The Historic South Carolina Rainfall and Major Floods of October 1-5, 2015

Hope Mizzell, Mark Malsick, Wes Tyler

AUTHORS: SC State Climatology Office, SC Department of Natural Resources, 1000 Assembly Street, Columbia, South Carolina, 29201, USA.

Abstract. A record setting and historic rainfall event occurred October 1-5, 2015, producing widespread and significant flooding across much of South Carolina. The rainfall resulted from several atmospheric and hydrometeorological factors. The record rainfall triggered flash floods and riverine flooding that resulted in emergency evacuations, travel disruptions, personal property damage, business losses, bridge collapses, dam failures and tragic loss of life. Precipitation records were broken from the midlands to the coast, with totals ranging from 10 to over 26 inches of rain. Sixteen National Weather Service Cooperative Weather Stations set new 24-hour rainfall records for October. The amount of rainfall during the event at various locations and for various durations (6-, 24-, 48-, 72-, 96- hours) had a statistical probability of occurrence of 0.1% or 1 in 1,000 chance of happening in any given year, according to the National Oceanic and Atmospheric Administration (NOAA) Atlas 14. Streams and creeks swelled out of their banks with at least 17 U.S. Geological Survey (USGS) stream gages reaching record peaks. The event was the worst flooding most residents had ever experienced. This report will provide a synoptic and chronological overview of how the historic rain and flooding unfolded with documentation of the meteorological and hydrological records. A comprehensive interactive journal of the event is available on-line at <http://www.dnr.sc.gov/flood2015>.

INTRODUCTION

Flooding is the most common and costly natural hazard in the United States (Federal Emergency Management Agency, 2016). About 75% of presidential disaster declarations are related to flooding. Flooding is the leading cause of severe weather related deaths (National Weather Service, 2016). While flooding can happen anywhere in South Carolina, flooding typically occurs in the floodplains. Floodplains are areas adjacent to streams and rivers that are prone to flooding. Approximately 13% of the State's land is mapped floodplain which does not account for waterways without

detailed mapping (South Carolina Department of Natural Resources, 2008). South Carolina ranks 6th in the nation for the highest number of National Flood Insurance Policies.

The flooding threat to South Carolina includes: flash floods, river flooding, storm surge and coastal inundation from tropical and non-tropical systems, local drainage issues and dam or levee failures. Additional elements affecting flooding include antecedent soil moisture, topography, and development. Many of these factors and elements played a role in the historic October 2015 rainfall. This report will provide the synoptic and chronological evolution of the historic October 2015 rain and flooding with documentation of the meteorological and hydrological records.

HYDROMETEOROLOGICAL EVOLUTION

Prior to the October 2015 flood most of South Carolina was dealing with drought which may have reduced the overall severity of flooding in some basins. Had the ground been completely saturated and surface water conditions been above normal the flood impacts would have likely been enhanced. Until the last week of September rainfall had been persistently below normal for most locations. However, from September 24, 2015 until September 30, 2015, rain showers fell across the state triggered by a frontal boundary that stalled along the coast which increased ground saturation and water levels in many ponds, lakes, creeks and rivers ahead of the October rain.

Rainfall amounts of one to six inches were recorded by various observing sites. On October 1, a cold front swept across the State and stalled offshore as a strong high pressure built over eastern Canada. Simultaneously, Hurricane Joaquin rapidly deepened to a Category 4 Hurricane over the Bahamas and an upper level cut-off low became blocked in place over southern Georgia by the ridge of high pressure to the north. As these features aligned, steady rain fell from October 1-3. By late on October 3, the strong flow of tropical moisture off the warm Atlantic waters was locked in place (Figure 1). The blocked features aloft created a strong divergence mechanism that forced intense convection producing

Figure 1. NOAA water vapor with overlay of parameters contributing to the heavy rain.

the torrential rains beginning before sunrise on Sunday, October 4th. The pattern rapidly weakened on Monday, October 5, as the stalled coastal front dissipated and the upper level cold core low drifted eastward over the Atlantic resulting in lingering light rain over the Pee Dee region.

