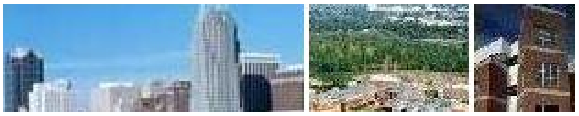
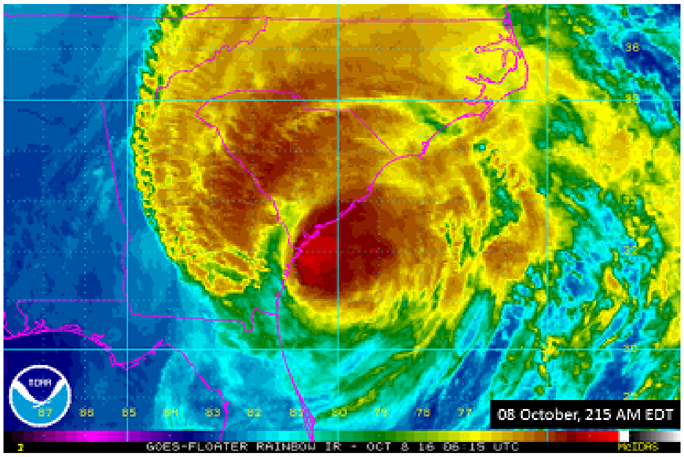
Event Summary
National Weather Service, Raleigh NC



Hurricane Matthew, October 2016

Note that this is a PDF version of the event summary and that some links, media or resources may not be avaiable in this format.



Event Headlines -

...A total of 29 deaths in North Carolina can be attributed to the storm, most due to drowning in freshwater flooding...
...Emergency management officials have estimated the damage in NC from the storm exceeded $1.5 billion...
...The NC State Climate office estimates that Matthew is the 4th-costliest and 5th-deadliest North Carolina tropical cyclone on record...
...More than 1.6 million customers lost power across North Carolina during Hurricane Matthew...
...The Neuse River at Smithfield and Goldsboro, as well as the Little River at Manchester near Fayetteville, reached all-time high crests, exceeding their peaks from Hurricane Floyd...
...A CoCoRaHS observer near Elizabethtown reported 18.38 inches of rain while a CoCoRaHS observer near Hope Mills reported a rain total of 17.00 inches...

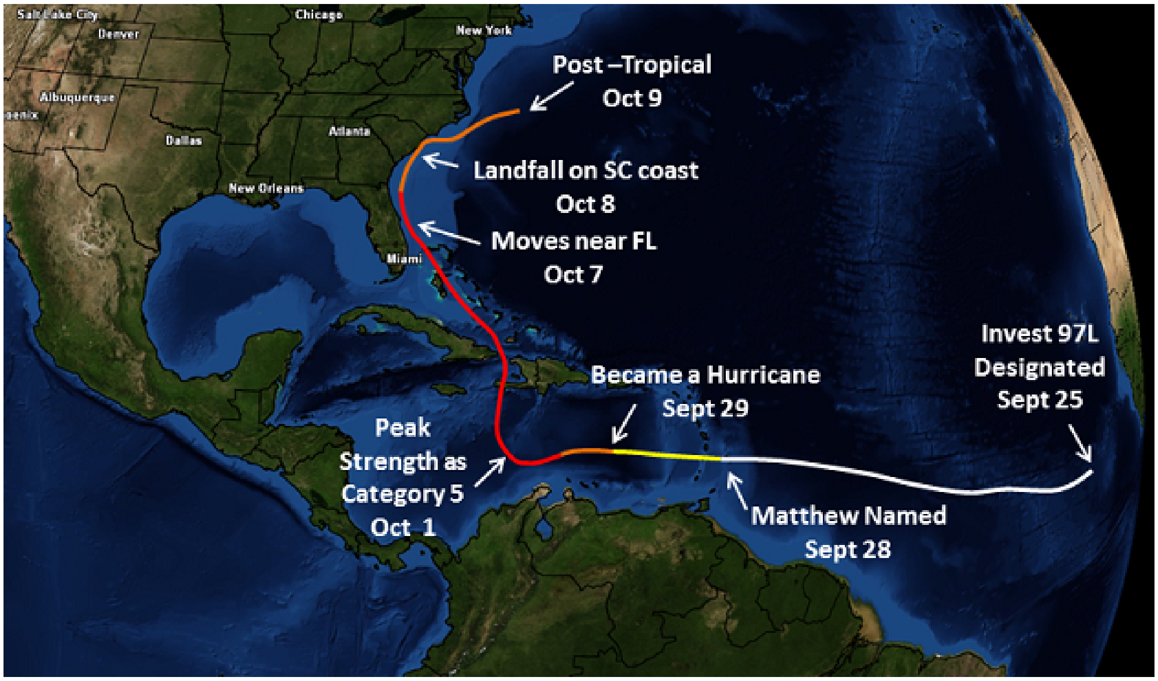
Event Overview -

Hurricane Matthew can be traced back to a strong tropical wave that moved off the African coast early on 23 September 2016. The system moved quickly west at fairly low latitude for several days and struggled to develop a closed, low-level circulation. The area of low pressure matured and Tropical Storm Matthew developed near Barbados around 1200 UTC on 28 September. As Matthew moved over the deep, warm waters of the Caribbean Sea, the tropical cyclone gradually strengthened into a hurricane north of Venezuela and Colombia by 1800 UTC 29 September. Matthew went through a period of rapid intensification with wind speeds increasing 85 MPH (75 kts) between 0000 UTC 30 September and 0000 UTC 01 October. Matthew reached Category 5 intensity at 0000 UTC 01 October and peaked with maximum sustained winds of 165 MPH or 145 kts.

Matthew weakened slightly and its intensity fluctuated as it turned north toward Haiti. The storm made landfall on the Tiburon Peninsula early on 4 October, before moving through the Windward Passage and then making another landfall in eastern Cuba early on 5 October. Matthew’s intensity fluctuated between category 3 and 4 winds as it tracked northwest across the Bahamas with the storm making a landfall on Grand Bahama Island around 0000 UTC 07 October as category 4 hurricane.

A broad, eastward-moving mid-latitude trough located over the central U.S gradually eroded the ridge to the north and east of Matthew, allowing the hurricane to turn toward the north-northwest on 7 October. Matthew weakened to a category 3 hurricane around 0600 UTC 7 October about 35 miles east of Vero Beach, FL, and became a category 2 hurricane by 0000 UTC 8 October about 50 miles east-northeast of Jacksonville Beach, FL.

Hurricane Matthew moved northward around the western periphery of a subtropical ridge early on 8 October, remaining about 50 miles offshore of the Georgia coast. The approaching mid-latitude trough eroded the subtropical ridge further, causing the category 2 hurricane to make a sharp turn toward the northeast and weaken further. The now category 1 hurricane took a track nearly parallel to the coast of South Carolina, making landfall around 1500 UTC 8 October just south of McClellanville, South Carolina. The center of the hurricane moved back offshore of the coast of South Carolina by 1000 UTC, and remained just offshore of the coast of North Carolina early on 9 October. Matthew moved east-northeastward and lost its tropical characteristics by 1200 UTC 9 October before merging with a frontal system on 10 October east of Cape Hatteras, NC. Due to the tremendous damage and the number of injuries and deaths across the Caribbean and Southeastern U.S., the name "Matthew" was officially retired from the list of Atlantic tropical cyclone names.



Additional Details

Additional details are available from the following National Weather Service Offices...

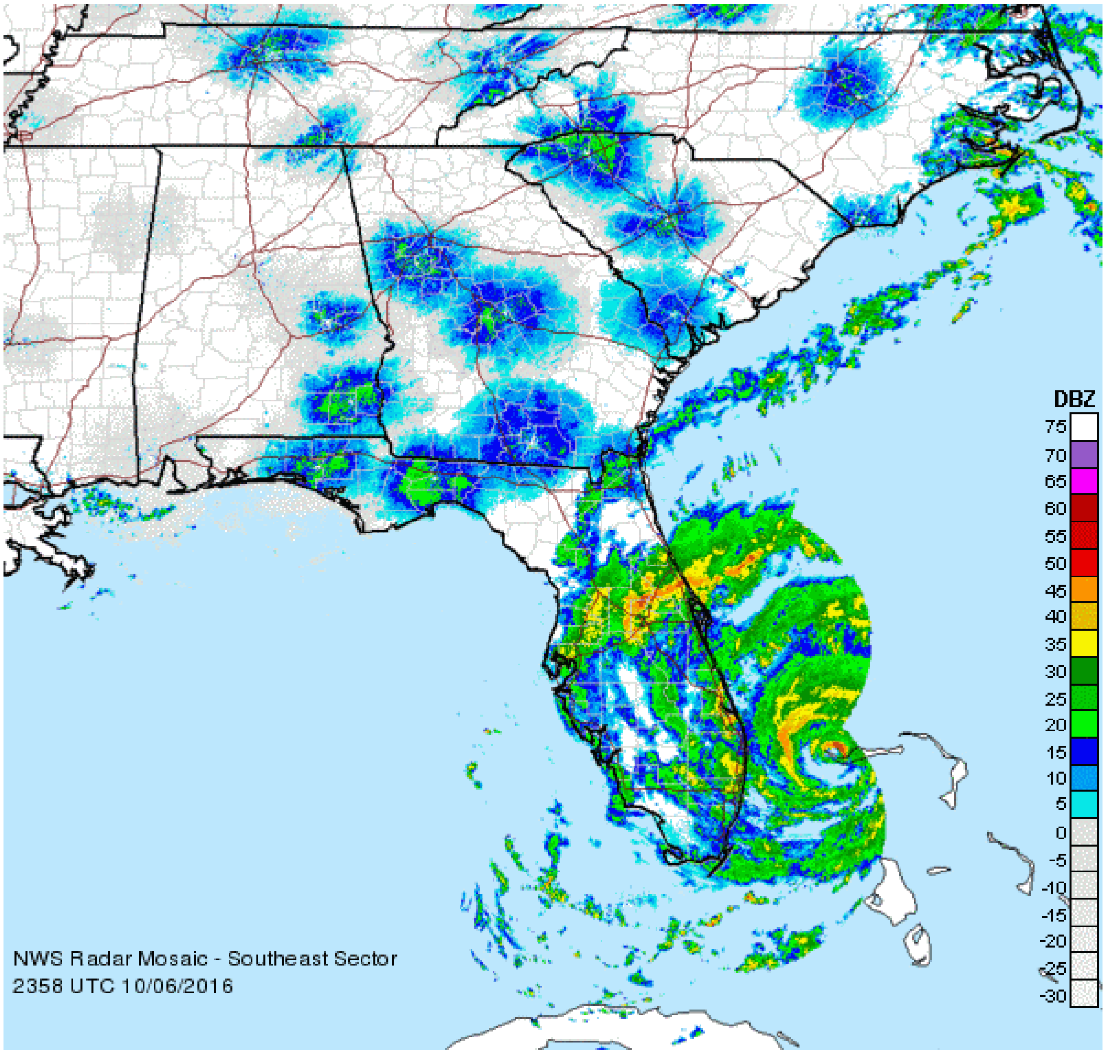
National Weather Service Wilmington, NC Hurricane Matthew Information

