NATIONAL HURRICANE CENTER TROPICAL CYCLONE REPORT

HURRICANE HELENE

(AL092024)

24–27 September 2024

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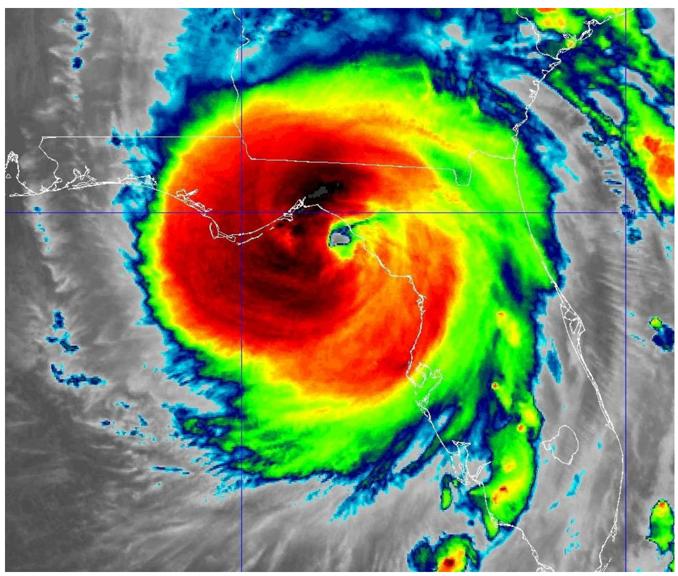

GOES-16 INFRARED IMAGE OF HELENE AT 0200 UTC 27 SEPTEMBER 2024 PRIOR TO LANDFALL IN FLORIDA. IMAGE COURTESY OF NOAA/NESDIS/STAR.

Helene made landfall in the Florida Big Bend region as a category 4 hurricane (on the Saffir-Simpson Hurricane Wind Scale). The storm brought catastrophic inland flooding, extreme winds, deadly storm surge, and numerous tornadoes that devastated portions of the southeastern United States and southern Appalachians. Helene is responsible for at least 248 fatalities in the United States (including at least 175 direct deaths), making it the deadliest hurricane in the contiguous U.S. since Katrina in 2005. Helene also produced tropical storm conditions and minor damage across portions of Mexico and Cuba.

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SYNOPTIC HISTORY

Helene originated from a Central American Gyre (CAG)[2] that developed on 20 September. During 20–22 September, the system had a large low-level cyclonic circulation (Fig. 1a) and closed cyclonic flow (Fig. 1b) with peak winds occurring over a broad region, well away from the center (Fig. 1c). The large gyre was initially centered over Central America, and it brought heavy rains to portions of Nicaragua and Honduras as it moved slowly northward. By 1200 UTC 23 September, the large circulation straddled Central America and the northwestern Caribbean Sea as deep convection began to organize near a mid-level vorticity maximum about 130 n mi south of Grand Cayman. However, the broad nature of the system meant it initially lacked the well-defined low-level center necessary to be a tropical cyclone. The National Hurricane Center (NHC) initiated potential tropical cyclone advisories at that time since the system was expected to become a tropical cyclone and bring tropical storm conditions to land areas within the next couple of days.

The disturbance moved slowly northwestward over the northwestern Caribbean Sea during the next 12 to 24 h while deep convection gradually increased. Satellite and aircraft data indicate that a well-defined low-level center formed by 1200 UTC 24 September, marking the formation of a tropical storm when the system was located about 175 n mi south of the western tip of Cuba. At the time of genesis, Helene was already producing 40-kt winds. The "best track" chart of Helene's path is given in Fig. 2, with the wind and pressure histories shown in Figs. 3 and 4, respectively. The best track positions and intensities are listed in Table 1[3].

Later that day, deep convection consolidated near the center and banding increased. Consequently, Helene steadily strengthened in conducive environmental conditions of low wind shear, high moisture, and very warm sea surface temperatures. Helene became a 55-kt tropical storm by 0600 UTC 25 September when the center was located about 50 n mi east of Cozumel, Mexico, and became a hurricane 6 h later while located just east of Cancun. Although Helene did not make landfall on the Yucatan Peninsula, Helene's large wind field brought tropical-storm-force winds to the far northeastern portions of the Yucatan Peninsula, including the Cancun and Cabo Catoche areas, and also brought tropical storm conditions to portions of western Cuba.

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[2] A Central American gyre (CAG) is a broad lower-tropospheric cyclonic circulation occurring near Central America. For more information please refer to Papin, P., L. F. Bosart, R. D. Torn, 2017: A Climatology of Central American Gyres. Mon. Wea. Rev., 145, 1983-2000. http://journals.ametsoc.org/doi/pdf/10.1175/MWR-D-16-0411.1

[3] A digital record of the complete best track, including wind radii, can be found on line at ftp://ftp.nhc.noaa.gov/atcf. Data for the current year's storms are located in the *btk* directory, while previous years' data are located in the *archive* directory.

Helene entered the Gulf of America later that day as a category 1 hurricane and turned northward on the western side of a subtropical ridge centered over the western Atlantic. Satellite and aircraft data indicate that Helene developed a secondary wind maximum farther from the center from late 25 September through early 26 September, which caused the intensity to level off. However, the wind field expanded significantly during this time, with tropical-storm-force winds extending outward up to 360 n mi from the center in the northeastern quadrant. After the outer wind maximum began to contract and Helene developed a better-defined inner core, the hurricane rapidly intensified on 26 September over the very warm Gulf waters while accelerating north-northeastward between the ridge and a deep-layer cut-off low centered over the Tennessee Valley. During this time, the inner core of the hurricane contracted further, but the outer wind field remained very large. Although aircraft reconnaissance reported the presence of an eye since about 0600 UTC 26 September, Helene lacked a clear eye in geostationary satellite images for most of the morning. Later, a relatively clear eye was able to maintain itself on geostationary imagery beginning around 1800 UTC that day until landfall 9 h later. Helene intensified into a 105-kt major hurricane by 1800 UTC 26 September when the eye was located about 150 n mi west-southwest of Tampa, Florida. The cyclone continued to rapidly strengthen and reached a peak intensity of 120 kt just 6 h later when it was located about 80 n mi south-southwest of the coast of the Florida Big Bend region. The category 4 hurricane maintained its intensity until it made landfall about 10 n mi southwest of Perry, Florida, around 0310 UTC 27 September, making it the strongest landfalling hurricane in the Florida Big Bend region since reliable records began around 1900.

Helene was moving extremely quickly when it made landfall in Florida, with a forward motion of 27 kt toward the north-northeast (Fig. 5). The hurricane then turned northward shortly after moving inland as it started to interact with the mid- to upper-level low located over the Ohio Valley, but its fast forward motion continued while it moved across Georgia. As a result of the fast forward motion, Helene's strong winds, especially in gusts, penetrated far inland. Surface and radar data indicate that Helene remained a hurricane as the center moved inland over southern Georgia, but the structure of the eye degraded, and Helene is estimated to have weakened to a 60-kt tropical storm around 0900 UTC 27 September when the center was located about 30 n mi east of Macon, Georgia. The center of the system quickly approached the Georgia-South Carolina-North Carolina border region by 1200 UTC that day, when widespread destruction from flooding, landslides and strong wind gusts was occurring across the southern Appalachians. The fast forward speed of the cyclone as it began to pivot around the cut-off low resulted in a widespread area of hurricane-force wind gusts primarily east of the center, especially in areas of elevated terrain in the southern Appalachians. Hurricane-force wind gusts spread as far east as coastal portions of Georgia and southern South Carolina, and as far northwest as the mountains of western North Carolina.

The storm turned northwestward during the afternoon hours (local time) on 27 September as it merged with the cut-off low to its west. This interaction and the loss of deep convection caused Helene to become post-tropical by 1800 UTC that day as it moved into southern Kentucky, with maximum sustained winds of around 40 kt. During the next day or so, the post-tropical low made a slow cyclonic loop and dissipated shortly after 1800 UTC 28 September over north-central Tennessee.

METEOROLOGICAL STATISTICS

Observations in Helene (Figs. 3 and 4) include subjective satellite-based Dvorak technique intensity estimates from the Tropical Analysis and Forecast Branch (TAFB) and the Satellite Analysis Branch (SAB), objective Advanced Dvorak Technique (ADT) estimates and Satellite Consensus (SATCON) estimates from the Cooperative Institute for Meteorological Satellite Studies/University of Wisconsin-Madison. Observations also include flight-level, stepped frequency microwave radiometer (SFMR), and dropwindsonde observations from ten flights of the 53rd Weather Reconnaissance Squadron of the U.S. Air Force Reserve Command and six flights from NOAA's Aircraft Operations Center (Fig. 6). These flights provided a total of 38 center "fixes" during Helene's lifecycle. In addition, there were two surveillance flights conducted by the NOAA G-IV jet. Data and imagery from NOAA polar-orbiting satellites including the Advanced Microwave Sounding Unit (AMSU), the NASA Global Precipitation Mission (GPM), the European Space Agency's Advanced Scatterometer (ASCAT), Defense Meteorological Satellite Program (DMSP) satellites, and the Time-Resolved Observations of Precipitation structure and storm Intensity with a Constellation of Smallsats (TROPICS) satellites, among others, were also useful in constructing the best track of Helene. In addition, radar data from the United States, the Cayman Islands, Mexico and Cuba provided important information on Helene. Saildrone observations, as well as observations from unmanned aircraft system (UAS) flights operated by NOAA (not shown in Figs. 3 or 4) were also helpful in analyzing Helene's wind field.

Ship reports of winds of tropical storm force associated with Helene are given in Table 2, and selected surface observations from land stations and data buoys are given in Table 3. A supplemental file containing a larger selection of surface and buoy observations is available for download on the NHC website at www.nhc.noaa.gov/data/tcr/supplemental/helene.zip. This file also contains rainfall reports from National Weather Service Cooperative (COOP) stations and the Community Collaborative Rain, Hail and Snow Network (CoCoRaHs) sites. A map of selected peak wind gusts across the eastern United States is shown in Figure 7.

Winds and Pressure

Helene rapidly intensified as it accelerated north-northeastward over the Gulf of America on 26 September, reaching an estimated peak intensity of 120 kt at 0000 UTC 27 September. The estimated peak intensity is based on a peak 700-mb flight-level wind of 134 kt measured by the Air Force Reserve Hurricane Hunters at 2346 UTC 26 September and a peak 750-mb flight-level wind of 139 kt measured by the NOAA Hurricane Hunters at 0035 UTC 27 September. Both observations correspond to approximately 120-kt winds at the surface using standard reduction factors. A sustained wind of 69 kt with a gust of 93 kt was measured by NOAA buoy 42036 in the northeastern Gulf of America when it was in the western eyewall of Helene at 2254 UTC 26 September. The buoy reported a minimum pressure of 949 mb at 2310 UTC. Around the time of peak intensity over the northeastern Gulf, satellite-based Synthetic Aperture Radar data captured the extent of Helene's inner-core wind field (Fig. 8).

At the time of the aforementioned flight-level wind observations, dropsonde data indicated that Helene's central pressure was around 941 mb. A later dropsonde at 0214 UTC 27 September measured 941 mb with 27-kt winds, about 1 h prior to landfall. The lowest pressure measured on land was 942.8 mb at 0312 UTC at a Texas Tech StickNet site situated about halfway between the landfall point and Perry, Florida. Taking into account the dropsonde data and the wind/pressure trace from the StickNet observation (Fig. 9), the landfall central pressure is analyzed to be 939 mb.

As previously mentioned, the size of Helene's wind field was quite large for most of its existence. In fact, comparing Helene's 34- and 50-kt wind field to other hurricanes at similar latitudes (while Helene was over the southeastern Gulf of America) over the past 20 years indicates that it was larger than about 90 percent of systems of similar strength and location.

Mexico and Cuba

Tropical storm conditions were observed over portions of the eastern Yucatan Peninsula of Mexico, including in the Cancun area, as well as on the islands of Cozumel and Isla Mujeres when Helene's center passed less than 50 n mi to the east of those areas. A weather station in Isla Mujeres measured winds of 46 kt with a gust to 60 kt at 1845 UTC 25 September. The station recorded a minimum pressure of 989 mb at 1745 UTC, while the center of Helene was located about 45 n mi north-northeast of the station.

Tropical storm conditions also occurred across portions of western Cuba. Cayo Largo, a barrier island off Cuba's southern coast, recorded 29-kt sustained winds with gusts to 49 kt on 25 September. Later, 32 kt winds with gusts to 50 kt were observed in Havana. A gust to 55 kt was measured in Santa Lucia, Pinar del Rio.

Florida, Georgia, South Carolina and North Carolina

Helene brought life-threatening wind gusts (Fig. 7) much farther inland across the southeastern United States than other hurricanes due to its fast forward motion (Fig. 5) and large size. The strongest low-elevation sustained wind measured on land was 64 kt at a Texas Tech StickNet site about 5 n mi southwest of Live Oak, Florida at 0359 UTC 27 September. Given that the anemometer height of this observation was only 2.25 m above ground level (AGL) and that it occurred about 50 minutes after landfall and 35 n mi inland, much stronger winds undoubtedly occurred at the 10 m level closer to the coast. A standard adjustment of that wind observation to 10 m using the wind profile power law[4] yields an estimated sustained wind of 79 kt. Hurricane-force winds spread across portions of northern Florida and southern Georgia near and to the east of the path of Helene's center. Some of the highest wind reports in Georgia include a WeatherStem site in Lowndes County, Georgia, located 5 to 10 n mi south-southeast of Valdosta that measured winds of 53 kt with a gust of 83 kt (anemometer height 7 m AGL) at 0420 UTC. A

[4] More information on the wind profile power law can be found at the following citation: Hsu, S. A., Meindl, E. A., & Gilhousen, D. B., 1994: Determining the Power-Law Wind-Profile Exponent under Near-Neutral Stability Conditions at Sea, J. Appl. Meteor. Climatol., 33(6), 757-765.

University of Georgia Weather Net station located in Coffee County, Georgia, measured a wind gust of 80 kt at 0615 UTC that day. Bacon County Airport in Alma, Georgia, recorded 49-kt sustained winds with a peak gust of 87 kt at 0703 UTC. In addition to the winds, many areas in Georgia and the eastern Florida panhandle set their all-time record lowest minimum pressures[5].

Outside of the sustained hurricane-force wind area, sustained winds over 50 kt with hurricane-force gusts impacted large swaths of eastern Georgia as well as southern and western portions of South Carolina. These winds were particularly damaging due to the large gust factor (1.5 to 2.0) that was observed with Helene, meaning that the ratio of the strength of the wind gusts to sustained winds was much larger than is typical. A wind gust to 71 kt was recorded at Augusta, Georgia, Regional Airport at 1005 UTC. Wind gusts in the 70–79 kt range were also measured by weather stations in Towns, Chatham, and Echols counties in Georgia. A WeatherFlow station on Jekyll Island, Georgia, measured winds of 53 kt with a gust to 68 kt at 0612 UTC, and Savannah Light located along the Georgia coast measured sustained winds of 54 kt with a gust to 68 kt at 0754 UTC (Fig. 7).

