StEER: Structural Extreme Event Reconnaissance Network

HURRICANE MICHAEL PRELIMINARY VIRTUAL ASSESSMENT TEAM (P-VAT) REPORT

Rescue personnel perform a search in the aftermath of Hurricane Michael in Mexico Beach, Florida, on October 11, 2018. (Source: Gerald Herbert/AP via Business Insider)

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Executive Summary

After a period of rapid intensification, Hurricane Michael made landfall around 1:45 pm EDT on Wednesday, October 10, 2018 near Mexico Beach, Florida, as a strong Category 4 hurricane, with maximum sustained wind speeds of 155 mph and a minimum central pressure of 919 MB. Based on these intensity measures, Michael is considered the fourth most-powerful hurricane to hit the United States, behind the Labor Day Hurricane (1935), Hurricane Camille (1969) and Hurricane Andrew (1992), and the most powerful storm to impact the Florida Panhandle in recorded history. Moreover, as the storm remained at Category 3 intensity as it crossed into Georgia and continued to deliver tropical force winds and significant rainfall as it moved into the Carolinas and up the Eastern seaboard, Michael caused wind damage, triggered flooding and resulted in deaths in a number of states, including those still recovering from Hurricane Florence.

Given that this hurricane is one of the most powerful storms in US recorded history, achieving design-level winds in some areas and generating significant storm surge in communities like Mexico Beach, it is an important validation of code and construction practices in the Gulf Coast. Specifically, this was an important test for the State of Florida, recognized for its high standards of hurricane-resilient construction, and especially the Florida Panhandle, which historically has not been exposed to storms of this intensity. Damage observed in the event was wide ranging, from compromised building envelopes with interior water damage to complete destruction of buildings under wind. Plentiful examples of storm-surge-induced damage left behind only foundation slabs. Critical facilities like hospitals experienced service disruption and envelope breach; schools lost roofs and suffered structural wall failures under wind. Many commercial buildings, airplane hangars, marina facilities and other metal building systems experienced similar severe envelope breach. Dramatic failures of power infrastructure were also documented.

This report overviews the meteorological features of Hurricane Michael, the regulatory context and pre-event response, the impacts of this storm event, and current conditions by collocating publically-reported information. The report places particular emphasis on Florida, but also summarizes impacts to other affected states. This Preliminary Virtual Assessment Team (P-VAT) Report represents the first product of StEER's larger coordinated response to this event, informing and supporting other research teams seeking to learn from this disaster.

Introduction

Hurricane Michael made landfall around 1:45 pm EDT on Wednesday, October 10, near Mexico Beach, Florida, as a strong Category 4 hurricane, with maximum sustained wind speeds of 155 mph (only 1 mph short of Category 5) and a minimum central pressure of 919 MB. Based on these intensity measures, Michael is considered the fourth most-powerful hurricane to hit the United States behind the Labor Day Hurricane (1935), Hurricane Camille (1969) and Hurricane Andrew (1992), and the most powerful storm to impact the Florida Panhandle in recorded history. Michael remained at Category 3 even as it crossed into Georgia, making it the most intense storm in that state since 1898 (Klotzbach, 2018). The storm's rapid intensification was particularly noteworthy both meteorologically as well as from a disaster management perspective: many decided to shelter in place assuming it would remain a Category 3 and did not have time to safely leave the area when it became clear that the storm had intensified.

Given that this hurricane is one of the most powerful storms in US recorded history, achieving design-level winds in some of the impacted areas, and generating significant storm surge, it is an important validation of code and construction practices in the Gulf Coast. Moreover, this was an important test for the State of Florida, recognized for its high standards of coastal construction, but specifically for the Florida Panhandle, not historically exposed to storms of this intensity. While StEER intends to mount a comprehensive response to this event, Hurricane Michael has generated tremendous volumes of perishable data that cannot be assessed by StEER alone. As such, StEER hopes its early assessments and recommendations will provide valuable guidance to other teams deploying to the affected areas.

StEER further hopes to use this event to exercise the protocols, procedures, policies and workflows it will be developing over the next two years in collaboration with the wider hazards community including the Natural Hazards Engineering Research Infrastructure (NHERI) and other members of the Extreme Events Reconnaissance Consortium.

The first product of the StEER response to Hurricane Michael is this **Preliminary Virtual Assessment Team (P-VAT) report**, which is intended to:

1. provide an overview of Hurricane Michael's evolution and hazard characteristics
2. introduce the regulatory and disaster response context for this event
3. summarize the preliminary reports of damage to wide-ranging infrastructure
4. overview StEER's event strategy in response to this event
5. enhance situational awareness to guide subsequent missions conducted by StEER and the engineering reconnaissance community

> It should be emphasized that all results herein are preliminary and based on the rapid assessment of publicly available online data within 3-4 days of the event. Damage assessments discussed herein are based largely on the judgment of the authors without access to additional aerial imagery and ground-truthing.

Storm History

Early Development

The National Hurricane Center (NHC) issued its first notice for this event at 4:00 pm on Saturday, Oct. 6, 2018 indicating a potential tropical cyclone was forming in the northwestern Caribbean Sea. Heavy rainfall and flash flooding were expected over portions of Central America, western Cuba, and the northeastern Yucatan Peninsula. Within 12 hours, the storm increased to a tropical depression with 50 mph sustained winds, and a predicted trajectory to accelerate across the southeastern United States over the next few days. By 4:00 pm Sunday, the storm advanced to tropical storm classification with models forecasting Michael to reach hurricane strength within two days, and to reach the Gulf of Mexico in three days. Michael strengthened to a Category 1 hurricane by mid-morning on Monday (Fig. 1).

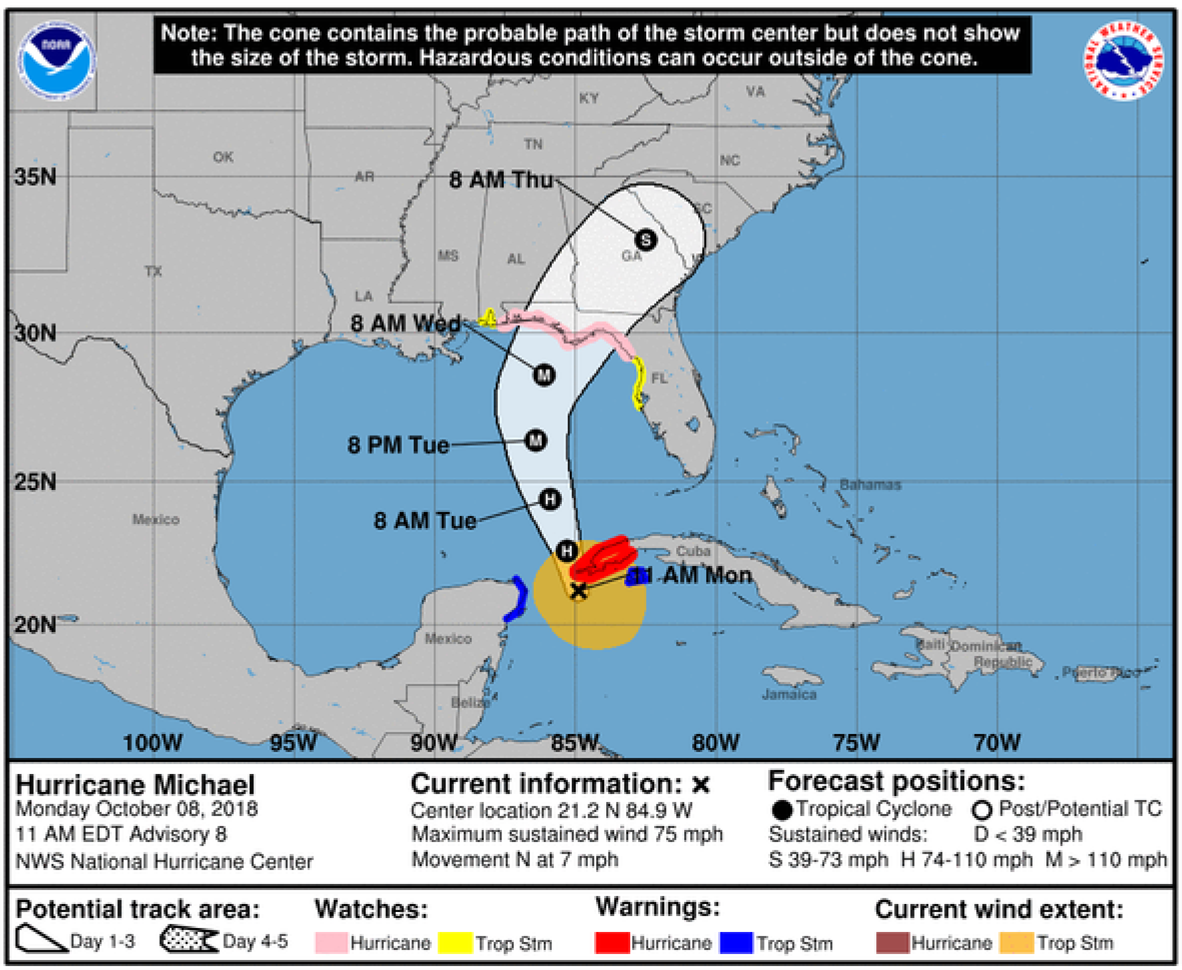


Figure 1: Hurricane Michael track (Source: National Hurricane Center)

Hurricane models forecasted Michael to rapidly strengthen over the next 2 to 3 days to become a dangerous major hurricane by the time it reached the northeastern Gulf Coast on Wednesday, Oct. 10, 2018. A hurricane warning was issued for parts of Florida Monday, Oct. 8, 2018, afternoon due to the expectation of life-threatening storm surge and winds. By Tuesday, Oct. 9, 2018, Hurricane Michael reached Category 3 sustained wind speeds, and continued on its trajectory to impact the Florida panhandle. Overnight, Michael's intensity accelerated, and by Wednesday, Oct. 10, 2018 morning Hurricane Michael reached Category 4 wind speeds with maximum sustained wind speeds of 150 mph and moving towards the Florida Panhandle at 13 mph with additional strengthening expected. Storm surge was predicted to reach between 9 and 13 feet of inundation in the hardest hit areas.

Landfall and Inland Progression

The following timeline and characteristics were based on Public Advisories issued by the National Hurricane Center (https://www.nhc.noaa.gov/archive/2018/MICHAEL.shtml). Around 1:45 pm EDT on Wednesday, Oct. 10, 2018 Hurricane Michael made landfall near Mexico Beach, Florida, as a Category 4 hurricane. At the time of landfall, the Category 4 hurricane was moving forward at approximately 14 mph, with maximum sustained wind speeds of 155 mph and a minimum central pressure of 919 MB (Fig. 2). When using minimum sea level pressure as a metric for intensity, Michael's landfall pressure of 919 millibars was the third-lowest on record in the United States, trailing only the Labor Day Hurricane of 1935 (892 millibars) and Camille in 1969 (900 millibars). Its pressure was the lowest on record for any October hurricane to strike the United States (Klotzbach, 2018). Perhaps more noteworthy was the speed of Michael's intensification as it moved over the warm waters of the Gulf of Mexico: sea surface temperatures along Michael's track were approximately 0.75-1.5°C warmer than average. This aided Michael in intensifying from a 35 mph tropical depression to a 145 mph hurricane in approximately 72 hours.

