INVESTIGATION OF STORM SURGE IMPACTS FROM HURRICANE IRMA ALONG COASTAL AREAS OF SOUTHERN MAINLAND FLORIDA

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Stephen Konarik, Kevin Scharfenberg, Arlena Moses, Maria Torres, Larry Kelly, Rob Molleda
NOAA/NWS, Weather Forecast Office, Miami-South Florida

1. INTRODUCTION

The 2017 Atlantic Hurricane season was one of the most active since the 1850s. The tenth tropical cyclone of the season, Major Hurricane Irma, had peak winds of 185 mph as it approached the Leeward Islands of the Caribbean Sea, making it the strongest Atlantic storm outside of the Gulf of Mexico and the Caribbean on record. During its most intense phase, Irma was recognized as a significant threat to South Florida, eventually making landfall at Marco Island on the southwest Gulf coast of the Florida Peninsula. Due to expected life-threatening storm surge impacts, a Storm Surge Warning was issued for all coastal areas of South Florida, in additional to the traditional wind-based Hurricane Warning. Hurricane Wilma of 2005 was the last major hurricane landfall along the Florida Peninsula, at which time Storm Surge Warnings were not in use.

This study focuses on the surge-related damage that occurred with Irma in the coastal areas of Palm Beach, Broward, Miami-Dade, Mainland Monroe, and Collier Counties in Florida. It includes a comparison of high water marks along coastal areas affected by storm surge to the storm surge forecast and related warnings. Comprehensive surveys conducted across the high density urbanized coastal areas of South Florida a few days after Hurricane Irma made landfall identified the hardest hit areas across the region and provided the data for this investigation.

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*Corresponding author address: Stephen Konarik

NOAA/NWS Miami/South Florida, FL, 11691 Southwest 17th Street, Miami, FL 33165. E-mail: stephen.konarik@noaa.gov

2. BACKGROUND

Due to its development over the Atlantic's Main Development Region more than week earlier (Figure 1), Hurricane Irma's approach to South Florida was well-anticipated. NWS Weather Forecast Office (WFO) Miami began sending out email briefings to partners and officials regarding the system's impact on South Florida as early as 30 August, over 10 days before landfall. Full webinar briefings were initiated by WFO Miami on 5 September, when the storm surge hazard began to be mentioned in NWS forecasts. By 6 September, the National Hurricane Center (NHC) forecast track showed a major hurricane landfall in South Florida (Figure 2). By 7 September, NWS Miami began using the Sea, Lake, and Overland Surges from Hurricanes (SLOSH) model Maximum Envelope of Water (MEOW) to convey the increasing magnitude of the Storm Surge Threat. The SLOSH model parameters chosen were a Category 4 storm moving toward the north or north-northwest at 10 mph at the time of high tide (Figure 3). A significant challenge at this point was the uncertainty as to when Irma's expected northward turn would occur, and consequently whether the greatest threat would focus on South Florida's Gulf or Atlantic coast. Later on 7 September, a Storm Surge Watch and a Hurricane Watch were issued for all coastal areas of South Florida (Figure 4). At this point, Hurricane Threat and Impact (HTI) surge threat graphics began to be produced (Figure 5). Shortly thereafter, watches were upgraded to warnings as confidence increased that the Gulf coast of South Florida would experience the greatest storm surge magnitude (Figure 6).

Hurricane Irma caused 1 direct death and 33 indirect deaths in NWS Miami's area of responsibility. However, no deaths were attributed to storm surge. Following landfall and the departure of significant weather to the north of the region, plans for NWS storm surveying began to evolve. Various significant challenges were posed to forecasters and surveyors, including the fact that all of NWS Miami area's coastline, in excess of 200 miles, was impacted by storm surge. Staff at the office were fatigued after more than a week of continuous emergency operations, and wind and tornado surveys were needed in addition to surge surveys. Many areas were still closed to the public, and numerous private gated communities exist along the coast that were particularly heavily impacted. Cleanup was also ongoing and being completed at a swift pace, thus there was a need to quickly survey as much as possible in the diverse area of responsibility, ranging from a highly dense metropolitan area of over four million residents to remote Everglades fishing communities with limited infrastructure.