In South Carolina, the strongest observed sustained wind was 48 kt with a gust of 67 kt at 0845 UTC in Laurens, which is located about 15–20 n mi south of the Greenville/Spartanburg area. Sustained winds of 46 and 47 kt occurred along the coast in Charleston Harbor and Beaufort County, respectively. Gusts to 65 kt were measured in Beaufort, South Carolina, while gusts as high as 63 kt were measured by weather stations farther inland in South Carolina. It is important to note that many of the weather stations along Helene's path in Georgia and South Carolina stopped reporting before the peak conditions occurred. NWS Weather Forecast Offices conducted ground surveys of damage which suggests wind gusts likely exceeded 70 kt in a large area from the Florida Panhandle, through eastern Georgia, and into central and western South Carolina. Tree and structural damage suggest wind gusts may have exceeded 90 kt in some of these areas.

In North Carolina, while the strongest observed winds were measured at sites located within high topography of the southern Appalachians, strong winds also spread elsewhere across much of the western and central portions of the state. Sustained wind observations of 70 and 55 kt were recorded at Mt. Mitchell and Frying Pan Mountain, respectively, around 1200 UTC 27 September, noting that these observations were at locations over 5000 ft in elevation. Similar wind speeds likely affected many of the mountainous areas in western North Carolina. Peak gusts measured at those stations were 92 and 76 kt, respectively. A wind gust to 88 kt was recorded near Banner Elk. Many mountain peaks in western North Carolina suffered extensive tree falls and damage due to these wind gusts. Farther east, a wind gust of 57 kt was recorded at Charlotte Douglas International Airport. Sustained winds to tropical storm force with gusts to 52 kt were also observed in Southport near the coast. The highest measured wind gusts in each state are listed in the table at the top of the next page.

[5] https://www.wpc.ncep.noaa.gov/research/roth/AllTimeWhenRecordLowSLPs.gif

Highest Measured Wind Gusts by State			
State	**County**	**Location**	**Wind Gust (kt)**
Florida	Taylor	Perry	86
Florida	Suwannee	Dowling Park	86
Florida	Taylor	Athena	84
Georgia	Bacon	Alma	87
Georgia	Lowndes	Lake Park	83
Georgia	Coffee	Douglas	80
South Carolina	Laurens	Laurens	67
South Carolina	Beaufort	Beaufort	65
South Carolina	Anderson	Anderson	63
South Carolina	Aiken	Aiken	63
South Carolina	Pickens	Sassafras Mountain	63
North Carolina	Yancey	Mt. Mitchell	92
North Carolina	Watauga	Banner Elk	88
North Carolina	Haywood	Frying Pan Mountain	76

Virginia, West Virginia, Kentucky, Tennessee, Ohio, Indiana and Illinois

Helene produced sustained winds of tropical storm force with gusts over 50 kt across portions of east Tennessee, southwestern Virginia, southwestern West Virginia and Kentucky on 27 September. Virginia Highland Airport in Abingdon, Virginia, recorded sustained winds of 34 kt with a gust to 43 kt, while Twin County Airport near Woodlawn measured a 55-kt gust. A Citizen Weather Observer Program (CWOP) station in Tazewell measured 36-kt winds with a gust to 56 kt. In Tennessee, a gust of 52 kt was measured in the mountains of the northeastern part of the state near Unicoi. In West Virginia, Huntington Tri-State Airport in Wayne County measured a gust of 61 kt, while a CWOP station in Monroe County measured a 50-kt gust. In Kentucky, Blue Grass Airport in Lexington measured sustained winds of 39 kt with a gust of 56 kt.

After Helene became post-tropical, gale-force winds continued across portions of Ohio, Indiana and Illinois through the remainder of the afternoon and evening hours of 27 September. In Ohio, Wilmington Air Park recorded winds of 38 kt at 1935 UTC, with a gust to 59 kt. In Indiana, Indianapolis International Airport measured sustained winds of 41 kt with a gust of 59 kt. In east-central Illinois, a wind observation of 37 kt and a gust to 57 kt was measured at Coles County Memorial Airport around 0200 UTC 28 September. Surface observations indicate that Helene's sustained winds dropped below gale force by 0600 UTC 28 September. See the table below for the highest measured wind gusts in each state related to Helene. The Ohio, Indiana and Illinois observations occurred after Helene became post-tropical.

Highest Measured Wind Gusts by State

State	County	Location	Wind Gust (kt)
Virginia	Grayson	Grayson Highlands	57
West Virginia	Wayne	Huntington	61
Kentucky	Fayette	Lexington	56
Kentucky	Wolfe	Pine Ridge	56
Tennessee	Unicoi	Unicoi	52
Ohio	Clinton	Wilmington	59
Indiana	Marion	Indianapolis	59
Illinois	Coles	Mattoon	57

Storm Surge[6]

Helene produced a catastrophic storm surge with significant impacts to coastal communities along a large portion of Florida's Gulf Coast. Figure 10 shows the NHC storm surge analysis, which represents the maximum inundation during Helene. In the Big Bend region, storm surge inundation of 12 to 16 ft AGL occurred from just west of Keaton Beach through Steinhatchee, where small coastal communities were devastated. Significant storm surge and wave impacts extended as far south as Naples, bringing dangerous storm surge to densely populated areas such as Tampa Bay and Sarasota. The large size of Helene's wind field exacerbated the storm surge impacts over an extensive area.

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[6] Several terms are used to describe water levels due to a storm. **Storm surge** is defined as the abnormal rise of water generated by a storm, over and above the predicted astronomical tide, and is expressed in terms of height above normal tide levels. Because storm surge represents the deviation from normal water levels, it is not referenced to a vertical datum. **Storm tide** is defined as the water level due to the combination of storm surge and the astronomical tide, and is expressed in terms of height above a vertical datum, i.e. the North American Vertical Datum of 1988 (NAVD88) or Mean Lower Low Water (MLLW). **Inundation** is the total water level that occurs on normally dry ground as a result of the storm tide, and is expressed in terms of height above ground level. At the coast, normally dry land is roughly defined as areas higher than the normal high tide line, or Mean Higher High Water (MHHW).

Figure 11 shows reflectivity data from the Tampa Bay (TBW) Doppler radar highlighting the storm structure near the time of landfall, overlaid with the available in situ maximum water level observations relative to Mean Higher High Water (MHHW, i.e. an approximation for inundation at the immediate coastline). Observations in Figure 11 include the NOAA tide gauges and U.S. Geological Survey (USGS) water level sensors that were deployed in the days prior to landfall. Note that the deployed USGS water level sensor data are wave-filtered (i.e., storm tide only) and measured relative to the North American Vertical Datum of 1988 (NAVD88) and then converted to MHHW using the vertical transformation tool (https://vdatum.noaa.gov/) provided by the National Geodetic Survey (NGS) Office of Coast Survey (OCS) and Operational Oceanographic Products and Services (CO-OPS) of NOAA.

Peak storm surge inundation levels of 12 to 16 ft AGL occurred from just west of Keaton Beach to south of Steinhatchee (Fig. 10) as observed by the deployed USGS water level sensor network in this remote area. Three water level sensors were placed just south of Keaton Beach near Fish Creek; two of these sensors reported maximum water levels greater than 13.5 ft above MHHW (Fig. 11), while the third was mounted to a pavilion that was destroyed. Of the reporting sensors, one was placed on a dock along a wave-protected waterway, while the other was located on the immediate coast and recorded significant waves on top of the storm tide. Aerial imagery collected by the NOAA Remote Sensing Division shows that many homes were removed from foundations leaving only the slab and stilts where the elevated home once was. Entire homes appear to have been picked up by the storm surge and moved to remote wetlands[7]. On-the-ground National Weather Service (NWS) survey crews also found significant damages in Dekle and Keaton Beach and identified a high confidence stilled high water mark of 13.8 ft AGL inside a brick building displaced from the immediate coast. The mark was also recorded relative to NAVD88 (17.0 ft NAVD88) and converted to 15.3 ft above MHHW, slightly higher than the in situ USGS data.

In Steinhatchee, a USGS streamgage located approximately two miles from the mouth of the Steinhatchee River reported 9.6 ft above MHHW prior to failing (not shown in Figure 11). A post-storm survey by the USGS field crew found a high water mark of 14.25 ft above NAVD88 (converts to 12.6 ft above MHHW) near the sensor, approximately 4.5 ft higher than the maximum water level recorded during Hurricane Idalia in August 2023. Additionally, NWS survey crews found a high confidence stilled high water mark of 11.25 ft above the building slab in the second story of a condominium located downstream of the sensor. This high water mark measured 17.8 ft above NAVD88, which converts to 16.1 ft above MHHW. The immediate coastline between Keaton Beach and the mouth of the Steinhatchee River likely received some of the strongest onshore winds and highest storm surge due to the location and structure of the eyewall, and based on high water marks collected, storm surge inundation up to 16 ft AGL is estimated to have occurred (Fig. 10).

North and west of Keaton and Dekle Beach, NWS survey crews found a high water mark measuring 10.4 ft above the building slab in an elevated home in Spring Warrior Fish Camp (14.7 ft NAVD88/12.9 ft MHHW). A gradient of storm surge exists west of this location across the storm

[7] https://storms.ngs.noaa.gov/storms/helene/index.html#17.08/29.822441/-83.592399

track, however, the western portion of the Big Bend still experienced a dangerous storm surge due to Helene's large wind field and the concave coastline despite mostly offshore winds. Maximum storm surge inundation of 6 to 9 ft AGL occurred west of Spring Warrior Creek to the Escofina River (Fig. 10), where the region is mostly remote evergreen forests/wetlands lacking structures to identify high water marks. Storm surge inundation of 5 to 7 ft AGL occurred from the Escofina River westward to the Ochlockonee River, where a deployed USGS water level sensor at Shell Point Beach in Wakulla County measured 6.53 ft above MHHW. The storm surge penetrated well inland, and NWS survey crews collected high water marks of 2 to 3 ft AGL in St. Marks. Farther to the west, 3 to 5 ft AGL of storm surge inundation occurred from Ochlockonee River to Indian Pass (Fig. 10), where the NOS tide gauge at Apalachicola measured 4.33 ft above MHHW. West of Indian Pass, water levels were elevated to 1 to 3 ft AGL, with the NOS tide gauges at Panama City and Panama City Beach measuring 3.02 and 3.26 ft above MHHW, respectively.

East of the landfall location, significant storm surge impacts extended well away from the storm center. Maximum storm surge inundation of 8 to 12 ft AGL occurred from south of Steinhatchee through Cedar Key, including Horseshoe Beach (Fig. 10). A deployed USGS water level sensor at Suwannee River measured 12.18 ft above MHHW (Fig. 11). Moreover, the NOS tide gauge at Cedar Key[8] measured 9.30 ft above MHHW, the highest recorded water level since the station started reporting in 1914. This measurement also breaks the previous record held by Hurricane Idalia in August 2023 (6.89 ft above MHHW). A nearby deployed USGS water level sensor reported a similar water level of 8.84 ft above MHHW.

Maximum storm surge inundation of 6 to 9 ft AGL occurred from south of Cedar Key to the Anclote River. USGS deployed water level sensors at the mouth of the Crystal River and on Pine Island (Hernando County) measured 9.0 ft and 8.84 ft above MHHW, respectively (Fig. 11). In Pasco County, a deployed USGS water level sensor measured 7.60 ft above MHHW, and was a protected sensor, with minimal wave impacts. NWS survey crews found significant impacts to communities along the rivers such as Homosassa Springs, Yankeetown, and Crystal River.

Maximum storm surge inundation of 5 to 7 ft AGL occurred from the Anclote River southward to Longboat Key (Fig. 10). In Pinellas County, deployed USGS water sensors located along exposed barrier islands measured water levels of 7.23 ft (Fred Howard Park), 6.75 ft (Clearwater Bach), and 7.26 ft (Madeira Beach) above MHHW, with significant waves on top. Nearby, the NOS tide gauge at Clearwater[9] (station record back to 1973) measured 6.67 ft above MHHW (Fig. 11), surpassing the previous record from the Superstorm of March 1993. Farther south in Manatee County, a deployed USGS water sensor located on Longboat Key measured a wave-filtered storm tide of 6.68 ft above MHHW. Widespread high water marks were observed by NWS survey crews along this very populated region of the Florida coast, with stilled waterlines inside many homes.

[8] Data courtesy of NOAA's National Ocean Service (NOS) Center for Operational Oceanographic Products & Services (CO-OPS)
[9] Data courtesy of NOAA's National Ocean Service (NOS) Center for Operational Oceanographic Products & Services (CO-OPS)

A USGS Hydrologic Imagery Visualization and Information System (HIVIS) camera captured the dangerous storm surge at Madeira Beach in coastal Pinellas County. Figure 12 shows the evolution of beach images: A) the beach a day prior to the landfall, B), C) and D) show the evolution in the afternoon and evening prior to landfall. The storm surge continued as darkness fell, and the last image E) shows the scene days after landfall when water levels subsided and the camera provided a clear picture. Image E) highlights the significant beach erosion that occurred, exposing a groin that is in place to maintain and trap sand. Significant erosion and sediment transfer occurred along a large portion of the Florida Peninsula, and communities were forced to dig roads and structures out of the sand.

Within Tampa Bay, maximum storm surge inundation of 5 to 7 ft AGL occurred. The NOS tide gauge at East Bay measured 7.2 ft above MHHW. Elsewhere, NOS tide gauges measured water levels relative to MHHW of 6.83 ft at Old Port Tampa, 6.31 ft at St. Petersburg, and 6.04 ft at Port Manatee. The St. Petersburg tide station has the longest record in Tampa Bay, dating back to 1947. The maximum water level of 6.31 ft above MHHW during Helene surpassed the previous record of 3.97 ft during Hurricane Elena (1985)[10]. Additionally, 4 to 6 ft AGL occurred from Venice to south of Englewood where a deployed USGS water level sensor measured 5.71 ft above MHHW near the Venice Fishing Pier.

Maximum storm surge inundation of 3 to 5 ft AGL occurred from south of Englewood to Bonita Beach including Charlotte Harbor. The NOS tide gauge on the Calossahatchee River in Fort Myers measured 5.12 ft above MHHW. South of Bonita Beach, maximum storm surge inundation of 2 to 4 ft AGL occurred in areas such as Naples, Marco Island, and Everglades City. The NOS tide gauge in Naples Bay measured 4.02 ft above MHHW. In the Florida Keys 1 to 2 ft of storm surge inundation occurred as NOS tide gauges at Key West and Vaca Key reported 1.57 and 1.40 ft above MHHW, respectively.

Elsewhere, Helene produced minor elevated water levels along the U.S. East Coast, where the NOS tide gauges at Fort Pulaski, Georgia and Charleston, South Carolina, reported water levels of 2.34 and 2.26 ft above MHHW, respectively. In Mexico, Helene produced water levels of 1 to 2 ft above normal tides along the east coast of the Yucatan Peninsula as supported by the tide gauge measurements at Isla Mujeres.