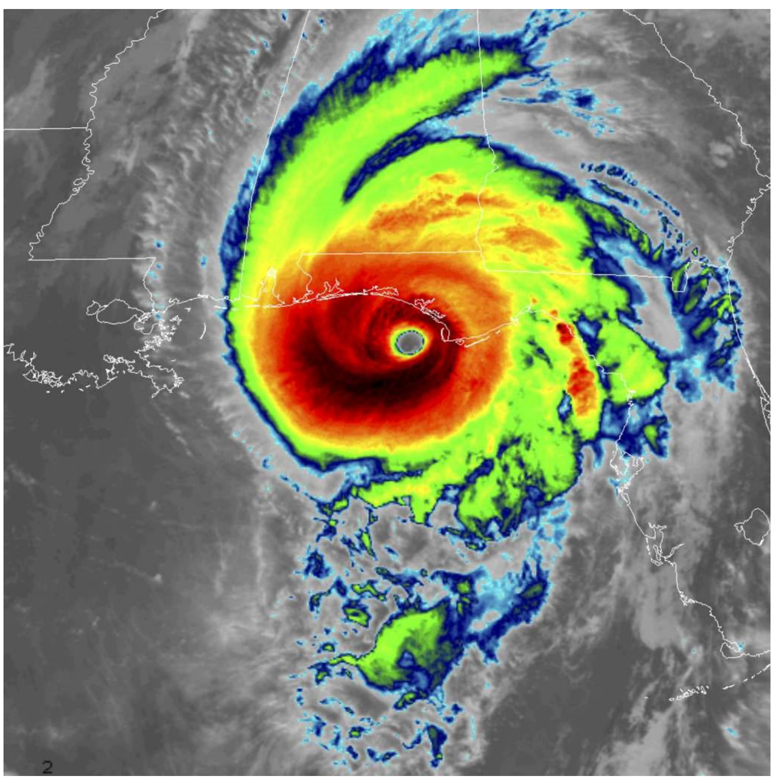


Figure 2: Infrared satellite image captured at approximately 11:40 am EDT as Hurricane Michael approached the Florida coastline as a Category 4. (Source: NOAA via Associated Press)

Hurricane Michael then continued Northeast, affecting the majority of the Florida Panhandle, Georgia, and eastern Alabama. At 4:00 pm EDT, the eye was located in Jackson County, FL, moving forward at 15 mph with maximum sustained wind speeds of 140 mph. The eye crossed into Seminole County, GA, around 6:00 pm EDT as a Category 3 hurricane, traveling forward at 13 mph with maximum sustained wind speeds of 115 mph. It weakened to a Category 2 hurricane by 7:00 pm EDT as it traveled across southern Georgia, with maximum sustained wind speeds of 100 mph. Michael became a tropical storm around 12:00 am EDT on October 11, with the eye located over central Georgia. Although it was in a weakened state, Michael continued to batter Georgia and the Carolinas with rain, tornadoes, and tropical storm-level winds (Fig. 3). In conclusion, Michael was a fast storm, escalating from tropical storm to Category 4 hurricane and back to a tropical storm in just three days.

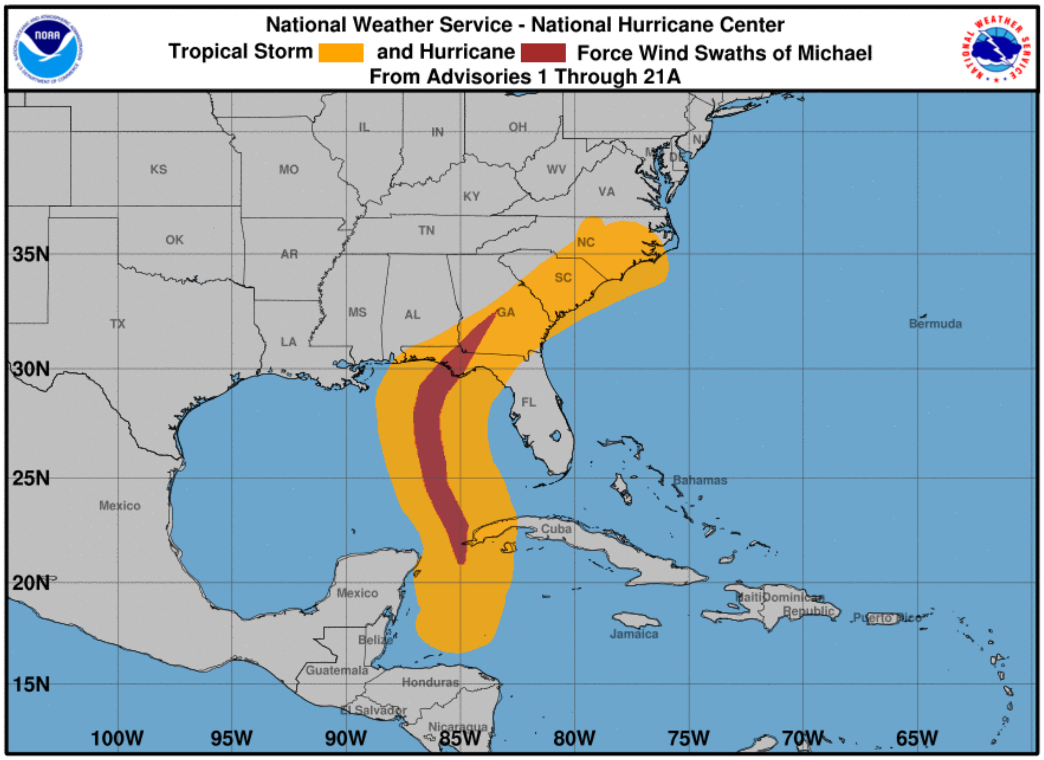


Figure 3: Graphic showing the locations of measured hurricane-level sustained winds as well as tropical storm-level sustained winds. (Source: National Hurricane Center https://www.nhc.noaa.gov/storm_graphics/AT14/refresh/AL142018_wind_history+png/234947_wind_history.png)

Hazard Profile

Hurricane Wind Field

Wind gusts over 50 mph were registered as far north as southern New Jersey, with reports of trees or power lines downed from the Florida Panhandle to the Washington D.C. metro area. Figure 4 summarizes the maximum wind gusts reported by meteorological stations near the landfall region. The National Weather Service reported that at the time of landfall, hurricane-force winds extended outward up to 45 miles (75 km) from the center and tropical-storm-force winds extended outward up to 175 miles (280 km). A wind gust of 129 mph was reported at the Panama City Airport and a gust of 107 mph was reported 1 mile south of Panama City. Other notable maximum wind gusts in the region were 89 mph in Apalachicola (FL), 71 mph in Tallahassee (FL), and 115 mph in Donalsonville (GA). It should be noted that these are isolated observations and winds in other locales were likely higher. Additionally many instruments failed during the storm so the maximum wind gusts were not captured in some locations. For example, the Florida Coastal Monitoring Program (FCMP) deployed three towers for this event, marked on Figure 5. One of these towers (Tower 3) recorded a wind gust of 130 mph near Tyndall Air Force Base before the tower was overturned, destroying the instrument.

FCMP Tower 2 reported a one hour period where wind gusts remained over 120 mph. ARA preliminary wind fields, displayed in Figure 5, illustrate that a narrow swath along the hurricane track experienced winds in excess of the design wind speed particularly for Risk Category II illustrating that Michael's wind gusts did not significantly dissipate as they moved inland where design wind speeds are lower.

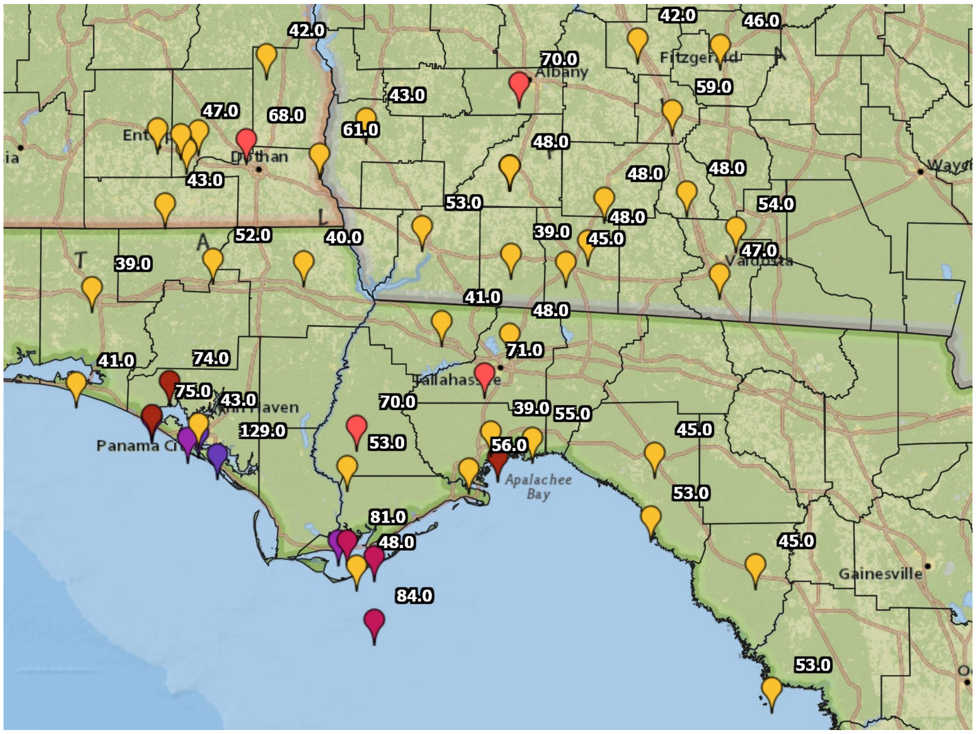
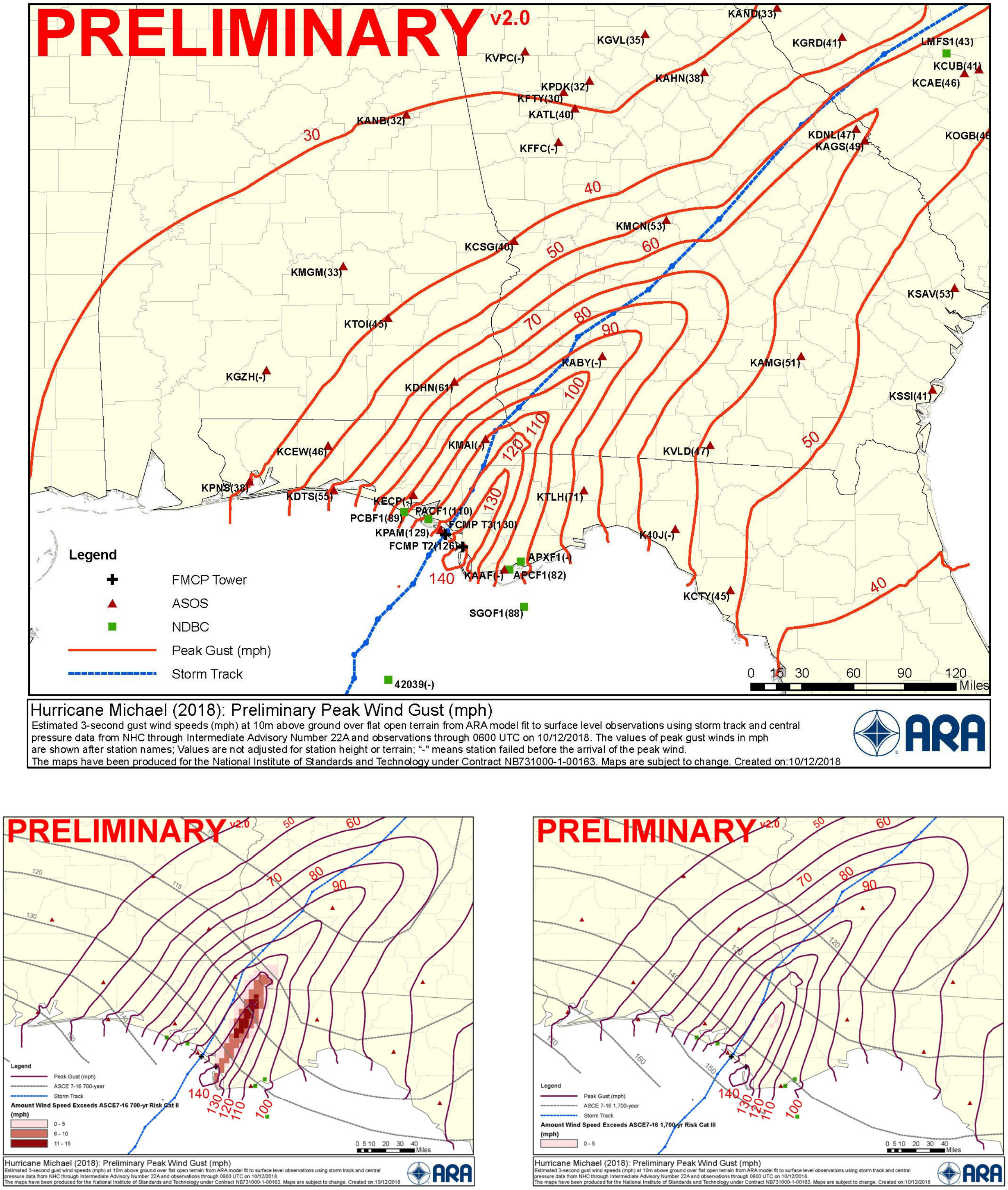