3. DATA/METHODOLOGY

Available NWS staff for surveys were broken into four geographically divided groups to survey all hazards in a specified region. Three of these groups had coastal areas to survey storm surge. The survey crews took three full days to complete their regions. Crews made use of such tools as the Damage Assessment Toolkit, iPads, and smartphones to take photographs while documenting damage and high water marks. Information from the surveys was then compiled and used to make GIS graphics of the impacts.

In addition to the data that was collected by NWS Miami surveying, the United States Geological Survey (USGS), the City of Fort Lauderdale, and NOAA tidal gauges all contributed to data utilized in developing surge graphics. Where exact inundation values could not be measured, debris/water lines were matched to terrain values using LiDAR in NAV88D.

All values were then converted to Mean Higher High Water (MHHW) using the NOAA's National Geodetic Survey, Office of Coast Survey, and Center for Operational Oceanographic Products and Services Vertical Datum Transformation Tool (VDatum). MHHW is used as a proxy for inundation in cases where it is not explicitly known. Values were then plotted using ArcMap.

4. RESULTS

Graphical maps were developed and compared to the Probabilistic Hurricane Storm Surge inundation graphics forecast issued by the National Hurricane Center leading up to landfall/impact (Figure 6). The results show that in general, storm surge inundation realized was within the "reasonable worst-case scenario" indicated by the NHC forecast (Figure 7).

Along South Florida's east coast, many observed values (Figure 8) were near or slightly in excess of the probabilistic storm surge forecast reasonable worst-case scenario. Due to excessive rainfall runoff in many urbanized locations along the Atlantic coast, water was found to be brackish and a mix of salt- and fresh- water during the peak storm surge, which accounts for flood levels above the salt-water surge inundation forecast. Across Broward and Palm Beach Counties, there exist fewer natural sand dunes and urban development has been allowed closer to the high tide lines. This contrasts to Miami Beach, with larger dunes and more restricted development behind the dunes. This lead to greater surge impacts across these counties, despite areas along Miami Beach having equal, or in some cases, higher surge values. In addition, the bathymetry consisting of relatively steep slope beyond the surf zone kept inundation from penetrating more than a few blocks inland.

The most significant inundation of storm surge across the Miami metropolitan area was locations along Biscayne Bay exposed to a long wind fetch over the water and unprotected by barrier islands (the northwestern areas of the bay). In and just south of downtown Miami, 4 to 6 feet of storm surge inundation combined with freshwater flooding was observed, and was responsible for the majority of residential flood damage to ground floors in the more susceptible neighborhoods. Wave run-up also likely contributed to the impact.

For the Gulf Coast of South Florida (Figure 9), storm surge values were highest just to the east of where the eye made landfall, over the remote communities of Chokoloskee and Everglades City. This area had inundation of over 8 feet above ground (8.2 MHHW). Many structures in the towns are elevated via pilings, so some escaped significant damage from flooding. Further north and west, Naples was a region of great concern for rapidly rising surge on the back side of Irma's eyewall. With landfall to the east of this region, much of the water had exited the shallow bay, contributing to a tidal level of 3.9 feet below MHHW at 1200 EDT on 10 September. However, as Irma progressed north, bay levels rose up to 3 feet per hour, reaching 4.13 feet above MHHW by 2124 EDT. This prompted a Flash Flood Emergency issuance by NWS Miami, and several structures were inundated and further damaged by the force of the rapidly rising water.