National Weather Service Newport, NC Hurricane Matthew Information

National Weather Service Charleston, SC Hurricane Matthew Information

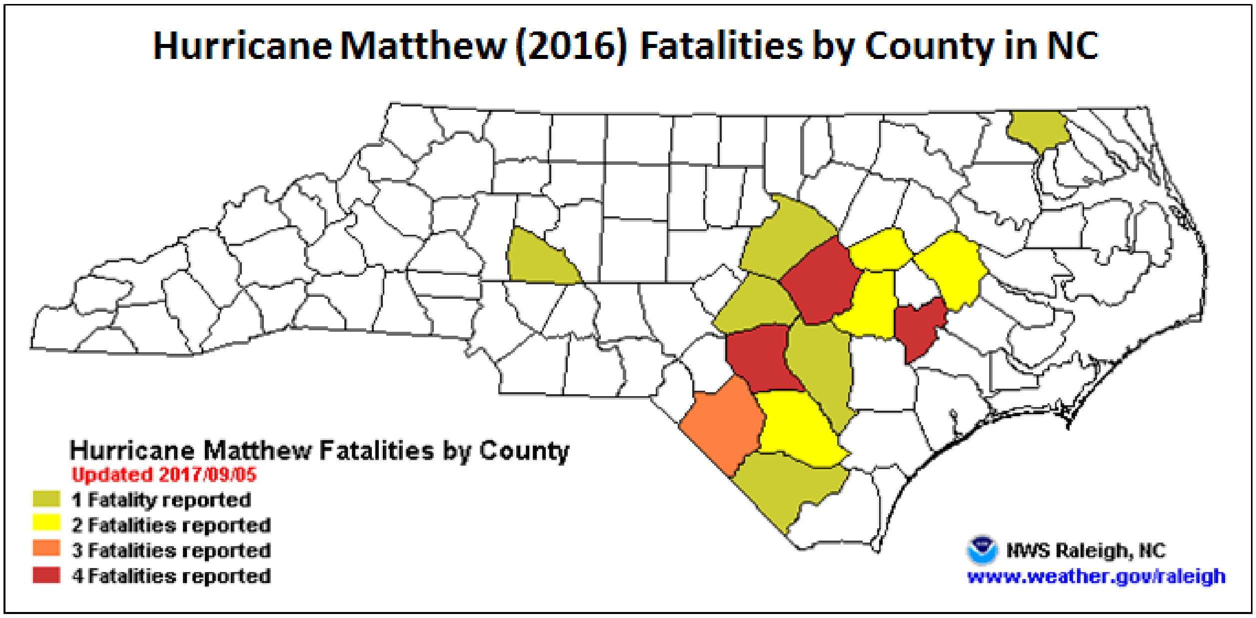
Regional Radar during Hurricane Matthew

The animation below is the base reflectivity regional radar composite across the Southeast during the time which Hurricane Matthew impacted the Southeast. The animation begins at 2358 UTC 06 October or 758 PM EDT on 06 October and runs through 1148 UTC 09 October or 748 AM EDT on 09 October. The radar loop shows the scattered showers and thunderstorms that moved into North Carolina from the southeast during the evening of 06 October which spread north and west through the morning and afternoon hours on 07 October. The main precipitation shield spreads into southern North Carolina during the evening on Friday 07 October and spreads north during the overnight hours into Saturday 08 October. Widespread heavy rain falls across most of central and eastern North Carolina during 08 October before gradually ending from southwest to northeast during the evening and overnight hours.

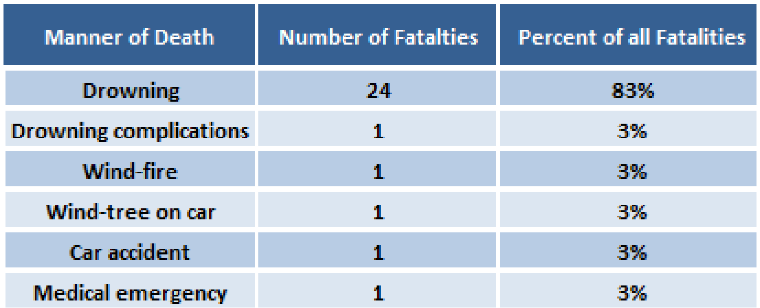


Fatalities across North Carolina from Hurricane Matthew

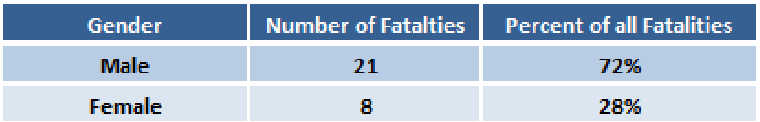
Hurricane Matthew impacted North Carolina with heavy rain and wind from late 07 October through early 09 October 2016. Detailed fatality information was collected from the NC Department of Public Safety, NC Emergency Management (NCEM) Division, and then merged with other local governmental and media reporting to produce a complete database. Based on an analysis of the data, we attributed 29 deaths across North Carolina to Hurricane Matthew. Four fatalities were attributed to Hurricane Matthew in Cumberland, Johnston, and Lenoir Counties. Three fatalities were associated with Matthew in Robeson County and two fatalities each in Bladen, Pitt, Wilson and Wayne Counties. It’s worth noting that the axis and location of the bulk of the fatalities is consistent and corresponds well with the location of the heaviest rain. All of the fatalities in North Carolina occurred across inland counties. Not a single fatality occurred in a county bordering the ocean, a sound or a bay.



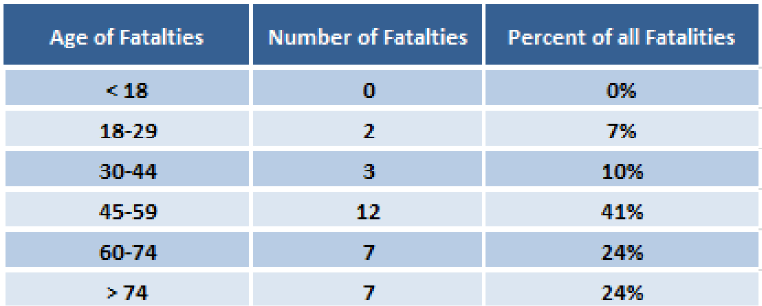
Rainfall-induced freshwater flooding that lead to drowning was responsible for more than three-quarters of the deaths (83%) associated with Hurricane Matthew. A total of 22 fatalities (76%) occurred in or in association with vehicles. Several of these fatalities were reportedly from drivers ignoring barricades or traveling down closed roads. Nearly three-quarters of the victims were males (72%). A plurality of fatalities (41%) were reported in the 45 to 59 year-old age group. Nearly 72% of the fatalities occurred on 9 October or later, after the heavy rain had ceased while nearly half of all of the fatalities (48%) occurred two days or more after the storm. Additional details and analysis of the fatalities across North Carolina were documented in a poster presented at the 42nd National Weather Association Meeting.



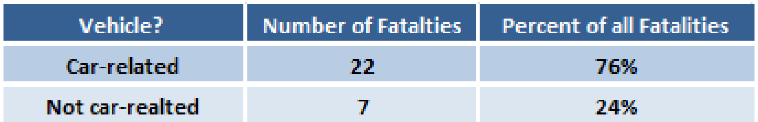
Manner of Death	Number of Fatalties	Percent of all Fatalties
Drowning	24	83%
Drowning complications	1	3%
Wind-fire	1	3%
Wind-tree on car	1	3%
Car accident	1	3%
Medical emergency	1	3%