Figure 4: Hurricane Michael wind gust reports, in miles per hour, as compiled by the National Weather Service, Tallahassee weather forecasting office. Note wind speeds are unadjusted for terrain, observation height, averaging time, and other factors. (Source: National Weather Service)

Storm Surge

The area from the Aucilla River to the Tyndall Air Force Base was forecasted to experience high storm surge of 9 to 14 ft (Berke 2018). The *Independent* referenced the National Hurricane Center in reporting that the actual storm surge ranged from 8 to 14 ft in areas from Mexico Beach to Apalachee Bay, a location noted for storm surge potential even from less-intense tropical cyclones. There in Apalachee Bay, Michael's storm surge produced a peak inundation of 7.72 feet above ground level, easily surpassing the previous record of 6.43 feet above ground set during Hurricane Dennis in July 2005. The peak inundation of 5.31 feet above ground recorded at Panama City, Florida, was second only to Hurricane Opal in 1995. Cedar Key, Florida, experienced peak inundation of just over 4 feet during the afternoon of Oct. 10. Predicted storm surge levels based on ADCIRC (ADvanced CIRCulation) simulations by the Coastal Emergency Risk Assessment (CERA) are visualized in Figure 6. The depth of inundation with strong waves riding on this storm surge (Fig. 7) completely destroyed many homes with insufficient freeboard, making storm surge a particularly damaging hazard in this hurricane.



Risk Category II **Risk Category III**

Figure 5: Preliminary peak wind gust for Hurricane Michael and exceedance beyond ASCE 7-16 700-year Risk Category II and III (Produced by ARA, shared by NIST)

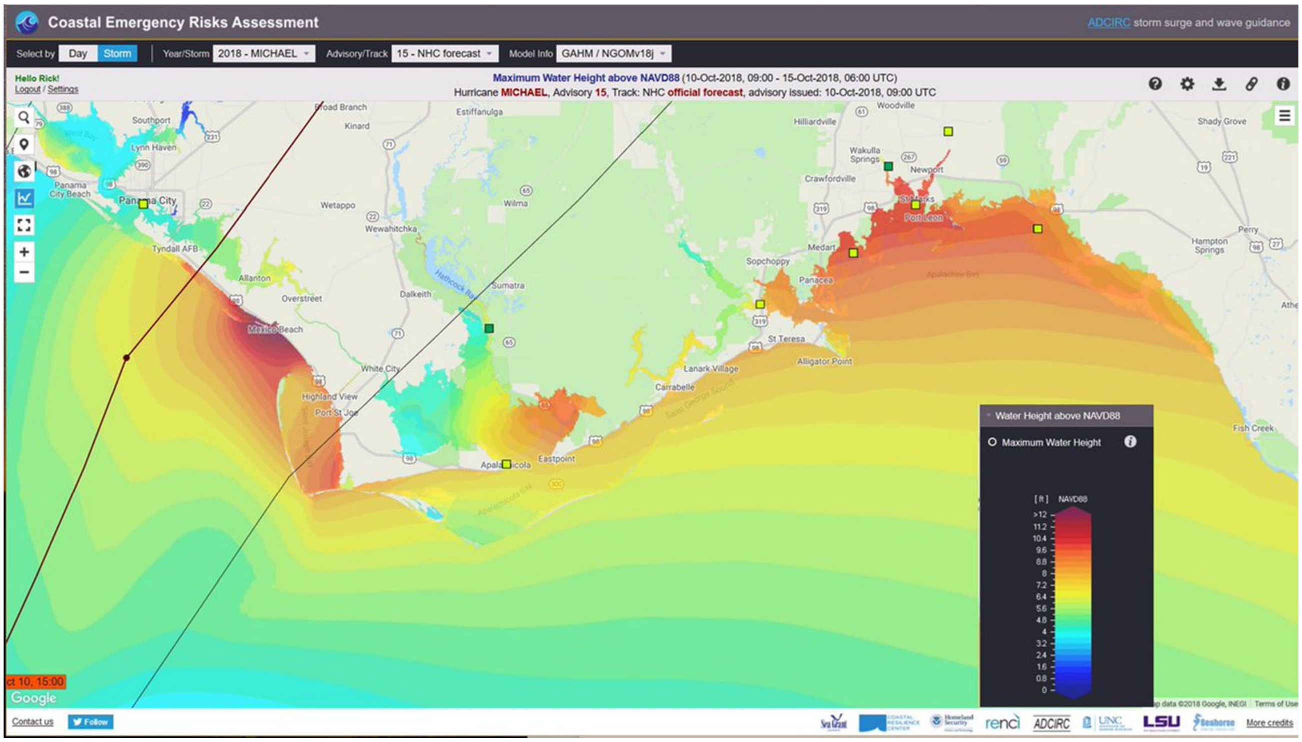


Figure 6: Storm surge projections for Michael (Source: Coastal Emergency Risks Assessment)

Figure 7: Storm surge and waves on October 10 in Shell Point Beach.
(Source: Berke 2018)

Rainfall and Flooding

As reported by the Weather Channel, Michael spread heavy rains from the Florida Panhandle to the mid-Atlantic/New England, though rainfall totals could have been far worse had Michael not been such a fast moving storm. Still, there were 204 reports of flash flooding in the 48-hour period ending 8 am EDT Oct. 12 attributed to Michael, spanning from Georgia to New Jersey. The majority of these were in Virginia (114 reports) and North Carolina (46 reports), where the heaviest of Michael's rain pounded areas already saturated from Hurricane Florence. Major flash flooding occurred in Danville, Farmville, Richmond and Roanoke, among other locations in Virginia, prompting flash flood emergencies from the National Weather Service. Water rescues were performed in Danville, and water entered homes, businesses and government buildings in Farmville and Prince Edward County. At least 20 roads were closed in Watauga County in the High Country of northwestern North Carolina, including the town of Boone. Widespread flooding was also reported in Forsyth County, including Winston-Salem, and in parts of the Raleigh metro area. The most notable rainfall totals were outside of Florida, with 9.62 inches near Black Mountain (NC), 8.04 inches in Bowling Green (VA), 7.39 inches near Jefferson (SC), 7.10 inches in Salisbury (MD), 6.75 inches near Boone (NC) and 6.48 inches near Powder Springs (GA). The highest total in Florida was 5.26 inches at Sumatra (see Fig. 8).

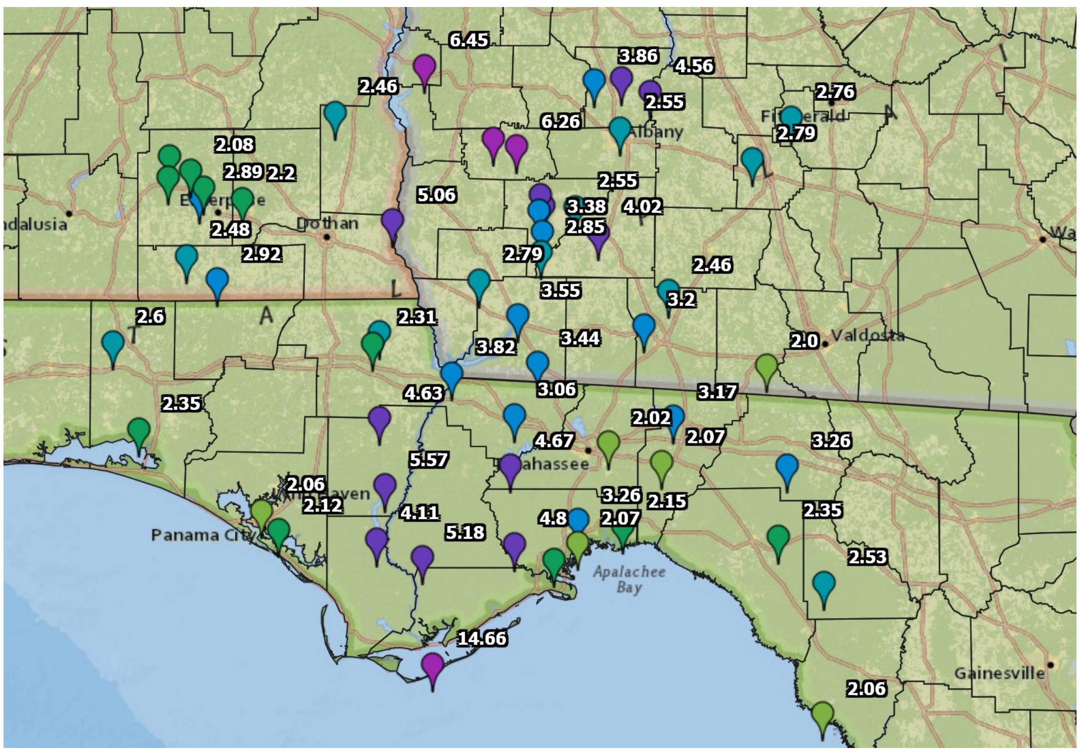


Figure 8: Reported total rainfall in the FL Panhandle resulting from Hurricane Michael (Source: National Weather Service).

Tornadoes

With exact totals not yet known, a number of tornadoes were generated during Michael's passage through the southeast (Fig. 9). According to the Weather Channel, three tornadoes were confirmed in Georgia, one of which snapped trees just southwest of downtown Atlanta on the evening of Oct. 10. Another tornado was sighted in Lake Brooklyn, Florida, northeast of Gainesville, on Oct. 10. The following day, damage in southern Virginia near Burkeville, Jamaica, Achilles, Lanexa, Mannboro and Danville was attributed to tornadoes, as was damage near Reidsville, North Carolina.

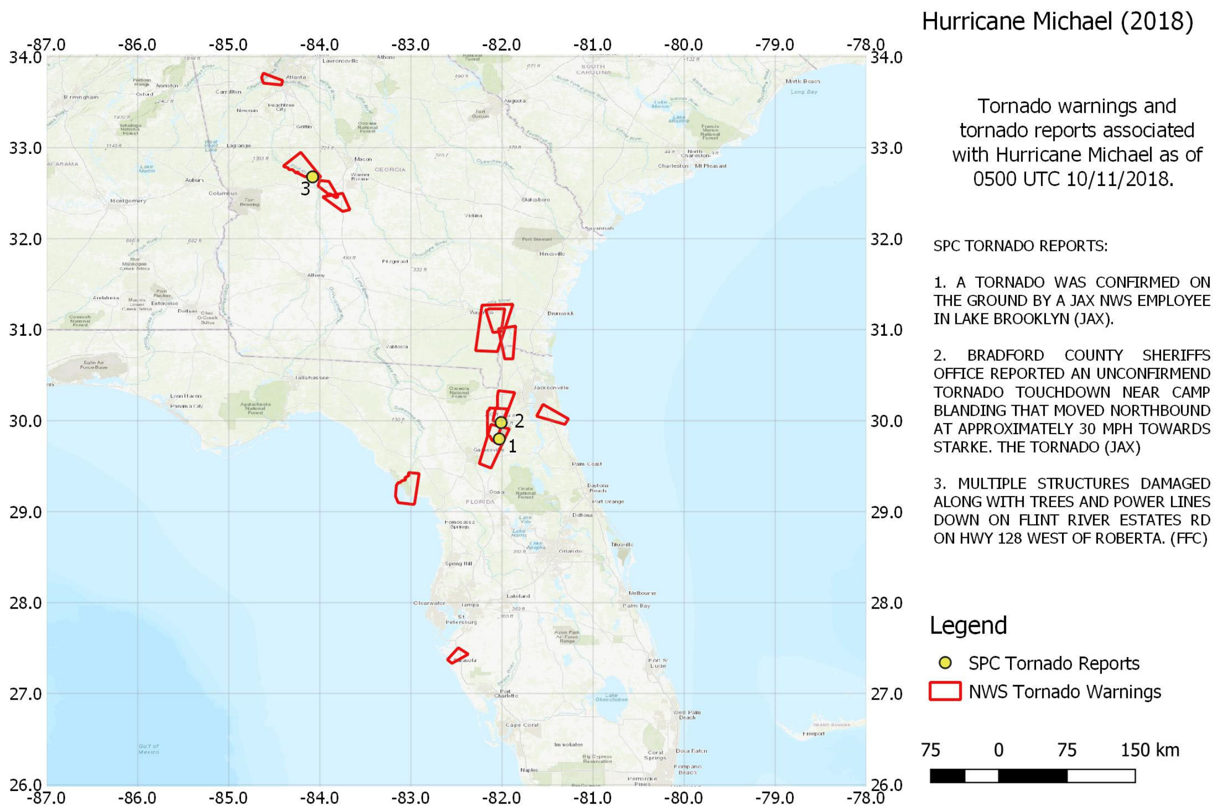


Figure 9: Map of reported tornadoes and tornado warnings in Florida and Georgia.