Rainfall and Flooding

United States

Helene, combined with its interaction with the baroclinic cut-off low over the southeastern United States, produced a prolonged period of heavy rainfall from 25–27 September, spanning from the Florida Panhandle northward into the southern Appalachians, where historic rainfall totals resulted in catastrophic flooding and widespread landslides. The large-scale weather

[10] Data courtesy of NOAA's National Ocean Service (NOS) Center for Operational Oceanographic Products & Services (CO-OPS)

pattern over the central to eastern United States favored heavy rainfall well ahead of Helene (Fig. 13), leading to a predecessor rain event (PRE)[11] that enhanced rainfall totals and exacerbated flooding impacts. In the lower levels of the atmosphere, a stationary front was analyzed from the central Gulf Coast northward towards the Tennessee Valley and southern Appalachians from 25–27 September (Fig. 13 middle panels). Strong low-level convergence along and east of the front was enhanced across the southern Appalachians where southeasterly winds resulted in additional orographically driven upward vertical motion. These factors contributed to a favorable setup for heavy rainfall well ahead of the center of Helene. The rainfall from the PRE resulted in saturated soil and increased stream and river levels in advance of the arrival of the core of Helene.

Rainfall amounts of 20 to 30 inches occurred over a large area within the mountainous region of western North Carolina. Pockets of rainfall amounts of 10 to 15 inches occurred over a larger area stretching from southwestern Virginia to northwestern South Carolina, as well as portions of Georgia and Florida. Widespread rainfall totals of 5 to 10 inches stretched from portions of the Florida Panhandle northward across Georgia and into the western Carolinas and southwestern Virginia (Fig. 14). The rainfall maximum over Florida into southern Georgia was west of Helene's track due to interactions with a surface front and a mid- and upper-level low pressure area. The maximum accumulations shifted along and east of track into the southern Appalachians, where orographic effects were maximized. As Helene continued to move inland and became post-tropical, rainfall totals of 3 to 6 inches were observed across portions of the Tennessee and Ohio Valleys.

The highest observed rainfall total was in Busick, North Carolina, where 30.78 inches was recorded from 1200 UTC 25 September to 1200 UTC 28 September. An NWS Cooperative Observer Program (COOP) observer near Celo, North Carolina measured 26.65 inches of rain. Both of those sites are located in Yancey County. Farther south, a rainfall total of 29.98 inches was measured in Transylvania County, a short distance north of the South Carolina border. A Hydrometeorological Automated Data System (HADS) site at Sunfish Mountain in Greenville County, South Carolina, measured 21.66 inches of rain. Available observations indicate that rainfall amounts in excess of 18 inches occurred across portions of Transylvania, Henderson, Buncombe, Polk, McDowell, Yancey, Mitchell, Burke, Avery and Watauga Counties in North Carolina, as well as in northern Pickens and northern Greenville Counties in South Carolina. The NOAA National Water Center (NWC) produced a map of 3-day Annual Exceedance Probabilities which details just how rare some of these rainfall totals were (Fig. 15). A large area stretching from northwestern South Carolina into western North Carolina and southwestern Virginia received 3-day rainfall totals that had less than a 1 in 1000 (<0.1%) chance of occurring in any given year.

A few other notable rainfall maxima occurred with Helene. Amounts as high as 12 to 13 inches were observed within the Atlanta metro area, which has just a 0.2% to 0.5% chance of occurring in any given year. A swath of around 12 to 13 inches also fell across east-central Georgia to just north of Augusta. Over the Florida Panhandle, a maximum of 14.39 inches fell in Sumatra to the west of Tallahassee. The highest rainfall total observed in each state affected are listed in the table at the top of the next page.

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[11] Galarneau, T. J., L. F. Bosart, and R. S. Schumacher, 2010: Predecessor Rain Events ahead of Tropical Cyclones. *Mon. Wea. Rev.*, **138**, 3272-3297, https://doi.org/10.1175/2010MWR3243.1

Highest Rainfall Totals by State			
State	**County**	**Location**	**Rainfall (inches)**
North Carolina	Yancey	Busick	30.78
South Carolina	Greenville	Sunfish Mountain	21.66
Georgia	Rabun	3.5 mi NE Dillard	14.64
Florida	Liberty	Sumatra	14.39
Tennessee	Washington	Embreeville	12.43
Virginia	Grayson	5.3 mi SW Galax	10.89
Ohio	Scioto	Rosemount	8.51
Alabama	Houston	1.6 mi NNE Pansey	8.50
Kentucky	Henderson	Henderson	7.67
Illinois	Massac	Ft. Massac St. Park	7.47
West Virginia	Mercer	Bluefield	6.11
Indiana	Clark	2.6 mi E Henryville	5.69

A total of 34 flash flood emergencies were issued in association with Helene (Fig. 16). Two were issued around the Atlanta metro area, with the remaining 32 across the southern Appalachians, with a maximum density over western North Carolina. An initial flash flood emergency was issued at 2154 UTC 26 September relating to a dam release in the Charlotte, North Carolina area, however the first weather-driven flash flood emergency was issued at 0739 UTC 27 September as the core of Helene approached the western Carolinas. The southern Appalachians were primed for flooding by the rainfall associated with the PRE ahead of Helene on 25-26 September. Thus, when heavy rainfall rates as high as 2 to 3 inches per hour associated with the core of Helene moved over these areas on the morning of 27 September, catastrophic flash flooding occurred, triggering numerous flash flood emergencies. Widespread landslides also occurred, with the USGS documenting over 2,000 landslides, with the majority located over western North Carolina (Fig. 17).

Preliminary estimates are that at least 63 stream and river gauges exceeded their record flood levels during Helene, from northwestern South Carolina into southwestern North Carolina, northeastern Tennessee and southwestern Virginia (Fig. 18). At least 22 of these gauges had a period of record of 50 or more years, with at least 14 having 100 years of records. The French Broad River at Asheville, North Carolina, is a notable record, as the height of 24.8 ft exceeds a record of 23.1 ft from 1916. The hydrograph shows a steady rise to minor flood stage during the night of 25 September into the next day (Fig. 19). However, as the rainfall intensity and coverage expanded with the approach of Helene's core, river levels rapidly rose from 10 ft at 2145 UTC 26 September, to major flood stage of 18 ft around 1600 UTC 27 September, before peaking at record levels around 2200 UTC that day. This is further evidence of how the rainfall in the days ahead of Helene's passage helped set the stage for the catastrophic flooding impacts brought on by the core of Helene. The Swannanoa River at Biltmore, North Carolina, reached a peak stage of 27.33 ft, far surpassing its previous record of 20.7 ft also set in 1916 (Fig. 20).

The highest rainfall total measurement in select counties in the state of North Carolina is listed below, along with any available record river crests in that county.

Highest Rainfall and Record River Crests by North Carolina County			
County	**Location of Rainfall Measurement**	**Rainfall (inches)**	**Record River Crests**
Yancey	Busick	30.78	South Toe River near Celo (broke record by 8.7 ft - records back to 1957)
Transylvania	Connestee Falls	29.98	French Broad River at Blantyre (broke record by 1.3 ft - records back to 1901)
Mitchell	7 mi SW Spruce Pine	23.31	Cane Creek at Bakersville (broke record by 2.2 ft - records back to 2009)
Avery	Banner Elk	22.85	N/A
Henderson	5 mi SW Hendersonville	21.70	Mills River near Mills River (broke record by 2.0 ft - records back to 1928); French Broad River near Fletcher (broke record by 10.5 ft - records back to 2002); Bat Fork Creek (broke record by 4.7 ft - records back to 2009)
McDowell	4 mi NW Old Fort	21.68	Catawba River near Pleasant Gardens (broke record by 4.3 ft - records back to 1981); NF Catawba River above US 221 (broke record by 3.6 ft - records back to 2009)
Watauga	Foscoe	21.60	N/A
Buncombe	6 mi SE Black Mountain	21.07	Swannanoa River at Biltmore (broke record by 6.6 ft - records back to 1901); French Broad River at Asheville (broke record by 1.7 ft - records back to 1901); Ivy River near Barnardsville (broke record by 8.7 ft - records back to 2009)
Polk	Saluda	18.24	N/A

Highest Rainfall and Record River Crests by North Carolina County			
County	**Location of Rainfall Measurement**	**Rainfall (inches)**	**Record River Crests**
Alleghany	4 mi SSW Sparta	17.37	N/A
Ashe	9 mi SSE West Jefferson	17.08	N/A
Jackson	3 mi NE Cashiers	15.97	Tuckasegee River at Barker's Creek (broke record by 1.1 ft - records back to 2004)

Nicaragua, Honduras, Mexico and Cuba

From 21–24 September, heavy rainfall occurred across portions of Nicaragua and Honduras from Helene's precursor disturbance. After the system became a tropical cyclone, heavy rainfall occurred across portions of western Cuba as well as the Mexican states of Quintana Roo and Yucatan. In Cuba, 8.60 inches (218.4 mm) of rain was measured in Herradura, Pinar del Rio. In Mexico, the highest rainfall measurement occurred in Cancun, where 9.65 inches (245.2 mm) of rain fell over the 2-day period of 24–25 September. A map of the rainfall in Mexico is shown in Figure 21. At the time of this writing, no rainfall data has been received from Nicaragua.

Tornadoes

Helene produced 33 tornadoes in the United States while it was a tropical cyclone on 26–27 September, and 6 additional tornadoes after it became post-tropical. There were a few tornadoes in the southeastern United States on 25 September, but they were not associated with the circulation of Helene. Of the 33 tornadoes that Helene produced while it was a tropical cyclone, 3 occurred in Florida, 3 in Georgia, 21 in South Carolina and 6 in North Carolina. These included 1 EF-3 tornado, with the remaining tornadoes rated EF-0 and EF-1. Of the 6 tornadoes that were observed after Helene became post-tropical, 3 were in North Carolina and 3 occurred in Virginia. These included 1 EF-2 tornado, and the rest were rated EF-1. Figure 22 shows the locations of all 39 tornadoes associated with Helene.

One of Helene's tornadoes was deadly. Two people lost their lives inside a mobile home that was hit by an EF-1 tornado in Wheeler County, Georgia, during the evening of 26 September. This tornado was briefly on the ground, with a documented path length of only 0.6 n mi. In South Carolina, a long-track EF-1 tornado occurred early on 27 September just after midnight local time, traveling through eastern Orangeburg and western Calhoun Counties. Although it only produced tree damage without much damage to structures, the tornado is notable for its path length of 29 n mi, its fast average forward speed of 49 kt, and its 800-yard width. Earlier on 26 September, another EF-1 tornado in Cordova, South Carolina is now the widest documented tornado (1,100 yards) in the entire U.S. *tropical cyclone* tornado database, which goes back to 1995. Another

EF-1 tornado in Sumter County, South Carolina, that occurred around 0932 UTC 27 September had a path width of about 1,000 yards. In North Carolina, one EF-3 tornado occurred around 1730 UTC 27 September in Nash County.

After Helene became post-tropical, an EF-1 tornado occurred in Rockingham County, North Carolina and an EF-2 tornado occurred in Pittsylvania County, Virginia.

CASUALTY AND DAMAGE STATISTICS

Reports from official state government sources as well as media reports indicate that Helene is responsible for at least 175 direct[12] deaths in the United States. Storm surge caused 14 of those fatalities - all in Florida. Helene's winds are responsible for 65 of the direct deaths - the most direct wind deaths from any tropical cyclone in the continental United States going back to at least 1963[13], according to data from Rappaport (2014) that covered the 1963–2012 period, and reports on U.S. hurricanes since that time available at NHC. Of the 65 direct wind fatalities, 61 were caused by falling trees during the storm. A breakdown of direct wind fatalities by state are as follows: Georgia (26), South Carolina (24), North Carolina (8), Florida (4), Virginia (2) and Indiana (1). Freshwater flooding, which includes landslides and debris flows, was responsible for at least 94 of the direct deaths: 77 in North Carolina, 15 in Tennessee and 2 in South Carolina. There were also 2 deaths caused by a tornado in Georgia that was associated with Helene, mentioned above. As of this writing there are 6 individuals listed as missing from western North Carolina and eastern Tennessee. A breakdown of direct deaths sorted by type and state is listed in the table below.

Direct Deaths by State and Type					
State	**Wind**	**Storm Surge**	**Freshwater Flooding**	**Tornado**	**TOTAL**
Florida	4	14			**18**
Georgia	26			2	**28**
South Carolina	24		2		**26**
North Carolina	8		77		**85**

[12] Deaths occurring as a direct result of the forces of the tropical cyclone are referred to as "direct" deaths. These would include those persons who drowned in storm surge, rough seas, rip currents, and freshwater floods. Direct deaths also include casualties resulting from lightning and wind-related events (e.g., collapsing structures). Deaths occurring from such factors as heart attacks, house fires, electrocutions from downed powerlines, vehicle accidents on wet roads, etc., are considered "indirect" deaths.

[13] Rappaport, E. N. 2014: Fatalities in the United States from Atlantic Tropical Cyclones. *Bull. Amer. Meteor. Soc.,* ***95****, 341-346.*

Direct Deaths by State and Type					
State	**Wind**	**Storm Surge**	**Freshwater Flooding**	**Tornado**	**TOTAL**
Tennessee			15		**15**
Virginia	2				**2**
Indiana	1				**1**
TOTAL	**65**	**14**	**94**	**2**	**175**

At least 70 indirect fatalities are linked to Helene: 23 in South Carolina, 20 in North Carolina, 16 in Florida, 9 in Georgia, 1 in Tennessee and 1 in Virginia. Many of the indirect fatalities were from medical issues, heart attacks, car accidents and incidents during post-storm cleanup. In addition to the 175 direct and 70 indirect fatalities, 3 people died of unknown causes related to Helene, which brings the total number of Helene-related fatalities in the United States to 248. Figure 23 shows a map depicting the locations of all known fatalities associated with Helene. A breakdown of direct fatalities by type is depicted in Figure 24. This figure shows that all the direct deaths occurred to the right of the path of Helene's center. The freshwater flooding fatalities were clustered in western North Carolina, eastern Tennessee and northwestern South Carolina. The wind fatalities were more spread out, with the largest number occurring in Georgia and South Carolina within 150 n mi to the right of the path of Helene's center. A breakdown of the total deaths by state is shown in the table below.

Total Deaths by State				
State	**Direct Deaths**	**Indirect Deaths**	**Unknown**	**TOTAL**
Florida	18	16		**34**
Georgia	28	9		**37**
South Carolina	26	23	1	**50**
North Carolina	85	20		**105**
Tennessee	15	1	2	**18**
Virginia	2	1		**3**
Indiana	1			**1**
Total	**175**	**70**	**3**	**248**

Across the Southeast U.S., Helene caused at least 117 injuries, and at least 2700 people were rescued from high water. About half of the rescues occurred due to storm surge along the west coast of Florida, and more than 1000 were due to freshwater flooding in western North Carolina.

According to the NOAA National Centers for Environmental Information (NCEI)[14], Helene caused an estimated $78.7 billion in damage in the United States. This makes Helene the 7th costliest U.S. hurricane (adjusted to 2024 values)[15] behind Katrina, Harvey, Ian, Maria, Sandy, and Ida. Most of this damage occurred in Florida, Georgia, South Carolina, North Carolina, eastern Tennessee and southwestern Virginia.

An estimated 7.4 million customers[16] (about 16.2 million people) lost power in the United States due to Helene between 26–28 September. The maximum outage count at any given moment in time was about 4.79 million customers (Fig. 25). Florida experienced the largest loss of power with ~1.69 million customers losing power. South Carolina, Georgia and North Carolina experienced an estimated 1.59 million, 1.28 million and 1.18 million outages, respectively.