Gender	Number of Fatalties	Percent of all Fatalities
Male	21	72%
Female	8	28%

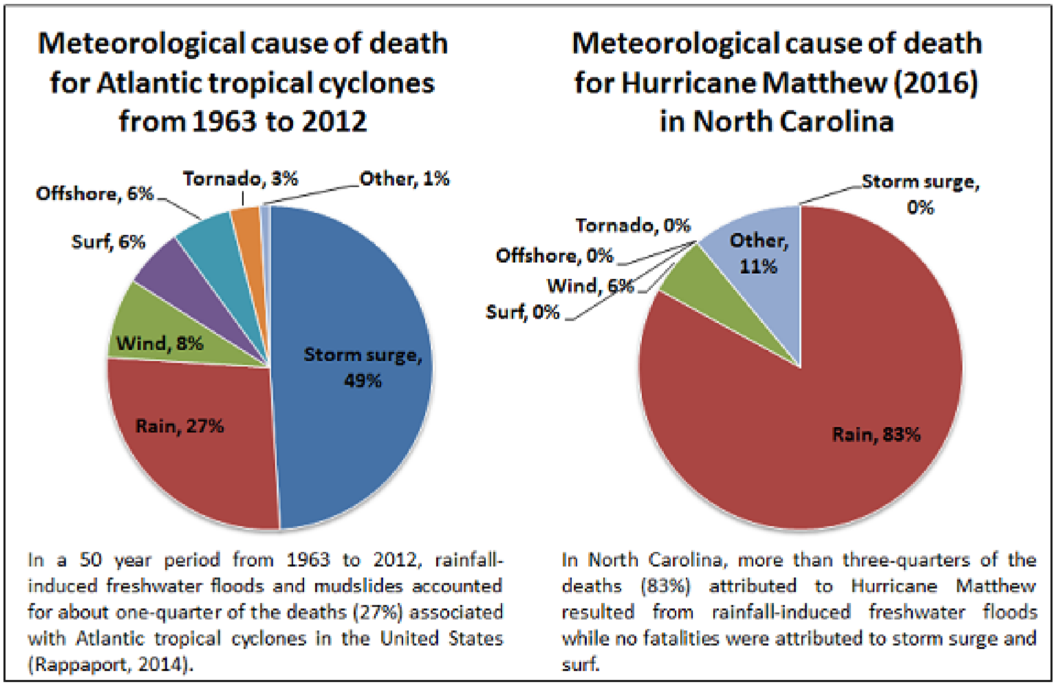


Age of Fatalties	Number of Fatalties	Percent of all Fatalities
< 18	0	0%
18-29	2	7%
30-44	3	10%
45-59	12	41%
60-74	7	24%
> 74	7	24%



Vehicle?	Number of Fatalties	Percent of all Fatalities
Car-related	22	76%
Not car-realted	7	24%

A study by Rappaport (2014) noted that in a 50 year period from 1963 to 2012, rainfall-induced freshwater floods and mudslides accounted for about one-quarter of the deaths (27%) associated with Atlantic tropical cyclones in the United States. In contrast, more than three-quarters of the deaths (83%) attributed to Hurricane Matthew in North Carolina resulted from rainfall-induced freshwater floods while no fatalities were attributed to storm surge and surf.



Meteorological cause of death for Atlantic tropical cyclones from 1963 to 2012

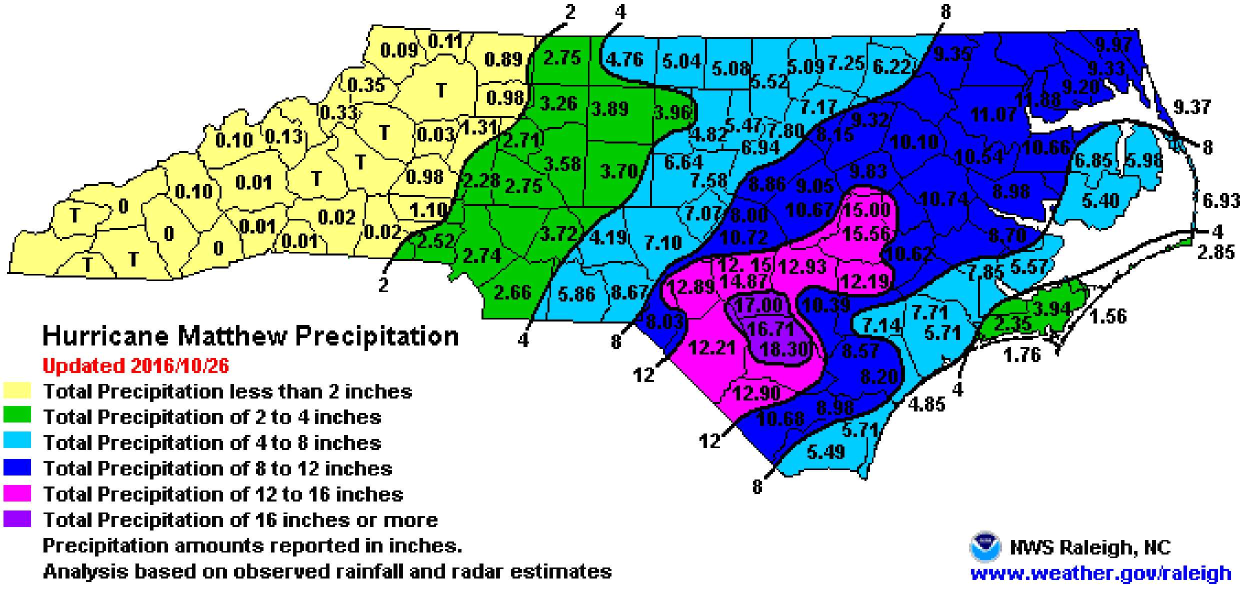
In a 50 year period from 1963 to 2012, rainfall-induced freshwater floods and mudslides accounted for about one-quarter of the deaths (27%) associated with Atlantic tropical cyclones in the United States (Rappaport, 2014).

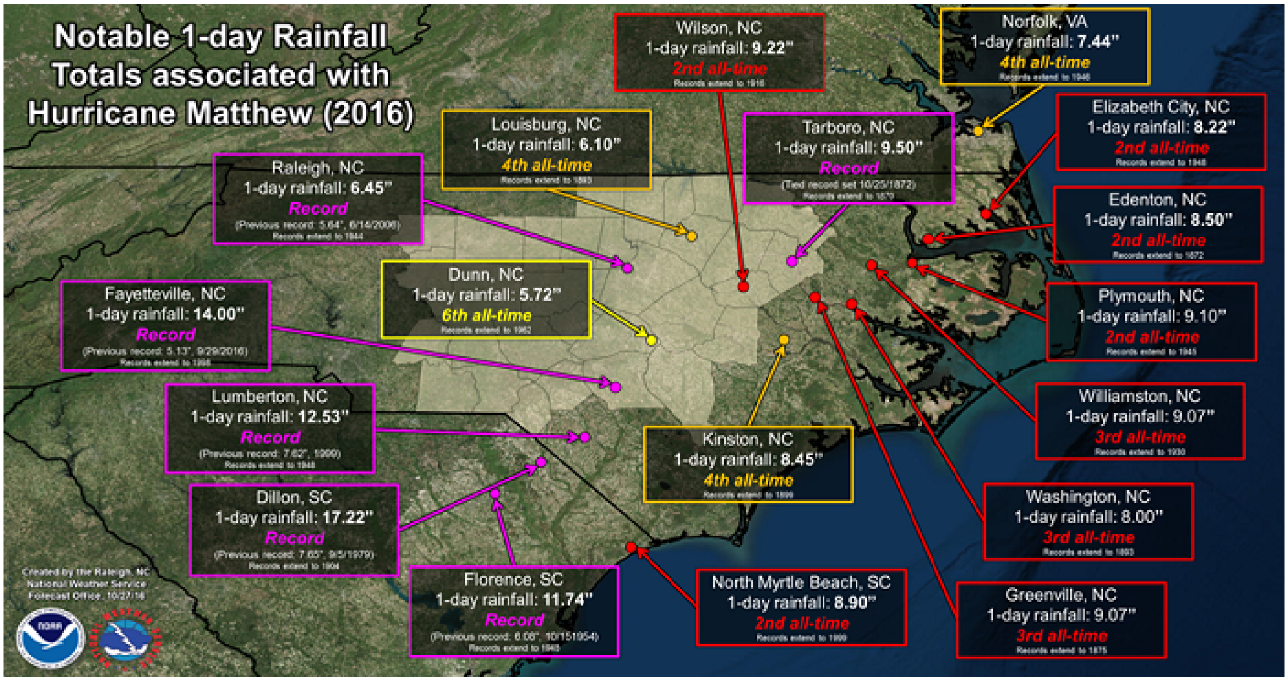
Meteorological cause of death for Hurricane Matthew (2016) in North Carolina

In North Carolina, more than three-quarters of the deaths (83%) attributed to Hurricane Matthew resulted from rainfall-induced freshwater floods while no fatalities were attributed to storm surge and surf.

Precipitation Totals from Hurricane Matthew

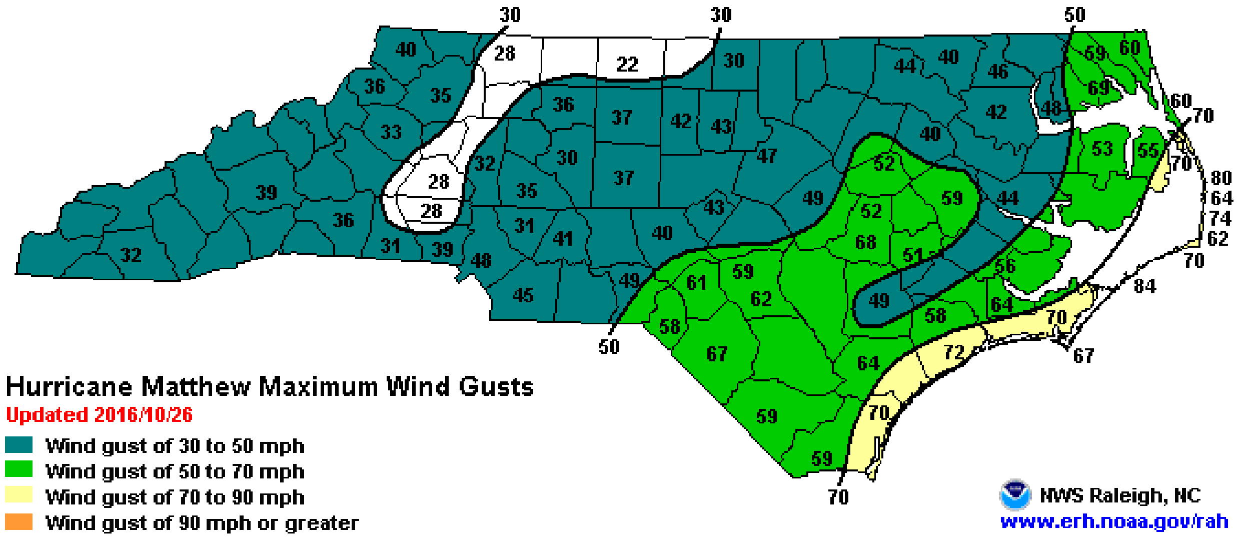
The axis of heaviest rain from Matthew across North Carolina fell west of the storm track in an arc from Lumberton northeast to near Fayetteville and Elizabethtown to near Goldsboro where rainfall amounts consistently ranged between 12 and 15 inches with a maximum of 16 to nearly 19 inches across portions of Bladen, Cumberland and Robeson Counties. Most locations from the eastern Piedmont near U.S. Route 1 east into the Coastal Plain near U.S. Route 17 received at least 6 inches of rain with most of these locations receiving between 8 and 10 inches of rain. Further west across the western Piedmont, rainfall totals were much less and ranged from 2 to 4 inches. Only an inch or so of rain fell in the Foothills with minimal values, mainly less than a third of an inch fell across the Mountains. It is also worth noting that there was a rainfall minimum in the Crystal Coast and southern Outer Banks regions where amounts ranged between 3 and 5 inches.