Regulatory Environment

Florida relies on two codes to regulate building construction: (1) the Florida Residential Code and (2) the Florida Building Code. While the Florida Residential Code provides regulations and guidance for the construction of one and two-family dwellings, the Florida Building Code addresses all other buildings and structures. The Florida Building Code released in 2010 was primarily based on 2009 International Building Code. The 2009 International Building Code did not incorporate the specifications of ASCE 7-10 at that time. From 2012, the ASCE 7-10 served as the foundation of the Florida Building Code. According to the latest version of Florida Building Code, wind loads on buildings must be calculated using Chapters 26-30 of ASCE 7. Design wind speeds should be determined from the maps given in Figures 1609.3(1), 1609.3(2), and 1609.3(3) of the 2017 Florida Building Code, Sixth Edition, provided in Appendix A. Figure 10 illustrates the design wind speeds from ASCE 7-16 for the landfall region, with exact values reported for Panama City, FL.

In 2000, while Florida was preparing to enact the first statewide building code, legislation created the so-called "Panhandle Exemption", which exempted the Panhandle from some of the more strict wind design requirements. In 2006, following Hurricane Ivan, this was repealed under Legislation HB 7A (2007)[1]. The exemption primarily related to wind-borne debris requirements. While the rest of the state was subject to wind-borne debris requirements, if the design wind speed was greater than 120 mph, wind-borne debris requirements in the Panhandle extended only one mile from the coast.

[1] See http://archive.flsenate.gov/data/session/2007A/House/bills/analysis/pdf/h0007A.GEAC.pdf

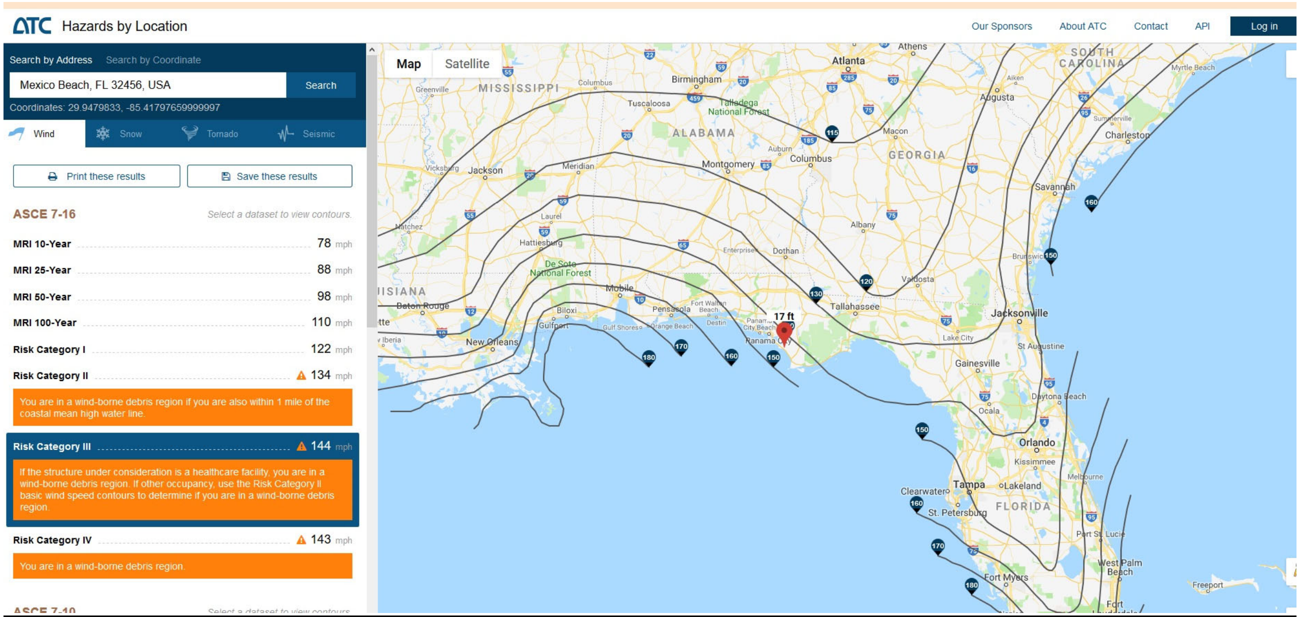


Figure 10: ASCE 7-16 Wind speed map for Risk Category III (Source: ATC website https://hazards.atcouncil.org/)

Federal, State and Local Response

On October 7th, Governor Scott declared a state of emergency in 26 Florida counties. The declaration was expanded to include a total of 35 counties, on October 8th. Following the Governor's request, President Trump approved the pre-landfall emergency declaration on October 9th (Scott, 2018). On October 9th, FEMA announced that ongoing federal emergency aid has been made available to the state of Florida, beginning on October 7 (FEMA, 2018a). Also, President Trump granted an emergency declaration request for Georgia counties on October 11 (FEMA, 2018b). Parts or all of the Counties of Bay, Citrus, Franklin, Dixie, Gulf, Jackson, Levy, Okaloosa, Taylor, Wakulla, and Walton in Florida had mandatory evacuation orders, while Escambia, Santa Rosa, Pasco, Madison, Liberty, Leon, Hernando, Gadsden, and Calhoun were under voluntary/phased evacuation orders. Figure 11a provides an example of the evacuation map for Bay County, which includes Mexico Beach. The county's four-tiered evacuation protocol is based primarily on the projected storm surge, with those adjacent to the water (Zone A) prioritized for evacuation. For Michael, the evacuations on the day before the storm focused on Zones A-C, as well as mobile homes and those living in low-lying areas. While a network of shelters were made available to Floridians (Fig. 11), Red Cross Officials reported that as many as 320,000 people did not evacuate.

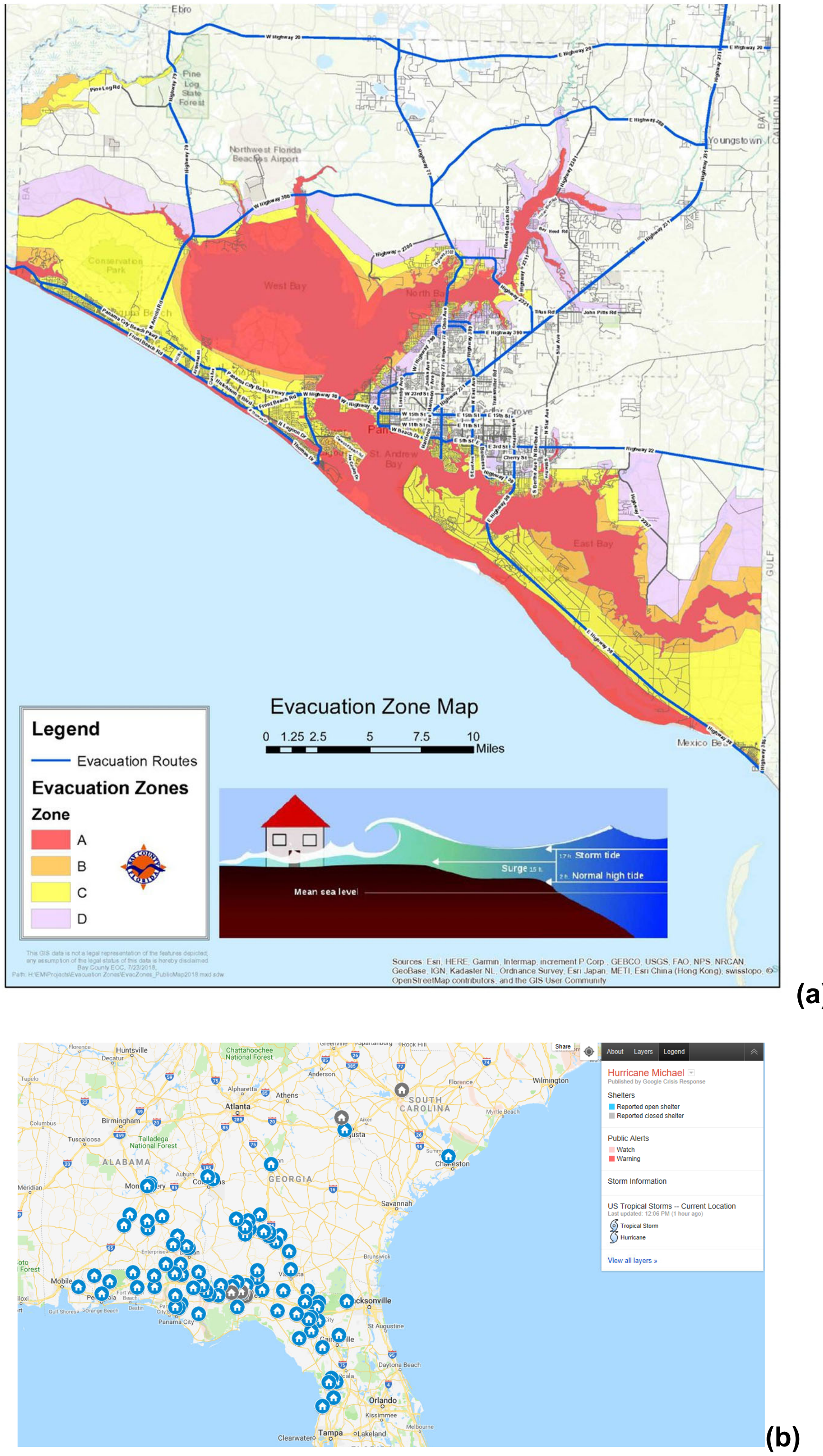


Figure 11: (a) Evacuation map issued for Bay County (Source: Bay County Emergency Services) and (b) reported open and closed shelters (Source: Google Crisis Response 2018).

First responders began the rescue efforts in Florida, following the hurricane landfall (FEMA, 2018c). The following federal, private sector and voluntary organizations took actions for response activities

(FEMA, 2018c), including: FEMA, American Red Cross, U.S. Department of Defense, National Guard Bureau, U. S. Coast Guard, U.S. Army Corps of Engineers, U.S. Department of Energy, U.S. Department of Health and Human Services, Corporation for National Community Service, U.S. Department of Transportation, U.S. Department of Homeland Security, National Protection and Programs Directorate, U.S. Environmental Protection Agency, U.S. Department of Interior, U.S. Immigration and Customs Enforcement and Customs and Border Protection, U.S. Department of Agriculture, U.S. Department of Labor, National Oceanic and Atmospheric Administration, and Whole Community Response Efforts.

