Preliminary Damage Report

Hurricane Florence (14 September 2018)

Flooding and Wind Damage in the Carolinas

Source: Christina Maxouris and Hollie Silverman, CNN

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23 September 2018

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20 September, 2018

Executive Summary

Hurricane Florence caused inland flooding of historic proportions that produced major disruption through large regions of North and South Carolina. The hurricane cut access to Wilmington, NC, a city of 120,000 when bridges failed, and all roads leading to it were flooded. Evacuation orders were issued to over 1 million residents and thankfully the number of fatalities remain low (44 deaths as of today). Yet thousands of residents are waiting for flood waters to recede before they can return to their homes and begin cleanup and repairs. Millions of chickens and thousands of pigs were killed in flooded farms, and authorities are dealing with potential environmental contamination from breached waste ponds. While thousands of North Carolina residents are living through a shocking nightmare, hundreds of peer-reviewed papers exist extolling the inevitability of such flooding and proposing solutions to mitigate the damage.

To the *Wind Hazard Damage Assessment Group,* wind damage observations from Florence is secondary to the need for us to adapt post-event damage assessments and communication in response to the changing nature of natural hazards today. For decades, the magnitude of societal losses have grown in spite of the best efforts and valuable research by the natural hazards researchers. Is the Hurricane Florence damage an admission that the best of our engineering knowledge has failed these millions of people?

A paradigm shift towards public engagement is needed within the natural hazards research community. The public needs to have timely information from us that places the disaster in context and for implementing immediate solutions. We do not serve communities well if our best ideas remain locked in bibliometric databases, not discussed, not debated nor transferred into public policy. Hurricane Florence is the third US hurricane in two years to cause extensive flooding and only moderate wind damage. Climate change may be causative, but so too are the urban planning and policy decisions that contributed to creating the disasters. Thus, how shall we best prepare natural hazards researchers who are able to work with others to minimize damage from natural hazards? One way is for natural hazards researchers and engineers to change how we currently engage with, learn from and educate our communities.

- Our current research-publication cycle does not serve the public well. Natural hazard researchers must use their voices to speak up in the public square and effectively contribute to discussions on hazard-resiliency policy. Post-hazard damage assessment reports are valuable to provide immediate (preliminary) findings and recommendations to affected communities in a timely manner so they can be used to develop appropriate solutions. The (re)building of resilient societies begins the day after a hazard, which is why communities need to hear our expertise at that critical time.
- The training and research of future natural hazard engineers must reflect imperatives to work collaboratively among many disciplines. We must become better at engaging with policymakers, community leaders, the private sector and the general population. Future hazards engineers must appreciate the nuances of politics, social science, health sciences, economics and the law, as these impact upon our work.

The natural hazards research community has an opportunity to engage with North Carolina communities as they produce a vision for hazard-resilient coastal communities. Most likely many solutions already exist in the literature, and as natural hazards researchers we are best able to locate and to propose them.

About the *Wind Hazard Damage Assessment Group*

This report was prepared from online sources by University of Florida civil engineering students in Prof. David O. Prevatt's Research Group. The study is done in parallel to our experimental research seeking to understand and quantify the strength of tornadoes and their impact on vulnerable wood-framed residential structures. Compilation of this information is part of student learning objectives in forensic engineering and post-disaster damage investigation, in which we seek to communicate and engage affected communities with timely discussion and conclusions related to damage caused by wind hazards.

We believe that using this approach of "co-incident self-publication" of reports we will be able to reach communities immediately affected and share the latest research with them, when they are able to make choices during the rebuild and repair of their homes and businesses.

The students gathered the information from reliable online sources, such as the National Weather Service, Accuweather, the US Census Bureau and the national media. We have made judgements as to veracity of information. Photographs were also obtained from publicly available Twitter and Facebook profiles and links are provided to the original source documents.

Please visit our website, http://windhazard.davidoprevatt.com for additional information, and to download previous damage reports, and filed survey results conducted by our group. Dr. Prevatt and his colleagues have published several papers on recent violent tornadoes that struck Tuscaloosa, AL, Joplin, MO, and Moore, OK. His group has also inspected damaged structures and compiled reports on tornadoes that occur in Florida. Information is also available on the research at www.davidoprevatt.com. Your questions and comments on any aspects of our work are most welcome. Please direct your enquiries to graduate research assistant, Mr. Rodrigo Castillo-Perez who can be reached at rcastilloperez@ufl.edu.

The Wind Hazard Damage Assessment Group was created through support from the NSF Award #1150975. Its mission is to train university students interested in building construction, engineering and architecture in the forensic engineering and techniques for post-hazard damage surveys and data collection. The team has surveyed damage after several Florida tornadoes and continuously monitors the prevalence of tornadoes worldwide. Our goal is to inspire upcoming engineers and building professionals, who appreciate the serious role we have to communicate hazard mitigation information to communities affected by these events.

Development of Hurricane Florence

On 28 August 2018, the National Hurricane Center first mentioned the likelihood for development of Hurricane Florence, a long-track Cape Verde hurricane. The weather system went through various intensification cycles, up to a Category 4 hurricane before weakening again. Hurricane Florence made landfall as a Category 1 strength hurricane on the south-east coast of North Carolina at 7:15 AM EDT 14 September 2018, about five miles east of Wilmington, NC and moving in a westerly direction at 6 mph.

