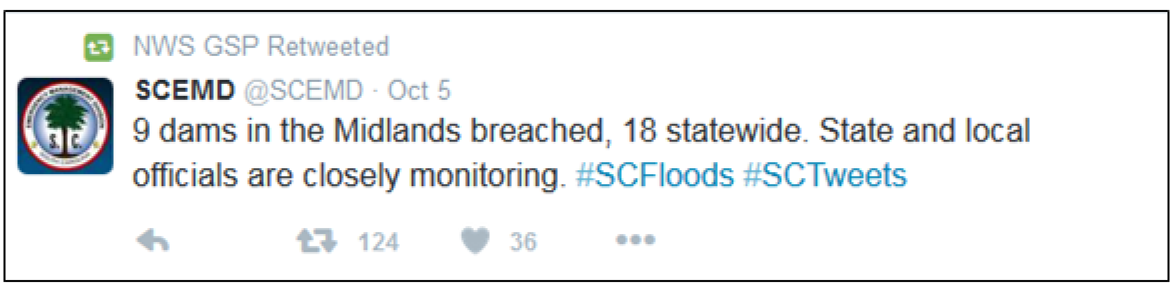
EMERGENCY ALERT: SCEMD asks you to remain where you are if you are safely able to do so. Call 911 for life-threatening emergencies #alert

Source: WFO Columbia Twitter Page

WFO Charleston

Source: WFO Charleston Twitter Page

WFO Greenville-Spartanburg



Source: WFO Greenville-Spartanburg Twitter Page

Appendix G: Referenced Findings and Recommendations from Previous Service Assessments

Description: The table below presents this South Carolina Flooding Service Assessment team's findings that are similar to those also found by previous service assessment teams. In such cases, the South Carolina Flooding Service Assessment team did not develop formal Findings and Recommendations in this South Carolina Floods Service Assessment document. However, in order to emphasize that these issues still exist, the issues are being listed in this table along with the existing corresponding Findings, Recommendations, and their Statuses, as of the date of this publication, from the previous service assessments.

South Carolina Flooding Section	Description	Previous Service Assessments	Status
Section 3.1.2	There were numerous forecast service requests for tidally influenced rivers, such as the Waccamaw River. The SERFC does not forecast tidally affected rivers because it cannot account for the numerous complexities in its hydrologic modeling schemes.	Hurricane/Post-Tropical Cyclone Sandy, October 22–29, 2012 in the Finding/Recommendation 16: NWS lacks sufficient forecast guidance on inundation associated with wave run-up and coastal rivers making it difficult to forecast impacts from coastal storms.	The Storm Surge Roadmap team assembled a roadmap in FY15. The roadmap lays the groundwork to build on what are actions related to tropical storm surge (storm surge watch/warning) and apply that knowledge to extratropical and riverine flooding from storm surge. The NWS is now forming a team to address extratropical storm surge flooding while the riverine storm surge related-flooding is a longer-term effort
Section 3.1.4	WPC should host a pre-coordination call for extremely impactful QPF in its guidance package when it expects big events of 10+ inches of rainfall	The Record Front Range and Eastern Colorado Floods of September 11-17, 2013, Finding 1	The action was closed since it is included in the FY2015 training milestone that

	or more.	addresses the issue of conducting WPC coordination calls with WFOs and RFCs when the potential exists for widespread heavy rain and flash flooding.)	directly addresses this issue. It has been signed by leadership and RDs. NWSTC is tracking completion of these training modules.
Section 3.1.4	The service assessment team thinks that interactions, roles, and responsibilities among WFOs, RFCs, Regional ROCs, the NOC; the NWS Communications Office; and the National Centers for providing impact decision support needs to be spelled out, such that there is a clear understanding when one office's role begins and ends.	NOAA NWS Operations and Service Assessment during Hurricane Irene in August 2011, Finding 12: The working relationship among NOAA/NWS liaisons/embedded meteorologists and the local WFO was strained and deficient under time sensitive, high visibility pressures.	To address this need, NWS staff has written an IDSS Instruction which is currently undergoing review by the NWS Regions.
Section 3.2.2	The Service Assessment Team believes that WFOs should become better aware of the content that partners find most useful in the social media context. It is also important to gain an understanding of such demographic groups in order to reach as diverse of an audience as possible. The Service Assessment Team thinks that WFOs should then provide content that EMs can quickly pass along via social media with no modification required.	Hurricane and Post-Tropical Cyclone Sandy, October 22-29, 2012, Finding 12 May 2013 Oklahoma Tornadoes and Flash Flooding, Finding 25 Colorado Flooding of September 11-17, 2013, Finding 12: WFOs Boulder and Pueblo used social media during this event to increase the dissemination of critical flood-related information. Use of social media varied in frequency, consistency, and specificity due, in part, to	The Social Media directive has been written to address these service assessment findings and the directive is currently going through the review process.