Maximum Wind Gusts from Hurricane Matthew

The map below contains the maximum wind gusts in miles per hour (MPH) from Matthew as it impacted the state from late on 07 October through early on 09 October. Most locations east of interstate 95 had wind gusts in excess of 50 MPH with gusts in excess of 70 MPH common across the across the coastal region from the northern Outer Banks southward to SC. Further west wind gusts of 40 MPH or more were observed across much of the Piedmont.

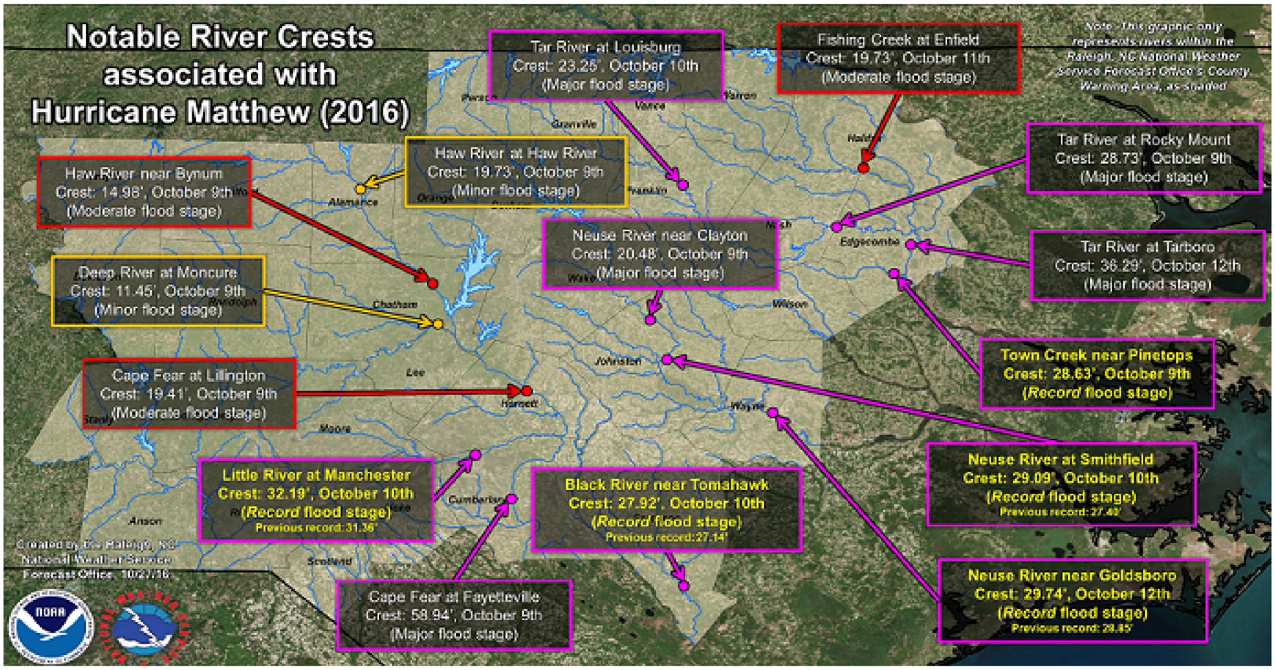


More than 1.6 million customers lost power across North Carolina during Hurricane Matthew. This total includes approximately 1.4 million Duke Energy Customers, 200,000 Dominion Power customers, and numerous other outages from other utilities. Most of the outages were associated with uprooted hardwood trees from a combination of strong winds and wind gusts along with saturated soils.

Across the RAH CWA, gusts in excess of 50 MPH were observed in 5 counties with gusts over 40 MPH observed in 15 counties.

River Flooding from Hurricane Matthew

Hurricane Matthew brought a period of very heavy rain to North Carolina from 07 October through 09 October 2016. Extreme rainfall amounts on the order or 12 to 18 inches produced several all-time one-day rainfall records, as well as widespread flash flooding and subsequent river flooding. More than 600 roads were closed, including portions of Interstates 95 and 40. More than 2,100 road repairs were required to fix shoulder washouts and damage to drainage structures such as pipes, reinforced concrete box culverts, and bridges. The N.C. Department of Public Safety's Floodplain Mapping Program reported that nearly 99,000 structures across the State were affected by floodwaters.



During extensive rainfall events like Hurricane Matthew, the NWS monitors the stage (you can think of this as the height or depth, in feet, of the water) on many streams and rivers across central NC. In addition, forecasts are routinely issued for points along the major rivers and both the actual stage and the forecasts are monitored using hydrographs (see images below). In the hydrographs below, the blue trace is the actual river stage and the purple trace is the forecast river stage issued by the NWS's Southeast River Forecast Center (SERFC). The stage axis on these hydrographs also indicates significant stages (Action stage, Minor flood stage, Moderate flood stage, Major flood stage, and the Record stage, when available).

During tranquil weather periods, the SERFC issues river forecasts once daily, however, during significant rainfall events forecasts are updated as often as needed to incorporate the latest information. These forecasts are crucial for issuing river flood warnings and conveying the severity of the event to the public and our partners, but there is one particular issue that NWS forecasters must consider. Given the uncertainty and potential inaccuracy of precipitation forecasts, the SERFC river forecasts only take into account the forecast precipitation for the next 48 hours. The river forecasts go out to 5 days, so if the precipitation is expected to fall beyond that 48 hour window, it will not be considered, and the resulting river forecast will seriously underestimate both how fast and how high the rivers will rise. This is illustrated well in the sequence of forecasts below for Goldsboro (GLDN7). Early forecasts for GLDN7 (figures 1 & 2 below) did not incorporate rainfall associated with Matthew until the evening of the October 6th, and even then the amount of rainfall was initially underestimated. Consequently, the forecasts only performed well for the first 48 hours, but rapidly became unrepresentative and in essence, useless beyond 48 hours. Subsequent forecasts (figures 3-5 below) were increasingly accurate as updated rainfall forecasts were incorporated nearer the onset of the event.