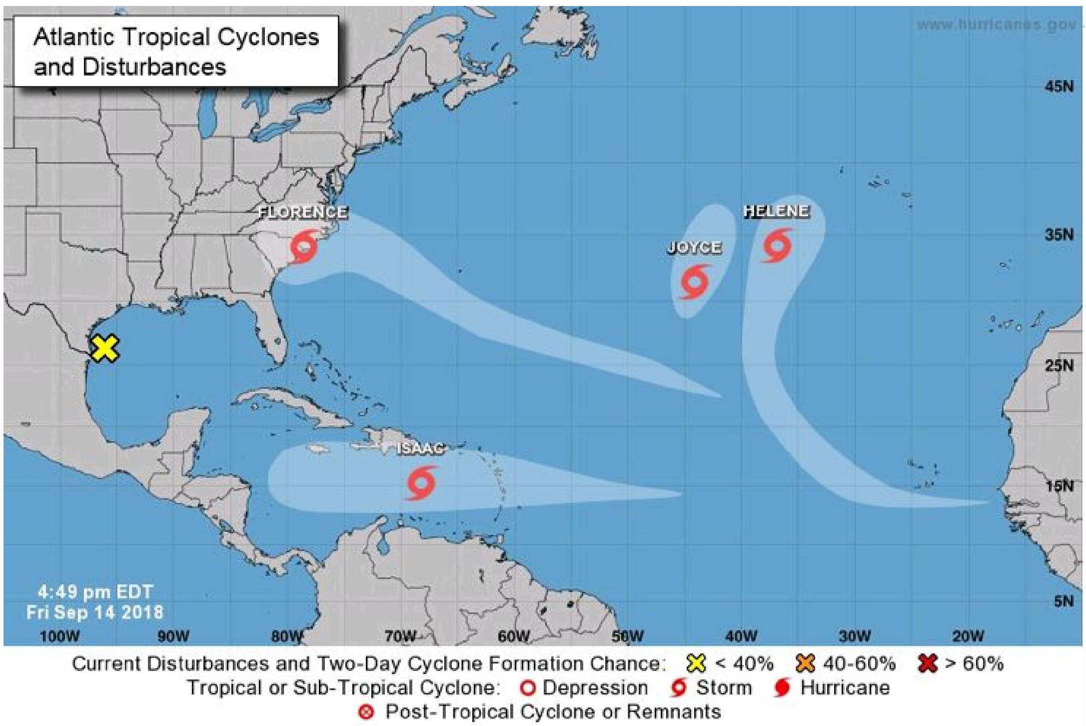


Figure 1: Four Hurricanes Active at the same time in September 2018,
Source NOAA: https://www.nhc.noaa.gov/archive/xgtwo/gtwo_archive.php?current_issuance=201809142050&basin=atl&fdays=5

Progress of Hurricane Florence from Cat 4 to Tropical Depression

Figure 2: shows the development of the Hurricane Florence during several stages from the National Hurricane Center Advisory Archive archive. Of interest is the fact that the hurricane progressively weakened from its peak Category 4 strength on 11 September,2018, through Cat. 3 on 12 Sept, Cat 2 on 13 Sept. through category 1 and tropical storm. During this time the forward speed of the hurricane slowed and it essentially lingered for several days blanketing North and South Carolina coastal regions with heavy rainfall given the storm heading and its wind strength high storm surge was predicted. The NC Governor issued a mandatory evacuation order that includes and applies to municipalities and counties located along the barrier islands of North Carolina.

Storm Surge, Heavy rainfall, and flooding

Hurricane Florence produced storm surge which combined with tides caused many coastal areas to experience flooding. The National Hurricane Center predicted storm surge heights between 7 and 11 ft between Cape fear and Cape Lookout NC, and lower urge heights in South Carolina of 2 to 4 ft from Edisto Beach to South Santee River.

After the hurricane made landfall, Florence essentially stalled over the Carolinas as it continued to generate moderately strong wind speeds of up to 70 mph while following a westerly track at 3 mph. The slow movement contributed to tremendous amount of rainfall, of up to 40 in. in places, causing many rivers there, i.e. the Neuse, Pamlico, and Bay Rivers in South Carolina and the Cape Fear and Salvo Rivers to reach extreme flood levels NHC.

Figure 2: Flooded waters in Jacksonville, NC reported by The Sun News
http://www.myrtlebeachonline.com/

The flooding was exacerbated by the heavy rainfall intensities within a few days. Coastal areas, including Wilmington, NC experienced between 30 and 50 in. of rainfall (Figure 3).

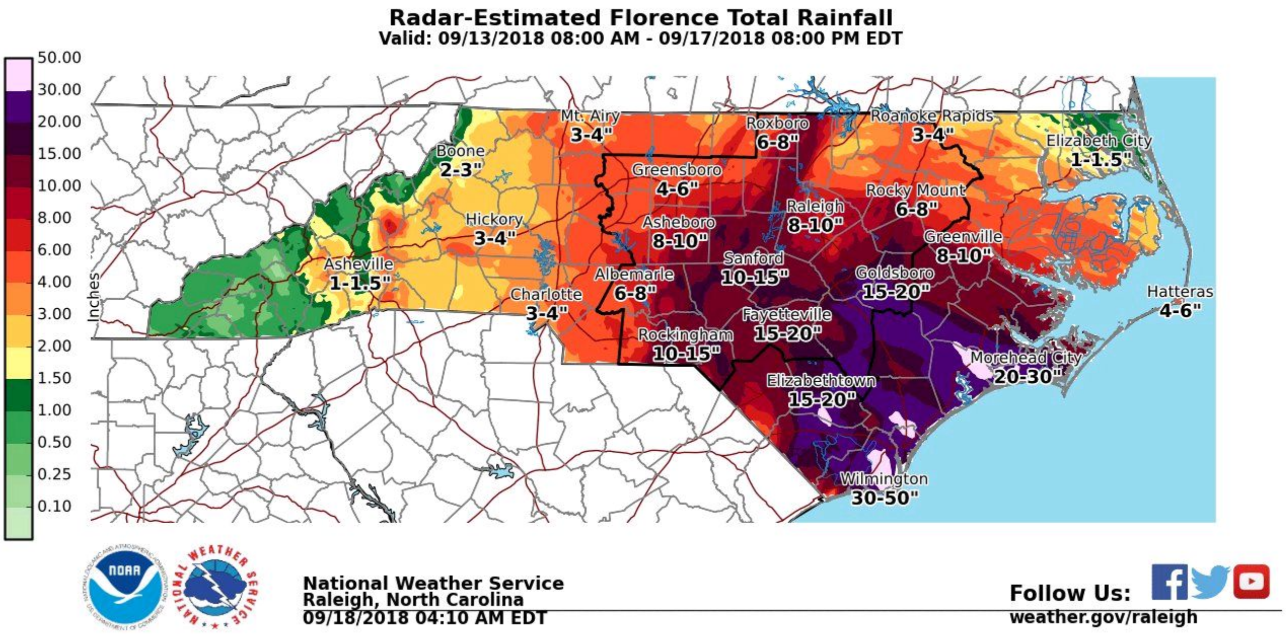


Figure 3: Estimated Total Rainfall in North Carolina
Source National Weather Service : https://twitter.com/NWSRaleigh