Storm Impacts

Loss of Life and Injuries

As Hurricane Michael formed and approached the U.S. over the weekend, its heavy rains caused at least 13 deaths, including 6 in Honduras, 4 in Nicaragua, and 3 in El Salvador (Wright 2018). According to CNN (Chavez and Hanna, 2018), at the time of this report's authorship, there were at least 18 deaths in the U.S. due to the storm.

Buildings

Besides claiming valuable lives, Hurricane Michael rendered catastrophic structural damage. A large cross section of the buildings impacted by Michael were built before the year 2000 and thus before the State of Florida started enforcing statewide wind-resistant building codes.

Medical Facilities

In Florida, four hospitals and eleven nursing facilities were closed due to Hurricane Michael, according to FEMA. Two of the biggest hospitals in Panama City, Bay Medical Sacred Heart, with 323 beds and providing shelter to 1500 people during the storm, and Gulf Coast Regional Medical Center, with 238 beds, experienced severe damage. A total of 330 patients were evacuated from these two hospitals on Wednesday, October 10, 2018 (PR Newswire, 2018). Specifically, Bay Medical Sacred Heart (Fig. 12) sustained roof, structural and water damage as double-paned glass cracked and cladding was stripped off of buildings in its complex; most notable was the damage to its intensive care unit on the upper floors of a newer glass-clad tower. Gulf Coast Medical Centre experienced disruptions in power, water supply and sewage systems. Similarly, Florida State Hospital in Chattahoochee was out of power and water supply after a tree downed during the storm caused a water line to break.

Tyndall Air Force Base

Tyndall Air Force Base, built in 1941, is located 12 miles east of Panama City, Florida. According to the base commander, every structure suffered roof damage, in addition to other structural damages. Of particular note were the damages to the envelope of the aircraft hangars (Fig. 13). Moreover, water, power and sewer facilities were also damaged making the base uninhabitable.

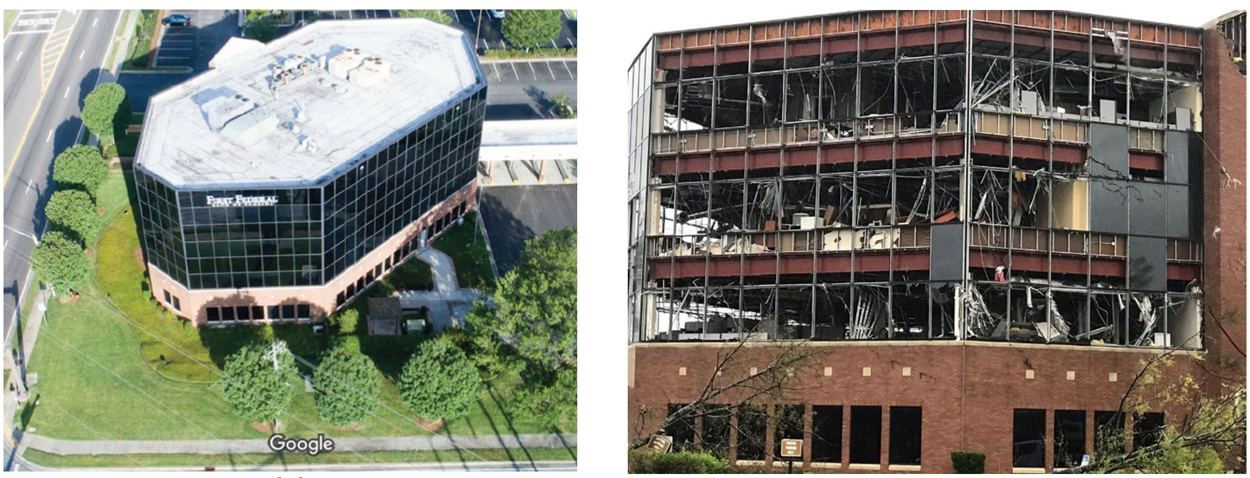
Commercial Construction

The following case studies illustrate the performance of common commercial typologies. The first illustrates the performance of metal frame and joist systems, where the building envelope has been completely detached from the primary structural system, as was the case with the Dollar General in Panama City shown in Figure 14 (see https://www.youtube.com/watch?v=E7zSfWTjqlg). While the failure sequence cannot be known with certainty, the loss of the glass curtain wall resulted in exposure of all contents of this retail store, which became a target of significant looting. Another noteworthy example is the First Federal Bank in Panama City, which suffered a complete loss of its cladding system resulting in significant damage to contents and interior finishes (Fig. 15).

Figure 12: Bay Medical Center Sacred Heart: The hospital sustained roof, structural and water damage (Source: Pensacola News Journal -- www.pnj.com/news/)

Figure 13: Catastrophic damage at Tyndall Air Force Base with fighter jets exposed inside of roofless hangars (Source: First Coast News -- www.firstcoastnews.com)

Figure 14: Family Dollar damaged by hurricane Michael (Source: First Coast News -- https://www.circa.com/story/2018/10/11/nation/family-dollar-looted-in-the-aftermath-of-hurricane-michael)



(a) (b)

Figure 15: First Federal Bank of Florida: (a) before Hurricane Michael, image from google maps June 2017; (b) after Hurricane Michael (Source: https://twitter.com/StormVisuals/status/1050118658717040640/photo/1)

Residential Construction

Hurricane Michael caused the full spectrum of damage scenarios in residential construction in the affected area, from wind-induced damages to the building envelope such as loss of roof and wall cover, to more substantive structural damage to the roof system (loss of sheathing and framing) to the complete destruction of the main force resisting system. However, some of the most staggering damage was noted in the regions experiencing large storm surge, e.g., Mexico Beach, FL, where homes were completely wiped from their foundations. While not surprising for homes that were not elevated or were of older construction not built to the latest Florida codes (such as the 1970s-era homes common to Mexico Beach), the loss of homes with elevated living spaces and concrete piers designed to the latest code provisions were particularly disconcerting for homeowners. In many cases, the lack of sufficient freeboard resulted in homes that had robust load paths being crushed under the force of breaking waves riding on the significant storm surge. Damage characteristic of that observed in Hurricane Ike in Texas and Superstorm Sandy in New Jersey was observed. Figure 16 shows one of the few exceptions on Mexico Beach, a home built above code minimums for Bay County, at a cost of roughly double per square foot. The home is reinforced concrete elevated on concrete pilings and lost only its stairs and breakaway walls, with some minor water damage.

Figure 16: Widespread devastation to wood-framed single and multi-family residences in Mexico Beach as noted by the bare slabs with few survivors in the areas with highest inundation, including the concrete “Sand Palace” (Source: New York Times)

Schools

Figure 17 provides an example of damage to long-span roof system in the gymnasium of the Jinks Middle School in Panama City, Florida. It is suspected that failure instigated with the breach of the roof, which is peeled back, followed by the failure of the windward and leeward masonry walls.

(a) After hurricane Michael **(b) Before hurricane Michael (Nov 2017)**

Figure 17: Jinks Middle School (Panama City) gym destroyed by Hurricane Michael (source: WMBB). (a) Post-storm imagery documenting failure of end wall adjacent to parking lot (yellow dashed boxes) and tennis court (red dashed boxes). Roof at the tennis court side (blue dash boxes) is completely peeled back. (b) Multiple views of building before Hurricane Michael from Google StreetView (captured Nov 2017). Each damaged element in (a) is boxed using the same colors but solid line in (b).

Lifelines: Power and Telecommunications

Hurricane Michael's powerful wind and rain disrupted power to up to 1.6 million customers across Florida, Georgia, Alabama and South Carolina at of the time this report was authored. Table 1 summarizes power outages state by state. Specifically, the Panhandle and Big Bend areas of Florida are served by two power companies: Gulf Power and Duke Energy. Gulf Power services the areas in the western Panhandle, while Duke Energy services most of the eastern Panhandle and western Big Bend areas. According to spokesmen from Gulf Power Co, at the peak of the storm, approximately 120,000 customers (26%) experienced power outages. A spokesman of Gulf Power, Jeff Rogers, mentions that for areas around Panama City, the power systems will have to be rebuilt from the ground up. Table 2 and Figure 18 show the evolution and location of outages for Gulf Power locations, while Table 3 and Figure 19 show outages for Duke Power locations.

Table 1: Power outages in Hurricane Michael as of 8:55 am ET on October 12 with comparison to prior day's total where available (Source: Data Fusion)

State(s)	Number of reported outages
Virginia	554,905 (up from 36,817)
North Carolina	493,400 (up from 297,723)
Florida	275,283 (down from 307,710)
Georgia	145,361 (down from 211,180)
Alabama	30,597 (down from 53,068)
New Jersey, New York, South Carolina, Maryland and Pennsylvania	less than 10,000 per state

Table 2: Gulf Power outage history as of October 12, 2018 (Source: Gulf Power)				
Time/Date	**Active Outages**	**Total Customers Out**	**Total Customers Served**	**System Reliability**
11:00 am Oct. 11, 2018	572	112,313	475,125	75.43%
2:30 pm Oct. 11, 2018	567	111,977	475,125	75.50%
5:00 pm Oct. 11, 2018	557	110,098	475,125	75.91%
8:00 pm Oct 11, 2018	531	107,452	475,125	76.49%
12:00 am Oct. 12, 2018	524	105,811	475,125	76.85%
9:30 am Oct. 12, 2018	537	106,133	475,125	76.78%
6:00 pm Oct. 13, 2018	627	79,045	475,125	82.70%
9:00 am Oct. 14, 2018	568	68,281	475,125	85.06%
9:00 pm Oct. 14, 2018	482	62,252	475,125	86.38%
9:00 am Oct 15, 2018	480	65,190	475,125	85.73%

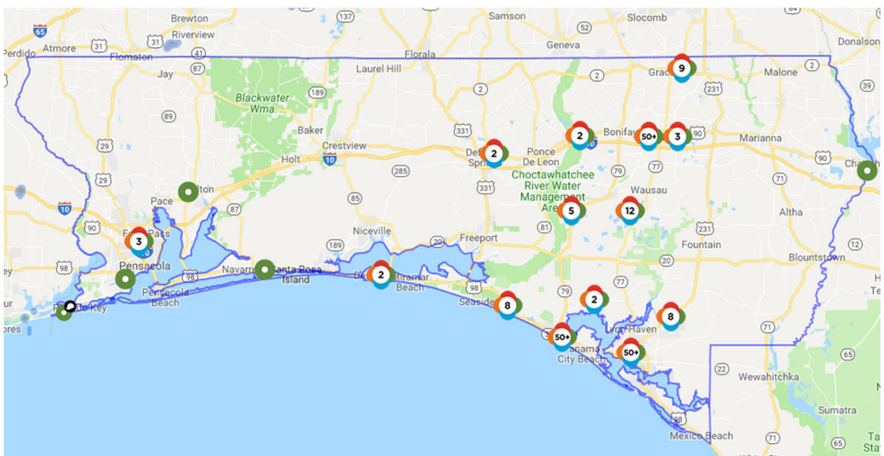


Figure 18: Gulf Power outage areas as of 10:15 am CST Oct. 12, 2018 (Source: Gulf Power)

Table 3: Duke Energy outage history (Source: Duke Energy)				
Time/Date	**Active Outages**	**Total Customers Out**	**Total Customers Served**	**system Reliability**
2:30 pm Oct. 11, 2018	1,458	29,793	1,475,102	97.98%
5:00 pm Oct. 11, 2018	1,409	29,023	1,475,102	98.03%
8:00 pm Oct. 11, 2018	1,407	28,281	1,475,102	98.08%
12:00 am Oct. 12, 2018	1,362	28,241	1,475,102	98.09%
9:30 am Oct. 12, 2018	1,353	30,061	1,475,102	97.96%
6:00 pm Oct. 13, 2018	657	19,442	1,475,102	98.68%
9:00 am Oct. 14, 2018	408	15,930	1,475,102	98.92%
9:00 pm Oct. 14, 2018	359	12,772	1,475,102	99.13%
9:00 am Oct. 15, 2018	361	12,800	1,475,102	99.13%