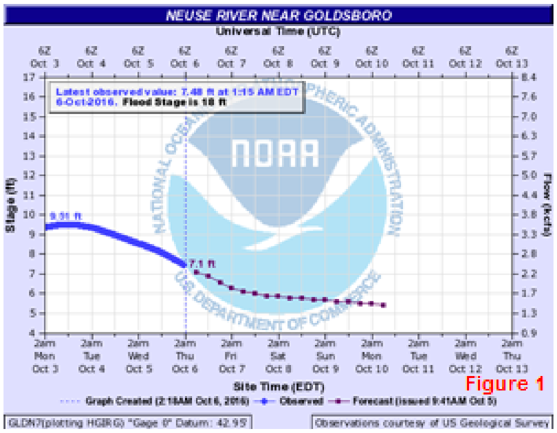


Figure 1

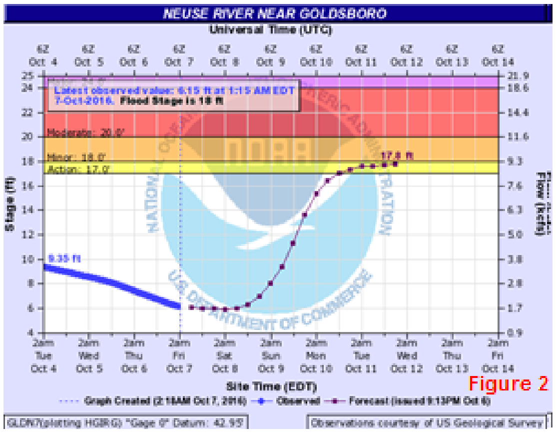


Figure 2

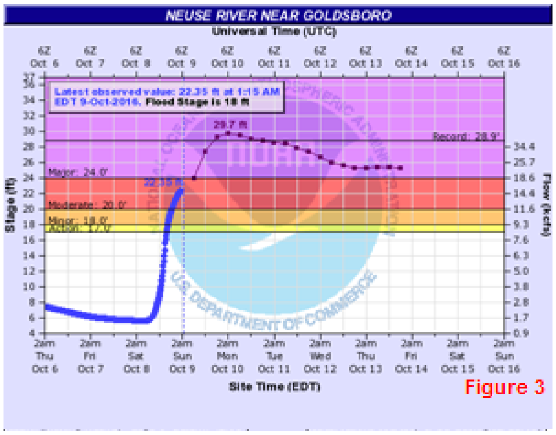


Figure 3

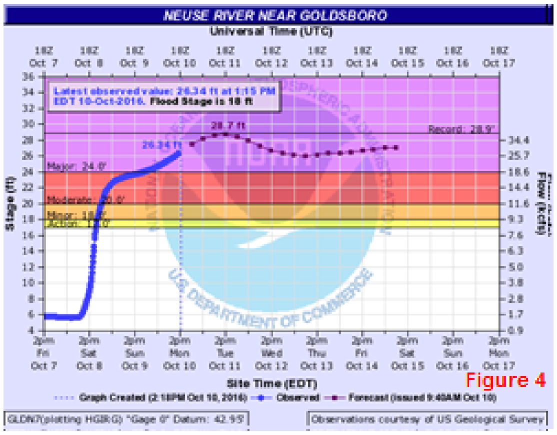


Figure 4

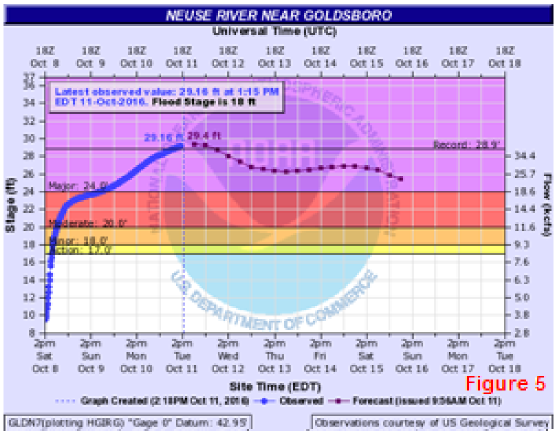
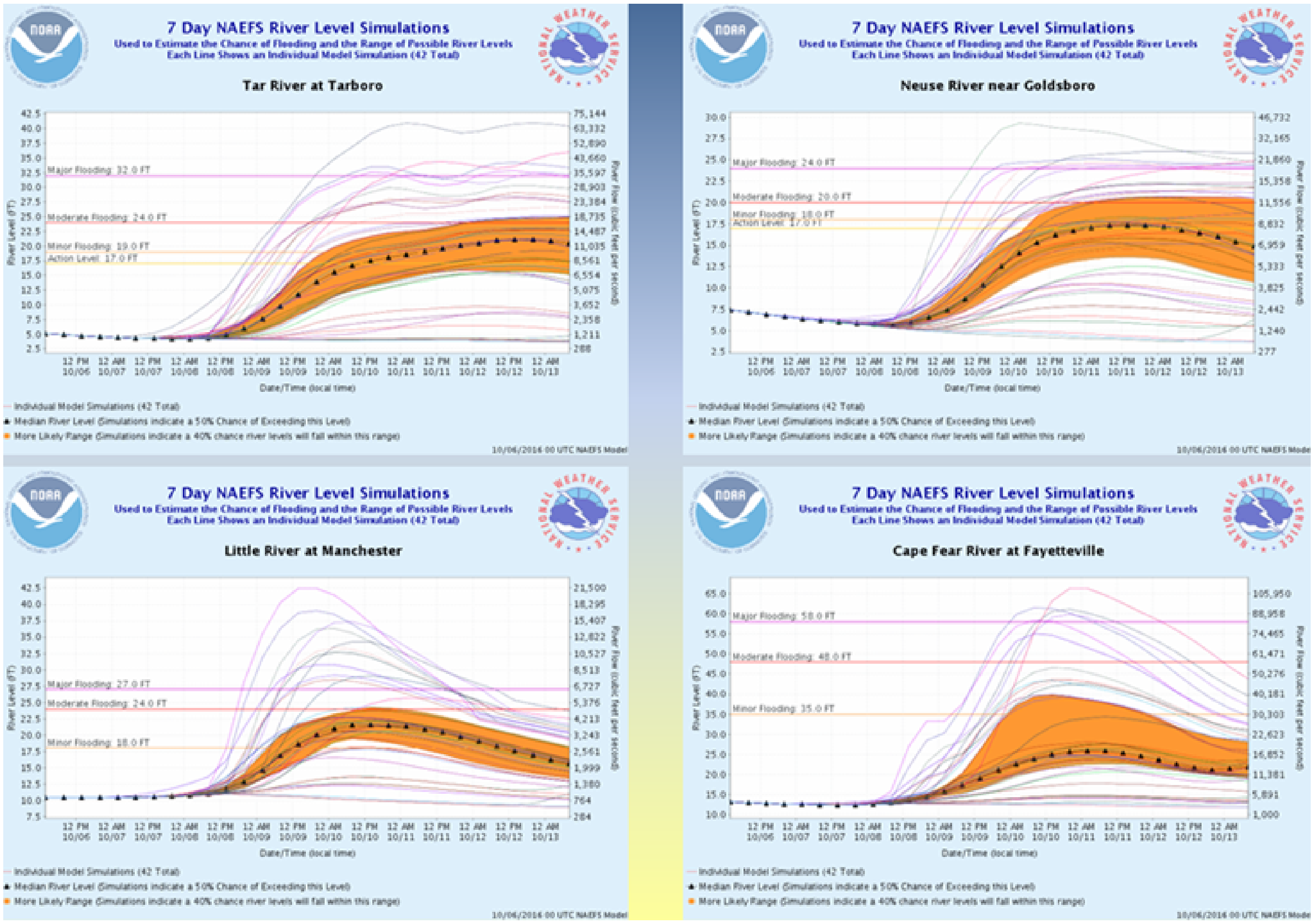
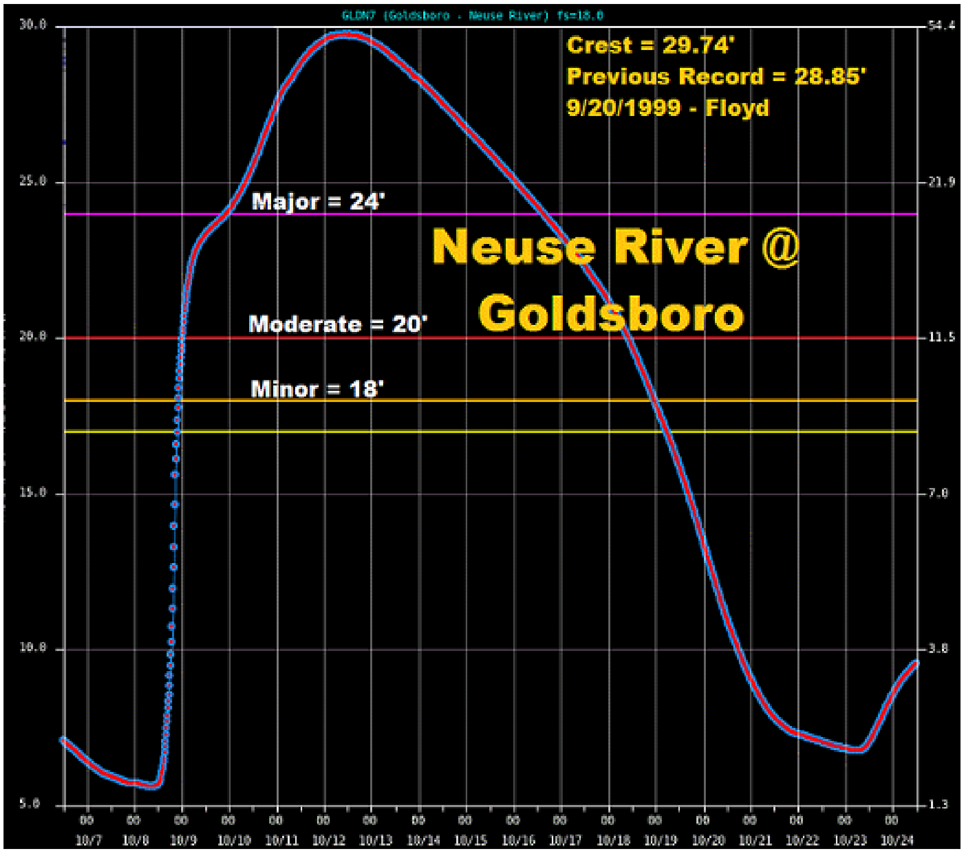


Figure 5

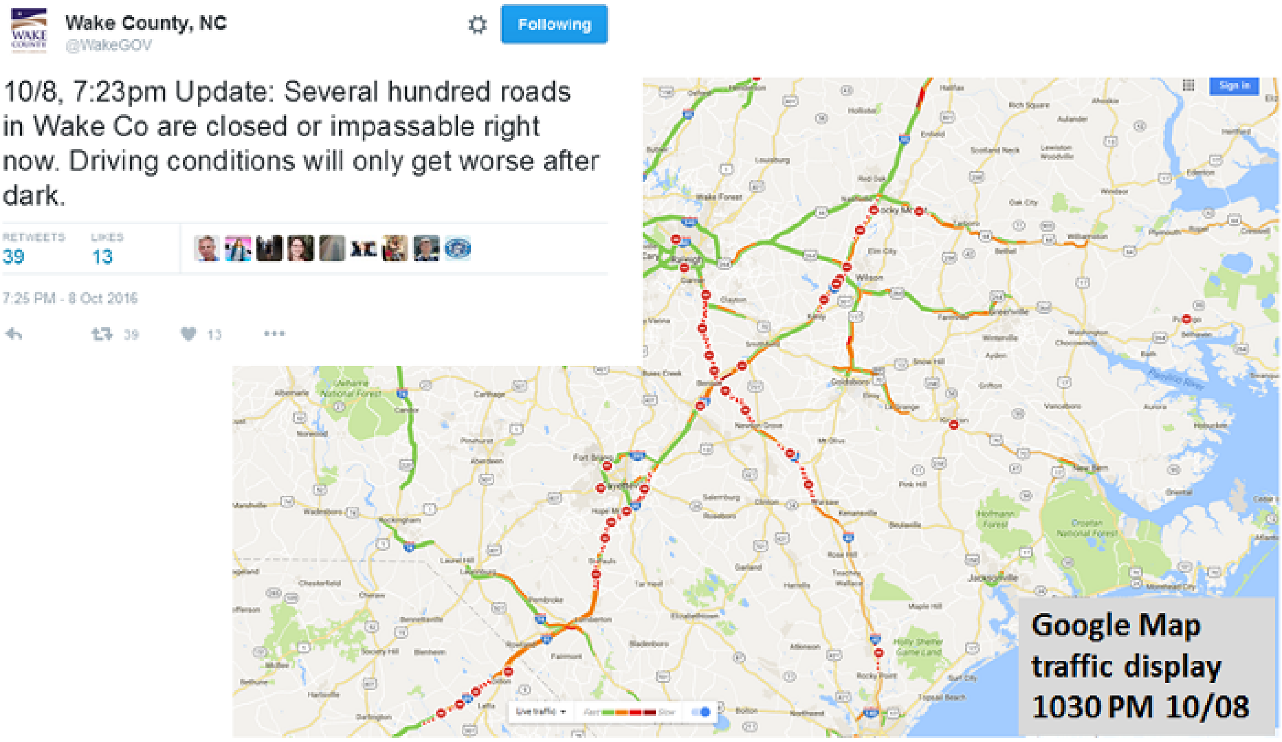
One resource available to forecasters and decision makers to help with longer term forecasts of river levels is the use of ensemble or probabilistic forecast data. Ensemble data allows the forecasters to see what the range of possible outcomes are and to infer the possible impacts and probability that they could occur. The image below shows probabilistic river forecast data for 7 days from the Meteorological Model Ensemble River Forecasts (MMEFS) system from the NAEFS ensemble system beginning on the morning of October 6 for the Tar River at Tarboro, the Neuse River at Goldsboro, the Little River at Manchester and the Cape Fear River at Fayetteville. Each line on the hydrograph shows a different ensemble member with the orange shaded area showing the most likely river level range.