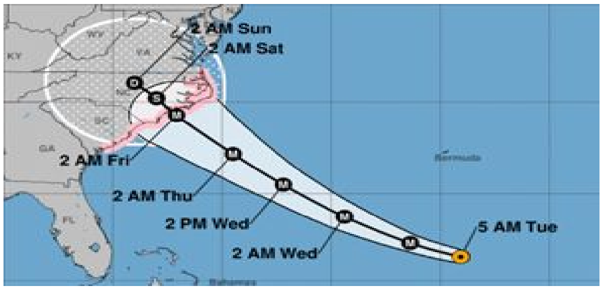
Loss of Life and Injuries

When NC Governor ordered mandatory evacuations for populations along the coast, this was considered precautionary in advance of a massive (400 miles diameter) hurricane, and hundred of thousands of people evacuated in advance of landfall. The death toll from Hurricane Florence currently stands at 37, with the majority attributed to flood waters, tree-fall and indirect causes such as fatal vehicular accidents related to Hurricane Florence. Many roads are submerged and impassable. The waters from Hurricane Florence have totally cut off access to Wilmington, NC a city of approximately 120,000 persons.

Hurricane Track

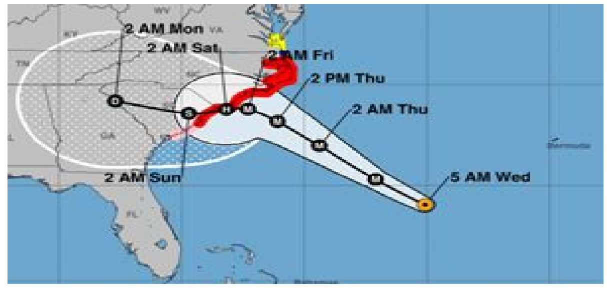
The following sequence of NOAA's forecasts shows the path and evolution of Florence. Although, Florence reached a category of four in the Simpson scale, it only impacted as category one in Wrightsville Beach, North Carolina.

Tuesday, September 11, 2018



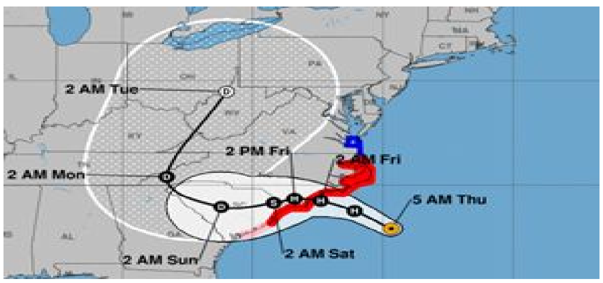
Sustained Wind Speed: 140 mph
Hurricane Category: 4
Hurricane Watch

Wednesday, September 12, 2018



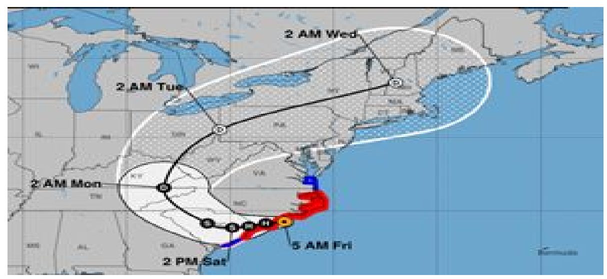
Sustained Wind Speed: 130 mph
Hurricane Category: 3
Hurricane Warning

Thursday, September 13, 2018



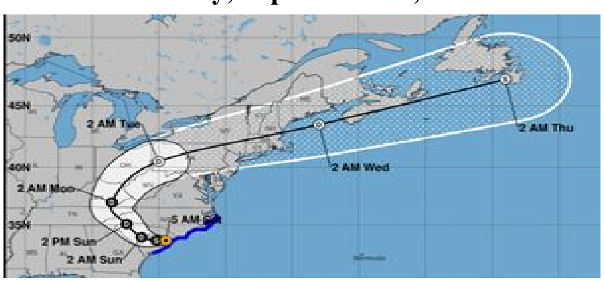
Sustained Wind Speed: 110 mph
Hurricane Category: 2

Friday, September 14, 2018



Sustained Wind Speed: 90 mph
Hurricane Category: 1
Landfall in Wrightsville Beach, NC

Saturday, September 15, 2018



Sustained Wind Speed: 50 mph
Tropical Storm

Sunday, September 16, 2018

Sustained Wind Speed: 35 mph
Tropical Depression

Track Area: Day 1-3 Day 4-5
Watches: Hurricane Storm **Warnings:** Hurricane Storm

Figure 4: Hurricane Florence Track
Source NOAA: https://www.nhc.noaa.gov/archive/2018/FLORENCE_graphics.php?product=5day_cone_no_line

Initial Observations Following Hurricane Florence

Maximum Wind Speeds in Hurricane Florence

The weather station of the National Weather Services at Wilmington Airport recorded a peak 90 mph sustained wind speed (equivalent to 105 mph 3-second gust speed) during Hurricane Florence. Florence had the highest wind speed of the previous eight tropical disturbances to affect Wilmington (Figure 3) within the past 60 years, though fortunately the peak wind speed was well below the design wind speed for the region.