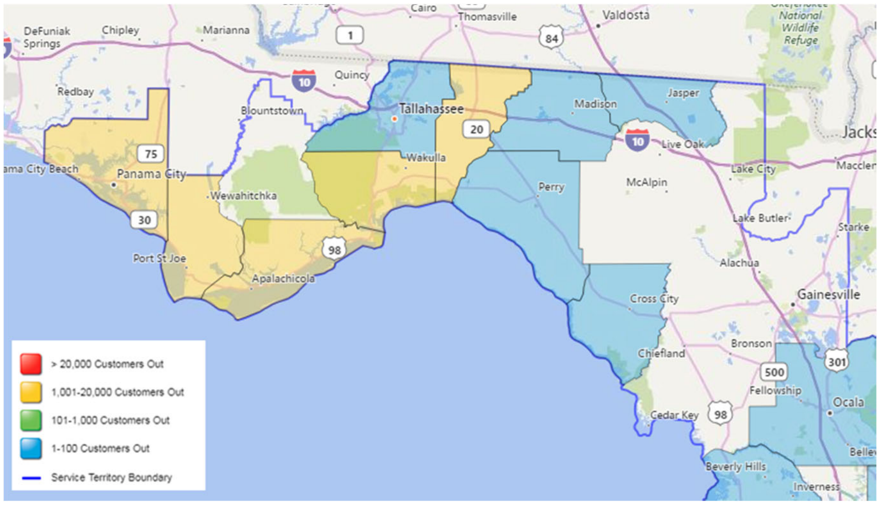


Figure 19: Duke Energy outages as of 10:15 am Oct. 12, 2018 (Source: Duke Energy)

The electric power network suffered losses to physical infrastructure, such as wooden and concrete distribution poles, lattice-type transmission towers, and substations. The damage to the distribution system is observed to be mostly due to a combination of high winds and fallen trees and the domino-like failure of tens to hundreds of distribution poles (Fig. 20 a-c). The damage to the transmission towers is more limited (Fig. 20 c-d), but considering the high voltage load carried by these towers, it is expected to have more lasting effects with widespread blackouts. There are reports of damage to the raised structures of substations due to high winds in addition to a number of flooding events that have hampered the operation of the substations.

In addition to power outages, telecommunication networks were severely impacted by Hurricane Michael. The Federal Communications Commission (FCC) reported as of 11:00 am ET on October 11, 2018, 554 cell sites or close to 19% of all services in the area, were completely down. In addition, approximately 264,000 cable and wireline customers were without service. The evolution of restoration is summarized in Figure 21.

Lifelines: Transportation Infrastructure

Roads and Bridges

Some of the hardest-hit areas were near impossible to reach because the roads were buried beneath either water, debris or both, e.g., Mexico Beach. Downed trees, power lines, and debris were the main cause of road closures. In coastal areas, this was amplified by the significant damage to buildings and other coastal infrastructure and their transport by storm surge (Fig. 22 b,c). At one point, an estimated 200 roads in Tallahassee were blocked by fallen trees. Ground saturation from previous rain events made trees particularly vulnerable to uprooting (Fig. 22d). The main east-west road across the Panhandle, Interstate 10, was closed for an 80-mile stretch. U.S. Highway 98 was the only reported roadway with damage due to washout (see Fig. 22a). Multiple bridges in states as far as South Carolina were closed along the coast for safety during high winds, but no sustained damage has been disclosed due to high winds thus far. The Georgia Department of Transportation had cleared its interstate highways, but were still working to clear over 100 state routes at the time this report was authored. Twenty-eight state roads were closed due to downed trees and other debris in South Carolina, where the interchange of I-85 and 385 had 3 ramps closed due to flooding. Appendix B lists specific road and bridge closures in Florida, Georgia and North Carolina as of October 12, 2018.

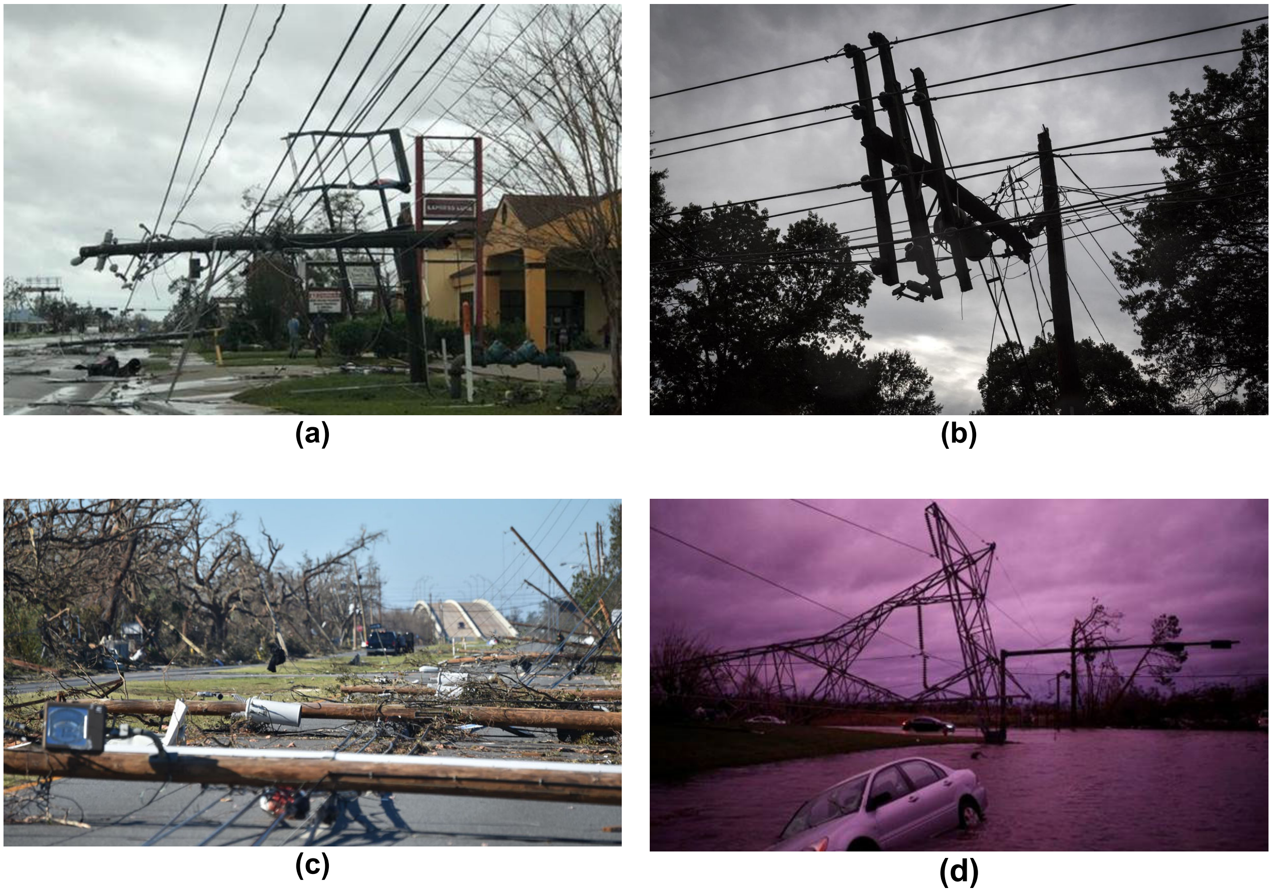
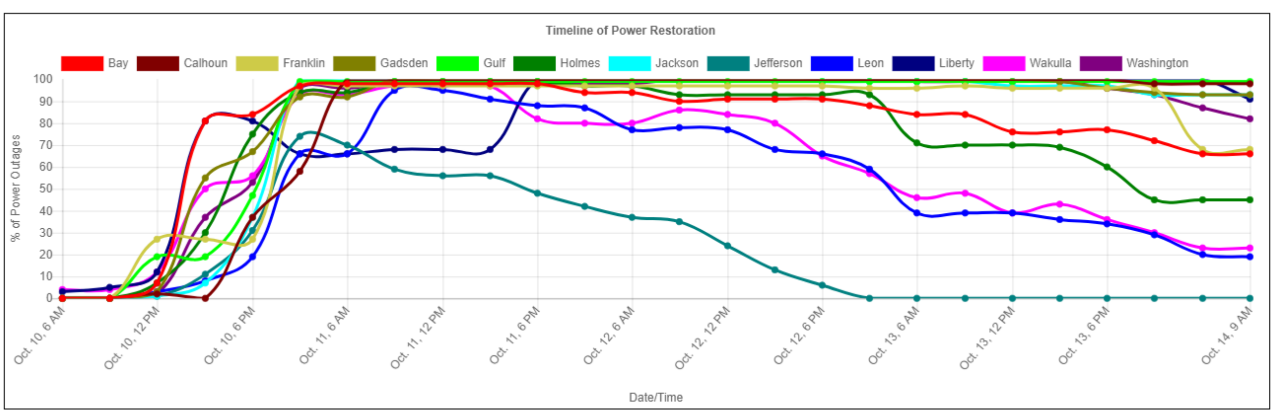


Figure 20: (a) Failed wooden power poles in Mexico Beach. (Source: Tallahassee Democrat); (b) Downed power lines in Winston-Salem, NC (Source: Winston-Salem Journal); (c) Fallen electrical poles block a road in the aftermath of Hurricane Michael on Oct. 12, 2018 in Panama City, FL representing a cascade failure in multiple poles that could be initiated either by fallen trees, extreme wind effects, or both (Source: Hector Retamal/AFP/Getty Images); (d) Vehicle sits partially submerged in floodwaters as a fallen electricity transmission tower lays on the ground in the background after Hurricane Michael hit in Panama City, FL on Wednesday, Oct. 10, 2018. (Source: Luke Sharrett/Bloomberg).



Source: Florida Division of Emergency Management

Figure 21: Timeline of power restoration in different Florida counties after Hurricane Michael landfall (Florida Division of Emergency Management)

(a) **(b)**

(c) **(d)**

Figure 22: (a) Damage to Highway 98 near Carrabelle (Source: The New York Times); (b) road obscured by debris in Mexico Beach, FL on Thursday, Oct. 11, 2018 (Source: CTV News); (c) debris from homes destroyed by Hurricane Michael and sand deposition block road on Oct. 11, 2018, in Mexico Beach, FL (Source: Lincoln Journal Star); (d) Trees blocking roadway in Panama City, FL (Source: Gerald Herbert, AP)

Railroads

The U.S. Freight railroads operate more than 11,400 miles of track in Florida, Alabama and other southeastern states. Railroads removed locomotives, rail cars, electric signals and switches from areas with a risk of flooding and worked with other railroads to re-route traffic. However, even with all the preparation, railroad operations were shut down between Jacksonville, Florida and Atlanta, Georgia due to the hurricane. Freight customers were told to expect about a 12-hour delay before work is back to normal due to inspections of the tracks after Hurricane Michael.

Ports

U.S. ports in the southeast were open to commercial traffic throughout the hurricane but were taking precautions, though the Port at Panama City and the Port of Pensacola were closed. The Port at Panama City handles shipments of a variety of products including, copper, wood pulp, steel plate, steel pipe and steel coils.

Airports

All commercial air travel was shut down in the affected area. Tallahassee International Airport, Northwest Florida Beaches Airport, and Destin Fort Walton Beach Airport were all closed the day the storm made landfall.