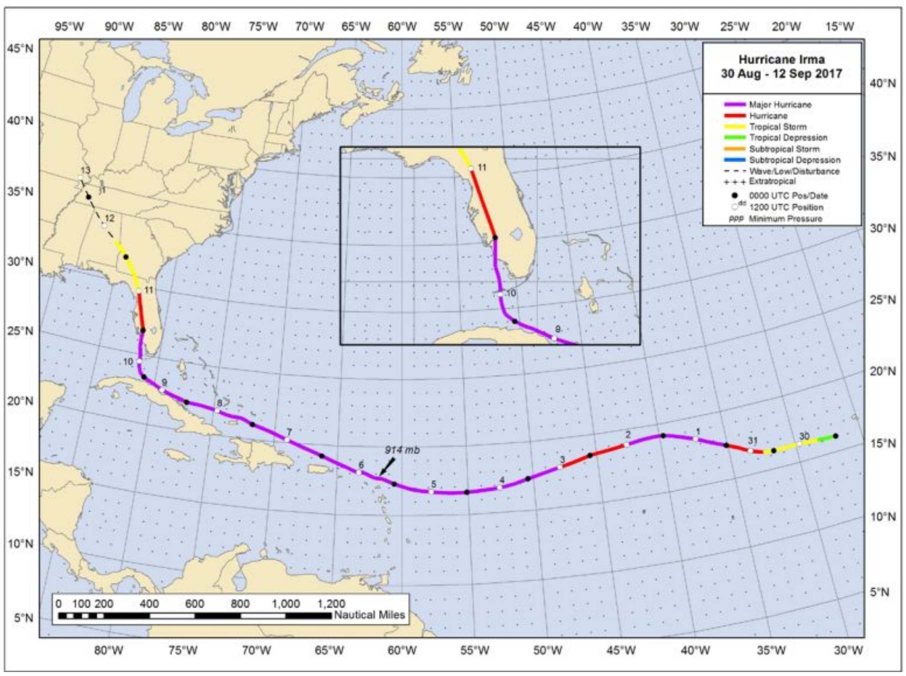


Figure 1: Track of Hurricane Irma, 30 August – 12 September 2017

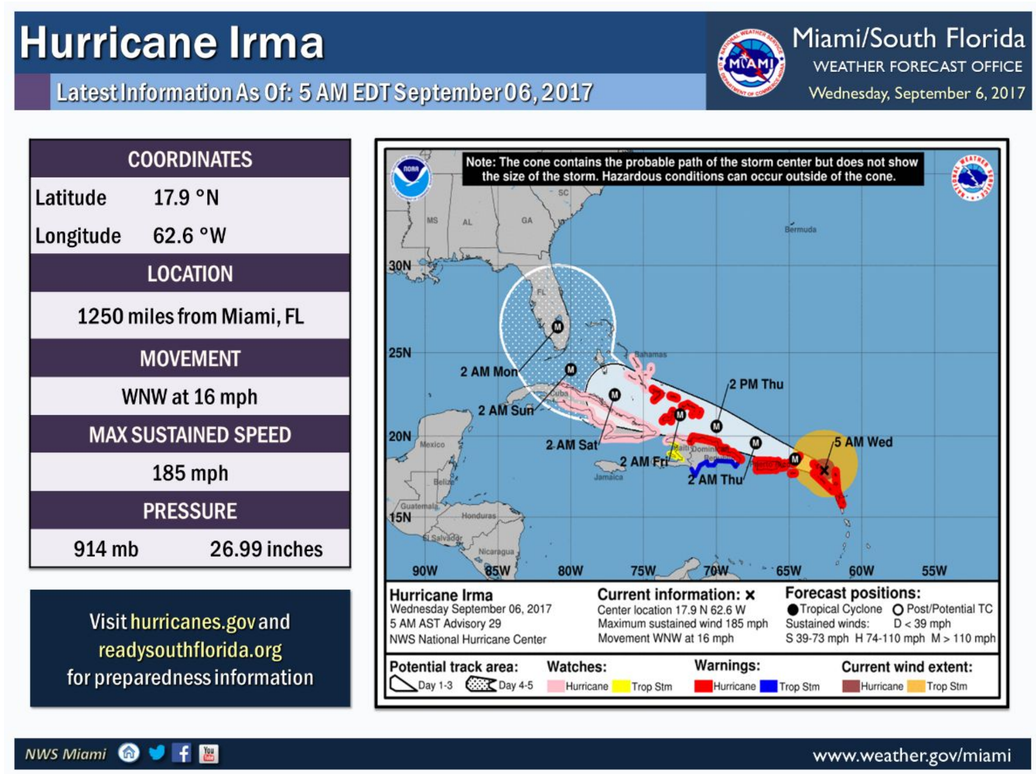


Figure 2: Hurricane Irma Advisory for 5 AM EDT 6 September 2017