		varying staffing and operational structure.	
Section 3.5	WFOs stated that they would like more NWS flash and river flood training incorporated into the Weather Event Simulator (WES) cases.	The Record Front Range and Eastern Colorado Floods of September 11-17, 2013, Service Assessment Finding 24: WFOs cannot play back archived hydrologic data to support event simulations for high impact hydrologic events using the core WFO WHFS applications.	The related simulation was released on September 28, 2015. There is a Simulation and Training guide for this WES-2 simulation in PDF. The two simulation developers provided a short Webinar on the Simulation's learning objectives and design approach for those sites that already had WES-2 workstations. The Webinar has been recorded for other training officers to use when their WES-2 workstation becomes operational
Section 4.2	Local SHs should work with WCMs, Social Scientists, local EMs, and Service Coordination Hydrologists to create impact-based graphics and statements that demonstrate the effect of specific flood hazards in reference to specific U.S. geographic regions.	The Record Front Range and Eastern Colorado Floods of September 11-17, 2013, Service Assessment Finding #9: The hydrologic product suite continues to be complex and cumbersome and often lacks the level of detail and specificity sought by partners. Recommendation 9a: The NWS should move from a product-driven framework to a hazards information-driven framework, which sequentially raises the	An operational impact-based tornado and severe thunderstorm warning at all WFOs milestone is in the FY2016 AOP. NWS is planning to have a graphic depiction of threat grids, called Hurricane Threat and Impact Graphics (HTI), experimental by the end of FY15. This page will show where

		level of situation awareness.	impacts are expected to occur and a measure of those impacts for Wind, Surge, Inland Flooding and Tornadoes. Page 6, Section 1.1.1 (Shift from Product-Focused Service to Interpretation and Consultation) of the NWS Weather-Ready Nation Roadmap, last paragraph, addresses this issue.
Section 5.2	The public did not know the significance of what minor, moderate, or major flood means. For people to take appropriate action, they need to know specific impacts (i.e., How many houses are going to be impacted? What roads are going to be closed?). In addition, the public does not understand that 15 inches of rain could mean more than 15 inches of water on their property.	The Record Front Range and Eastern Colorado Floods of September 11–17, 2013, Service Assessment Finding #9: The hydrologic product suite continues to be complex and cumbersome and often lacks the level of detail and specificity sought by partners. Recommendation 9a: The NWS should move from a product-driven framework to a hazards information-driven framework, which sequentially raises the level of situation awareness.	Same as above.
Section 5.3	The South Carolina EMD indicated prior to the event they did not need a NWS liaison at the state EOC but if offered this option they would have accepted. In retrospect, they thought a liaison would have	NOAA NWS Operations and Service Assessment during Hurricane Irene in August 2011 Finding/Recommendation #12: NOAA/NWS should develop a protocol	To address this need, the IDSS Directive has been written and is currently undergoing review by the NWS Regions.

	been beneficial. An example was the scheduling of the different WFO driven conference calls. Having a liaison at the state EOC might have helped with this effort. WFOs should work with the EM community to become fully integrated in the nomenclature and structure. This knowledge ultimately helps to more effectively facilitate the flow of communication with respect to conference call/webinars, etc..	for building, sustaining, and evaluating working relationships among embedded meteorologists/NWS liaisons, WFOs, and RFCs. This protocol should include reciprocal, face-to-face visits to build trust and a robust understanding of the work demands and needs of each entity.	

Appendix H: Assessments Flood Fatalities

County	Time	Cause of Death
Spartanburg	3:35 am 10/1/15	Drowning
Aiken	6:50 am 10/2/15	Traffic Collision
Anderson	1:20 pm 10/2/15	Traffic Collision
Greenville	3:30 am 10/3/15	Traffic Collision
Aiken	12:45 pm 10/4/15	Traffic Collision
Richland	N/A* 10/4/15	Drowning
Richland	N/A* 10/4/15	Drowning
Richland	N/A* 10/4/15	Drowning
Kershaw	N/A* 10/4/15	Drowning
Richland	N/A* 10/4/15	Drowning
Richland	N/A* 10/4/15	Drowning
Richland	N/A* 10/4/15	Drowning
Greenville	7:25 pm 10/5/15	Traffic Collision
Horry	12:50 am 10/6/15	Traffic Collision
Richland	11:00 pm 10/5/15	Drowning
Richland	1:45 am 10/7/15	Drowning
Richland	1:45 am 10/7/15	Drowning
Horry	11:00 pm 10/6/15	Traffic Collision/Drowning
Horry	11:00 pm 10/6/15	Traffic Collision/Drowning