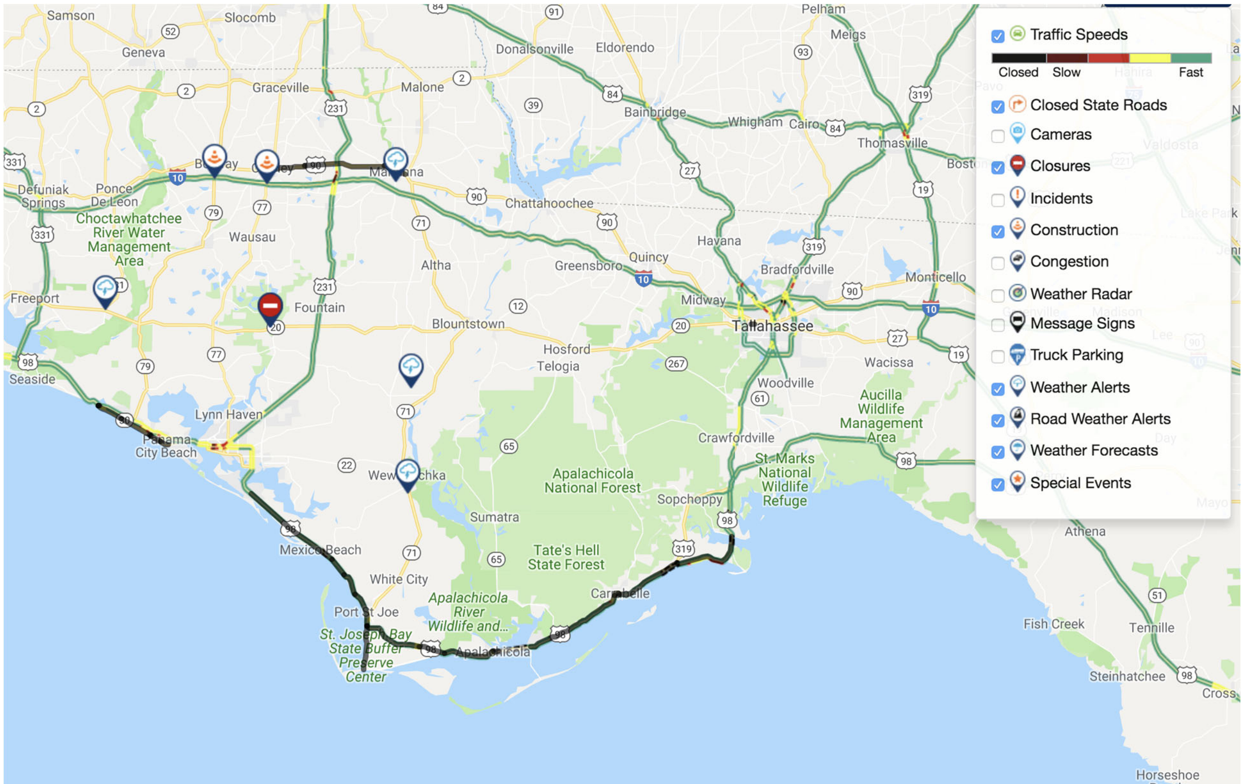


Figure 23: Florida Department of Transportation Fl511 Post-Hurricane Michael access restriction as of October 12, 2018 15:22 (EST) (Source: https://fl511.com/#:News)

Current Conditions

Given Hurricane Michael's intensity, a large segment of the Florida Panhandle and southern Georgia has been impacted, with some of the most significant impacts are in Panama City and Mexico Beach. Access to Mexico Beach, in particular, is restricted to only those with official credentials. Power, cellular communications and water services have not been restored in these regions. While search and rescue operations have largely concluded, debris removal will be an ongoing process for weeks to come. The Florida Department of Transportation continues to update road closure information, but even those roads that are open are experiencing significant traffic and delays as evacuees attempt to return to their properties. Figure 23 summarizes restrictions on access and closed state roads obtained from Florida Department of Transportation Fl511 (https://FL511.com) as of October 12, 2018 15:22 (EST). A summary of some of the access restrictions, at the time this report was authored, are as follows:

- All lanes US highway 98 are blocked due to storm surge and debris (West to East):
  - Tyndall Dr. through Columbus St.
  - Forbes St. through SR 372 Surf Rd near Walker Bridge
  - SR-377xUS-98 has debris on roadway
- County Rd 30A is closed from Cape San Blas Rd to US98

- Closed bridge and roadway barricaded at SR-300 (North end) at St. George Island Bridge and Big Bend Scenic Byway.
- Other closed roads and streets described from South to Northeast:
    - Ochlockonee Bay Bridge (US-98)
    - Bottoms Road/CR 372A (connects to US-98)
    - Chattahoochee Street (connects to US-98)
    - Beaty Taff Drive (crosses with Shell Point Road)
    - Kornegay Way (from Canal St to Shell Point Rd)
    - Old Fort Drive (connects to Riverside Drive)

StEER Response Strategy

Based on prior event experience and preferences, volunteers were offered positions on two types of StEER Teams:

- **Virtual Assessment Teams (VATs)** were formed to assemble data on the event from public sources and lead authorship of two reports: this Preliminary Virtual Assessment Team (P-VAT) Report and the Early Access Reconnaissance Report (EARR) based on the data from the first field assessment team (FAT). VATs also work to enrich FAT data with other information gleaned from inventory data and high-resolution imagery, and participate in quality assurance and data cataloging processes.
- **Field Assessment Teams (FATs)** were formed by invitations to individuals with prior field experience and expertise relevant to this type of event. FATs were used to rapidly gather essential data only visible on the ground, with the understanding that these will be enriched with additional sources of data through aligned StEER efforts. FAT targets are selected using inventory data in the landfall region, identifying potential clusters where damage assessments could capture a range of typologies and ages of construction under comparable wind and storm surge levels.

Given the magnitude of Hurricane Michael, StEER deployed its first Field Assessment Team (FAT-1) October 13-15, 2018. This team was drawn from regional expertise with prior hurricane reconnaissance experience. FAT-1 was tasked with covering as much of the affected area as possible to identify recommended locations for future study, as well as conducting targeted sampling in select locations. To accomplish this, FAT-1 subdivided into an **Advance Scout Subteam** and a **Targeted D2D Assessment Subteam** to maximize coverage during this mission. The specific objectives of FAT-1's subteams includes:

1. **Advance Scout Subteam:**
    a. gather high level impressions of the damage to buildings and other infrastructure with emphasis on wind and storm surge over a wide area using StreetView rapid surveying technology, recording spot observations of representative performance (damaged and undamaged) using the Fulcrum App
    b. Identify targets for follow up assessment and establish which areas are accessible and for those that are not, make inquiries to determine when access will be granted
2. **Targeted D2D Assessment Subteam:**
    a. Conduct door to door (D2D) damage assessments sampling every third house in targeted areas with a blend of typologies, using Fulcrum App with unmanned aerial surveys (UAS) overhead
    b. Record spot observations of damage or evidence of hazard intensity (wind, surge) using Fulcrum App

VAT will review damage reports and data from FAT-1 as swiftly as possible, as well as other public data from this event. This will be used to generate an Early Action Reconnaissance Report (EARR) to be released on DesignSafe. StEER is coordinating with other organizations responding to this event to further develop this event strategy. As many of the affected coastal areas will not be accessible to FAT-1, StEER anticipates sending a second Field Assessment Team (FAT-2) shortly thereafter.

Acknowledgements

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The authors also thank Eric Merschman (University of Alabama, Huntsville) for compiling data on the impact of Hurricane Michael on power and telecommunications infrastructure. The assistance received from graduate students Faiaz Khaled, Nader Yousef, and Suvash Chapain, from the Windstorm Impact, Science and Engineering (WISE) Research Program, Louisiana State University (LSU), is acknowledged with thanks.

The sharing of videos, damage reports and briefings via DesignSafe-CI's Slack channel was tremendously helpful and much appreciated. These collaborations and exchanges of critical data in the landfall stages benefited greatly from the work of the DesignSafe CI team who continuously supported and responded to StEER's emerging needs.

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Appendix A: Florida Building Code Design Wind Maps

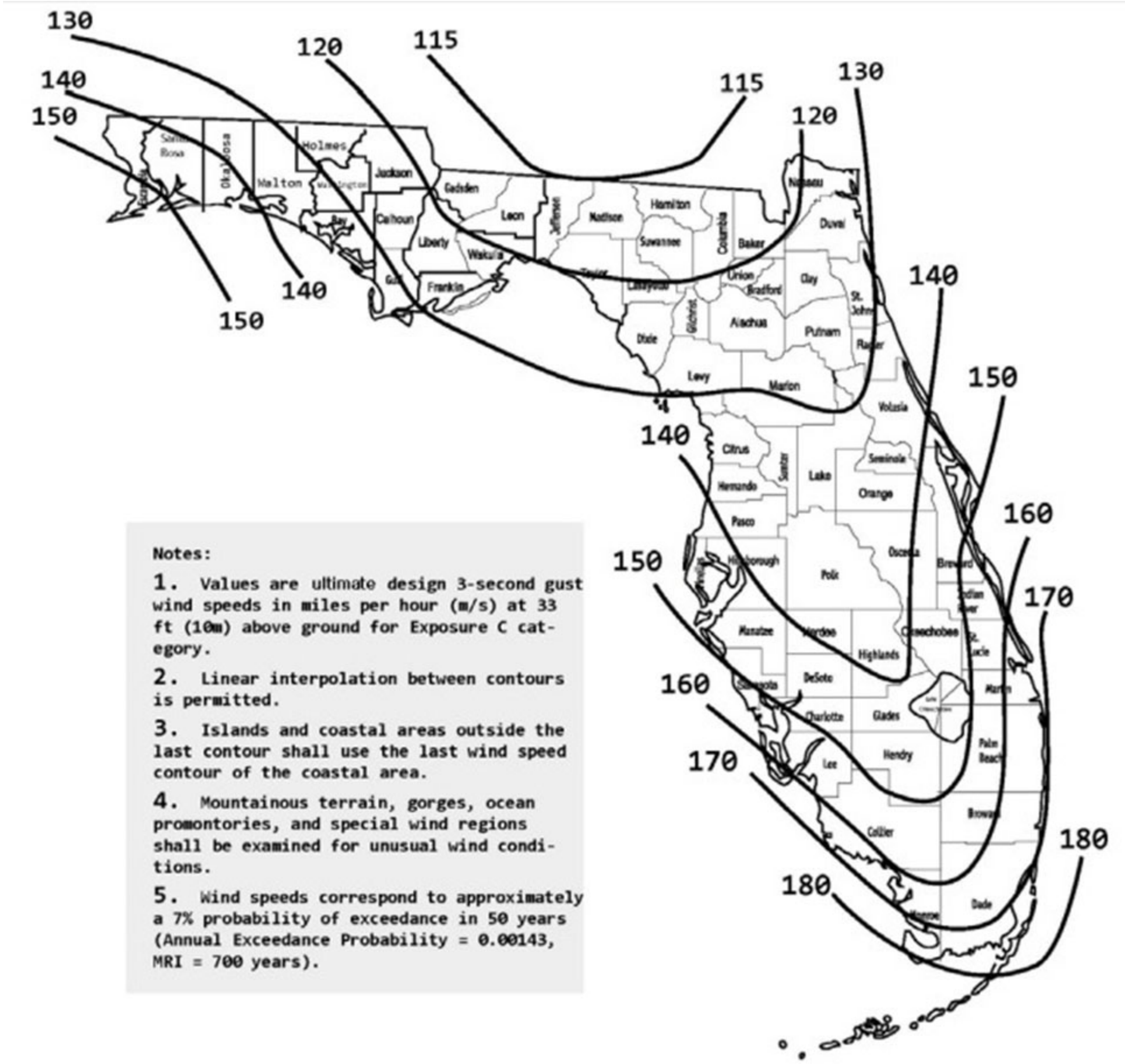

Figure A.1: Ultimate design wind speeds for Risk Category II buildings and other structures (Florida Building Code, Sixth Edition Fig. 1609.3(1))