More detailed information about the impacts and damage for each region affected by Helene are given below. Maps showing U.S. counties by state can be found at: https://www.census.gov/geographies/reference-maps/2000/geo/state-county-outline-2000.html

Florida

Helene produced significant storm surge damage along Florida's Gulf Coast from Taylor County southward to Collier County. Near where the landfall occurred, Helene's peak storm surge, estimated at 12–16 ft AGL, destroyed about 80 percent of the buildings in Keaton Beach and Steinhatchee (Fig. 26). In Horseshoe Beach, storm surge destroyed roughly 70 percent of the town. Notably, high evacuation rates in those areas resulted in no reported storm surge deaths. In coastal Levy County, the towns of Cedar Key and Yankeetown were devastated by record-breaking storm surge. Media reports[17] indicate that about 25 percent of the homes in Cedar Key were destroyed, along with numerous businesses. In Yankeetown, 20 people were rescued from their rooftops. In Citrus County, storm surge inundated at least 300 homes in Crystal River and Homosassa Springs with water up to 5 ft deep inside homes, and crews rescued 85 people and pets from the floodwaters.

In Hernando County, at least 500 homes suffered major damage, mostly from storm surge flooding along the barrier islands and immediate coast, and 18 people were rescued from the floodwaters. In Pasco County, first responders had to make 200 high water rescues from coastal areas due to storm surge, and at least 9,900 structures suffered damage, the majority of which were due to storm surge flooding in coastal parts of the county. In Pinellas County, 12 people drowned in the surge. Media reports indicate that 9 of these 12 victims were located on the barrier

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[14] https://www.ncei.noaa.gov/access/billions/events

[15] https://www.ncei.noaa.gov/access/billions/dcmi.pdf

[16] Estimate is based on PowerOutage.US storm summary. https://poweroutage.us/about/majorevents

[17] https://www.palmbeachpost.com/story/news/2024/09/29/reality-of-hurricanes-devastation-setting-in-along-with-relief/75430622007/

islands on Pinellas County's west coast from St. Pete Beach to Indian Rocks Beach, 2 were in St. Petersburg and 1 was in Dunedin. Two storm-surge related fatalities were reported in Hillsborough County. Helene destroyed at least 419 homes in Pinellas and Hillsborough Counties combined, and at least 18,512 structures suffered major damage, with at least 13,909 others reporting minor or moderate damage.

In Manatee County, Anna Maria Island was heavily damaged by storm surge. Media reports and estimates from emergency managers indicate that 90 to 95 percent of the structures on Bradenton Beach were destroyed by Helene's storm surge. At least 594 structures were destroyed in mainland Manatee County. An additional 1,699 homes and commercial buildings reported major damage with 2,177 more reporting minor or moderate damage. Helene's storm surge damaged numerous structures in Sarasota County's coastal areas, where dozens of rescues took place during the storm. In Charlotte County, 8 structures were destroyed, 1,900 others had major damage and 750 others had minor or moderate damage, and most of this was due to storm surge. In Ft. Myers, at least 102 structures were damaged, with 52 of these reporting major damage. To the left of Helene's track, in Wakulla, Franklin and Gulf Counties, storm surge, freshwater flooding and wind caused minor to moderate structural damage.

Helene's winds caused extensive damage across Taylor, Dixie, Lafayette, Suwannee, Hamilton and Madison Counties including the cities of Perry, Cross City, Mayo, Live Oak, Jasper, and Madison. Much of this area experienced the eastern eyewall of Helene, where the majority of structures suffered damage and numerous trees and powerlines were down, according to the emergency managers of those counties. The strong winds extended to Atlantic coastal areas of northeastern Florida, and one person was killed in Duval County by a falling tree. At least one home in Liberty County (where the highest rainfall total in Florida was recorded) had damage due to freshwater flooding, and many roads were flooded.

Georgia

Helene produced at least $5.5 billion in agricultural and timber losses in Georgia[18], most of which was wind damage across southern and eastern portions of the state. The most significant wind damage occurred over the counties along and to the east of the path of Helene's center including Lowndes, Echols, Lanier, Clinch, Ware, Atkinson, Coffee, Bacon, Jeff Davis, Telfair, Appling, Toombs, Montgomery, Wheeler, Treutlen, Laurens, Johnson and Washington. Within the aforementioned counties, Helene's winds were directly responsible for 12 fatalities, while a tornado in Wheeler County killed two additional people. At least 82 injuries were reported there (77 of those occurred in Lowndes County - in and around the city of Valdosta - mainly from trees falling on homes) (Fig. 27). Hundreds of homes and buildings were destroyed, with tens of thousands of others damaged. In Coffee County, where gusts to 80 kt were recorded, 80-85% of the homes in the county were damaged. In Echols County, many roofs were damaged by both high winds and fallen trees, and about 1,000 power poles were snapped. In Telfair County, large trees and powerlines were down on most streets. In Toombs County, the town of Lyons was heavily damaged.

[18] https://extension.uga.edu/topic-areas/timely-topics/helene-report.html

Significant wind damage was also reported in other nearby southern Georgia counties. Candler County had widespread downed trees and powerlines, and 100% of the county was without power. In Cook County, many trees fell on homes and businesses, with many roads blocked. In Jefferson County, 24 homes were destroyed and $75 million worth of timber was lost, while power was knocked out to the entire county. In Pierce County, a firefighter was killed in the line of duty when a tree fell onto his truck while responding to calls during Helene. Numerous trees fell on residences in Pierce County. Wayne County reported widespread trees and powerlines down.

Hurricane-force wind gusts extended eastward to the coast of Georgia, causing numerous injuries and damaging well over a thousand homes/structures in Georgia's six coastal counties including Glynn and Chatham, home to the cities of Brunswick and Savannah, respectively. In the six coastal counties, 223 structures sustained major damage with an additional 19 homes/buildings destroyed.

Widespread hurricane-force wind gusts on the east side of Helene associated with the decaying eyewall moved northward into Richmond, McDuffie and Columbia Counties, in the greater Augusta area. In that area, Helene's winds were responsible for killing 11 people - all from trees falling onto homes. At least 362 homes/buildings were destroyed in this three-county area, while 3,000 others suffered major damage, and 3,500 others experienced minor to moderate damage.

The greater Atlanta area experienced serious freshwater flooding issues during the predawn and early morning hours of 27 September. Media sources and reports from emergency managers indicate that floodwaters entered at least 200 homes/buildings in the greater Atlanta area along with numerous vehicles. Dozens of people were rescued from the floodwaters by first responders. The National Weather Service issued two flash flood emergencies along with several other flash flood warnings, as shown in Figure 16. No casualties were reported in the greater Atlanta area.

South Carolina

In South Carolina, the mountainous regions in the northwest part of the state and the western portion of the Piedmont suffered the most damage, due to the widespread hurricane-force and near-hurricane-force wind gusts and scattered areas that experienced major flooding. Areas along and to the northwest of a line from Charlotte, North Carolina to Columbia, South Carolina through Aiken, South Carolina to Augusta, Georgia suffered significant damage from wind, as well as flash flooding and river flooding. The South Carolina Forestry Commission reported total timber damage of $83 million across a 20-county area, primarily in western and northwestern parts of the state.

In Greenville County, home to a population of over half a million people, 50 homes/buildings were destroyed, 650 suffered major damage and at least 1,350 others incurred minor to moderate damage. The majority of this damage was due to falling trees caused by strong wind gusts. There were four direct wind deaths in the county, all from falling trees. Flood damage to homes occurred as well, especially along the Saluda River, where the nearest river gauge site above Old Easley Road exceeded its all-time record river level. The city of Spartanburg also reported significant damage with 170 structures suffering major damage and an additional 269 structures with minor to moderate damage. The majority of these structures were damaged due to falling trees, but 35 were due to flooding. There were five direct deaths in Spartanburg County - four due to the wind knocking down trees and one due to freshwater flooding.

In Anderson County, hurricane-force wind gusts produced wind damage and knocked down trees (Fig. 28). In that county, 53 structures were destroyed, 642 had major damage, and an additional 1,297 had minor or moderate damage. While most of the damage was from strong wind gusts knocking down trees, multiple homes and structures were inundated with water along the Saluda River from Powdersville to Pelzer. There were 3 direct deaths in Anderson County - two due to the wind knocking down trees onto homes and one due to freshwater flooding in a vehicle. Farther south, in Laurens, Greenwood, Newberry and Saluda Counties, a large number of structures were damaged, and 9 people were killed by falling trees. Along the Georgia border in Aiken and Edgefield Counties, 46 homes/buildings were destroyed, 391 suffered major damage, and an additional 1,126 structures incurred minor or moderate damage. Four direct wind deaths occurred in Aiken County due to falling trees. In Lexington and Richland Counties, which includes the Columbia area, damage was significant, but not quite as widespread as farther upstate. In these two counties combined, 21 structures were destroyed, 112 others suffered major damage, and at least 161 other homes/buildings reported minor to moderate damage due to a combination of wind and freshwater flood damage. One person in Richland County was killed by a falling tree.

Strong winds also produced damage along coastal areas from Charleston to the Georgia border, and over the southern inland areas west of Charleston to the Georgia border. Additionally, 21 tornadoes were reported across the state over a wide area, stretching from near Hilton Head northward to near Sumter. These tornadoes caused significant tree damage.

North Carolina and eastern Tennessee

Rainfall associated with Helene and its predecessor rain event resulted in catastrophic flooding impacts across western North Carolina and eastern Tennessee, particularly in the mountainous regions, where landslides and debris flows destroyed numerous homes, roads, bridges, electrical infrastructure and water treatment plants. Helene is the most devastating natural disaster in western North Carolina's history. In addition to the 85 direct and 20 indirect fatalities in North Carolina, at least 21 injuries were reported in the state, and the Coast Guard rescued at least 865 people in western North Carolina, mostly from flood-waters. Media reports indicate that the storm damaged or destroyed more than 125,000 housing units across western North Carolina. The North Carolina Forest Service estimated 822,000 acres of damaged timberland, which resulted in $214 million in damages to North Carolina forests. In extreme examples, trees on entire mountainsides were blown down in the higher elevations of North Carolina. Many people in remote areas were cut off due to landslides, fallen trees and debris flows, which destroyed numerous roads and bridges in many smaller mountain communities. Many residents did not have access to clean water or electricity for a long period of time after Helene's passage.

In Buncombe County, flash flooding, river flooding and landslides were directly responsible for at least 37 deaths. Landslides killed 16 people in the Fairview area. In the towns of Swannanoa and Black Mountain, at least 9 people drowned in the Swannanoa River's floodwaters, where multiple homes, businesses and roads were destroyed. At least 6 of the deaths occurred in the city of Asheville, and the exact locations of the other 6 deaths are unknown. More than 490 water rescues were performed across the county. Historic river flooding was particularly damaging to the lower-lying areas of Asheville along the French Broad and Swannanoa Rivers (Fig. 29). In the historic Biltmore Village, located on the south bank of the intersection of where the Swannanoa River flows into the French Broad River, lower-lying buildings were severely inundated with deep water or swept away. Asheville's historic River Arts district, located 1 n mi north of the Biltmore Estate along the French Broad River, was largely destroyed (Fig. 30). In addition, significant flooding was reported along the Ivy River in Barnardsville, where multiple structures were inundated. In the southeast part of the county, flooding from the Broad River impacted several structures and multiple roads. At least 300 landslides occurred in the county. Helene caused extensive damage to Asheville's water treatment infrastructure, and clean water was not restored to the city until 18 November, 53 days after Helene passed through the area. Power was restored to more than half of Asheville's customers within a week, although media reports indicate that 25,000 Asheville customers were still without power two weeks after Helene. Tens of thousands of trees were knocked down across the county, with hundreds down on homes due to a combination of strong wind gusts and debris flows. Media reports indicate that more than 560 structures were destroyed and at least 901 structures sustained major damage in the county, with an additional 8,920 homes/buildings incurring minor or moderate damage.

Another area that was devastated was the Chimney Rock and Lake Lure area of Rutherford County, where numerous landslides and debris flows destroyed the majority of buildings, homes and businesses. In addition to the landslides, catastrophic flash flooding along the Broad River was responsible for portions of the damage that occurred in these communities. This was the highest ever crest of the Broad River in this area by several feet and the most severe flooding in recorded history for the area. Bridges were wiped out and roads were completely washed away, essentially cutting off communities. Much of the debris from these communities piled into the waters of Lake Lure (Fig. 31). Tens of thousands of trees are estimated (by county emergency managers and the NWS) to have fallen due to a combination of strong wind gusts and debris flows. Three direct deaths occurred - two from falling trees due to wind and one from freshwater flooding. Numerous water rescues were reported, with hundreds of homes and buildings destroyed.

More than 20 inches of rain was reported in portions of Henderson County. Catastrophic flash flooding occurred along the Rocky Broad River and its tributary Reedy Patch Creek, and numerous homes were swept away along both streams. Major flooding also occurred along Mud Creek and Bat Fork, with numerous businesses and other structures inundated in the Hendersonville area (Fig. 32). Eight direct deaths occurred in Henderson County (five in Hendersonville from freshwater flooding and three from landslides in the Bat Cave area), along with numerous water rescues. According to media reports and county officials[19], roughly 300 homes/buildings in the county were destroyed, with about 1,400 others incurring major damage. At least 86 landslides were documented in the county, and numerous roads were damaged or washed out. Hundreds of trees were down on homes due to strong wind gusts. Impacts in Transylvania County were also significant. Dozens of homes were damaged in Rosman with some structures destroyed after being inundated with several feet of water from the French Broad River. Flooding also occurred along the Davidson River area of Pisgah National Forest, where several water rescues occurred.

Madison and Yancey Counties, located along the Tennessee border, experienced devastating damage from Helene. In Madison County, aerial drone footage shows floodwaters from the French Broad River inundating the majority of buildings in Downtown Marshall (Fig. 33). Farther downstream, the town of Hot Springs was also devastated, where floodwaters from the river destroyed numerous businesses and critical infrastructure. Water, sewer, electricity and communication systems were heavily impacted. The French Broad River at Hot Springs set a record crest, surpassing the level from the Great Flood of 1916 by 0.3 ft. Four people died in Madison County, along with numerous water rescues reported. Hundreds of homes and buildings were either destroyed or sustained major damage. In Yancey County, which includes Busick where the largest storm-total rainfall occurred, rivers and their tributaries inundated hundreds of homes, with some structures completely destroyed. More than 200 landslides occurred, damaging or destroying numerous roads (Fig. 34). Media sources[20] indicate that about 1,400 homes/buildings were destroyed in the county while 2,300 others were severely damaged, with an additional 2,000 structures incurring minor to moderate damage. The Coast Guard performed numerous water rescues. There were ten direct fatalities in Yancey County, eight from flooding, one in a landslide, and one in a vehicle.