Much of the river flooding on the Cape Fear, Neuse and Tar Rivers spanned several days to over a week in some cases. While during Floyd the worst of the flooding was along the Tar River, during Matthew it was the Neuse that was hit the hardest. Record stages were set at both Smithfield (29.09 feet) and Goldsboro (29.74 feet), exceeding the records set by Fran and Floyd, respectively. Also quite impressive was the length of time the forecast points along the Neuse and Tar River basins stayed above Major flood stage. Along the Tar, Roanoke Rapids was in major flood for over 3 days and Tarboro was in major flood for over 5 days. Along the Neuse, Clayton was in major flood for almost 2 days, Smithfield was in major flood for over 3 days and Goldsboro was in major flood for well over 6 days. One could infer the effect the river forecast issue would have on trying to accurately reflect the extent and duration of this flooding event.



In addition to river flooding, flash flooding was also an issue. The image below shows a Google map of traffic and road closures across central and eastern North Carolina from 1030 Pm EDT on 08 October 2016. Orange and red shading on highways indicate slow or stopped traffic with red circle icons depicting road closures. The overlaid tweet from @WakeGov notes that at 723 PM EDT on 08 October, several hundred roads in Wake County alone were closed or impassable.



Wake County, NC
@WakeGOV

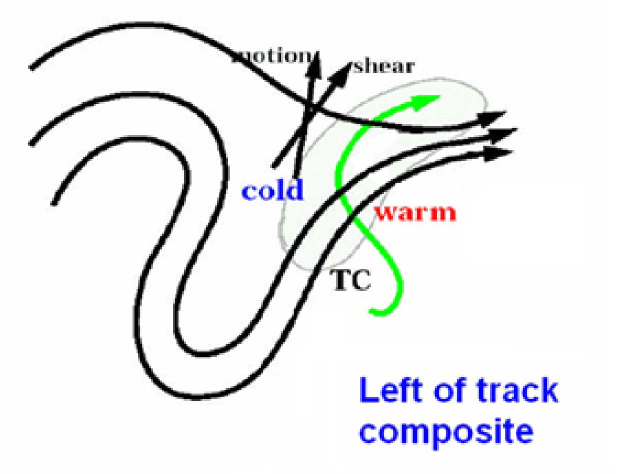
10/8, 7:23pm Update: Several hundred roads in Wake Co are closed or impassable right now. Driving conditions will only get worse after dark.

RETWEETS 39 LIKES 13

7:25 PM - 8 Oct 2016

<

Left of Track Precipitation Distribution



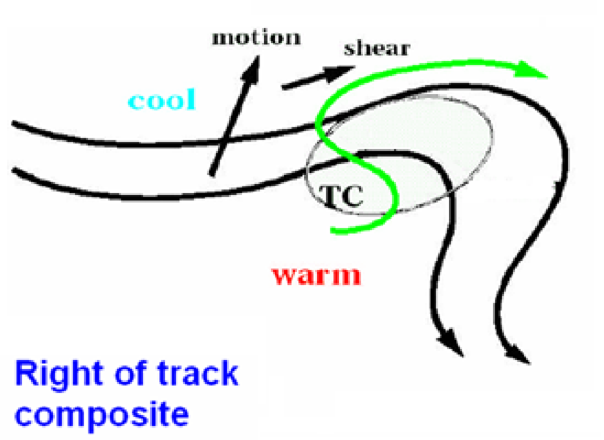
Adapted from Atallah et al. (2007)

Atallah et al. (2007) studied the distribution of precipitation accompanying U.S. landfalling and transitioning tropical cyclones. In the two conceptual models from Atallah et al. (2007) shown to the right and below, the curved black lines represent streamlines of the upper-tropospheric flow. Arrows represent motion and deep tropospheric shear with the relative magnitudes given by the length of the arrow. The curved green line represents the trajectory of a parcel starting near the surface in the warm sector and ending in the mid to upper-troposphere in the cool sector. The area inside the light gray circle represents regions of precipitation.

One portion of the study composited 14 cyclones that had the bulk of their rainfall occur to the left (west) of the track (LOT) of the cyclone circulation. Their composite argues strongly that storms that have most of their rainfall distributed on the west side of storm's track interact with upper level trough and potential vorticity maximum in a synergistic way. In addition, the axis of precipitation of LOT storms often is aligned parallel to the movement of the storm which increases the period of heavy rainfall. The 850-200 hPa shear in the composite suggests that there was a strong jet streak present to the north or northwest of the cyclone and implies that the storm was located near the right entrance region of a jet streak where frontogenesis is favored. The composite also suggests that the axis of the upper trough shifts from having a slight positive tilt or neutral one to having a negative tilt as the storm undergoes extratropical transition. Storms undergoing a transition to becoming extratropical typically have their heaviest rainfall LOT.

A left of track precipitation distribution is often characterized by a positively tilted mid-latitude trough approaching the tropical cyclone from the northwest. The precipitation stretches out well north of the system due to impulses moving around the upper trough and frontogenesis ahead of the trough. The trough often transitions from a positive to negative tilt during its interaction with tropical cyclone.

Recent tropical cyclones with a left of track precipitation distribution include Alberto (2006), Gaston (2004), and Floyd (1999).



Adapted from Atallah et al. (2007)

Another portion of the Atallah et al. (2007) study composited 16 cyclones that had the bulk of their rainfall occur to the right (east) east of the track (ROT) of the cyclone circulation. These composites indicate that the axis of the 850-200-hPa shear is typically oriented more westerly than the more north-south oriented axis associated with LOT cases. The location of the upper level jet streak is much farther removed for ROT cases than for LOT cases. The baroclinic zone as shown by the leading edge of the 1000-500 hPa thickness is also much farther removed from the storm. The 1000 hPa circulation is much weaker, especially on the northern side where there is a much weaker gradient implying that the easterly low-level winds are quite a bit weaker for ROT storms than LOT storms.

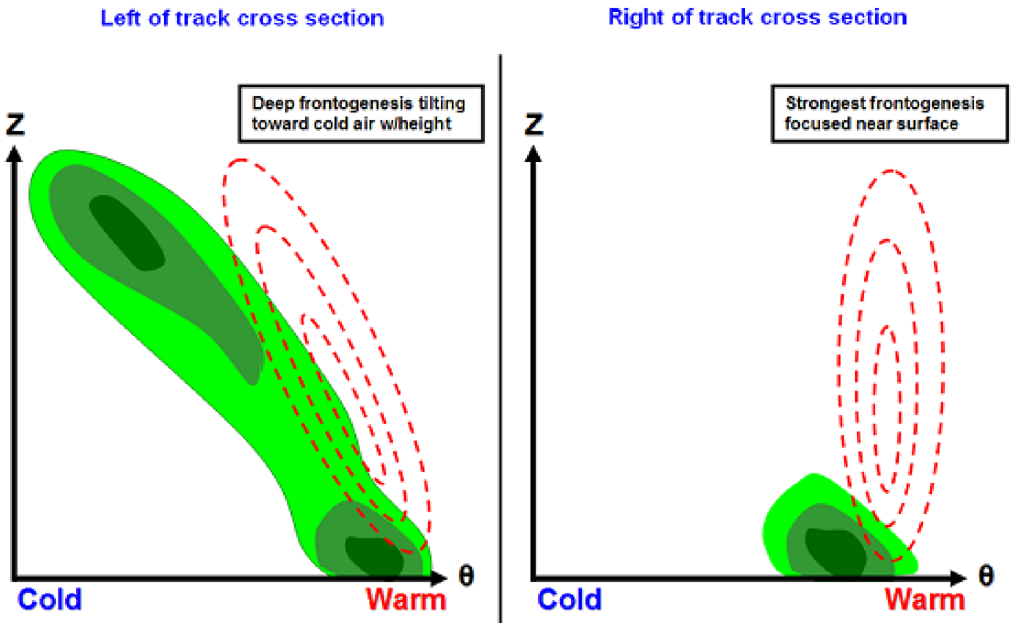
A right of track precipitation distribution is often characterized by tropical cyclones that are generally steered by shear lines or through a break in the subtropical ridge. Rainfall tends to be concentrated near and right of track. When the downstream ridge amplifies in response to diabatic heating ahead of a weak mid-latitude trough, the increased shear shifts precipitation to the right of the storm track.