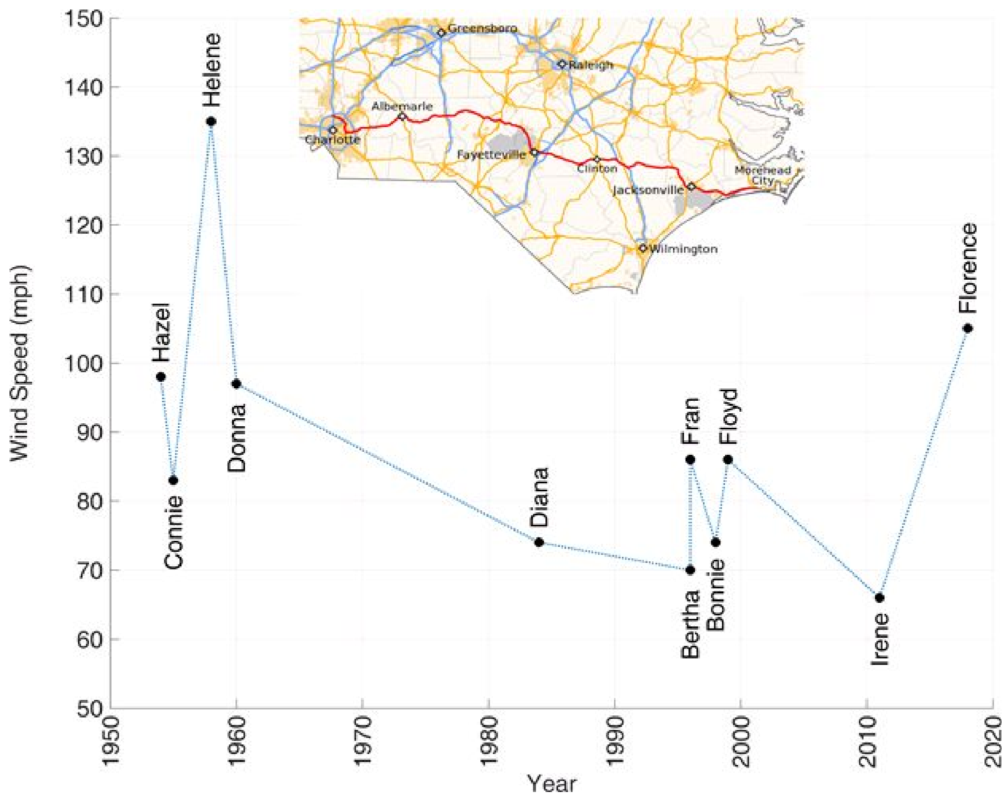


Figure 6: Historic Peak Wind Speed at Wilmington Airport, Sep 14 2018

Source NWS: https://forecast.weather.gov/product.php?site=NWS&issuedby=ILM&product=PNS&format=CI&version=8&glossary=1

Field Data on Wind Speeds

The University of Florida's Florida Coastal Monitoring Program deployed before landfall in order to set up three portable weather stations that gathered high-fidelity time histories of the Hurricane Florence wind speeds, pressure and humidity. Two towers were 15 m tall and one tower was 10 m. The peak 3 second gust wind speed measured by the FCMP program was 97.2 mph at 10 m height, by T2 located in Scotts

Hill in open terrain. T3 measured a peak 3 second gust of 73 mph at 10 m height in suburban terrain in Holly Ridge (Figure 6).

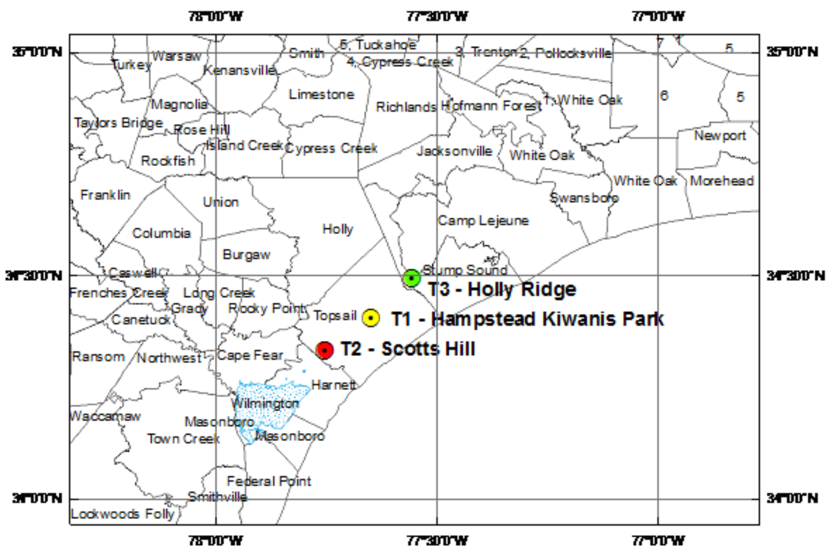


Figure 7: Florida Coastal Monitoring Program Towers Locations

Texas Tech University' Hurricane Research team (TTUHRT) also deployed a suite of mobile weather stations, nearly 48 StickNet Stations in advance of landfall to monitor wind speeds during the event. Researchers should contact Dr. John Schroeder at Texas Tech University for further information.

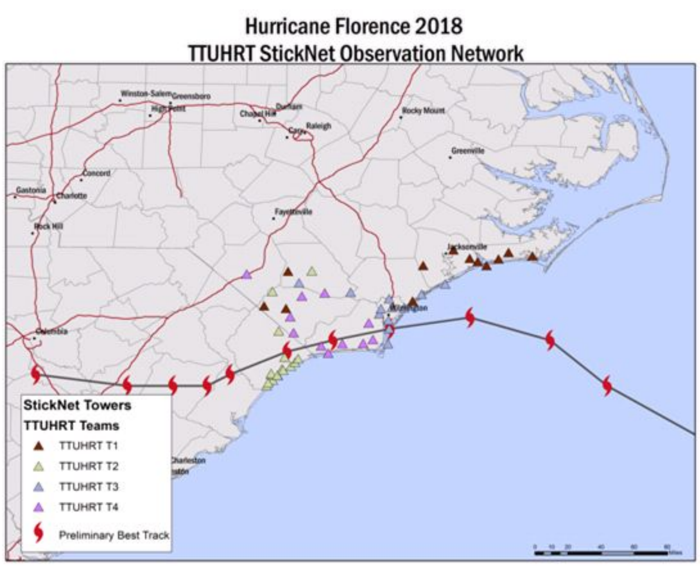


Figure 8: Locations of the Texas Tech University's StickNet Network in Hurricane Florence (TTECH)

Building Codes for North Carolina

The state of North Carolina regulates building constructions by the North Carolina Building Code and the North Carolina Residential Code which were last revised in 2012 based substantially on material from the 2009 International Building Code as amended by the North Carolina Building Council. The North Carolina Residential Code (NCRC) provides comprehensive regulation for the construction of single-family houses, two-family houses, and buildings consisting of three or more townhouse units. The North Carolina Building Code (NCBC) applies to all other buildings.

Figure 5 shows a contour map of the the basic 3-second design wind speed (in mph), for the state of North Carolina. The considered annual probability in the development of these wind speeds is 0.02 (i.e. 50-year man recurrence interval). However for special wind regions near mountainous terrain and near gorges utilize local jurisdiction requirements. The landfall of Hurricane Florence in the southeast corner of the state only produced peak wind speed of 97 mph.