*Time of fatality was not available at the time of report publication

Appendix I: Hurricane Joaquin Analysis/Assessment

Model Performance for Hurricane Joaquin

The tropical depression that eventually became Hurricane Joaquin formed northeast of the Bahamas on September 28, 2015. During the next 3 days, it moved to the southwest, causing significant damage in the Bahamas before looping back to the northeast and continuing that track out to sea. During the first few days of Joaquin's life, most guidance suggested a threat to the U.S. East Coast; however, the European Center for Medium Range Forecasting (ECMWF) model predicted early on that the storm would not make landfall, while NCEP's Global Forecast System (GFS) was slower to capture the decreasing threat. The same was true for the Weather Research for Forecasting (WRF) model specifically tuned for hurricanes guidance (HWRF). The European Center Ensemble Prediction System (EPS) and the NCEP Global Ensemble Forecast System (GEFS) performed similarly to the deterministic runs. The GFS parallel (also called the GFSX) was slightly better than the operational GFS. This parallel model, which features several changes to the data assimilation, is scheduled for implementation as the next GFS model during spring of 2016.

Deterministic Models

Figures 1–9 show tracks for the GFS, ECWMF, and (when available) the parallel GFSX. **Figure 1** shows the 1200 UTC 28 September cycle, with both the GFS and ECMWF making landfall, but with the ECMWF targeting southern Virginia before making an odd loop that allowed for a second landfall farther north; the GFS was taking the storm into southern New England. Starting with the 0000 UTC 29 September cycles (**Figure 2**), the ECMWF correctly locked onto a track well offshore that posed no threat to the East Coast. The GFS did not show an actual landfall, but brought Joaquin perilously close to the Outer Banks of North Carolina. In both of these cycles, it was evident that the ECMWF correctly captured the initial south-southwest motion of Joaquin, accurately showing a threat to the Bahamas before a turn back to the northeast. The GFS immediately moved Joaquin to the north-northwest.

The 1200 UTC 29 September cycle (**Figure 3**) has the GFS, ECMWF, and GFSX all indicating no threat to the East Coast from Joaquin, although the three solutions were very different. The ECMWF correctly moved the storm south of 25 N initially, before turning it back to the northeast. The initial GFS movement was to the west before a turn to the north, followed by very slow movement before turning again to the east. The GFSX track ended up being more accurate than that of the GFS, but it was actually too far east, and like the GFS, initially moved the storm to the west instead of south.

A major change occurred with the 0000 UTC 30 September cycle (**Figure 4**). The ECWMF continued with its remarkably accurate track, but the GFS and GFSX had nearly identical tracks to the north with final curves into southern Virginia and remnants tracking into New England. The GFS and GFSX both finally had more of a southerly component in the initial motion, although still not moving Joaquin sufficiently southward. **Figure 5** shows that the GFS and GFSX did an even better job with the initial southward movement in the 1200 UTC 30

September cycle, but the GFS still brought the storm into the Carolina coast, while the GFSX showed landfall in the Delmarva Peninsula.

The 0000 UTC 1 October cycle (**Figure 6**) still saw the GFS and GFS turn Joaquin too far to the west after the initial southwest motion. The resulting turn was therefore more to the north, compared to the northeast turn by the ECMWF. The GFS simulation of Joaquin was possibly influenced by the large upper low over the southeast, and the model still made landfall, although dramatically farther north than previous cycles. The GFSX, however, did not show landfall, although its track was still too far to the west. The GFSX maintained a very similar track in the 1200 UTC 1 October cycle (**Figure 7**), but the GFS shifted well to the east and now joined the camp showing no landfall.

The 0000 UTC 2 October cycle (**Figure 8**) saw the GFS shift back to the west but still offshore, although indicating some impact in the Canadian Maritimes. The GFSX correctly curved Joaquin more to the east such that much of its later track matched that of the ECMWF. The 1200 UTC 2 October cycle (**Figure 9**) saw all three models keep Joaquin well offshore, with the GFSX slightly farther east than the GFS or ECMWF.

Table 1 summarizes the cycle at which various deterministic models first showed Joaquin not making landfall along the East Coast and then continued to not show a landfall in all subsequent runs. In addition to the GFS, GFSX, and ECMWF, times are given for the United Kingdom Meteorological Office Model (UKMET), the Japan Meteorological Agency Model (JMA), the Geophysical Fluid Dynamics Laboratory Model (GFDL), the Navy Global Environmental Model (NAVGEM), the Canadian Meteorological Center Global Model (CMC), and the North American Mesoscale Model (NAM).

HWRF

Figure 10 shows a composite of all HWRF tracks for Joaquin, every 6 hours, starting with 1800 UTC on 26 September and ending with the 1200 UTC cycle on 6 October, with the observed track in black. The first 19 cycles either made landfall or threatened the eastern U.S. coast. The 1200 UTC cycle on 1 October was the first cycle that did not show a U.S. landfall, although it still had the storm threatening the Canadian maritime region. Each cycle thereafter adjusted the track a little to the east.