CHRONOLOGICAL SUMMARY

The October historic rainfall occurred a week after an extended period of one to six inches of state-wide rain. This was the slow beginning of South Carolina's record rains and flooding. Weather models were consistently projecting another 10 to 20 inches of rain could be expected and the National Weather Service began issuing warnings that a "historic and potentially-life threatening rainfall event" was possible. Rainfall intensities and reports of flooded roadways started to increase for many coastal counties on October 1-2. Forty-eight hour rainfall measurements ending on the morning of October 3, included Community, Collaborative, Rain, Hail, and Snow Network (COCORAHs) volunteer reports of 12.64 inches near Georgetown and 11.28 inches at Folly Beach. Rainfall continued statewide on October 3; however, there was a distinct gradient of heavy rains falling over the coastal plain to much lower totals being reported across the Upstate. For the three day period ending at midnight October 3, Greenville-Spartanburg Airport had only received 2.25 inches while Charleston Airport had already set an all-time monthly October rainfall record of 14.48 inches in just three days (Table 1). Just after midnight on October 3, intense rains expanded into the Midlands. The Richland County Emergency Services, Gills Creek automated gage reported an unprecedented total of 10.64 inches in four hours (1.76" from 2-3:00 a.m., 3.76" from 3-4:00 a.m., 3.00" from 4-5:00 a.m. and 2.12" from 5-6:00 a.m.). Rainfall rates over many central South Carolina watersheds overwhelmed flood control structures resulting in a succession of dam and spillway failures. The Congaree River went to a "major flood" stage of 31.81 feet on October 4 before the 120-year old Broad River diversionary Canal breached on the morning of October 5 (Tyler, W, 2015).

Table 1. October 1-5 Daily Rainfall for NWS Stations, Columbia Hamilton-Owens Airport, Charleston Airport, Greenville-Spartanburg Airport, and Florence.

Station	Daily Rainfall Totals (inches) Ending at Midnight				
	10/1	10/2	10/3	10/4	10/5
Columbia Hamilton-Owens	0.03	0.60	2.95	8.35	0.52
Charleston	1.37	1.61	11.50	2.81	0.03
Greenville-Spartanburg	0.06	1.26	2.99	1.99	Trace
Florence	0.55	4.73	2.03	3.04	0.79

RAINFALL SUMMARY

Many locations in South Carolina received between four to seven consecutive days of rainfall during the event. All-time precipitation records were broken from the midlands to the coast, with totals ranging from 10 to over 26 inches of rain (Figure 2a). Figure 2b provides the average return interval (ARI) for the highest 96-hour rainfall totals that fell between September 30-October 7. The map was created by translating observed rainfall into its equivalent average return interval (ARI) using NOAA Atlas 14 Volume 2. Many locations received 96-hour rainfall totals exceeding the ARI of 100 years and 17% of the State received rainfall exceeding the 1,000 year ARI. Figure 2c shows the average return interval graph for the COCORAHs gage in Mount Pleasant. The graph illustrates the 2-day, 4-day, and 7-day rainfall at this site exceeded the 1,000 year average return interval, which in terms of annual exceedance probability (AEP), is equal to a 0.1% probability of occurring in any given year.

The rainfall associated with the flooding set records at many weather stations across South Carolina. Nine stations set annual daily records for highest rainfall for any 24-hour observation period (Table 2), 16 stations set highest rainfall recorded for any 24-hour observation period during the month of October, and 22 stations received the highest total October monthly rainfall ever (only stations with at least 30 years of record were included). Numerous station set new records for greatest 2-, 3-, and 4-day totals. The combination of the early October rainfall and a persistent pattern of above normal precipitation throughout the remainder of October and November resulted in monthly and seasonal records for many stations such as:

- Statewide average October 2015 rainfall of 12.17 inches surpassed the previous record of 11.56 inches set in October 1990

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Figure 2. (a) 96-Hour Highest Rainfall Total, (b) Highest Average Return Interval Occurring Between 9/30-10/7, 2015, and (c) Average Return Interval Graph for the Mount Pleasant COCORAHs gage.