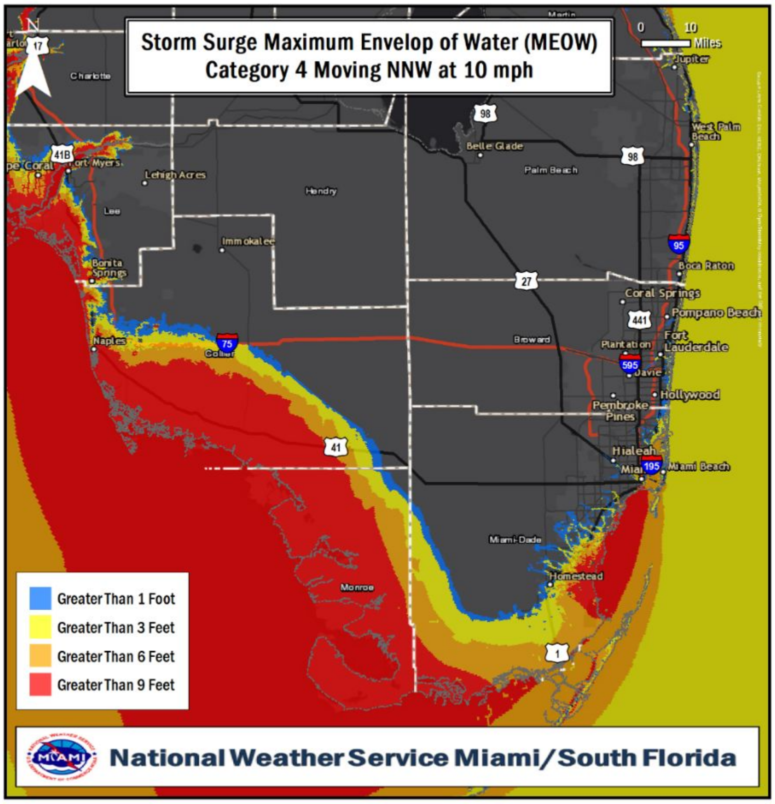


Figure 3: Storm Surge Maximum Envelope of Water (MEOW) - Category 4 Hurricane Moving NNW at 10 mph at high tide from the Sea, Lake, and Overland Surges from Hurricanes (SLOSH) model