Ensembles

This section assesses the performance of the GEFS and EPS with plots showing the ensemble mean (black line), individual members (white lines), and probabilities (color fill). Beginning with the 1200 UTC 29 September cycle (**Figure 11**), the ensemble means kept Joaquin offshore, but with many members indicating landfall. The 1200 UTC 30 September cycle (**Figure 12**) saw the EPS shift to showing a majority of members with a track out to sea, while the GEFS suggests high confidence in a North Carolina landfall. The 0000 UTC 1 October cycle (**Figure 13**) saw only a couple of EPS members with any landfall, while a majority of GEFS members had Joaquin striking the Outer Banks. The GEFS solutions were strongly bi-modals, with a large number of members showing landfall and a sizeable cluster showing a track well out to sea with nothing in between.

The 1200 UTC 1 October GEFS (**Figure 14**) made a large shift to the east, looking very much like the EPS (not shown but extremely similar), with only one member showing landfall. However, the 0000 UTC 2 October GEFS (**Figure 15**) again showed a significant number of members with landfall, although the larger cluster had a track well to the east. The 1200 UTC 2 October GEFS (not shown) finally saw all members keeping Joaquin well offshore.

Summary

All models during the development of Joaquin showed a significant threat of a major hurricane landfall along the East Coast. The ECMWF mode, however, quickly locked in on the idea that Joaquin would remain well offshore. The GFS, however, took two more days before showing that the threat did not exist. The GFSX parallel was 6 hours faster than the operational GFS in dismissing the East Coast threat. Like their deterministic systems, the EPS was significantly faster than the GEFS in dismissing a high threat of landfall. The GEFS solutions for many cycles showed a bi-modal distribution.

The ECMWF runs consistently and accurately captured the initial movement of Joaquin to the south-southwest, while the GFS had a very difficult time capturing the initial track. This resulted in less warning given to the Bahamas, where significant storm impacts occurred. It is not known whether successful simulation of the early part of the track was critical in accurately simulating the track of the storm after the turn to the north.

ECMWF	00Z Sep 29
GFSX	00Z Oct 1
UKMET	00Z Oct 1
GFS	06Z Oct 1
HWRF	12Z Oct 1
JMA	12Z Oct 1
GFDL	18Z Oct 1
NAVGEM	06Z Oct 2
CMC	12Z Oct 2
NAM	18Z Oct 2

Table 1: Lists of the first cycles for which various forecast models first indicated that Joaquin would not make landfall along the East Coast and kept the storm offshore in all subsequent cycles. Global models are in bold.

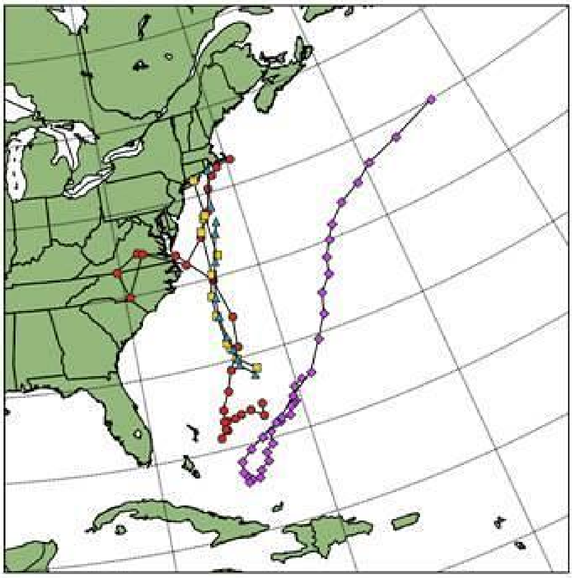


Figure 1: Tracks for the GFS (blue triangles), the ECMWF (red dots), the parallel GFSX (yellow squares), and the observed track (purple diamonds) for the 1200 UTC cycle 28 September 2015. The observed track is shown through 0300 UTC 7 October 2015.

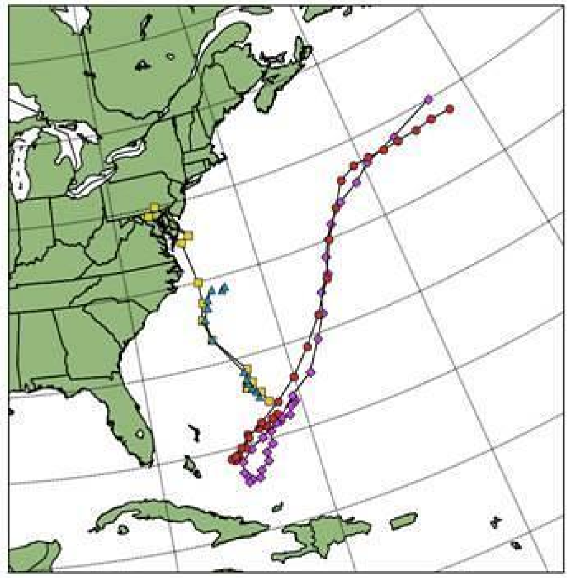


Figure 2: Same as in Figure 1, but for the addition of the 0000 UTC cycle 29 September.