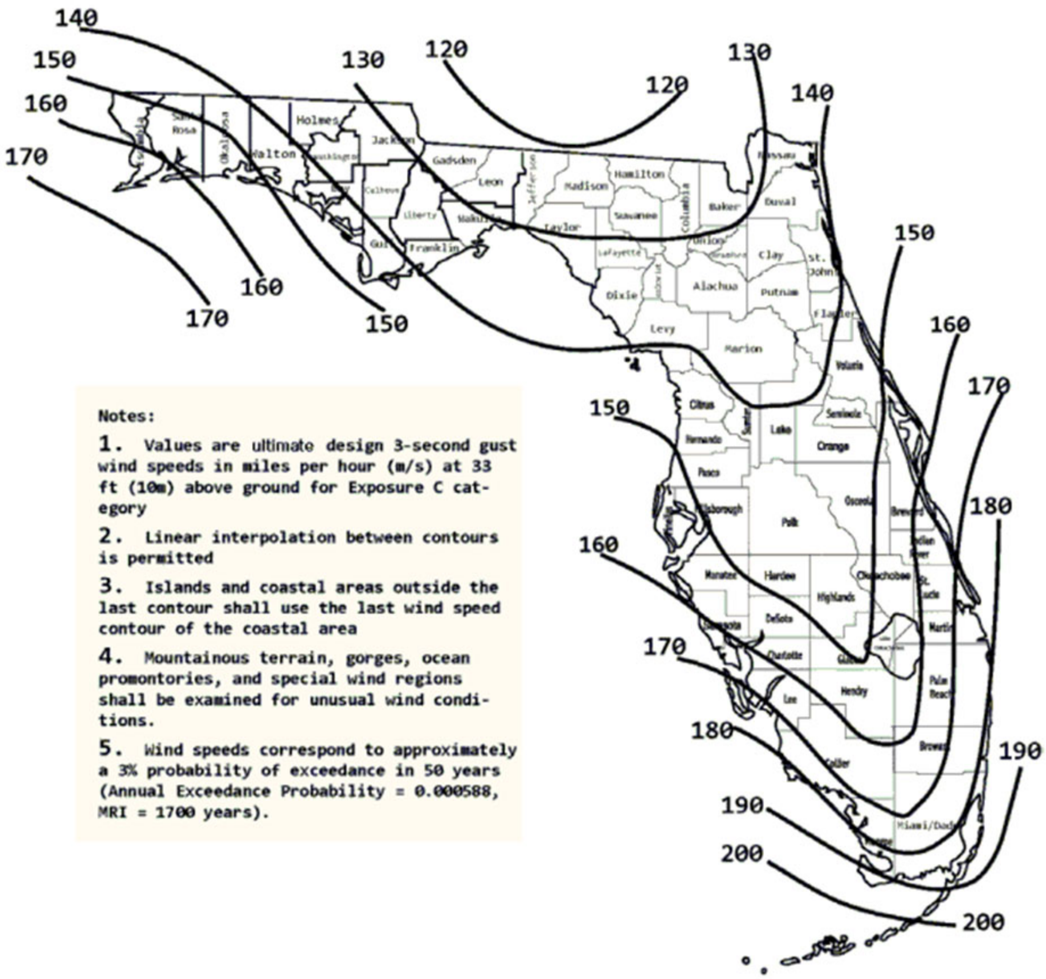

Figure A.2: Ultimate design wind speeds for Risk Category III & IV buildings and other structures (Florida Building Code, Sixth Edition Fig. 1609.3(2))

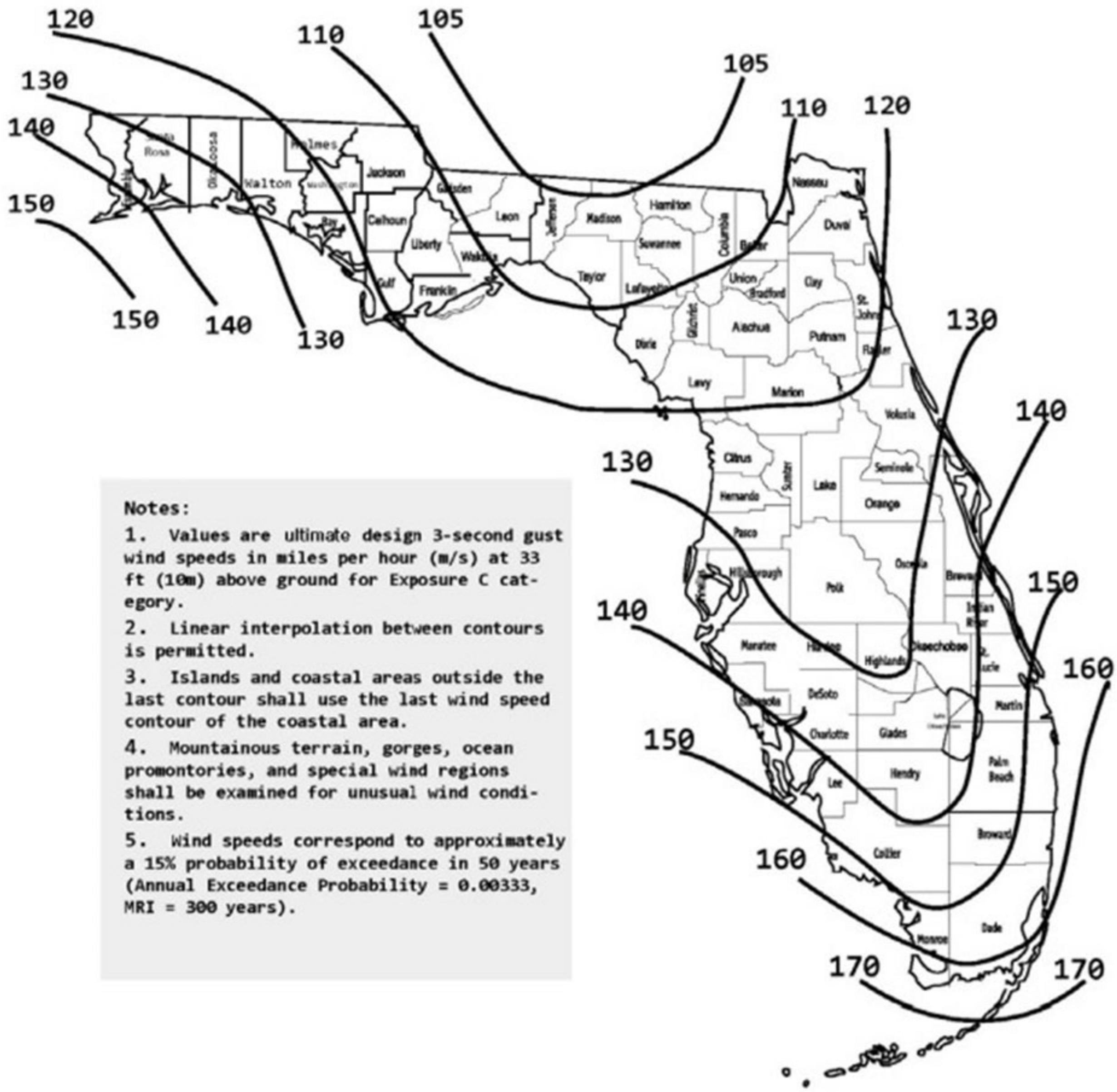

Figure A.3: Ultimate design wind speeds for Risk Category I buildings and other structures (Florida Building Code, Sixth Edition Fig. 1609.3(3))

Appendix B: Bridge and Road Closures by State

Table B.1: Florida bridge and road closures

Bridge or Road Name	Reason for Closure	County	Section Closed
St. George Island Bridge	High Winds	Franklin	
John Gorrie Memorial Bridge	High Winds	Franklin	
Walker Bridge	High Winds	Franklin	
SR-20 Bridge (Trammel Bridge)	High Winds	Calhoun	Apalachicola River
SR-20 Bridge	Flooding	Bay	Econfina Creek
US Hwy 98	Debris/Washout	Multiple	Tyndall AFB - Walker Bridge
Hwy 30	Downed Powerline/Trees	Bay	Jct. US Hwy 98 - Jct. 392A
East Gulf Beach Dr	Storm Overwash		
SR 30A		Gulf	West Rutherford Street south to Cape San Blas Road.
County Road 30A		Gulf	from Cape San Blas Road to the Franklin County Line.
SR 363		Wakulla	from St. Marks City Hall to the St. Marks River
Clyde B. Wells U.S. Highway 331 bridge		Walton	
Source: https://www.wjhg.com/content/news/Road-Closures-due-to-Hurricane-Michael-496578231.html			

Table B.2: Georgia bridge and road closures		
Bridge or Road Name	**Reason for Closure**	**County**
SR 62 Westbound	Debris	Early
SR 91 Northbound	Debris- Tree or Branches	Dougherty
SR 50 Southbound	Debris- Tree or Branches	Sumter
SR 55 Southbound	Debris- Tree or Branches	Sumter
SR 118 Both Directions	Debris- Tree or Branches	Sumter
Talmadge Memorial Bridge	Caution	Chatham
Sidney Lanier Bridge	Caution	Glynn
I-75 at milepost 128 near Perry	Debris	Houston

Table B.3: North Carolina bridge and road closures	
Bridge or Road Name	**County**
Creedmoor Road	Wake
New Hill Olive Chapel Road	Wake
US 264	Wake
US 64	Wake
Knightdale Blvd	Wake
NC 157	Durham
Amhurst Road	Durham
Pickett Road	Durham
Andover Road	Durham
Snow Hill Road	Durham
US 15	Durham
Orange Grove Road	Orange
Hillsborough Road	Orange
Bradshaw Quary Road	Orange
Stanford Road	Orange
Hebron Church Road	Orange

West Hille Ave N	Orange
Governor Scott Road	Orange
Mckee Road	Orange
Turkey Farm Road	Orange
Jones Ferry Road	Orange

About StEER

The National Science Foundation (NSF) awarded a 2-year EAGER grant (CMMI 1841667) to a consortium of universities to form the Structural Extreme Events Reconnaissance (StEER) Network. StEER's mission is to deepen the structural natural hazards engineering (NHE) community's capacity for reliable post-event reconnaissance by: (1) promoting community-driven standards, best practices, and training for RAPID field work; (2) coordinating official event responses in collaboration with other stakeholders and reconnaissance groups; and (3) representing structural engineering within the wider extreme events reconnaissance (EER) consortium in geotechnical engineering (GEER) and social sciences (SSEER) to foster greater potentials for truly interdisciplinary reconnaissance. StEER also works closely with the NSF-supported Natural Hazards Engineering Research Infrastructure (NHERI) RAPID facility and cyberinfrastructure Reconnaissance Portal to more effectively leverage these resources to benefit StEER missions.

StEER relies upon the engagement of the broad NHE community, including creating institutional linkages with dedicated liaisons to existing post-event communities and partnerships with other key stakeholders. While the network currently consists of the three primary nodes located at the University of Notre Dame (Coordinating Node), University of Florida (Atlantic/Gulf Regional Node), and University of California, Berkeley (Pacific Regional Node), StEER aspires to build a network of regional nodes worldwide to enable swift and high quality responses to major disasters globally.

StEER's founding organizational structure includes a governance layer comprised of core leadership with Associate Directors for the two primary hazards as well as cross-cutting areas of Assessment Technologies and Data Standards, led by the following individuals:

- **Tracy Kijewski-Correa (PI),** University of Notre Dame, serves as StEER Director responsible with overseeing the design and operationalization of the network.
- **Khalid Mosalam (co-PI),** University of California, Berkeley, serves as StEER Associate Director for Seismic Hazards, leading StEER's Pacific Regional node and serving as primary liaison to the Earthquake Engineering community.
- **David O. Prevatt (co-PI),** University of Florida, serves as StEER Associate Director for Wind Hazards, leading StEER's Atlantic/Gulf Regional node and serving as primary liaison to the Wind Engineering community.
- **Ian Robertson (co-PI),** University of Hawai'i at Manoa, serves as StEER Associate Director for Assessment Technologies, guiding StEER's development of a robust approach to damage assessment across the hazards.
- **David Roueche (co-PI),** Auburn University, serves as StEER Associate Director for Data Standards, ensuring StEER processes deliver reliable and standardized reconnaissance data.

StEER's response to Hurricane Michael preceded the formation of its official policies, protocols and membership, which are still in active development. All policies, procedures and protocols described in this report should be considered preliminary and will be refined with community input as part of StEER's operationalization in 2018-2019.

StEER Event Report Library

2018

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