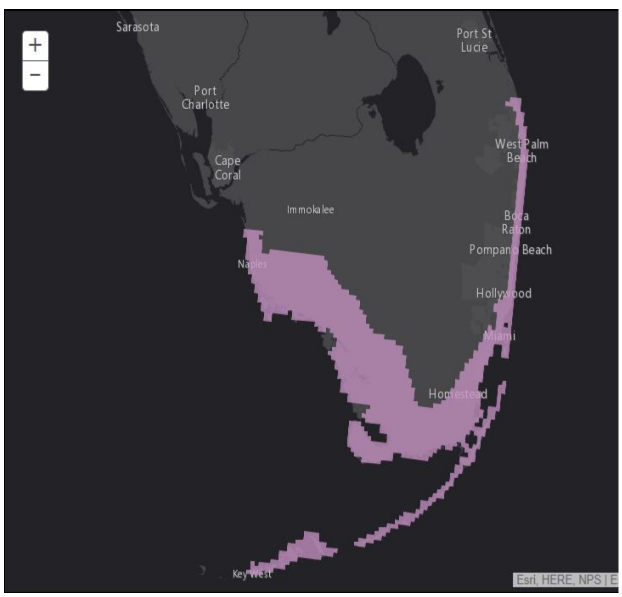
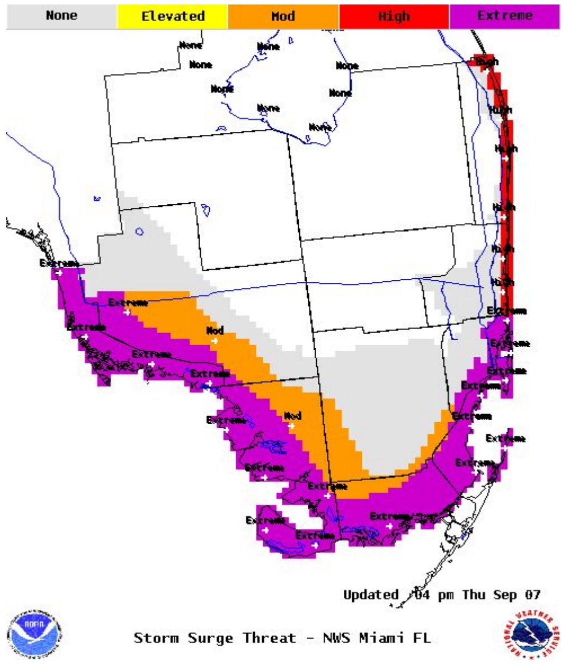


Figure 4: Storm Surge Watch issued at 11 am EDT, 7 September 2017



Storm Surge Threat
Potential for storm surge flooding > 9 ft above ground
Potential for storm surge flooding > 6 ft above ground
Potential for storm surge flooding > 3 ft above ground
Potential for storm surge flooding > 1 ft above ground
Little to no storm surge flooding

Figure 5: Hurricane Threat and Impact (HTI) Surge Threat Graphic issued 7 September 2017 by NWS Weather Forecast Office Miami, FL