Farther north along the Tennessee border, Mitchell, Avery and Watauga Counties are home to the cities of Spruce Pine, Bakersville, Banner Elk, Newland and Boone. Some rivers, creeks and streams in Mitchell County rose to their highest levels in recorded history, and numerous water rescues took place. The highest reported rainfall in the county was 23.31 inches. Over 200 landslides were documented in the southern part of Mitchell County, near the McDowell County line. Very strong wind gusts knocked down an estimated 100,000 trees in Mitchell County. Several bridges and roads were completely wiped out and washed away, cutting off several small communities from the outside world. One direct death in Mitchell County was due to drowning from the floodwaters of the North Toe River. In Avery County, where up to 22.85 inches of rain was recorded, numerous homes and businesses in Downtown Newland were inundated and damaged by floodwaters from the North Toe River, with several structures swept away. Dozens of landslides occurred in this area, damaging or destroying multiple structures and killing 3 people. Two additional fatalities in Avery County are attributed to flooding. In Watauga County, flash flooding occurred in Downtown Boone, where water was deep enough to enter some homes and businesses. Several streets in Beech Mountain were washed out and destroyed by floodwaters.

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[19] https://www.hendersonvillelightning.com/news/14600-for-homeless-helene-victims-fema-housing-lags-behind-demand.html#:~:text=Left%20in%20Helene's%20wake%20after,businesses%20that%20escaped%20storm%20damage.

[20] https://wlos.com/news/local/we-are-yancey-strong-over-7700-structures-yancey-county-affected-hurricane-helene-damaged-destroyed-storm

Multiple vehicles became stranded on the flooded roads (Fig. 35). There were at least 220 rescues in Watauga County (mostly in vehicles). A total of 118 buildings were destroyed, 479 with major damage and 538 with minor or moderate damage. Among the damaged buildings include several at Appalachian State University due to flooding from Boone Creek, which inundated some of the classroom buildings.

In McDowell, Burke, Caldwell and Cleveland Counties major flooding impacts occurred and damaging wind gusts knocked down many trees. In the western half of McDowell County, rainfall amounts of 15–22 inches fell, and hundreds of landslides were documented. The Catawba River near Pleasant Gardens surpassed its all-time record river level by more than 4 ft. Dozens of structures were damaged or destroyed in the Old Fort area along with some being swept away, and there was one reported fatality. Tens of thousands of trees are estimated to have fallen in McDowell County, with hundreds down on homes, vehicles and powerlines. In Burke County, major flooding occurred along the Catawba River and its numerous tributaries (with some of the gauge sites recording record flooding), inundating numerous homes (with some swept away) and prompting swift water rescues. Landslides washed out many roads, and nearly the entire county was left without power or water after the storm. In Caldwell County, hundreds of structures and roads were inundated and damaged or destroyed, several landslides occurred, major flash flooding and river flooding occurred, and several homes had roof damage due to strong wind gusts. In Cleveland County, numerous homes were inundated and damaged near Abes Mountain Road. Widespread trees and powerlines were down across the county, including several on houses and vehicles in the Shelby area, and two people were killed by falling trees during the storm while they were outside.

To the west of Asheville, significant damage occurred in Haywood County. Floodwaters from the East Fork of the Pigeon River swept through the Cruso community, causing significant damage to structures, vehicles, and road infrastructure. Record catastrophic flooding occurred on the Pigeon River from Canton and Clyde downstream to the Tennessee border. Numerous buildings in Canton were inundated. Around 600 homes were impacted by flooding in the county, with a couple of hundred of those destroyed. Numerous vehicles were swept away or damaged, and hundreds of people were rescued. Many roads and bridges were damaged or destroyed. This includes part of Interstate 40 along the North Carolina/Tennessee border, which was washed out and destroyed by overflowing waters from the Pigeon River, which parallels the interstate for several miles from Haywood County, North Carolina into Cocke County, Tennessee.

In eastern North Carolina, an EF-3 tornado in Nash County damaged 11 buildings and caused 15 injuries and in Rockingham County an EF-1 tornado damaged at least 5 homes.

In Tennessee's Cocke County, the flooding on the Pigeon River affected the city of Newport, where the river gauge measured a river level more than 6 ft higher than the previous record crest that stood for over 120 years. Numerous structures in and around the vicinity of Newport were destroyed or damaged. Two people drowned in Cocke County near the Nolichucky River as their vehicle was swept away by floodwaters when they tried to escape their home. The Nolichucky River at Lowland, located in Greene County, crested 9 ft above its previous all-time record.

Severe flooding of the Nolichucky River also occurred upstream in Unicoi County, Tennessee where at least 9 people drowned in the city of Erwin. Three of these fatalities were residents of North Carolina that were found in eastern Tennessee. The Unicoi County Hospital flooded, leaving everything but the roof submerged. Hospital staff evacuated all 70 people to the roof, including 11 patients. Everyone was rescued by helicopter (Fig. 36), and nobody was injured. Interstate 26 in Unicoi County was closed for several weeks due to washouts from the Nolichucky River. Two people drowned in the city of Embreeville in Washington County, which is just a couple of n mi downstream from Erwin along the Nolichucky River. In this area, the river is estimated to have crested nearly 10 ft above its all-time record flood stage (Fig. 37). Many homes were destroyed in Embreeville. Many homes, structures, bridges and roadways were also wiped out farther downstream in Washington County.

In Johnson County, which is the northeasternmost county in Tennessee, floodwaters damaged numerous structures in Trade, Mountain City and Laurel Bloomery. Employees at Parkdale Plant were evacuated by helicopter. A church near Midway was completely washed away by floodwaters from Roan Creek. One person drowned in their vehicle. Very strong wind gusts caused trees to fall on powerlines, and the power wasn't restored for 3 weeks in some areas. In Carter County, located in between Johnson and Unicoi Counties, flash flooding from the Doe River flooded homes, businesses and vehicles in the Valley Forge and Elizabethton areas. A hospital in Elizabethton was evacuated. Extremely strong wind gusts were reported higher up and caused many large trees to fall along the Appalachian Trail.

Virginia and West Virginia

Helene caused severe flooding (Fig. 38) and wind damage across southwestern Virginia. Some of the most severe damage and impacts occurred in Grayson, Pulaski, Smyth, Washington and Wythe counties. In Pulaski County, flooding along the New River destroyed 12 homes and damaged 104 others (65 of those major damage). In Smyth and Washington Counties, severe flooding necessitated over 100 swift water rescues, destroyed dozens of structures and damaged hundreds more. Grayson County, which measured gusts to 57 kt and rainfall amounts around 11 inches, reported over $61 million in agricultural losses. Severe flooding damaged or destroyed many homes in Grayson County, and 3 people were injured. An EF-2 tornado in Pittsylvania County, Virginia, damaged 30 structures, including a mobile home that was destroyed. One injury occurred to an occupant in the mobile home. In total in Virginia, there were 2 direct deaths and at least 6 injuries.

In West Virginia, strong wind gusts from Helene downed numerous trees and powerlines, causing damage to some homes and vehicles and knocking out power for many customers, especially for southern and southwestern portions of the state. Major flooding was only an issue for extreme southern portions of the state, particularly in Mercer County, where floodwaters rushed through the streets into a few homes and structures, due to overflowing creeks. The wind damage was comparatively more widespread across the state.

Kentucky, Ohio, Indiana and Illinois

In Kentucky, widespread wind gusts of 45–55 kt combined with wet ground conditions to knock down numerous trees, powerlines and power poles, especially in the eastern half of the state, leading to over 200,000 power outages. There were several reports of trees falling onto homes, leading to isolated instances of structural damage across eastern Kentucky. Strong to damaging wind gusts were also widespread on the north side of post-tropical Helene across much of southern and southwestern Ohio, where numerous trees and powerlines were brought down, including in Cincinnati. The winds knocked out power to at least 120,000 customers in southern Ohio. In Scioto County, flooding was also an issue, and media reports indicate that hundreds of homes were damaged by floodwaters, with a few homes swept away. The strong winds then moved westward, affecting southern and central Indiana, causing numerous trees and powerlines to fall, with over 130,000 power outages. Some of the trees fell on homes and vehicles, causing structural damage. There was one fatality in Gibson County due to a tree falling on a home. Similar impacts from wind occurred in eastern Illinois during the evening of 27 September, with many trees and powerlines down (some on homes) and scattered power outages reported.

Nicaragua, Honduras, Cayman Islands, Mexico and Cuba

From 21–24 September, heavy rain fell across portions of Nicaragua and Honduras that was associated with Helene's precursor disturbance. Flooding from this rainfall caused damage in portions of Honduras with water entering some homes and structures. According to media sources, flooding rains and heavy surf also led to minor damage in the Cayman Islands on 23–24 September.

Helene caused some impacts along the east coast of the Yucatan Peninsula in the Mexican state of Quintana Roo, including in the Cancun area as well as on the islands of Cozumel and Isla Mujeres. In Isla Mujeres, where the strongest winds were recorded, there was significant damage. Most of the island lost electricity and many trees fell. Fallen trees and power poles caused some power outages on Cozumel and portions of Quintana Roo, where minor damage was reported to a few structures.

No monetary damage estimates have been received from Mexico or Cuba.

FORECAST AND WARNING CRITIQUE

Genesis

The genesis of Helene was adequately forecast (Table 4), but in general the system developed sooner than anticipated. The disturbance from which Helene developed was introduced in the Tropical Weather Outlook (TWO) 6.5 days prior to genesis with a low chance (<40%) of development within 7 days. The 2-day formation probabilities were introduced 48 h prior to genesis. The probabilities reached the medium and high categories in the 7-day TWO 126 h and 60 h before formation, respectively. The lead times for the 2-day TWO were 42 h and 30 h for the medium and high categories, respectively. NHC initiated potential tropical cyclone advisories at 1500 UTC 23 September, about 21 hours before the system is shown to have become a tropical cyclone in the best track in order to issue watches and warnings with appropriate lead time for land areas in the northwestern Caribbean Sea. All of the Graphical TWOs issued by NHC correctly captured the location where genesis occurred (Fig. 39).

Track

A verification of NHC official track forecasts for Helene is given in Table 5a. The official track forecast errors were near the mean official errors for the previous 5-yr period at 12–48 h, and lower than the 5-yr means at 60–72 h, albeit for a small sample size. The larger than average Climatology-Persistence (OCD5) track errors indicate Helene's track was more difficult to forecast than normal. All of the NHC track forecasts were tightly clustered and consistently highlighted the landfall threat to the Florida Big Bend and eastern Florida Panhandle areas (Fig. 40), however some of the earlier forecasts predicted landfall in the Florida Big Bend occurring a few hours sooner than what occurred. Most of the NHC forecasts were biased slightly west for the landfall and overland portion of Helene's actual track over the southeastern United States. A homogeneous comparison of the official track errors with selected guidance models is given in Table 5b and depicted in Figure 41. The official forecast errors were similar to the best-performing track models for the 12- and 24-h forecasts. Some of the global models and consensus approaches outperformed the official forecast at time ranges of 36–60 h, including the Florida State Superensemble (FSSE) and the European Center for Medium Range Weather Forecasting (ECMWF) Model. However, the official forecast errors were lower than most of the hurricane regional model forecasts.

Intensity

A verification of NHC official intensity forecasts for Helene is given in Table 6a. Official intensity forecast errors were greater than the 5-yr means at 12–24 h and 48–60 h, but outperformed the 5-yr means at 36 and 72 h. The very large Climatology-Persistence (OCD5) errors indicate that Helene's intensity was much harder than average to forecast. All but one NHC intensity forecast issued starting 78 h before landfall explicitly called for Helene to become a major hurricane prior to landfall in Florida. Every NHC forecast from the first advisory correctly predicted that Helene would undergo rapid intensification in the Gulf of America, defined as a 30 kt or greater increase in the maximum sustained wind speed within a 24-h period. Additionally, the second advisory (issued at 2100 UTC 23 September) on the potential tropical cyclone that became Helene marked the first time that NHC forecast a disturbance to become a major hurricane before the system became a tropical cyclone. Figure 42 shows that the NHC intensity forecasts were consistent and fairly accurate. Some of the earlier NHC forecasts indicated that the peak intensity would occur a bit earlier than what occurred.

A homogeneous comparison of the official intensity errors with selected guidance models is given in Table 6b and depicted in Figure 43. The NHC forecast outperformed all the available intensity models at ranges of 12–36 h and at 72 h, but was outperformed by a few of the intensity models at 48–60 h. The statistical guidance and intensity consensus models were the best-performing intensity models, followed by the regional hurricane models.

Wind Watches and Warnings

Coastal wind watches and warnings associated with Helene are given in Table 7. Coastal and inland tropical cyclone wind watches and warnings are illustrated in Figure 44, colored by highest warning type. A verification discussion of select coastal watches and warnings is provided below.

In the United States, a Hurricane Watch was issued at 0900 UTC 24 September from north of Tampa Bay to Indian Pass, Florida, which includes the Florida Big Bend and the landfall location, 57 h in advance of the arrival of tropical-storm-force winds. At 2100 UTC 24 September a Hurricane Warning was issued for the Gulf Coast of Florida from the Anclote River to Mexico Beach, about 45 h before the onset of tropical-storm-force winds. Farther south, from the Tampa Bay area southward to Englewood, Florida, a Hurricane Watch was issued with 54 h of lead time and a Tropical Storm Warning was issued 42 h prior to the onset of tropical-storm-force winds. Portions of this area experienced sustained winds over 50 kt with gusts to hurricane force, so the Hurricane Watch with the concurrent Tropical Storm Warning was warranted. For the southwest coast of Florida between Flamingo and Bonita Beach, the Tropical Storm Watch provided 57 h of lead time and the Tropical Storm Warning had 39 h of lead time. For the Lower Florida Keys, Tropical Storm Watches and Warnings were issued 48 and 30 h before the onset of conditions, respectively.

The northeast coast of Florida had 48 h of lead time for the Tropical Storm Watch and 36 h notice for the Tropical Storm Warning. The coast of Georgia had 51 and 33 h notice for their Tropical Storm Watch and Warning, respectively. A Tropical Storm Watch was issued for the coast of South Carolina from the Georgia border to the South Santee River about 43 h prior to the onset of tropical-storm-force winds, and a Tropical Storm Warning was issued there 37 h in advance.

Storm Surge Watches and Warnings

Storm surge watches and warnings associated with Helene are given in Table 8. A Storm Surge Watch was first issued at 0300 UTC 24 September for the southwest coast of Florida from Bonita Beach to Flamingo. The watch was extended northward and westward to Indian Pass, including Tampa Bay and Charlotte Harbor, at 0900 UTC that day. The entire watch area from Flamingo to Indian Pass was upgraded to a Storm Surge Warning at 2100 UTC that day. A Storm Surge Watch was issued from Mexico Beach to Indian Pass at 1500 UTC 25 September, and was upgraded to a warning 6 h later. Figure 45 shows the Storm Surge Warning in effect at 2100 UTC 25 September, with the observations overlaid. No changes were made until water levels receded after landfall.

Storm surge observations indicate greater than 3 ft of inundation occurred through the storm surge warning area (Fig. 45). In Tampa Bay, based on the timing of when tropical-storm-force winds first reached the area (1500 UTC 26 September), the lead times for the storm surge watch and warning were 60 and 36 h, respectively. Lead times in the Big Bend were 3 to 6 h longer, with tropical-storm-force winds spreading throughout the entire Big Bend by 2100 UTC 26 September.