- 34 stations set new fall (September-November) total rainfall records
- Statewide average autumn (September-November) precipitation total of 23.62 inches was 13.77 inches above average and bested the previous autumn record of 18.42 inches set in 1959

STREAMFLOW RECORDS

U.S. Geological Survey (USGS) peak streamflow and peak stage data for the October 2015 flood indicated new peak streamflow records were set at 17 USGS stream gages, with an additional 15 USGS stream gages having October 2015 peaks that ranked in the top 5 for the period of record (Feaster and others, 2015). In the Pee Dee River Basin, a new peak of record was recorded on October 6, 2015, for station 02136000, Black River at Kingstree, which has 87 years of record going back to 1928. In addition, historic peak stage data from the National Weather Service indicates the October 2015 peak was the largest since at least 1893. The probability of occurrence for the October 2015 peak flow at Black River was determined to be greater than a 1 in 500 chance flood in any given year, which in terms of AEP, is less than a 0.2 percent chance flood, and in terms of recurrence intervals, is greater than a 500-year flood (Musser and others, 2016). At other USGS stream gages in the Midlands and

Table 2. Annual daily records for highest rainfall recorded for any 24-hour observation period.

Highest Rainfall Recorded for Any 24-hour Observation Periods				
Station	New Record (inches)	New Record Ending Date	Old Record (inches)	Old Record Date
Andrews	8.80	10/4/15	7.60	10/06/05
Antreville	6.10	10/4/15	5.10	9/17/75
Charleston Airport	11.50	10/3/15	10.52	9/20/98
Columbia Airport	6.87	10/4/15	5.79	07/08/59
Little Mtn.	7.35	10/4/15	7.04	06/23/24
Manning	8.55	10/4/15	5.65	09/04/79
Moncks Corner	9.40	10/4/15	7.60	12/18/09
Saluda	7.74	10/4/15	7.15	09/30/29
Sumter	10.67	10/4/15	8.68	09/16/45

Coastal areas of South Carolina, the October 2015 flood recurrence intervals ranged from about a 0.5 percent AEP to a 10 percent AEP (200-year recurrence interval to a 10-year recurrence interval, respectively). USGS station 02169500, Congaree River at Columbia, SC, has one of the longest peak-flow records of all of the USGS stream gages in South Carolina going back to 1892. The October 2015 peak flow at the Congaree River station was 185,000 cubic feet per second (ft³/s) and was the eighth largest peak flow out of 123 years of record. The October 2015 peak flow was the largest recorded at the Congaree River gage since 1936 when the river peaked at 231,000 ft³/s (Feaster, 2016).

CONCLUSIONS

The historic rainfall of October 1-5, 2015 resulted from the interaction of several hydrometeorological factors. Diffluent outflow dynamics from a rapidly intensifying Hurricane Joaquin, interacting aloft with a deepening upper-level trough over southern Georgia, and a stalled surface frontal boundary off the coast, provided a powerful lift mechanism for a steady plume of abundant sub-tropical moisture from abnormally warm Gulf of Mexico and western Atlantic waters (Malsick, 2015).

Thirty-six counties received a Presidential Disaster Declaration which allowed federal-relief programs to be made available to affected communities. Emergency responders completed over 1,500 water rescues. The flooding displaced over 20,000 citizens, closed over 500 roads and bridges, resulted in 50 dam failures, disrupted drinking water supply to over 40,000 residents and tragically took the lives of 19 persons. According to the South Carolina Emergency Management Division, the total cost of the disaster was \$2.2 billion (as of 9/12/16) which includes total government agency cost, private insurance claims and estimated agriculture losses (South Carolina Emergency Management Division, 2016).

Floods have the potential, in any given year, to be a destructive natural hazard for the citizens of South Carolina. Our varied topography and geographical proximity to the warm Gulf of Mexico and Atlantic waters render a regime capable of producing a spectrum of inundation ranging from short-term flash floods to large-scale watershed flooding. The historic rain and flooding in early October 2015 illuminated the State's vulnerabilities and deficiencies; highlighting the need for enhanced streamflow monitoring, improved flood modeling, and proactive floodplain management.

A comprehensive interactive journal of the October 2015 event is available on-line at <http://www.dnr.sc.gov/flood2015>.

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