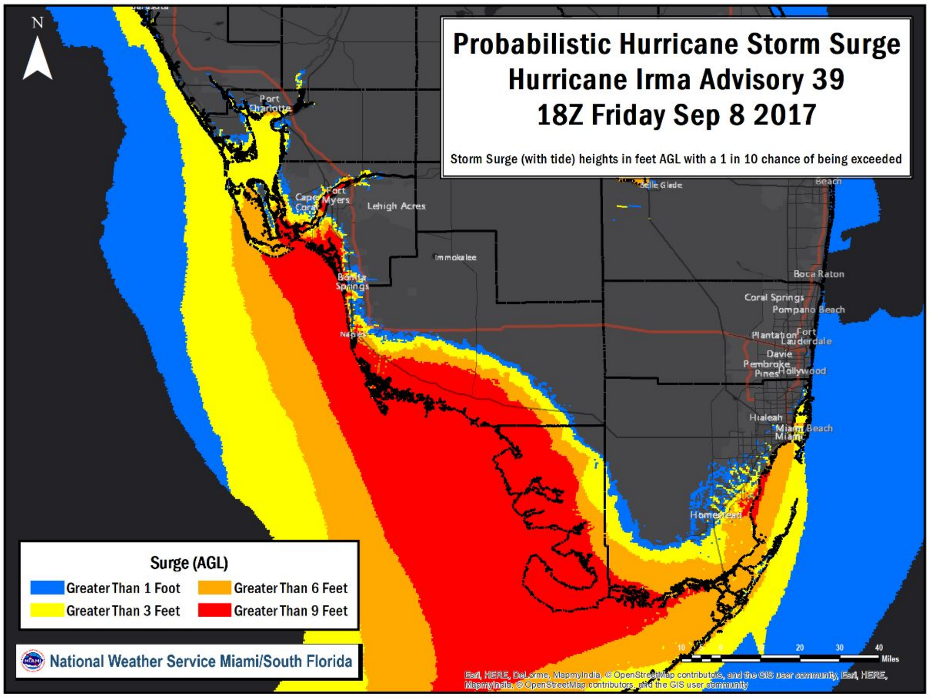


Figure 6: Probabilistic Storm Surge Graphic Based on Hurricane Irma Advisory 39

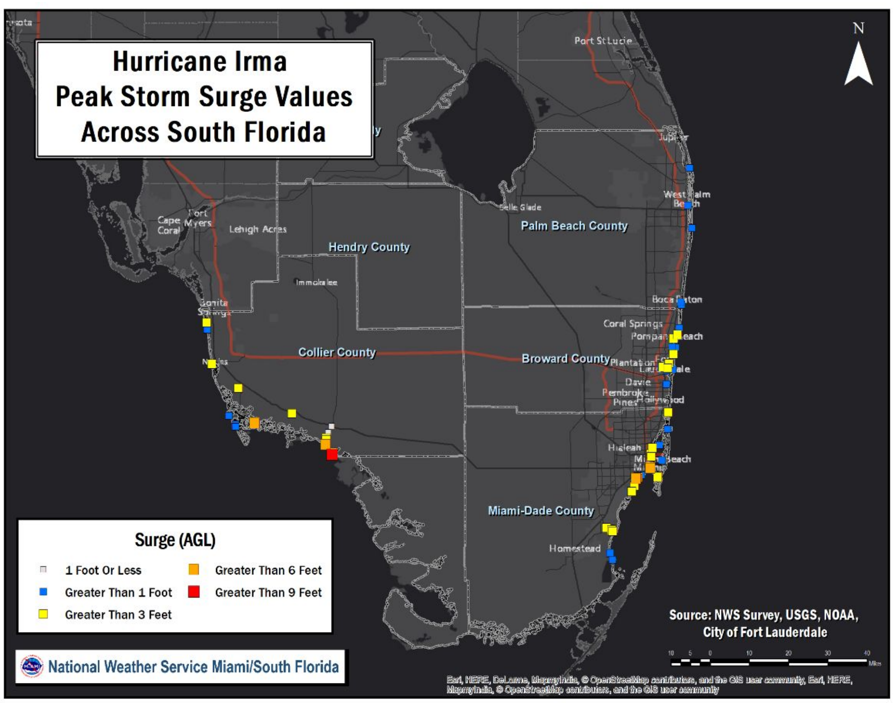


Figure 7: Hurricane Irma Peak Observed Storm Surge Values in South Florida