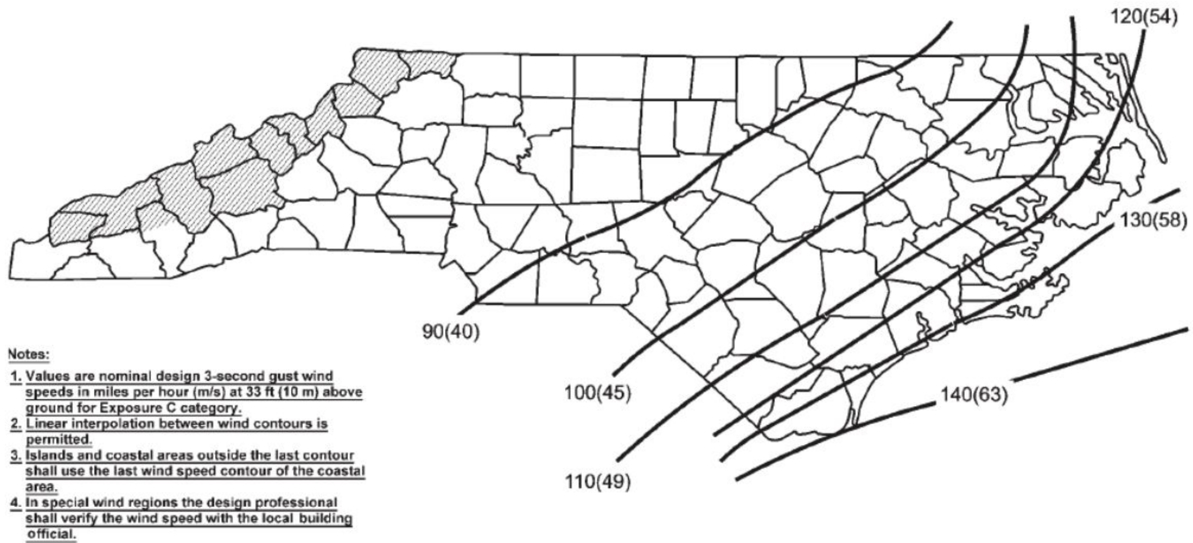


Figure 5: North Carolina Basic 3-second gust Wind Speed Map at 10m in Open Exposure (mph)

Source: https://cdn-codes-pdf.iccsafe.org/public/getpdf/9459/2012_NC_Building.pdf

Tornadoes During Hurricane Florence

The Storm Prediction Center reported that Hurricane Florence spawned 32 tornadoes through North and South Carolina and the Virginia from September 14th to September 17th (Figure 8). The tornadoes were low-intensity rated at EF-0 or EF-1, and they caused some damage to trees, minor damage to houses and to automobiles damaged by falling trees.

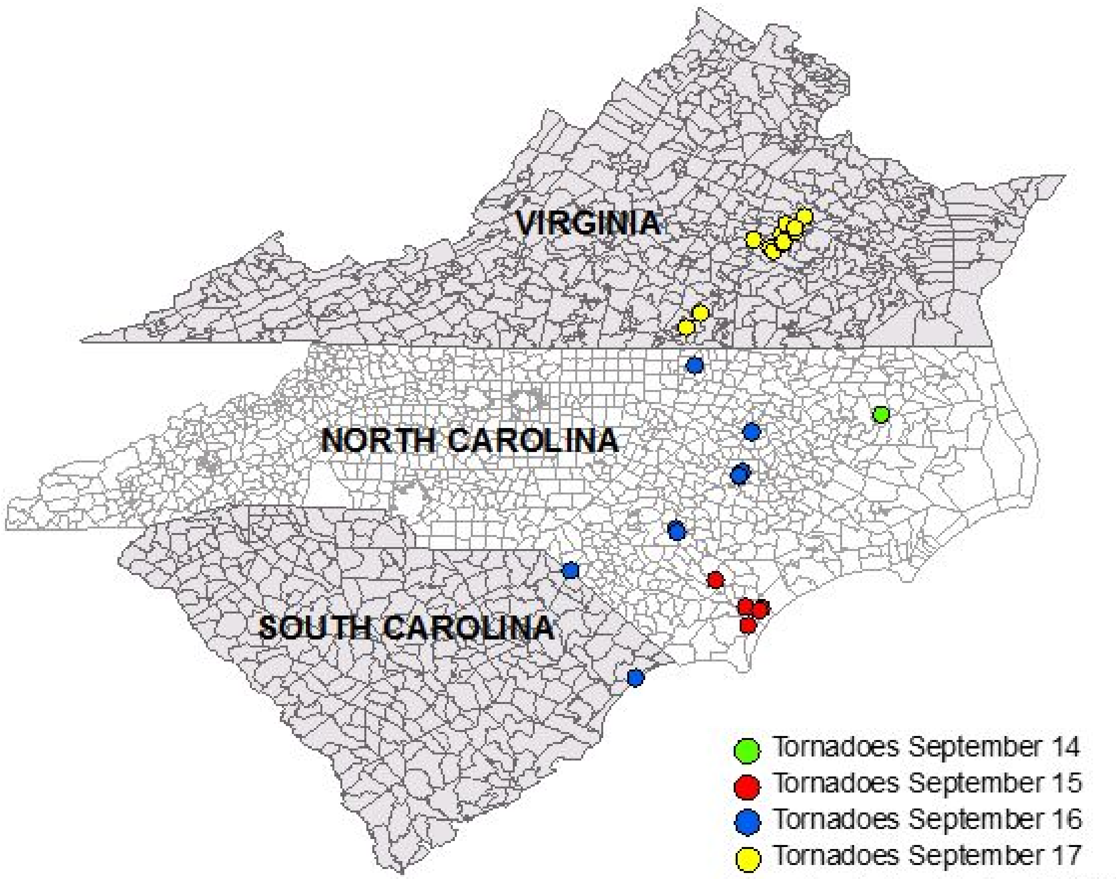


Figure 9: Location of Tornadoes Reported during Hurricane Florence
Source Storm Prediction Center: https://www.spc.noaa.gov/climo/reports/180917_rpts.html

Date	Description
9-14-2018	Tornado in Bertie County, NC
9-15-2018	Five tornadoes reported near New Hanover, NC. A dozen trees (diameter up to 14 in.) damaged by NWS-estimated wind speed 75 mph - EF-0
9-16-2018	Ten tornadoes reported, Horry County, SC, and in towns of Robeson, Vance, Sampson, Wayne, and Wilson, NC. EF-0 strength. Minor structural damage
9-17-2018	Sixteen tornado reports - eight tornadoes confirmed - in Mecklenburg, Chesterfield, City of Richmond, and other towns in Virginia. Structural damage to buildings caused by wind, debris and falling trees. Highest intensity was an EF2 tornado in Chesterfield County, which caused one fatality.