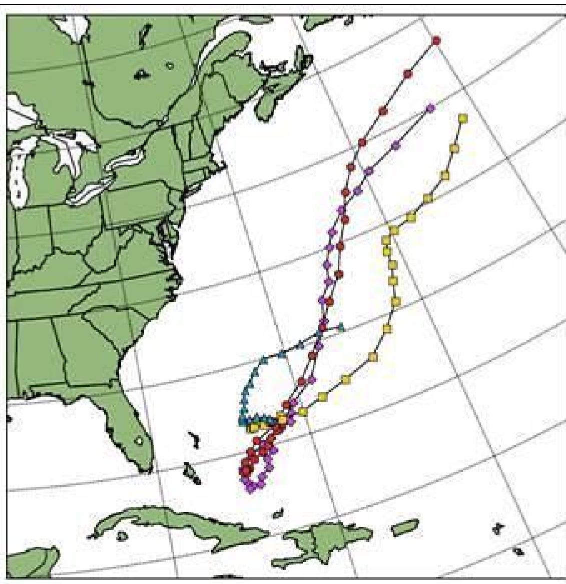


Figure 3: Same as in Figure 1, but for the addition of the 1200 UTC cycle 29 September.

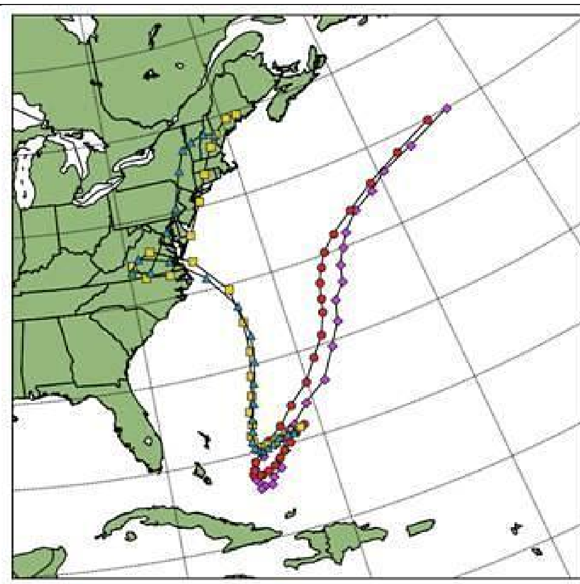


Figure 4: Same as in Figure 1, but for the addition of the 0000 UTC cycle 30 September.

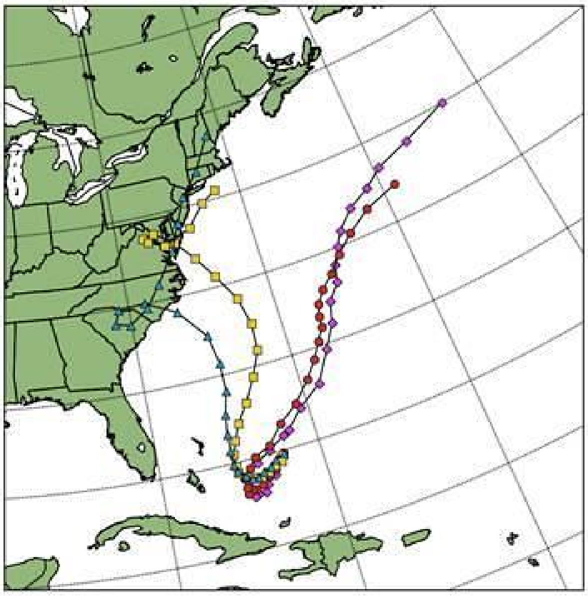


Figure 5: Same as in Figure 1, but for the addition of the 1200 UTC cycle 30 September.

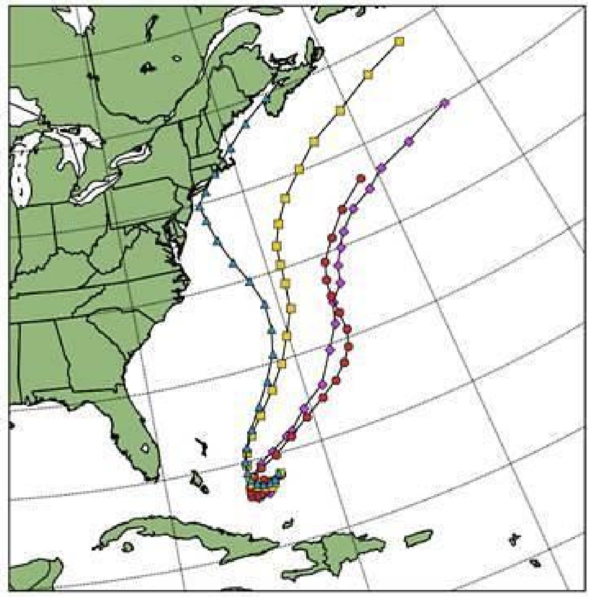


Figure 6: Same as in Figure 1, but for the addition of the 0000 UTC cycle 1 October.