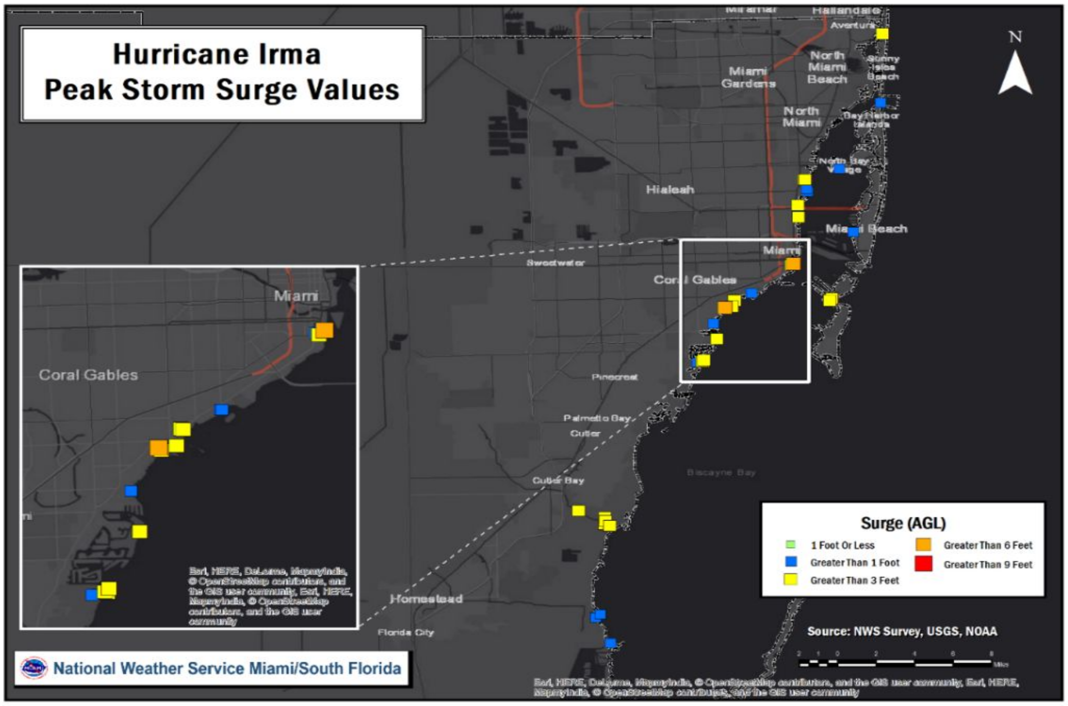


Figure 8: Hurricane Irma Peak Observed Storm Surge Values in Miami-Dade County

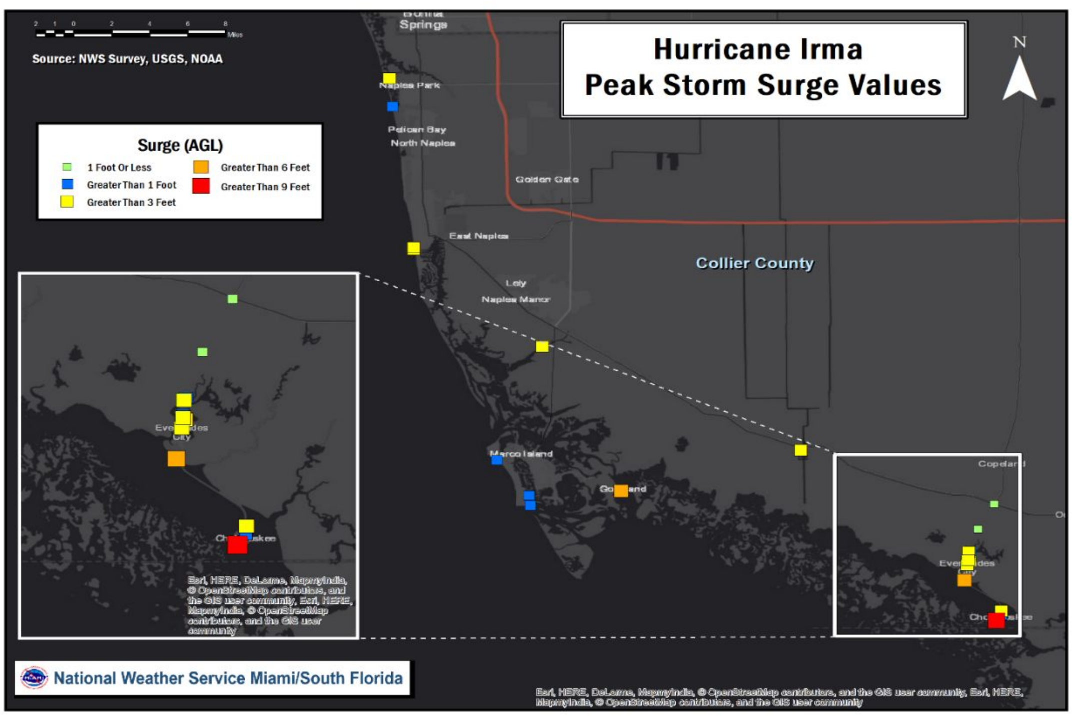


Figure 9: Hurricane Irma Peak Observed Storm Surge Values in Collier County