Power Outages

There were about 1.7 million reported power outages within North and South Carolina due to Hurricane Florence, and as of 19th September 2018, 114,000 customers remained without power. Most of the remaining power outages are located in coastal regions and that experienced heavy fooding (Figure 9). Duke Energy, the power company expects to restore power for most customers by 26 September. However, many structures that suffered extensive flood damage may yet require additional electrical repairs before service can be restored.

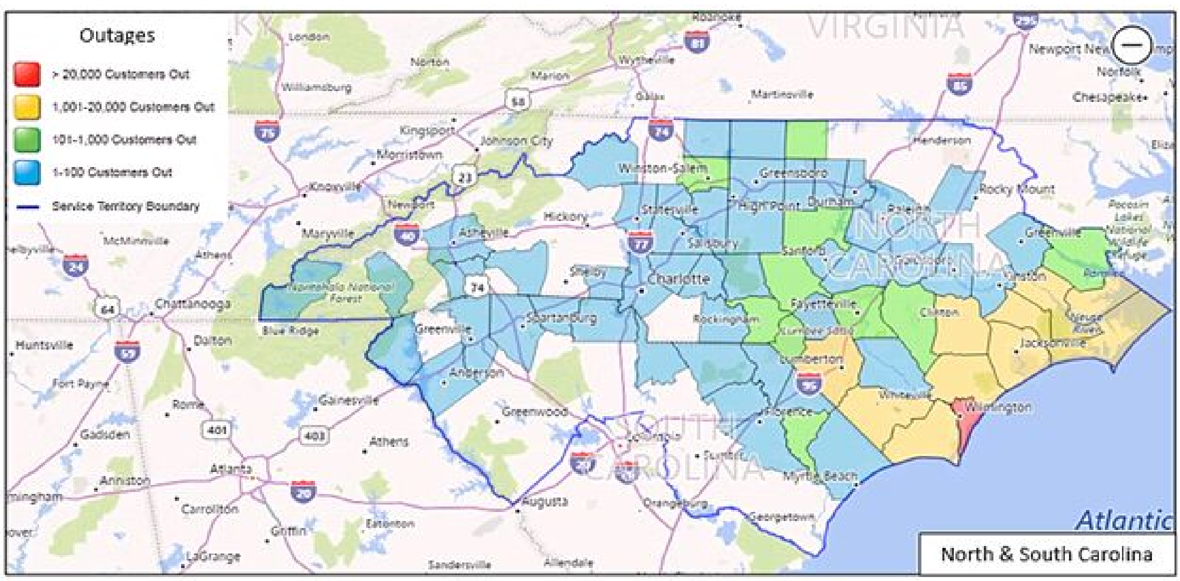


Figure 10: Power Outages in North & South Carolina Duke Energy: https://www.duke-energy.com/outages/current-outages

Road Closures

Due to extensive flooding, the North Carolina Department of Transportation advised that hundreds of roadways are closed and still impassable at this time. NCDOT advises motorists not to travel in these counties because many roads are still flooded or flooding:

Bladen, Brunswick, Columbus, Western Craven (west of US 17), Cumberland, Duplin, Harnett, Hoke, southern Johnston (south of 70), Jones, Lenoir, New Hanover, Pender, Robeson, Sampson, Scotland, and southern Wayne (south of 70 Business)

Table 1: Available Roadways in North Carolina affected area as of 20 September 2018

From Raleigh to Kinston ◦I-440 to US 64 East ◦Take Exit 436 to US 264 East ◦US 264 East to NC 11 South in Greenville ◦Continue on NC 11 South to Kinston	**From Raleigh to New Bern** ◦I-440 to US 64 East ◦Take Exit 436 to US 264 East ◦US 264 East through Greenville to Washington ◦In Washington, take US 264 East to US 17 South ◦US 17 South to New Bern	**From Raleigh to Havelock** ◦I-440 to US 64 East ◦Take Exit 436 to US 264 East ◦US 264 East through Greenville to Washington ◦In Washington, take US 264 East to US 17 South ◦US 17 South to New Bern ◦In New Bern, take US 17 South to US 70 East ◦US 70 East to Havelock
From Raleigh to Morehead City I-440 to US 64 East ◦Take Exit 436 to US 264 East ◦US 264 East through Greenville to Washington ◦In Washington, take US 264 East to US 17 South ◦US 17 South to New Bern ◦In New Bern, take US 17 South to US 70 East ◦US 70 East through Havelock to Morehead City	**From Raleigh to Jacksonville** I-440 to US 64 East Exit 436 to US 264 East US 264 East thru Greenville to Washington In Washington, take US 264 east to US 17 south US 17 south to New Bern In New Bern, take US 17 south to US 70 east US 70 east through Havelock to Morehead City In Morehead City take US 70 east to NC 24 west NC 24 west through Swansboro to Jacksonville	**Note:** Several sections of I-95 and I-40 are still flooded. I-95 Southbound traffic from Virginia should use US-64 West (Exit 138) to I-540 West to I-40 West to US-321 South to I-85 South. Follow directions in South Carolina to re-access I-95.