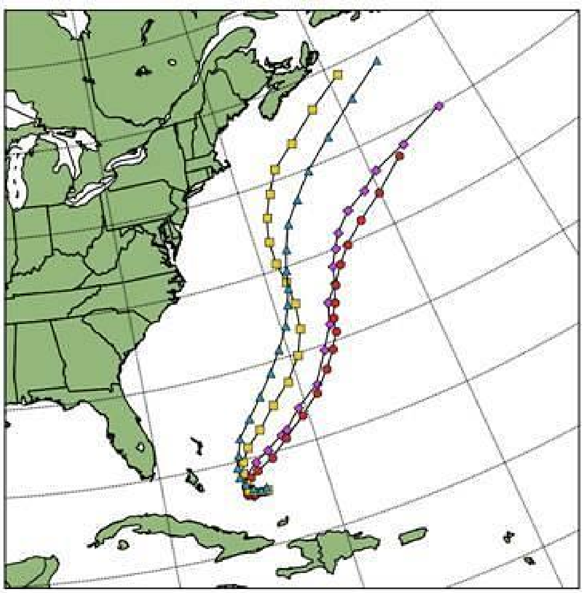


Figure 7: Same as in Figure 1, but for addition of the 1200 UTC cycle 1 October.

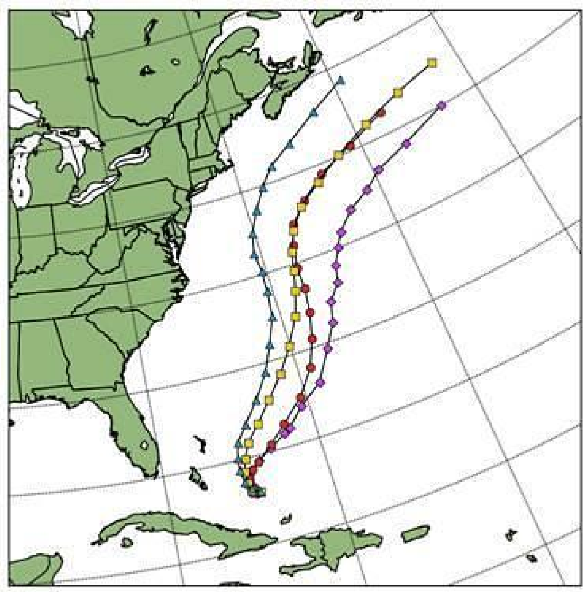


Figure 8: Same as in Figure 1, but for the addition of the 0000 UTC cycle 2 October.

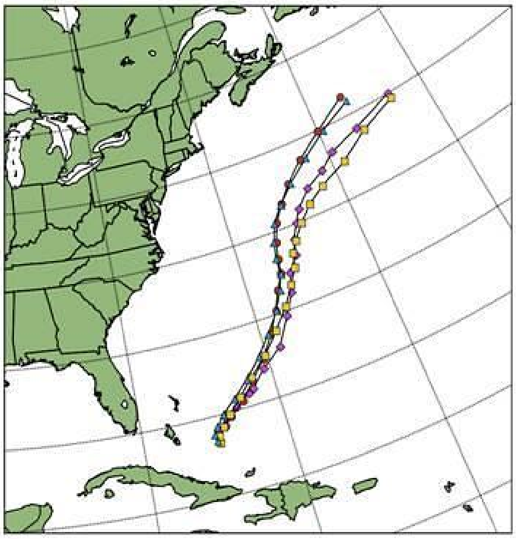


Figure 9: Same as in Figure 1, but for the addition of the 1200 UTC cycle 2 October.

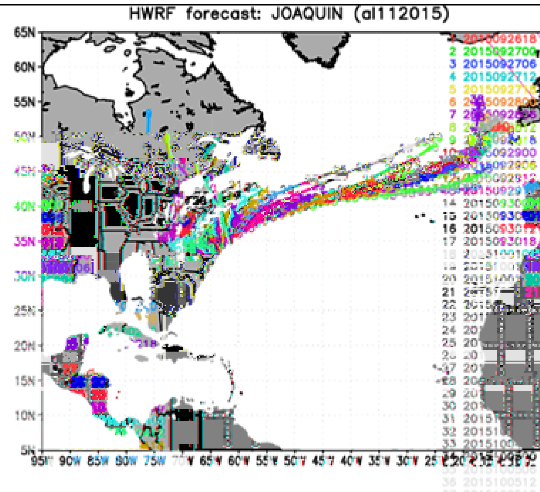


Figure 10: Composite of tracks for all HWRF runs between 1800 UTC 26 September and 1200 UTC 6 October.