The initial peak storm surge forecast was for 10 to 15 ft AGL somewhere between Ochlockonee River and Chassahowitzka (issued at 0900 UTC 24 September). The peak forecast was increased and adjusted slightly westward as the forecast evolved, ultimately resulting in a forecast of 15 to 20 ft AGL somewhere between Carrabelle and Suwannee River at 2100 UTC 25 September, approximately 30 h prior to landfall. The NHC storm surge analysis of 12 to 16 ft AGL falls within this forecast area. The peak storm surge forecast in Tampa Bay remained steady at 5 to 8 ft AGL from the first issuance of the Storm Surge Watch, and the NHC storm surge analysis of 5 to 7 ft AGL verifies this forecast. Similarly, the peak storm surge in Fort Myers and Charlotte Harbor was 3 to 5 ft AGL from the first issuance of the Storm Surge Watch, and the NHC storm surge analysis verifies this forecast.

Rainfall Forecasts and Flooding Outlooks

The PRE that occurred ahead of Helene on 25-26 September was challenging to forecast due to uncertainty in the forecast position and strength of the upper-level low pressure area and surface front, and how these features interacted with Helene. The Weather Prediction Center (WPC) forecast first indicated that heavy rainfall could occur over portions of the Southeast U.S. and southern Appalachians well ahead of Helene with about 3 days of lead time, when a Slight risk was issued in the Excessive Rainfall Outlook (ERO) [21]. However, initially the heaviest rain with this PRE was forecast too far west, with the forecast shifting east with the update issued on the afternoon of 24 September and again the next morning, when a Moderate risk was issued in the ERO (Fig. 46).

Rainfall forecasts for when Helene moved inland proved to have more skill and lead time. Initial forecasts on days 5 and 6 depicted a heavy rainfall risk over the southeastern U.S., but were too slow moving the heaviest rain inland. WPC forecasts correctly sped up the timing with 4 days of lead time, and by 2 to 3 days out, rainfall amounts continued to trend upwards closer to observed values. Figure 47 shows the WPC forecast rainfall evolution in the days leading up to the event.

For the discussion that follows, lead time will be defined as the number of hours before the first weather-driven flash flood emergency over the southern Appalachians, which was issued at 0739 UTC 27 September. The first Slight risk in the WPC ERO was issued early on the morning of 23 September, with 96 h of lead time. There was a mention of a heavy rainfall and flooding risk over the southeastern United States in the first NHC Public Advisory for the potential tropical cyclone that became Helene at 1500 UTC that day. Wording was enhanced with the 2100 UTC Public Advisory (83 h of lead time) to mention that some of the flooding could be considerable. The ERO was upgraded to a Moderate risk around 0800 UTC 24 September (72 h of lead time) as confidence increased on the timing and track of Helene moving into the Southeast U.S. At that time, there was still uncertainty regarding the magnitude of the PRE ahead of Helene, and the degree of overlap between the rainfall associated with the PRE and core of Helene. Around 2100 UTC that day (59 h of lead time), a WPC Excessive Rainfall Discussion (ERD) mentioned this was a “higher-end Moderate risk, with increasing potential of eventually needing a High risk

[21] The ERO forecasts the probability that rainfall will exceed flash flood guidance within 25 miles of a point. More information on the WPC ERO can be found at: www.wpc.ncep.noaa.gov/html/fam2.shtml#excessrain

upgrade." At about the same time, the first mention of landslide potential was introduced into the Helene Public Advisory and Key Messages. Forecasters upgraded to a High risk around 0800 UTC 25 September (48 h of lead time) as it continued to become more apparent that the rainfall from the PRE and core of Helene would indeed have significant overlap, increasing confidence of a catastrophic event. This is the 3rd longest High risk lead time for a tropical cyclone since 2017. Wording was enhanced even further in the 2100 UTC Public Advisory on 25 September (34 h of lead time): "This rainfall will likely result in catastrophic and potentially life-threatening flash and urban flooding, along with significant river flooding. Landslides are possible in areas of steep terrain." At about the same time, a rare, coordinated NOAA news release[22] was posted on the noaa.gov website about the inland flood threat: "We urge the news media to continue focusing the public's attention on the major impacts from the inland flooding expected along the path of Helene well after landfall."

IMPACT-BASED DECISION SUPPORT SERVICES (IDSS) AND PUBLIC COMMUNICATION

The NHC began communication with emergency managers on 23 September as Helene was forming in the northwestern Caribbean Sea. Sixteen decision support briefings were provided to emergency managers and coordinated through the FEMA Hurricane Liaison Team embedded at the NHC. These briefings included video-teleconferences with FEMA HQ, FEMA Region 4, the states of Georgia, South Carolina, North Carolina, Tennessee, the state and counties of Florida, the Seminole Tribe of Florida, and the Miccosukee Tribe of Indians. Briefing support continued through 27 September as Helene moved inland over the southeast United States. Additionally, in coordination with the Florida Division of Emergency Management and the NHC Storm Surge Unit, the Hurricane Liaison Team directly supported several counties along the west coast of Florida with evacuation planning and decision making. The NHC's Tropical Analysis and Forecast Branch provided 13 decision-support briefings to the U.S. Coast Guard Districts 7 and 8 during Helene.

NHC activated the television media pool on 24 September and continued through 27 September, providing 145 interviews with national, local and international outlets. Of those interviews, 30 were in Spanish. NHC provided 9 live stream broadcasts on YouTube and Facebook during this event. Five short-content videos in the form of "reels" were posted to the NHC Instagram and Facebook accounts, reaching 1.3 million plays. In addition, a total of 141 manual social media posts were provided on Facebook, Instagram and X, with total engagements of over 301,906.

The WPC, NWC and NOAA ramped up their IDSS and public communication of the inland flood threat in the days leading up to Helene's landfall. Figure 48 provides a sample of some of WPC's forecast messaging in the days leading up to landfall.

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[22] https://www.noaa.gov/news-release/communities-need-to-prepare-for-catastrophic-life-threatening-inland-flooding-from-helene-even-well

NHC began communicating the significant inland wind threat Helene posed during the morning of 25 September in the Key Messages as well as in public communications with the media and on social media. That afternoon, NHC began forecasting higher-than-normal gust factors for the inland forecast points over the southeastern U.S. in the Forecast/Advisory (TCM) product.

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Table 1. Best track for Hurricane Helene, 24–27 September 2024.

Date/Time (UTC)	Latitude (°N)	Longitude (°W)	Pressure (mb)	Wind Speed (kt)	Stage
23 / 1200	17.2	81.7	1004	30	disturbance
23 / 1800	17.8	81.9	1004	35	"
24 / 0000	18.2	82.2	1002	35	"
24 / 0600	18.6	82.8	1001	35	"
24 / 1200	19.2	83.7	999	40	tropical storm
24 / 1800	19.4	84.6	997	45	"
25 / 0000	19.7	85.2	990	50	"
25 / 0600	20.3	85.9	985	55	"
25 / 1200	21.1	86.2	979	65	hurricane
25 / 1800	22.0	86.5	978	70	"
26 / 0000	22.8	86.7	973	70	"
26 / 0600	23.6	86.5	970	75	"
26 / 1200	24.7	85.8	963	85	"
26 / 1800	26.6	85.0	958	105	"
27 / 0000	28.7	84.3	941	120	"
27 / 0310	30.0	83.7	939	120	"
27 / 0500	30.8	83.5	947	95	"
27 / 0600	31.3	83.3	957	80	"
27 / 0900	32.9	83.1	967	60	tropical storm
27 / 1200	34.4	83.2	973	45	"
27 / 1800	36.8	84.9	983	40	low
28 / 0000	38.1	86.6	985	40	"

Date/Time (UTC)	Latitude (°N)	Longitude (°W)	Pressure (mb)	Wind Speed (kt)	Stage
28 / 0600	37.4	88.1	992	30	“
28 / 1200	36.6	87.6	997	25	“
28 / 1800	37.1	87.0	1000	20	“
29 / 0000					dissipated
27 / 0310	30.0	83.7	939	120	maximum wind, minimum pressure and landfall 10 miles SW of Perry, FL

Table 2. Selected ship reports with winds of at least 34 kt for Hurricane Helene, 24–27 September 2024.

Date/Time (UTC)	Ship call sign	Latitude (°N)	Longitude (°W)	Wind dir/ speed (kt)	Pressure (mb)
25 / 1200	DB5108	21.2	86.7	360 / 40	992.4
25 / 1600	DB5108	21.2	86.7	350 / 55	992.8
26 / 1000	C6CL6	20.3	85.6	230 / 36	1002.8
26 / 1200	KCHV	26.1	79.9	130 / 38	1005.9
26 / 1900	WDBH	24.8	80.3	150 / 48	1004.9
27 / 0400	9HA206	29.9	77.3	120 / 40	1008.8
27 / 0500	9HA567	26.2	79.0	190 / 35	
27 / 0600	9HA537	27.6	79.4	180 / 60	1005.0
27 / 0700	3FLO4	26.1	79.2	190 / 45	
27 / 0700	OYAU2	27.4	79.6	210 / 38	1003.6
27 / 0800	9HA537	27.7	79.6	180 / 50	1004.0
27 / 0900	WTEA	32.8	79.9	*** / 49	997.9
27 / 1000	WTEA	32.8	79.9	*** / 54	998.1
27 / 1400	KRU	33.0	78.2	150 / 45	1004.2
27 / 1600	VGWM	42.1	81.2	060 / 36	
27 / 1600	WTDL	35.7	75.3	150 / 38	1013.4
27 / 1600	VRVC3	31.9	80.0	180 / 38	1002.0
27 / 1700	WNTL	33.9	76.7	150 / 40	1005.6
27 / 1800	VCPK	41.9	82.6	060 / 42	
27 / 1900	THLO1	41.8	83.2	050 / 35	1007.6
28 / 0240	CHII2	42.0	87.5	030 / 38	
28 / 0300	CFJ830	41.9	82.1	040 / 40	
28 / 0500	CHII2	42.0	87.5	050 / 38	

Table 3. Selected surface observations for Hurricane Helene, 24–27 September 2024.

Location	Minimum Sea Level Pressure		Maximum Surface Wind Speed			Storm surge (ft)[c]	Storm tide (ft)[d]	Estimated Inundation (ft)[e]	Total rain (in)
	Date/ time (UTC)	Press. (mb)	Date/ time (UTC)[a]	Sustained (kt)[b]	Gust (kt)				
Buoys									
41004 - NOAA (32.50N, 79.10W)	27/0950	1000.1	27/0900	35 (4 m)	49				
41008 - NOAA (31.40N, 80.87W)	27/0700	993.8	27/0740	42 (4 m)	62				
41009 - NOAA (28.51N, 80.19W)	27/0200	1001.8	26/1434	44 (1 min, 4 m)	51				
41010 - NOAA (28.88N, 78.47W)	27/0753	1006.1	27/0625	38 (1 min, 4 m)	41				
41029 - CORMP (32.80N, 79.62W)	27/1008	998.2	27/0908	35 (3 m)	53				
41033 - CORMP (32.28N, 80.41W)	27/1008	993.9	27/1008	34 (3 m)	55				
41066 - CORMP (32.54N, 79.66W)	27/1008	998.0	27/0908	35 (3 m)	52				
41069 - CORMP (29.29N, 80.80W)	27/0408	999.3	27/0208	37 (3 m)	52				
42013 - COMPS (27.17N, 82.92W)	26/2205	991.2	26/2005	46 (8 min, 3 m)	67				
42023 - COMPS (26.01N, 83.09W)	26/1905	995.2	26/1835	43 (8 min, 3 m)	60				
42026 - COMPS (25.17N, 83.48W)	26/1635	995.2	26/1405	41 (8 min, 3 m)	55				
42036 - NOAA (28.50N, 84.51W)	26/2310	949.4	26/2254	69 (1 min, 4 m)	93				
42056 - NOAA (19.82N, 84.98W)	25/0130	990.9	25/1004	37 (1 min, 4 m)	41				
Saildrone									
1057 (29.02N, 84.38W)	27/0038	954.1	27/0039	67 (1 min)	93				
1083 (28.25N, 84.63W)	26/2238	951.8	26/2231	63 (1 min)	95				
CAYMAN ISLANDS									
Grand Cayman MWCR) (19.30N, 81.35W)	24/0730	1005.0	24/1114	21	39				
CUBA									
Cayo Largo (MUCL) (21.62N, 81.55W)	25/0950	1005	25/1508	29	49				
Havana (23.14N, 82.34W)				32	50				
Herradura (22.51N, 83.41W)									8.60
Santa Lucia (22.67N, 83.96W)					55				

Location	Minimum Sea Level Pressure		Maximum Surface Wind Speed			Storm surge (ft)[c]	Storm tide (ft)[d]	Estimated Inundation (ft)[e]	Total rain (in)
	Date/ time (UTC)	Press. (mb)	Date/ time (UTC)[a]	Sustained (kt)[b]	Gust (kt)				
MEXICO									
Cancun (21.32N, 86.81W)	25/1325	991.0	25/1340	31	63				9.65
Isla Mujeres (21.25N, 86.74W)	25/1745	989.0	25/1845	46	60				
WeatherFlow Sites									
Cancun (XCNN) (21.06N, 86.78W)	25/1251	992.0	25/1121	32	47				
Cozumel (XCOZ) (20.53N, 86.94W)	25/1056	995.0	25/1336	35	45				
UNITED STATES									
Florida									
International Civil Aviation Organization (ICAO) Sites									
Clearwater (KPIE) (27.91N, 82.69W)	26/2348	991.2	27/0029	44 (2 min, 10 m)	62				
Jacksonville (KNIP) (30.23N, 81.67W)	27/0453	991.1	27/0514	41 (2 min, 10 m)	64				
Perry (KFPY) (30.07N, 83.58W)	27/0320	948.2	27/0315	48 (2 min, 10 m)	86				
Sarasota (KSRQ) (27.40N, 82.56W)	26/2013	993.6	26/2014	44 (2 min, 10 m)	64				
St. Petersburg (KSPG) (27.76N, 82.63W)	26/2207	990.2	26/2347	48 (2 min, 8 m)	71				
Hydrometeorological Automated Data System (HADS) Sites (NWS)									
Lake Lamonia 2.7 E (LAIF1) (30.64N, 84.21W)									10.58
Coastal-Marine Automated Network (C-MAN) Sites									
St. Augustine (SAUF1) (29.86N, 81.26W)	27/0500	995.0	27/0300	48 (8 min, 16 m	61				
Venice (VENF1) (27.07N, 82.45W)	26/2100	995.1	26/2130	48 (10 min, 12 m)	62				
National Ocean Service (NOS) Sites									
Apalachicola (APCF1) (29.72N, 84.98W)						4.28	5.18	4.33	
Cedar Key (CKYF1) (29.14N, 83.03W)	27/0148	980.2	27/0148	56 (4 m)	73	10.34	10.84	9.3	
Clearwater Beach (CWBF1) (27.98N, 82.83W)	26/2306	989.2	26/2354	48 (2 min, 7 m)	64	7.29	7.62	6.67	
East Bay (EBEF1) (27.92N, 82.42W)						7.84	8.05	7.2	