Source: https://tims.ncdot.gov/tims/

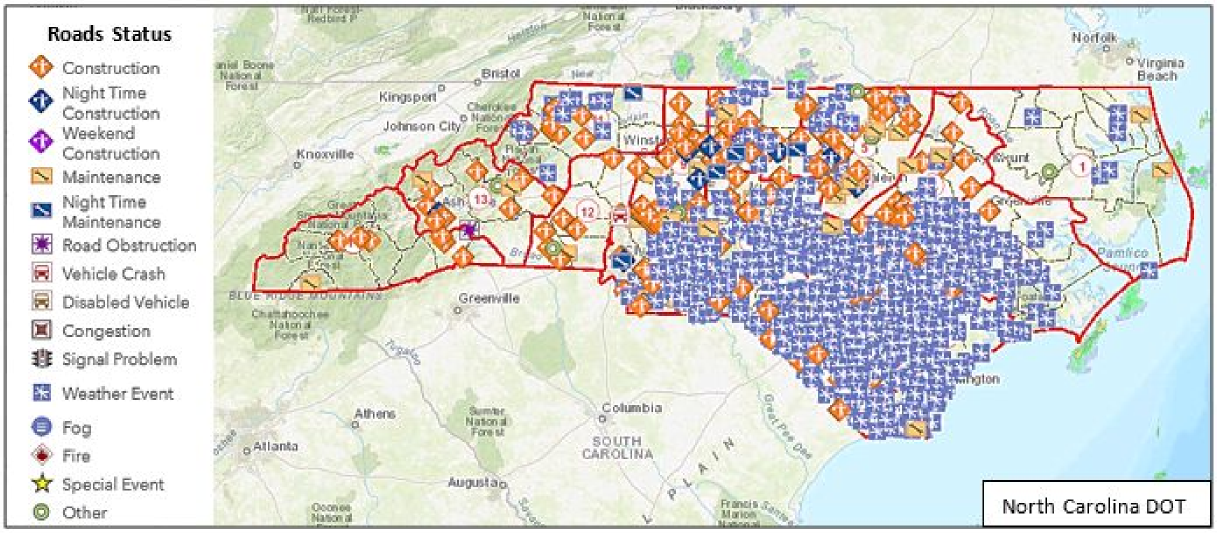


Figure 11: Roads Status North Carolina September 18, 2018
Source NCDOT: http://ncdot.maps.arcgis.com/home/webmap/viewer.html?webmap=52734443786545ba8f3ee302f6c33b00

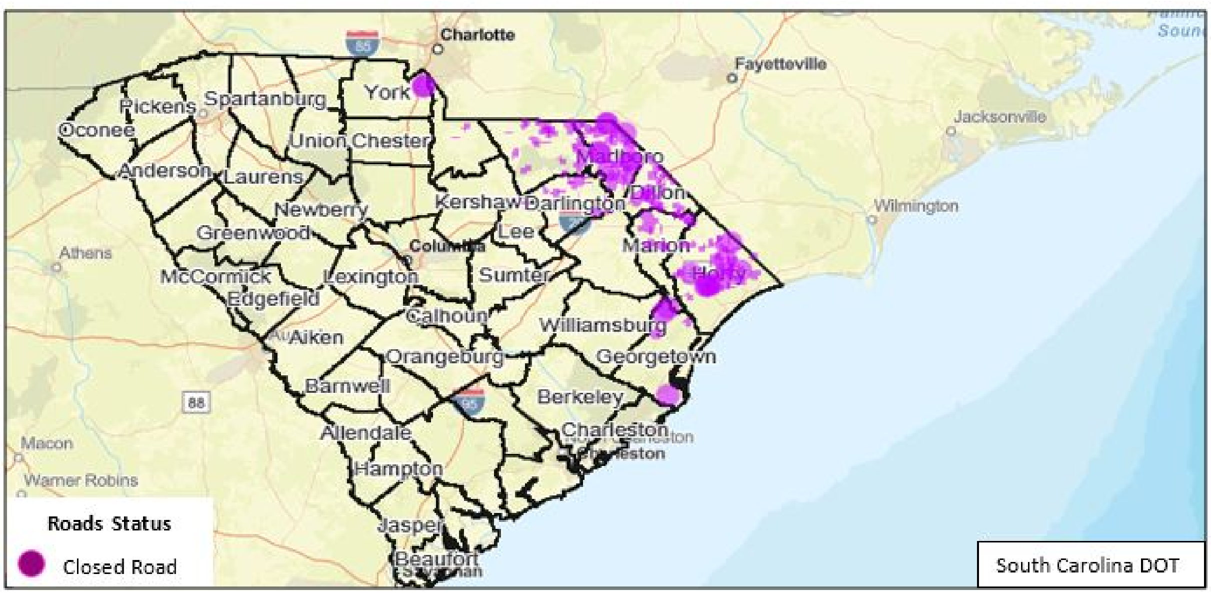


Figure 12: Roads Status South Carolina September 18, 2018
Source SCDOT: https://scdot.maps.arcgis.com/apps/MapSeries/index.html?appid=f89dbb607181411b86e999ed2897fb21

Wind Hazard Damage Assessment Team
Engineering School of Sustainable Infrastructure and Environment
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Summary

Hurricane Florence made a direct hit on North Carolina with moderate wind speeds and storm surge. The storm stalled once it made landfall and caused extensive flooding that resulted in the majority of damage, loss of life and economic loss. As this preliminary assessment is being prepared researchers supported by the National Science Foundation's research grant EAGER: Operationalization of the Structural Extreme Events Reconnaissance (StEER) Network (#1841667) are deployed to gather first-hand information of conditions. Their efforts have mobilised structural engineers within the natural hazards research community who are working in conjunction with the NHERI supported experimental facilities teams and other parties to critically look at and learn from the disasters. Every effort will be made to engage affected communities with natural hazards investigators in order to support community efforts to rebuild hazard-resilient communities. All report from the StEER Field Assessment Teams will be archived in the NHERI Design-Safe portal and made available shortly for use by other researchers, and affected communities. It is our hope that these efforts continue to make our communities more resilient and robust in the face of natural hazards.

Engineering, Education and Engagement - The Purpose for Publishing *WHDAG* Reports

Since 2012, the University of Florida *Wind Hazard Damage Assessment Group (WHDAG*) has published 20 preliminary damage assessment reports. Our purpose initially was to get engineering students familiar with reporting forensic investigations within 48-72 hours of an event, and by so doing helping the communities understand the engineering context of the event, and how the damage might have been prevented. Over this time, we recognize there is a dearth of conversation between hazards researchers and the communities affected by such hazards. Our goals is to fill the gap by demystifying wind events providing factual information to the affected populations, emergency managers and building officials. Knowing the scale of the problems in our view is the first step to addressing them and developing solutions.