Recent tropical cyclones with a right of track precipitation distribution include Ernesto (2006), Isabel (2003), and Bertha (1996).

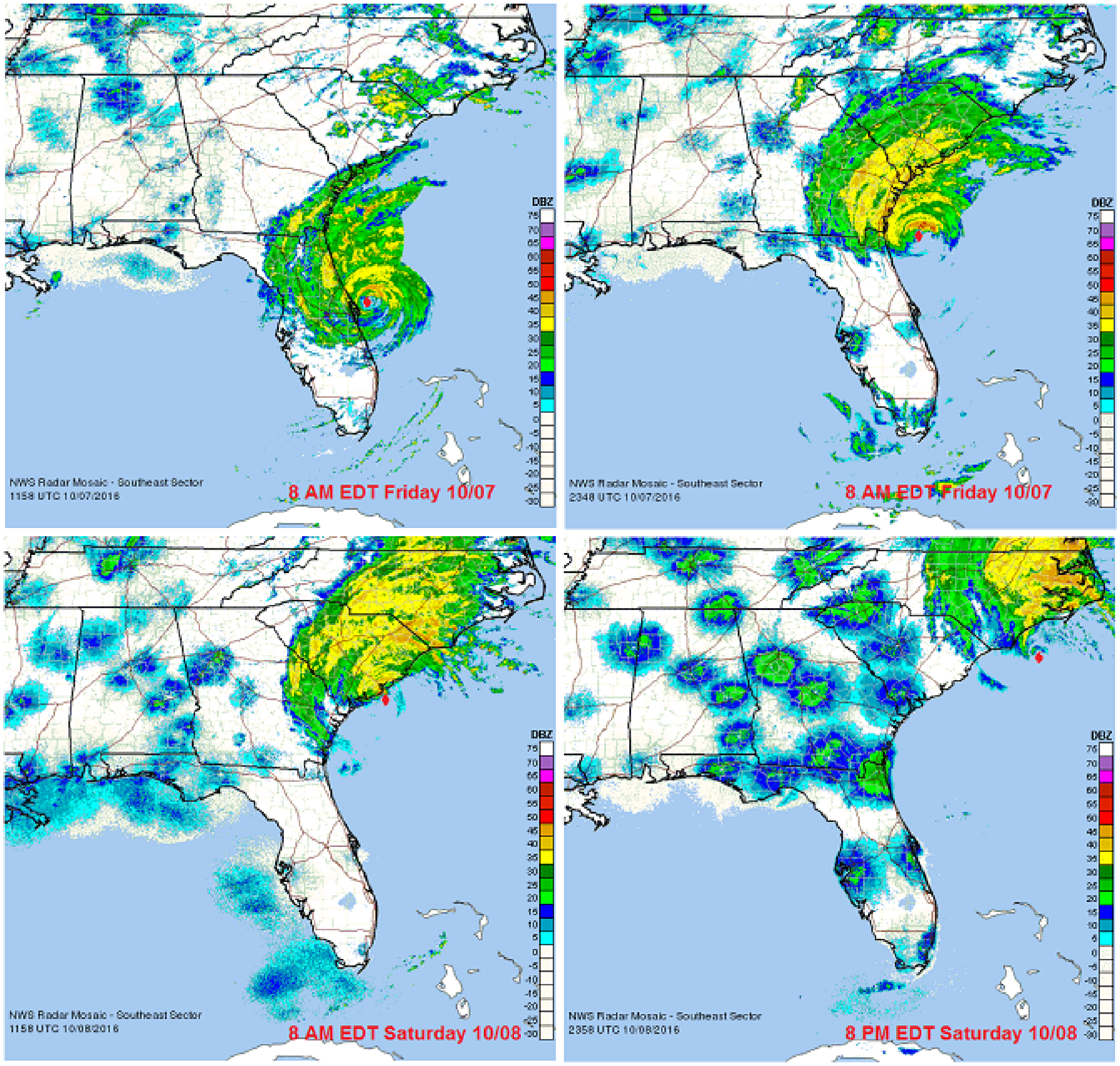
Klein (2007) noted important differences in the vertical structure across the surface boundary in the LOT and the ROT conceptual cross sections. These cross sections, which are constructed parallel to the lower-level (e.g., 925–500-hPa) layer-averaged thermal gradient and across the region of strongest frontogenesis, include the frontogenesis and vertical motion fields. The cross section include frontogenesis which is shaded in green and vertical velocity dashed and contoured in red.

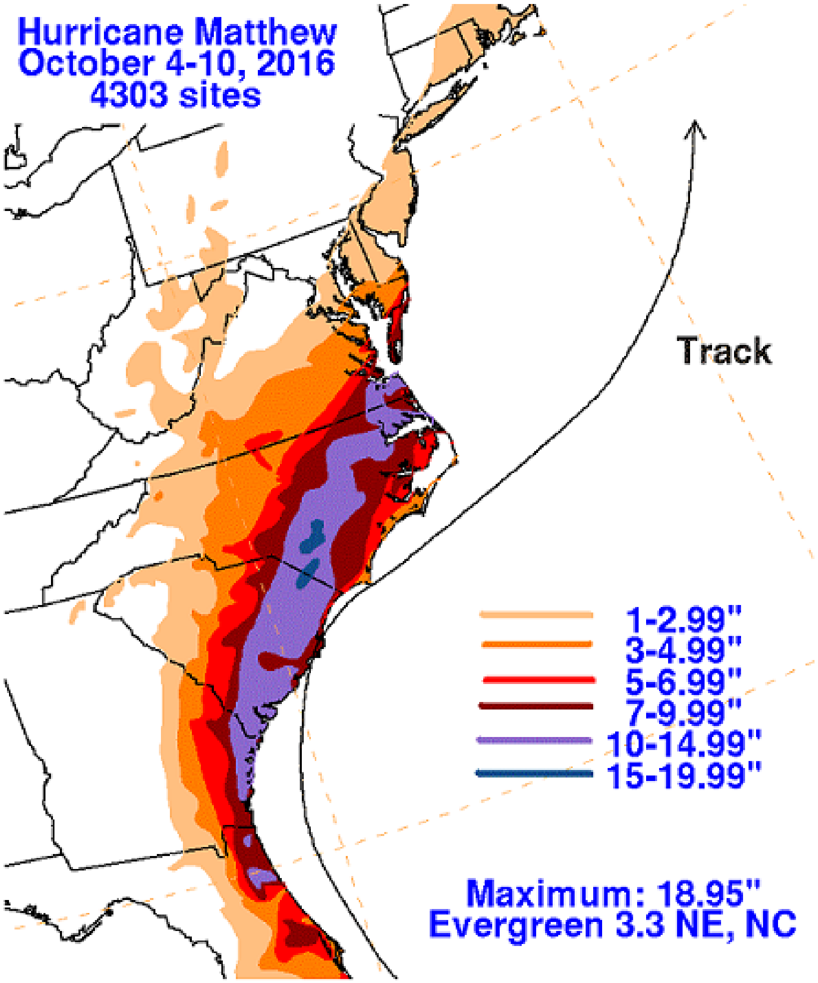
The warm-frontal boundary associated with LOT cases is characterized by a very deep frontogenesis pattern that tilts toward the cooler air with height and is strongest in the boundary layer and at upper-levels. The ascent pattern tilts toward cooler air with height and is located on the warm side of the frontogenesis maximum. Ascent is greatest in the mid-troposphere above and on the warm side of the frontogenesis region. The warm-frontal boundary illustrated in the ROT schematic contains strong frontogenesis that is largely confined near the surface. Strong, upright ascent is located over and on the warm side of the frontal boundary with the largest values immediately above the boundary layer.

The four panel image below shows the regional radar reflectivity at approximately 8 AM EDT Friday 07 October, 8 PM EDT Friday 07 October, 8 AM EDT Saturday 08 October, and 8 PM EDT Saturday 08 October with the storm center noted by the red tropical cyclone icon. The imagery shows the evolution to a left of track precipitation distribution as the storm moved north on 07 October. This precipitation distribution fits the pattern recognition technique as noted by Atallah et al. (2007). In addition, the impacts of processes associated with Matthew beginning the extratropical transition, the adjustment of precipitation distribution via cold air damming and surface boundaries, and larger scale shear.