Location	Minimum Sea Level Pressure		Maximum Surface Wind Speed			Storm surge (ft)[c]	Storm tide (ft)[d]	Estimated Inundation (ft)[e]	Total rain (in)
	Date/ time (UTC)	Press. (mb)	Date/ time (UTC)[a]	Sustained (kt)[b]	Gust (kt)				
Ft. Myers (FMRF1) (26.65N, 81.87W)						5.57	5.39	5.12	
Naples Bay N (NBNF1) (26.14N, 81.79W)						4.66	4.71	4.02	
Old Port Tampa (OPTF1) (27.86N, 82.55W)						7.29	7.62	6.83	
Panama City (PACF1) (30.15N, 85.66W)						2.66	3.8	3.02	
Panama City Beach (PCBF1) (30.21N, 85.88W)						2.92	4.12	3.26	
Port Manatee (PMAF1) (27.64N, 82.56W)						6.43	6.62	6.04	
St. Petersburg (SAPF1) (27.76N, 82.63W)						6.77	7.09	6.31	
Josh Morgerman, iCyclone Sites									
Hampton Springs (30.09N, 83.66W)	27/0316	944.1							
Perry (30.09N, 83.57W)	27/0331	947.2							
WeatherFlow Sites									
Egmont Channel (XEGM) (27.61N, 82.76W)	26/2214	990	26/2344	51 (1 min, 12 m)	70				
Tampa Bay (XTAM) (27.77N, 82.57W)	26/2329	993	27/0034	50 (5 min, 15 m)	63				
WeatherSTEM Sites									
Athena (29.99N, 83.49W)	27/0312	945.2	27/0252		84 (2 m)				
Dowling Park (2205W) (30.25N, 83.24W)	27/0400	959.7	27/0350	61	86				
Fish Creek (2003W) (29.77N, 83.58W)	27/0256	950.6	27/0210		72[l] (6 m)				
Horseshoe Beach (29.44N, 83.29W)	27/0151	971.6	27/0210		73 (6 m)				
Jacksonville (1483W) (30.39N, 81.44W)	27/0510	992.2	27/0340	53	70				
Live Oak (2208W) (30.40N, 83.01W)	27/0420	968.9	27/0420	47	70				
Madison (1623W) (30.45N, 83.42W)	27/0413	951.4	27/0413	58 (3 m)	70				

Location	Minimum Sea Level Pressure		Maximum Surface Wind Speed			Storm surge (ft)[c]	Storm tide (ft)[d]	Estimated Inundation (ft)[e]	Total rain (in)
	Date/ time (UTC)	Press. (mb)	Date/ time (UTC)[a]	Sustained (kt)[b]	Gust (kt)				
Stuart Beach (1534W) (27.20N, 80.17W)	26/2350	1003.1	26/1310	51	63				
Florida Automated Weather Network (FAWN) Sites									
Mayo (MAYFL) (30.08N, 83.24W)	27/0345	963	27/0400	47 (15 min, 9 m)	80				
Florida Coastal Monitoring Program Sites									
Fish Creek (T6) (29.76N, 83.49W)			26/2242	55 (1 min, 5 m)	78				
Texas Tech StickNet Sites									
Hampton Springs (102) (30.04N, 83.68W)	27/0312	942.8							
Live Oak (329) (30.21N, 83.09W)	27/0359	964.4	27/0359	64 (1 min, 2 m)	79				
Mayo (328) (30.09N, 83.24W)	27/0352	961.3	27/0412	56 (1 min, 2 m)	80				
Perry (325) (30.02N, 83.53W)	27/0325	946.3	27/0307	45 (1 min, 2 m)	63				
West Lake (336) (30.49N, 83.16W)	27/0424	958.3	27/0424	59 (1 min, 2 m)	73				
Remote Automated Weather Stations (RAWS)									
Sanborn (SNDF1) (30.07N, 84.59W)									10.26
Sumatra (SURF1) (30.02N, 84.99W)									14.39
Wilma (WHSF1) (30.18N, 84.94W)									11.47
Community Collaborative Rain, Hail and Snow Network (CoCoRaHS) Sites									
Alford 0.6 SSE (FL-JK-2) (30.69N, 85.39W)									11.72
Midway 6.9 SW (FL-LN-18) (30.42N, 84.54W)									10.30
Deployed USGS Water Level Sensors									
FLCIT35742 (28.91N, 82.69W)							10.33	9.0	
FLDIX25020 (29.39N, 83.20W)							13.69	12.18	
FLHER35741 (28.57N, 82.66W)							9.9	8.44	
FLLEV35745 (29.14N, 83.03W)							10.39	8.84	
FLPAS35743 (28.29N, 82.73W)							8.79	7.6	
FLPIN26405 (28.15N, 82.81W)							8.39	7.23	

Location	Minimum Sea Level Pressure		Maximum Surface Wind Speed			Storm surge (ft)[c]	Storm tide (ft)[d]	Estimated Inundation (ft)[e]	Total rain (in)
	Date/ time (UTC)	Press. (mb)	Date/ time (UTC)[a]	Sustained (kt)[b]	Gust (kt)				
FLPIN31148 (27.98N, 82.83W)							7.7	6.75	
FLPIN36348 (27.80N, 82.80W)							8.02	7.26	
FLPIN36349 (27.62N, 82.74W)							7.19	6.6	
FLSAR25010 (27.36N, 82.62W)							7.22	6.68	
FLSAR26282 (27.07N, 82.45W)							6.28	5.71	
FLTAY35738 (29.79N, 83.57W)							15.33	13.68	
FLTAY35739 (29.80N, 83.59W)							15.41	13.74	
FLWAK29937 (30.06N, 84.29W)							8.16	6.53	
NWS High Water Mark Observations									
HWM1 (29.83N, 83.59W)							17.0	15.3	
HWM2 (29.67N, 83.40W)							17.8	16.1	
HWM3 (29.92N, 83.68W)							14.7	12.9	
USGS Streamgauges									
Steinhatchee River at Steinhatchee (2324170) (29.67N, 83.38W)							14.25	12.5	
Georgia									
International Civil Aviation Organization (ICAO) Sites									
Alma (KAMG) (31.54N, 82.51W)	27/0630	973.9	27/0703	49 (2 min, 10 m)	87				
Augusta (KAGS) (33.36N, 81.96W)	27/0940	976.3	27/1005	45 (2 min, 10 m)	71				
Moody AFB (KVAD) (30.98N, 83.19W)	27/0455	962.3[l]	27/0440	38[l] (2 min, 10 m)	60[l]				
Reidsville (KRVJ) (32.06N, 82.15W)	27/0635	982.5[l]	27/0635	41[l] (2 min, 10 m)	69[l]				
Savannah (KSAV) (32.13N, 81.20W)	27/0815	989.5	27/0815	47 (2 min, 10 m)	66				
Hydrometeorological Automated Data System (HADS) Sites (NWS)									
Brasstown Bald (BRBG1) (34.87N, 83.81W)			27/0949	43	75				
Canton-Etowah River (CNNG1) (34.24N, 84.50W)									13.07

Location	Minimum Sea Level Pressure		Maximum Surface Wind Speed			Storm surge (ft)[c]	Storm tide (ft)[d]	Estimated Inundation (ft)[e]	Total rain (in)
	Date/ time (UTC)	Press. (mb)	Date/ time (UTC)[a]	Sustained (kt)[b]	Gust (kt)				
Darien 7 NNE (MERG1) (31.45N, 81.36W)	27/0730	990.2	27/0730	51					
St. Simons Island (BRNG1) (31.13N, 81.40W)			27/0645	50					
National Ocean Service (NOS) Sites									
Fort Pulaski (FPKG1) (32.04N, 80.90W)	27/0748	993.6	27/0836	37 (3 m)	59				
Public/Other									
Baxley (BXYG1) (31.71N, 82.39W)			27/0638	35	63				
WeatherFlow Sites									
Jekyll Island (XJEK) (31.05N, 81.41W)		992.7	27/0612	53 (1 min, 10 m)	68				
Savannah Light (XSEL) (32.01N, 80.81W)	27/0838	987.7	27/0758	54 (1 min, 11 m)	68				
WeatherSTEM Sites									
Lake Park (1771W) (30.65N, 83.23W)	27/0441	957.7	27/0420	53 (7 m)	83				
Texas Tech StickNet Sites									
Lake Park (215) (30.65N, 83.11W)	27/0445	958.2	27/0515	47 (1 min, 2 m)	67				
Quitman (446) (30.80N, 83.49W)	27/0455	946.8	27/0431	46 (1 min, 2 m)	63				
Valdosta (330) (30.83N, 83.25W)	27/0508	949.3	27/0429	51 (1 min, 2 m)	72				
Remote Automated Weather Stations (RAWS)									
Brasstown (BRSG1) (34.81N, 83.71W)									13.18
Clayton 4 NE (TULG1) (34.91N, 83.33W)									14.44
Louisville (LOUG1) (32.99N, 83.38W)			27/0903		65				
McRae (MRAG1) (32.09N, 82.88W)			27/0703	36 (2 min)	65				
Waycross (OKEG1) (31.25N, 82.40W)			27/0604	36	62				
Citizen Weather Observer Program Stations (CWOP)									
Montgomery (F7647) (31.94N, 81.10W)	27/0743	991.5	27/0804	49	70				

Location	Minimum Sea Level Pressure		Maximum Surface Wind Speed			Storm surge (ft)[c]	Storm tide (ft)[d]	Estimated Inundation (ft)[e]	Total rain (in)
	Date/ time (UTC)	Press. (mb)	Date/ time (UTC)[a]	Sustained (kt)[b]	Gust (kt)				
University of Georgia Weather Network Sites									
Baxley (31.75N, 82.44W)	27/0700	974.4	27/0645	34 (3 m)	67				
Douglas (UGA52) (31.49N, 82.79W)	27/0615	968.6	27/0615	40 (3 m)	80				
Lake Park (30.67N, 83.12W)	27/0500	964.3	27/0515	37 (3 m)	78				
Vidalia (UGA58) (32.14N, 82.35W)		975.0	27/0724	35 (2 min)	68				
Community Collaborative Rain, Hail and Snow Network (CoCoRaHS) Sites									
Dillard 3.5 NE (GA-RB-1) (34.99N, 83.30W)									14.64
Martinez 1.3 SE (GA-RC-18) (33.51N, 82.07W)									13.17
McDonough 3.6 E (GA-HY-21) (33.44N, 84.08W)									13.64
South Carolina									
International Civil Aviation Organization (ICAO) Sites									
Anderson (KAND) (34.50N, 82.71W)	27/1125	974.6	27/1050	39 (2 min, 10 m)	63				
Beaufort (KNBC) (32.48N, 80.72W)	27/0856	993.9	27/0835	34 (2 min, 10 m)	65				
Charleston (KCHS) (32.90N, 80.04W)	27/0950	996.2	27/0900	35 (2 min, 10 m)	55				
Columbia (KCAE) (33.94N, 81.12W)	27/1015	989.2	27/1015	38 (2 min, 10 m)	58				
Greenville (KGMU) (34.85N, 82.35W)	27/1132	979.1	27/1055	36[I] (2 min, 10 m)	56[I]				
Greer (KGSP) (34.91N, 82.21W)	27/1145	979.4	27/1140	38 (2 min, 10 m)	59				
Orangeburg (KOGB) (33.46N, 80.85W)	27/1015	992.2	27/1055	38 (2 min, 10 m)	59				
Hydrometeorological Automated Data System (HADS) Sites (NWS)									
Sunfish Mountain (SFMS1) (35.05N, 82.75W)									21.66
National Ocean Service (NOS) Sites									
Charleston (CHTS1) (32.78N, 79.92W)	27/1000	997.5	27/1006	46 (19 m)	58				
Myrtle Beach (MROS1) (33.66N, 78.92W)	27/1300	1000.7	27/1448	41 (8 min, 7 m)	52				

Location	Minimum Sea Level Pressure		Maximum Surface Wind Speed			Storm surge (ft)[c]	Storm tide (ft)[d]	Estimated Inundation (ft)[e]	Total rain (in)
	Date/ time (UTC)	Press. (mb)	Date/ time (UTC)[a]	Sustained (kt)[b]	Gust (kt)				
Public/Other									
Laurens (34.46N, 82.11W)	27/1055	979.8	27/0845	48	67				
St. Phillips Island (SSXXG) (32.30N, 80.58W	27/0854	994.2	27/0924	47					
WeatherFlow Sites									
Beaufort (XBUF) (32.34N, 80.59W)	27/0741	993.5	27/0906	42 (1 min, 10 m)	61				
Calibogue Sound (XCLB) (32.11N, 80.84W)	27/0756	991.9	27/0846	43 (1 min, 6 m)	59				
Folly Beach (XFSE) (32.64N, 79.97W)	27/0932	998	27/0757	44	58				
WeatherSTEM Sites									
Aiken (1347W) (33.57N, 81.73W)	27/0950	985.1	27/1010	42	63				
Beaufort (1190W) (32.42N, 80.69W)	27/0850	994.6	27/0820	43	56				
NWS Cooperative Observer Program (COOP) Sites									
Joscassee 8 WNW (JOCS1) (34.99N, 83.07W)									19.69
Table Rock (388472) (35.02N, 82.69W)									14.48
Remote Automated Weather Stations (RAWS)									
White Hall (COBS1) (32.68N, 80.71W)			27/0849	30	57				
North Carolina State University ECONet Sites									
Sassafras Mountain (SASS) (35.07N, 82.78W)	27/1148	974.5	27/1038	42 (1 min, 10 m)	63				
Community Collaborative Rain, Hail and Snow Network (CoCoRaHS) Sites									
Anderson 5 NW (SC-AN-50) (34.57N, 82.71W)									13.41
Edgefield 10.5 N (SC-ED-5) (33.94N, 81.96W)									13.17
McCormick 13E (SC-ED-18) (33.88N, 82.07W)									13.08
Salem 0.8 SW (SC-OC-78) (34.88N, 82.99W)									13.06

Location	Minimum Sea Level Pressure		Maximum Surface Wind Speed			Storm surge (ft)[c]	Storm tide (ft)[d]	Estimated Inundation (ft)[e]	Total rain (in)
	Date/ time (UTC)	Press. (mb)	Date/ time (UTC)[a]	Sustained (kt)[b]	Gust (kt)				
Salem 1.9 NE (SC-OC-92) (34.91N, 82.95W)									13.86
Salem 3.1 WNW (SC-OC-4) (34.91N, 83.03W)									13.22
Slater-Marietta 6.4 NW (SC-GV-81) (35.11N, 82.56W)									15.48
Sunset 4.4 ENE (SC-PC-53) (35.01N, 82.73W)									14.39
Tamassee 0.9 NW (SC-OC-95) (34.89N, 83.03W)									13.24
North Carolina									
International Civil Aviation Organization (ICAO) Sites									
Charlotte (KCLT) (35.22N, 80.94W)	27/1252	994.2	27/1052	30 (2 min, 10 m)	57				
Jefferson (KGEV) (36.43N, 81.42W)	27/1325	993.8	27/1305	34[l] (2 min, 10 m)	46[l]				
National Ocean Service (NOS) Sites									
Wrightsville Beach (JMPN7) (34.21N, 77.79W)	27/1942	1004.4	27/1718	36 (8 min, 15 m)	43				
WeatherSTEM Sites									
Charlotte (1412W) (35.20N, 80.80W)	27/1210	994.2	27/1050	36					
NWS Cooperative Observer Program (COOP) Sites									
Celo 2 S (CELN7) (35.83N, 82.18W)									26.65
Remote Automated Weather Stations (RAWS)									
Blantyre (BLAN7) (35.30N, 82.62W)									20.21
Busick (BSKN7) (35.74N, 82.22W)									30.78
Citizen Weather Observer Program Stations (CWOP)									
Banner Elk (E9464) (36.20N, 81.85W)	27/1200	990.2[l]	27/1200	50[l]	88[l]				
Southport (F6543) (33.76N, 77.95W)	27/1201	1004.4	27/1115	43[l]	50[l]				
North Carolina State University ECONet Sites									
Frying Pan Mountain (FRYI) (35.39N, 82.77W)	27/1209	975.1	27/1152	55 (1 min)	76				