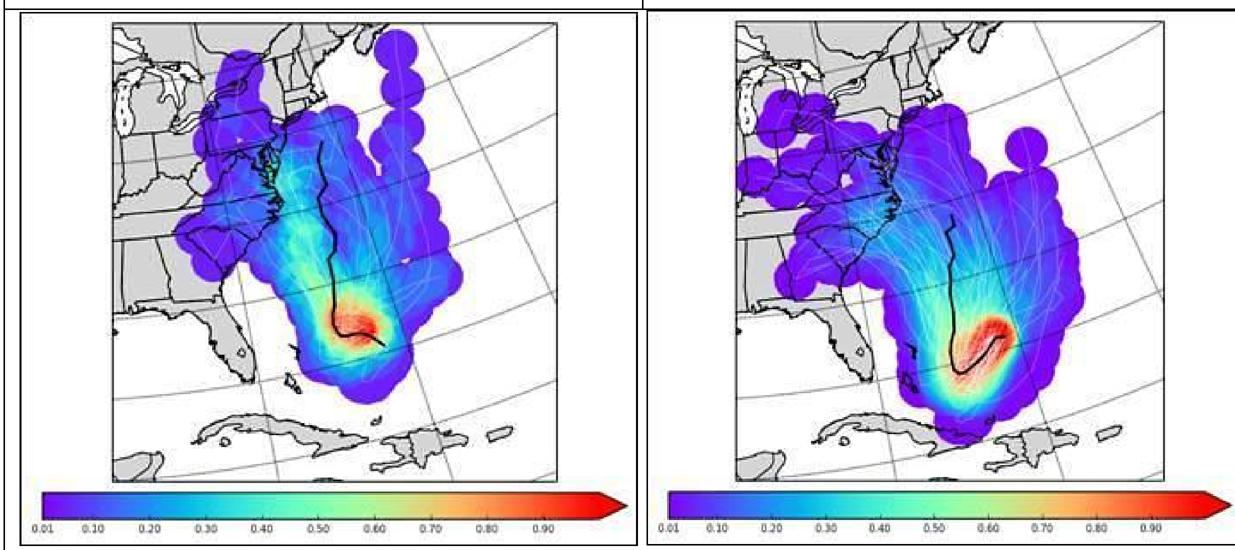


Figure 11: Ensemble forecasts showing mean (solid black line), individual members (thin white lines), and probabilities (color fill) from the 1200 UTC 29 September 2015 cycles of GEFS (left) and EPS (right).

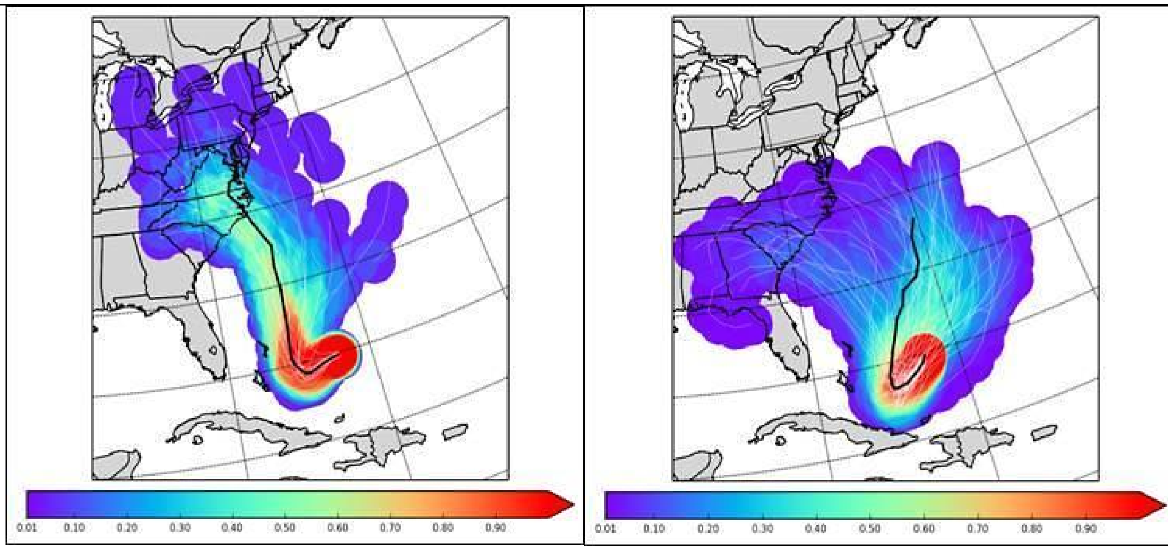


Figure 12: Same as in Figure 11, but for the addition of the 1200 UTC cycle 30 September.