Our efforts have included international events (three hurricanes in Australia, partnering with the James Cook University), and direct collaborations with other universities (i.e. the January 2017 report on the ALbany, GA tornado, in which we collaborated with University of Illinois, Urbana-Champaign. Since our first report, we have had nearly 4,000 reads of these papers, which extends our purpose of Engineering Education and Engagement.

In hindsight these preliminary damage reports may have far greater impact than was first anticipated. Our reports reached critical stakeholders within several days of a wind damage event, usually when the event still was in the news. We are told having such information collated was beneficial to officials in the highest levels of government. Over that period of time, much has changed in the landscape of tornado-resilient construction. Indeed the efforts of engineers, legislative leaders, contractors and the community input in Moore, OK came together to produce the first building code specially to address tornadoes, and this year when ASCE 7-16 is published it will include 16 pages in the commentary of procedures for tornado resilient design.

We believe that our approach for co-incident self-publication of reports has helped to change minds - to accept that catastrophic losses from tornadoes and other wind events need not be inevitable, that there are numerous options for strengthening houses. We endeavor to share our message with affected communities, and with stakeholders and engineers involved in the building industry. In addition, our reports have been disseminated to meteorologists and building officials in the affected communities. We will continue to strengthen dissemination channels to increase the outreach in our efforts to provide this service to our community.

Acknowledgements

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About the PI

David O. Prevatt is an Associate Professor of Civil & Coastal Engineering, in the School of Sustainable Infrastructure & Environment, University of Florida, Gainesville, FL. He is a registered professional engineer registered in Massachusetts and in Trinidad and Tobago and Fellow of the American Society of Cvil Engineers. His research focus on wind mitigating damage to buildings primarily by developing methods to improve the performance of single-family residential structures. Over the past seven years his group conducted dozens of forensic investigations of tornado damage and they have used the data to develop models for predicting the loads due to tornadoes.

Peer-Reviewed Publications

Egnew, Alyssa C.; Roueche, David B.; Prevatt, David O. “Linking Building Attributes and Tornado Vulnerability Using a Logistic Regression Model,” Natural Hazards Review, v 19, n 4, November 1, 2018

William L. Coulbourne, David O. Prevatt, T. Eric Stafford, Christopher C. Ramseyer, and John M. Joyce, “Moore, Oklahoma, Tornado of 2013: Performance of Schools and Critical Facilities,” ASCE, Reston, VA (2017)

Roueche, D.B., Prevatt, D.O., Lombardo, F.T. “Uncertainties in Fragility Curves Derived from Post-Disaster Damage Assessments.” ASCE-ASME Journal of Risk and Uncertainty in Engineering Systems, Part A: Civil Engineering, Volume: 4 Issue: 2, JUN 2018

Kijewski-Correa, Tracy L.; Kennedy, Andrew B.; Prevatt, David O.; et al. “Field reconnaissance following the passage of Hurricane Matthew over Haiti's Tiburon Peninsula”; 2017 Americas Conference on Wind Engineering, ACWE 2017 Pages: Air Worldwide; American Association for

Wind Engineering (AAWE); Herbert Wertheim College of Engineering, University of Florida (UF); International Association for Wind Engineering (IAWE) Published: 2017

Prevatt, D.O. and Roueche, D.B. "A Tale of Two Houses: Investigation of Disproportionate Damage in 2011 Tuscaloosa, AL Tornado." Wood Design Focus, V. 25, N. 1, Spring 2015

Prevatt, D. O., Coulbourne, B., Graettinger, A., Pei, S., Gupta, R., and Grau, D. (2013). "Tornado of May 22, 2011 – Structural Damage Survey and Case for Tornado-Resilient Building Codes", http://dx.doi.org/10.1061/9780784414095; 47 p ASCE/SEI, Reston, VA.

Prevatt, D. O., Roueche, D. B., et al. (2011c). "Building damage observations and EF classifications from the Tuscaloosa, AL and Joplin, MO tornadoes." *Proc., 2012 Structures Congress*, ASCE, Reston, VA, in press. Prevatt, D. O., van de Lindt, J. W., Graettinger, A., et al. (2011a). *Damage study and future direction for structural design following the Tuscaloosa tornado of 2011*. University of Florida, Gainesville.

Prevatt, David. O., van de Lindt, J.W., Back, E., Graettinger, A.J., Pei, S., Coulbourne, W., Gupta, R., James, D., Agdas, D.; (2012) Making the Case for Improved Structural Design: The Tornado Outbreaks of 2011, October 2012 ASCE's Leadership and Management in Engineering Journal

Prevatt, D.O., van de Lindt, J.W., Graettinger, A.,Coulbourne, B., Gupta, R., Pei, S., Hensen, S., Grau, D. (2011a) Damage Study and Future Direction for Structural Design Following the Tuscaloosa Tornado of 2011, University of Florida, Gainesville, FL (April 5, 2012).

Prevatt, D. O., van de Lindt, J. W., Gupta, R., and Coulbourne, B. (2011d). "Structural performance—Tuscaloosa tornado." *Structure Magazine*, July, 24–26.

Links to Previously Issued Preliminary Damage Reports (partial list)

Prevatt, DO, Lombardo, F.T; Roueche, D.B.; "Southeast US Tornado Outbreak 21-22 January 2017,"; Wind Hazard Damage Assessment Group Report. available at: http://windhazard.davidoprevatt.com/wp-content/uploads/2017/01/20-22-January-2017-SE-Tornado-Outbreak.pdf

Roueche, D.B., Bhusar, A.A., Gutierrez, A.M., Shah, A.D., Talele, M.S., Viswanathan, A., Prevatt, D.O. "The 2015 Christmas Tornado Outbreak". Wind Hazard Damage Assessment Group Report. Available at http://windhazard.davidoprevatt.com/wp-content/uploads/2015/12/The-2015-Christmas-Tornado-Outbreak1.pdf

Thompson, A., Roueche, D.B., Ammons, M., Doreste, J., Prevatt, D.O. "The 6 May 2015 Great Plains Tornado Outbreak and Flooding" Wind Hazard Damage Assessment Group Report. Available at http://windhazard.davidoprevatt.com/wp-content/uploads/2015/05/6-May-2015-Oklahoma-Tornado-Summary-Report_Final.pdf

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