Adapted from Klein 2007





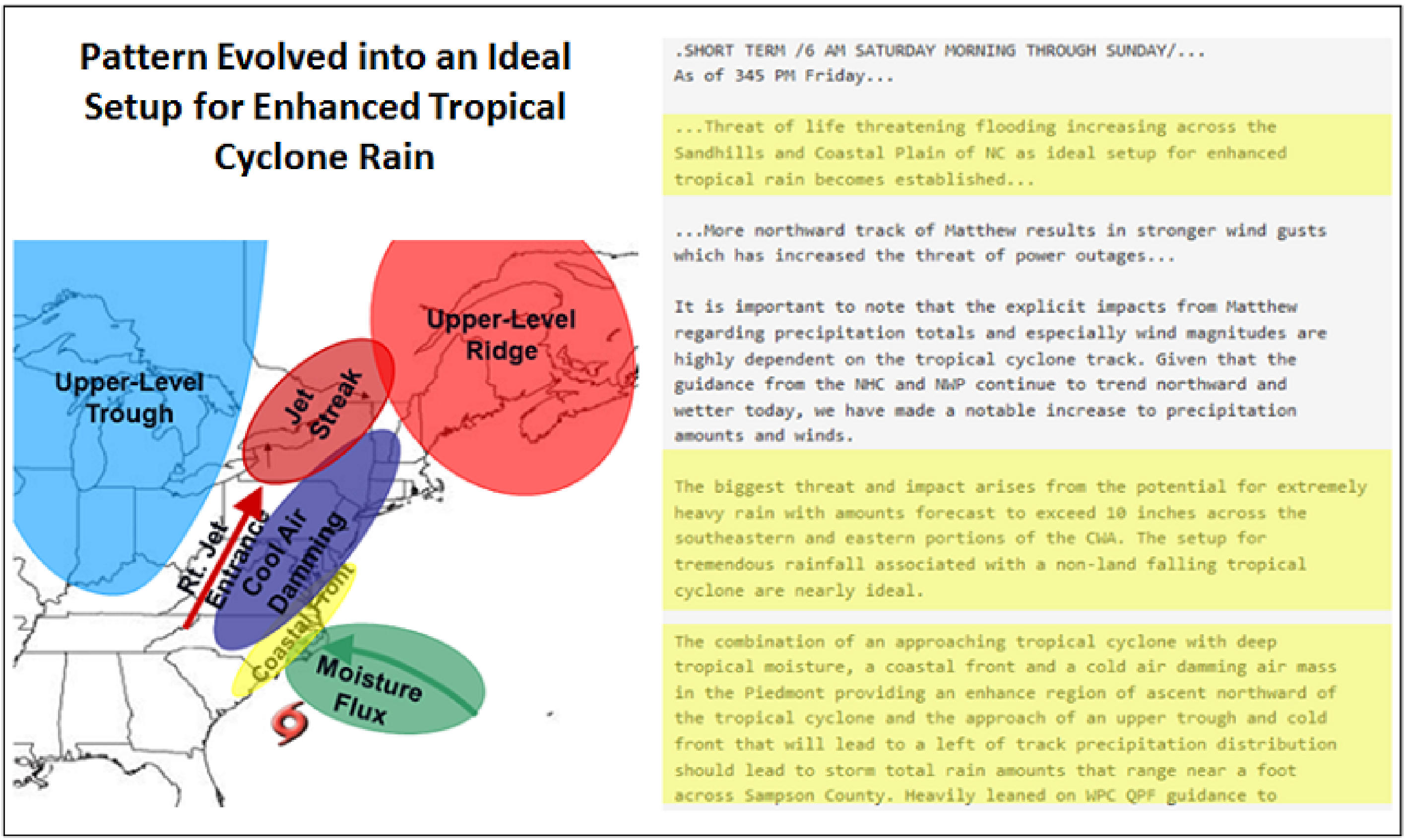
Weather Pattern Evolved into An Ideal Setup for Enhanced Tropical Cyclone Rain

Enhanced precipitation and the distribution of the heaviest rainfall associated with tropical cyclones have been examined in numerous studies. Croke (2006), in collaborative research between NC State and several Mid-Atlantic National Weather Service Forecast Offices, developed a conceptual model of a pattern favorable for enhanced precipitation due to the interaction of a tropical cyclone with other meteorological features prior to landfall. This paradigm gives forecasters an indication of the potential for an enhanced precipitation event by identifying features that may exist at different temporal and spatial scales outside of the tropical cyclone.

The synoptic and mesoscale patterns across the eastern United States prior to and during the time in which Hurricane Matthew impacted North Carolina fit the conceptual model for enhanced tropical cyclone precipitation. Recognition of the pattern in the days leading up to the storm’s arrival allowed forecasters at the NWS Raleigh, NC to highlight the potential for anomalously high rainfall amounts and flooding in forecast products prior to the storm. This was noted in the 345 pm Friday Area Forecast Discussion. The pattern was documented in a poster presented at the 17th Conference on Mesoscale Processes.

Features consistent with the conceptual model included...

1. Tropical cyclone in close proximity to the Carolinas with slow to moderate tropical cyclone translation speed
2. Upper level trough over Great Lakes/Ohio Valley
3. Strong upper-level divergence inland and poleward of the tropical cyclone associated with a northern stream jet streak
4. Strong inland moisture flux prior to landfall
5. Development of a coastal front
6. A cold air damming wedge of cooler/more stable air with a surface high pressure system centered over the northeast



Pattern Evolved into an Ideal Setup for Enhanced Tropical Cyclone Rain

```
.SHORT TERM /6 AM SATURDAY MORNING THROUGH SUNDAY/...
As of 345 PM Friday...

...Threat of life threatening flooding increasing across the
Sandhills and Coastal Plain of NC as ideal setup for enhanced
tropical rain becomes established...

...More northward track of Matthew results in stronger wind gusts
which has increased the threat of power outages...

It is important to note that the explicit impacts from Matthew
regarding precipitation totals and especially wind magnitudes are
highly dependent on the tropical cyclone track. Given that the
guidance from the NHC and NWP continue to trend northward and
wetter today, we have made a notable increase to precipitation
amounts and winds.

The biggest threat and impact arises from the potential for extremely
heavy rain with amounts forecast to exceed 10 inches across the
southeastern and eastern portions of the CWA. The setup for
tremendous rainfall associated with a non-land falling tropical
cyclone are nearly ideal.

The combination of an approaching tropical cyclone with deep
tropical moisture, a coastal front and a cold air damming air mass
in the Piedmont providing an enhance region of ascent northward of
the tropical cyclone and the approach of an upper trough and cold
front that will lead to a left of track precipitation distribution
should lead to storm total rain amounts that range near a foot
across Sampson County. Heavily leaned on WPC QPF guidance to
```

Damage Photos

The photos below were obtained by the NWS Raleigh from various sources including local government officials, local media, storm spotters and the public. Click on the images below to open a larger image.

Flooding off of Highway 701 in Four Oaks. Photo by Robert Richardson (WNCN)

Flooding in Grantham, Wayne County. Photo by Renee Best Young via WNCN.


Road washed out on Greenock Avenue in Fayetteville. Photo taken by Fayetteville Police via WNCN.


Flooding in the Hood Road area of Wayne County. Photo by Renee Best Young via WNCN.


Aerial view of flooding in Princeville. Photo taken by NCDOT via WNCN.

Flooding on Walking Trail Way in Hope Mills. Photo by Jimmy Money via WNCN.


Flood Rescue in Stoney Point. Photo taken by Capt Joe Belcher via ABC 11

National Guard in Lumberton, NC Photo Credit: Princess Meryn and James Davis

F-15 fighter jets return home to a flooded Seymour Johnson AFB. Photo Via Seymour Johnston AFB Facebook page.
Photo by Robert Richardson (WNCN)

A sinkhole opened up on Ticker Rd in Sampson County. Photo taken by WNCT via WNCN

Archived Text Data from the Event

Select the desired product along with the date and click "Get Archive Data."
Date and time should be selected based on issuance time in GMT (Greenwich Mean Time which equals EDT time + 4 hours).

Product ID information for the most frequently used products...

RDUAFDRAH - Area Forecast Discussion
RDUHWORAH - Hazardous Weather Outlook
RDUSPSRAH - Special Weather Statement
RDULSRRAH - Local Storm Reports (reports of severe weather)
RDUFFWRAH - Flash Flood Warning
RDUFFSRAH - Flash Flood Statement
RDUFLSRAH - Flood Statement
RDUSVRRAH - Severe Thunderstorm Warning
RDUSVSRAH - Severe Weather Statement
RDUTORRAH - Tornado Warning
RDUZFPRAH - Zone Forecast Products
RDUAFMRAH - Area Forecast Matrices
RDUPFMRAH - Point Forecast Matrices

* Scroll down for list from October 08 2016

Get Archive Data

References

Atallah, E., L. F. Bosart, and A. Aiyyer 2007: Precipitation Distribution Associated with Landfalling Tropical Cyclones over the Eastern United States. *Mon. Wea. Rev*., **135**, 2185-2206.

Atallah, E and L. F. Bosart, 2003: Extratropical transition and precipitation distribution: A case study of Floyd (1999). Mon. Wea. Rev., **131**, 1063-1081.

Blaes, J.L. and B. Locklear, 2017: Analysis of Fatalities across North Carolina Resulting from Hurricane Matthew. 42nd NWA Annual Meeting, 16-21, Sep 2017.

Croke, M.S., 2006: Examining Planetary, Synoptic, and Mesoscale Features that Enhance Precipitation Associated with Landfalling Tropical Cyclones in North Carolina.

Hart, R. E., 2003: A cyclone phase space derived from thermal wind and thermal asymmetry. *Mon. Wea. Rev*., **131**, 546-564.

Hart and Evans, 2001: A climatology of the extratropical transition of Atlantic tropical cyclones. J. Climate, 14, 546– 564.

Hart, and Evans, 2003: Analyzing and forecasting cyclone structural transition using cyclone phase diagrams. Proc. Second Int.

Klein, J. R., 2007: Mesoscale Precipitation Structures Accompanying Landfalling and Transitioning Tropical Cyclones over the Northeast United States. M.S. thesis, University at Albany.

Klein, J. R., 2006: Mesoscale Precipitation Structures Accompanying Landfalling and Transitioning Tropical Cyclones over the Northeast United States. Northeast Regional Operational Workshop 8, Albany, New York.

Musser, J.W., Watson, K.M., and Gotvald, A.J., 2017, Characterization of peak streamflows and flood inundation at selected areas in North Carolina following Hurricane Matthew, October 2016 (ver. 2.0, August 2017): U.S. Geological Survey Open-File Report 2017–1047, 23 p., https://doi.org/10.3133/ofr20171047.

Rappaport, E. N., 2014: Fatalities in the United States from Atlantic tropical cyclones: new data and interpretation. Bull. Amer. Meteor. Soc., 95, 341–346.

Acknowledgements

Many of the images and graphics used in this review were provided by parties outside of WFO RAH. GOES satellite data was obtained from National Environmental Satellite, Data, and Information Service. Other satellite imagery was obtained from CIRA and the Naval Research Laboratory Monterey Marine Meteorology Division. SPC meso-analysis graphics provided by the Storm Prediction Center. Google Earth map imagery used under license. Web based power outage maps provided by Progress Energy. Photos courtesy of the National Weather Service in Raleigh.

Case Study Team

Kathleen Carroll
Shawna Cokley
William Ellis
Brandon Locklear
Michael Moneypenny
Keith Sherburn
Brandon Vincent
Nick Petro
Jonathan Blaes