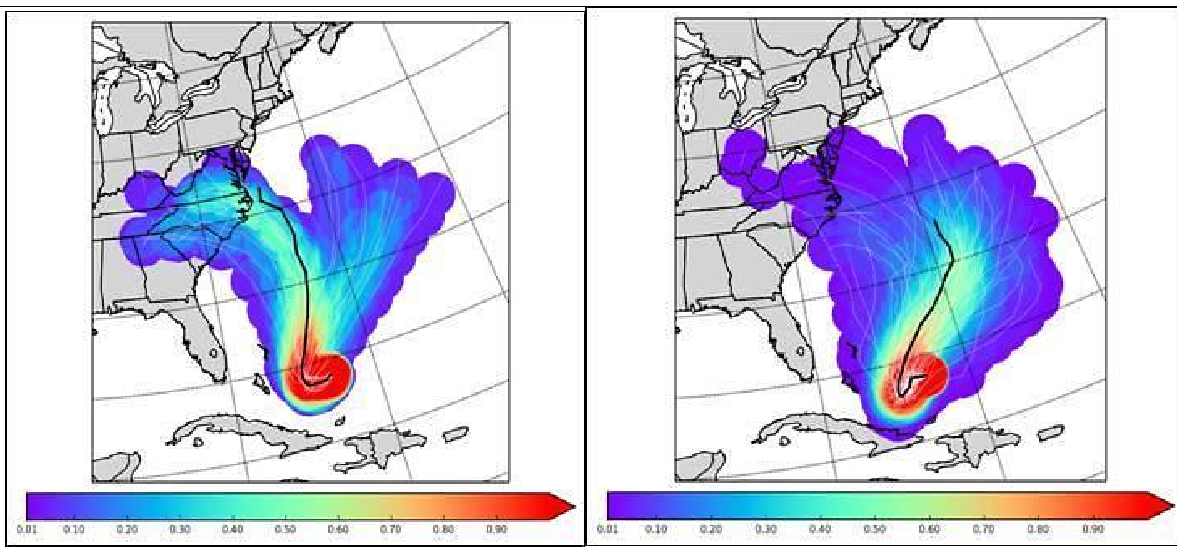


Figure 13: Same as in Figure 11, but for the addition of the 0000 UTC cycle 1 October.

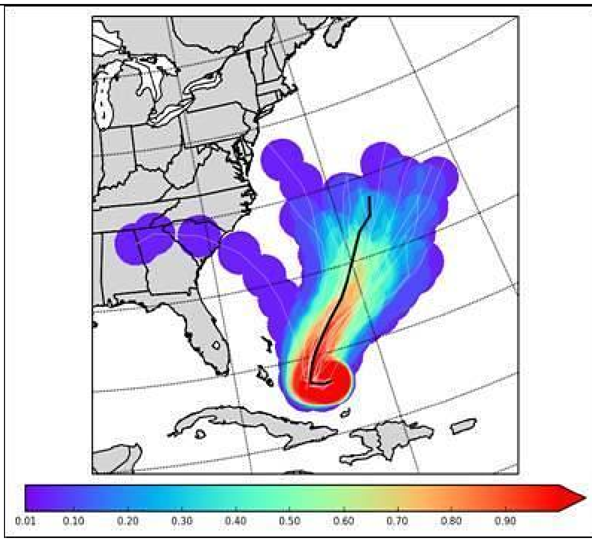


Figure 14: Same as in Figure 11, but for the addition of the 1200 UTC cycle 1 October, and only the GEFS is shown.

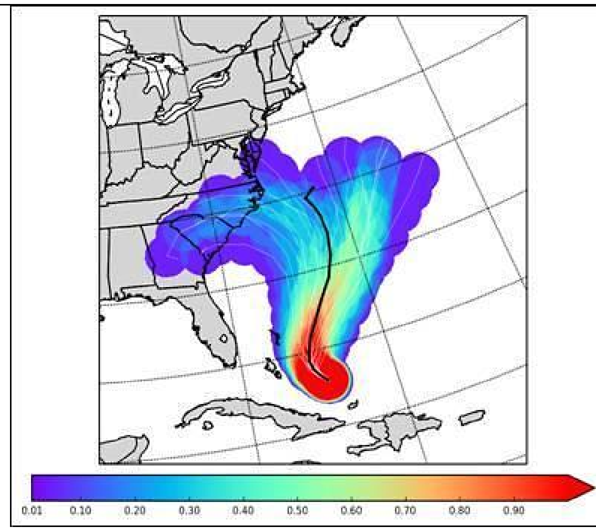


Figure 15: Same as in Figure 11, but for the addition of the 0000 UTC cycle 2 October, and only the GEFS is shown.