Location	Minimum Sea Level Pressure		Maximum Surface Wind Speed			Storm surge (ft)[c]	Storm tide (ft)[d]	Estimated Inundation (ft)[e]	Total rain (in)
	Date/ time (UTC)	Press. (mb)	Date/ time (UTC)[a]	Sustained (kt)[b]	Gust (kt)				
Mt. Mitchell (MITC) (35.76N, 82.27W)			27/1227	70[l] (1 min, 10 m)	92[l]				
Community Collaborative Rain, Hail and Snow Network (CoCoRaHS) Sites									
Banner Elk 1 W (NC-AV-13) (36.16N, 81.89W)									22.85
Black Mountain 5.5 SE (NC-BC-115) (35.55N, 82.26W)									21.07
Boone 4 ENE (NC-WT-79) (36.22N, 81.60W)									20.19
Connestee Falls 1 SW (NC-TR-30) (35.14N, 82.74W)									29.98
Foscoe 1 WSW (NC-WT-11) (36.15N, 81.79W)									21.60
Hendersonville 5 SW (NC-HN-14) (35.28N, 82.53W)									21.70
Hendersonville 6 SSW (NC-HN-25) (35.24N, 82.50W)									20.01
Linville Falls (NC-AV-7) (35.95N, 81.95W)									21.82
Old Fort 4 NW (NC-MD-8) (35.68N, 82.21W)									21.68
Sapphire 5 SW (NC-TR-29) (35.06N, 83.01W)									20.51
Spruce Pine 7 SW (NC-ML-10) (35.84N, 82.14W)									23.31
Swannanoa 3 WNW (NC-BC-25) (35.62N, 82.43W)									20.22
Tennessee									
International Civil Aviation Organization (ICAO) Sites									
Alcoa (KTYS) (35.82N, 83.99W)	27/1400	980.9	27/1725	33 (2 min, 10 m)	43				
Hydrometeorological Automated Data System (HADS) Sites (NWS)									
Embreeville (EMBT1) (36.18N, 82.46W)									12.43
Trade (TRAT1) (36.35N, 81.73W)									10.98

Location	Minimum Sea Level Pressure		Maximum Surface Wind Speed			Storm surge (ft)[c]	Storm tide (ft)[d]	Estimated Inundation (ft)[e]	Total rain (in)
	Date/ time (UTC)	Press. (mb)	Date/ time (UTC)[a]	Sustained (kt)[b]	Gust (kt)				
NWS Cooperative Observer Program (COOP) Sites									
Mt. Leconte (406328) (35.66N, 83.44W)									10.20
Remote Automated Weather Stations (RAWS)									
Unicoi (UNIT1) (36.20N, 82.39W)			27/1516	20 (6 m)	52				
Virginia									
International Civil Aviation Organization (ICAO) Sites									
Abingdon (KVJI) (36.68N, 82.03W)	27/1455	986.6	27/1315	34 (2 min, 10 m)	43				
Hillsville (KHLX) (36.77N, 80.82W)	27/1515	995.1	27/1455	32[I] (2 min, 10 m)	55[I]				
Hydrometeorological Automated Data System (HADS) Sites (NWS)									
Troutdale 4 S (TRTV2) (36.62N, 81.38W)									10.75
Public/Other									
Grayson Highlands (DY006) (36.64N, 81.52W)	27/1420	994.9	27/1220	30	57				
Citizen Weather Observer Program Stations (CWOP)									
Tazewell (F0183) (37.10N, 81.34W)	27/1630	993.9	27/1530	36	56				
Community Collaborative Rain, Hail and Snow Network (CoCoRaHS) Sites									
Fries 7 WSW (VA-GR-4) (36.70N, 81.10W)									10.81
Galax 5.3 SW (VA-GR-6) (36.61N, 80.99W)									10.89
Marion 2.4 ENE (VA-SM-4) (36.85N, 81.47W)									10.78
West Virginia									
International Civil Aviation Organization (ICAO) Sites									
Bluefield (KBLF) (37.30N, 81.21W)									6.11
Huntington (KHTS) (38.37N, 82.56W)	27/1735	988.0	27/1700	32 (2 min, 10 m)	61				
Public/Other									
Lockbridge (37.83N, 80.85W)					57				

Location	Minimum Sea Level Pressure		Maximum Surface Wind Speed			Storm surge (ft)[c]	Storm tide (ft)[d]	Estimated Inundation (ft)[e]	Total rain (in)
	Date/ time (UTC)	Press. (mb)	Date/ time (UTC)[a]	Sustained (kt)[b]	Gust (kt)				
Community Collaborative Rain, Hail and Snow Network (CoCoRaHS) Sites									
Bluefield 5 NNW (WV-MC-15) (37.32N, 81.27W)									6.68
Kentucky									
International Civil Aviation Organization (ICAO) Sites									
Hebron (KCVG) (39.04N, 84.67W)	27/2100	989.7	27/2000	35 (2 min, 10 m)	54				
Lexington (KLEX) (38.03N, 84.61W)	27/1930	986.0	27/1700	39 (2 min, 10 m)	56				
WeatherSTEM Sites									
Bowling Green (0683W) (36.99N, 86.45W)	27/2040	985.4	27/2130	34	39				
Community Collaborative Rain, Hail and Snow Network (CoCoRaHS) Sites									
Greenup 6 W (KY-GP-6) (38.58N, 82.93)									6.55
Henderson 0.4 SSW (KY-HS-1) (37.83N, 87.58W)									7.67
Ohio									
International Civil Aviation Organization (ICAO) Sites									
Cincinnati (KLUK) (39.11N, 84.42W)	27/2000	989.8	27/1930	31 (2 min, 10 m)	56				
Dayton (KFFO) (39.83N, 84.05W)	27/2035	994.9	27/2124	35 (2 min, 10 m)	49				
Springboro (KMGY) (39.59N, 84.22W)	27/2012	992.6	27/2012	35 (2 min, 10 m)	54				
Springfield (KSGH) (39.84N, 83.84W)	27/2110	995.3	27/2130	36 (2 min, 10 m)	50				
Wilmington (KILN) (39.43N, 83.78W)	27/1950	990.5	27/1935	38[l] (2 min, 10 m)	59[l]				
NWS Cooperative Observer Program (COOP) Sites									
Piketon (336630) (39.07N, 83.02W)									7.92
Community Collaborative Rain, Hail and Snow Network (CoCoRaHS) Sites									
Rosemount 0.3 W (OH-SC-4) (38.79N, 82.98W)									8.51
Indiana									
International Civil Aviation Organization (ICAO) Sites									
Columbus (KBAK) (39.27N, 85.90W)	27/2245	990.2	27/2045	35 (2 min, 10 m)	50				

Location	Minimum Sea Level Pressure		Maximum Surface Wind Speed			Storm surge (ft)[c]	Storm tide (ft)[d]	Estimated Inundation (ft)[e]	Total rain (in)
	Date/ time (UTC)	Press. (mb)	Date/ time (UTC)[a]	Sustained (kt)[b]	Gust (kt)				
Indianapolis (KIND) (39.73N, 86.28W)	27/2320	993.2	27/2245	41 (2 min, 10 m)	59				
New Castle (KUWL) (39.88N, 85.33W)	27/2215	995.3	27/2155	36 (2 min, 10 m)	46				
Community Collaborative Rain, Hail and Snow Network (CoCoRaHS) Sites									
Evansville 9 WSW (IN-VN-37) (37.93N, 87.69W)									5.19
Henryville 2.6 E (IN-CK-35) (38.54N, 85.72W)									5.69
Illinois									
International Civil Aviation Organization (ICAO) Sites									
Lawrenceville (KLWV) (38.76N, 87.60W)	28/0105	989.8	27/2335	33 (2 min, 10 m)	50				
Mattoon (KMTO) (39.48N, 88.28W)	28/0050	996.8	28/0200	37 (2 min, 10 m)	57				
Hydrometeorological Automated Data System (HADS) Sites (NWS)									
Cairo (CIRI2) (37.00N, 88.16W)									6.91
NWS Cooperative Observer Program (COOP) Sites									
Ft. Massac St Park (113120) (37.14N, 88.71W)									7.47
Alabama									
International Civil Aviation Organization (ICAO) Sites									
Auburn (KAUO) (32.62N, 85.43W)									7.13
Citizen Weather Observer Program Stations (CWOP)									
Huntsville (AR191) (34.74N, 86.53W)			28/0338	28	37				
Community Collaborative Rain, Hail and Snow Network (CoCoRaHS) Sites									
Eufaula 7 S (AL-BR-7) (31.81N, 85.17W)									7.28
Pansey 2 NNE (AL-HS-23) (31.18N, 85.17W)									8.50

[a] Date/time is for sustained wind when both sustained and gust are listed.
[b] Except as noted, sustained wind averaging periods for C-MAN and land-based reports are 2 min; buoy averaging periods are 8 min.
[c] Storm surge is water height above normal astronomical tide level.

[d] For most locations, storm tide is water height above the North American Vertical Datum of 1988 (NAVD88). Storm tide is water height above Mean Lower Low Water (MLLW) for NOS stations in Puerto Rico, the U.S. Virgin Islands, and Barbados.

[e] Estimated inundation is the maximum height of water above ground. For some USGS storm tide pressure sensors, inundation is estimated by subtracting the elevation of the sensor from the recorded storm tide. For other USGS storm tide sensors and USGS high-water marks, inundation is estimated by subtracting the elevation of the land derived from a Digital Elevation Model (DEM) from the recorded and measured storm tide. For NOS tide gauges, the height of the water above Mean Higher High Water (MHHW) is used as a proxy for inundation.

I Incomplete Data

Table 4. For Hurricane Helene, 24–27 September 2024, the number of hours in advance of formation associated with the first NHC Tropical Weather Outlook forecast in the indicated likelihood category. Note that the timings for the “Low” category do not include forecasts of a 0% chance of genesis.

	Hours Before Genesis	
	48-Hour Outlook	**168-Hour Outlook**
Low (<40%)	48	156
Medium (40%-60%)	42	126
High (>60%)	30	60

Table 5a. NHC official (OFCL) and climatology-persistence skill baseline (OCD5) track forecast errors (n mi) for Hurricane Helene, 24–27 September 2024. Mean errors for the previous 5-yr period are shown for comparison. Official errors that are smaller than the 5-yr means are shown in boldface type.

	Forecast Period (h)							
	12	24	36	48	60	72	96	120
OFCL	**22.8**	40.6	52.4	**59.9**	**55.5**	**45.9**		
OCD5	62.6	157.9	267.4	432.6	581.1	630.2		
Forecasts	11	9	7	5	3	1		
OFCL (2019-23)	23.9	36.5	49.3	63.4	79.2	93.4	132.9	190.4
OCD5 (2019-23)	45.7	97.1	153.0	205.4	254.9	297.8	372.7	439.1

Table 5b. Homogeneous comparison of selected track forecast guidance models (in n mi) for Hurricane Helene, 24–27 September 2024. Errors smaller than the NHC official forecast are shown in boldface type. The number of official forecasts shown here will generally be smaller than that shown in Table 5a due to the homogeneity requirement.

Model ID	Forecast Period (h)							
	12	24	36	48	60	72	96	120
OFCL	24.3	43.3	57.4	68.8	64.4	45.9		
OCD5	66.5	165.3	281.4	448.5	555.4	630.2		
GFSI	**21.3**	**39.7**	**56.3**	71.9	73.1	**16.0**		
HWFI	31.5	55.6	88.2	110.5	98.8	**38.1**		
HMNI	33.2	56.5	67.6	86.3	80.9	99.6		
HFAI	30.7	48.7	60.7	69.8	**63.1**	66.2		
HFBI	**22.9**	**37.8**	**56.0**	78.4	73.6	60.2		
EGRI	27.2	**43.2**	**44.7**	**47.5**	81.9	162.8		
EMXI	27.5	**41.3**	**43.3**	**52.5**	**46.1**	56.0		
CMCI	31.5	55.7	69.3	**68.5**	**53.1**	49.8		
CTCI	**23.9**	**37.9**	**39.7**	**67.9**	101.5	158.8		
TVCA	25.0	**41.8**	**52.1**	**62.8**	**60.1**	65.6		
TVCX	25.1	**42.5**	**51.3**	**62.8**	**58.3**	57.8		
GFEX	**24.0**	**39.2**	**45.6**	**57.5**	**53.9**	**30.0**		
TVDG	25.0	**41.9**	**50.1**	**61.3**	**56.6**	62.4		
HCCA	25.7	45.0	**56.0**	**66.9**	**54.5**	**30.4**		
FSSE	**22.3**	**37.7**	**48.7**	**57.6**	**45.7**	53.6		
AEMI	24.6	**40.6**	58.1	81.3	85.8	48.0		
TABS	47.8	68.7	74.0	85.9	93.0	170.6		
TABM	38.2	55.6	61.6	79.6	94.6	140.2		
TABD	33.3	50.0	76.0	122.2	152.1	108.1		
Forecasts	10	8	6	4	2	1		

Table 6a. NHC official (OFCL) and climatology-persistence skill baseline (OCD5) intensity forecast errors (kt) for Hurricane Helene, 24–27 September 2024. Means errors for the previous 5-yr period are shown for comparison. Official errors that are smaller than the 5-yr means are shown in boldface type.

	Forecast Period (h)							
	12	24	36	48	60	72	96	120
OFCL	7.7	8.3	**6.4**	11.0	18.3	**0.0**		
OCD5	11.9	19.9	30.7	40.0	31.0	24.0		
Forecasts	11	9	7	5	3	1		
OFCL (2019-23)	5.0	7.3	8.5	9.7	10.4	10.9	12.9	15.5
OCD5 (2019-23)	6.6	10.2	13.1	15.6	17.2	18.6	21.8	22.6

Table 6b. Homogeneous comparison of selected intensity forecast guidance models (in kt) for Hurricane Helene, 24–27 September 2024. Errors smaller than the NHC official forecast are shown in boldface type. The number of official forecasts shown here will generally be smaller than that shown in Table 6a due to the homogeneity requirement.

Model ID	Forecast Period (h)							
	12	24	36	48	60	72	96	120
OFCL	8.5	8.8	6.7	12.5	17.5	0.0		
OCD5	12.6	19.1	29.8	34.5	28.5	24.0		
HWFI	12.0	8.9	12.5	21.2	23.0	4.0		
HMNI	12.3	10.2	12.8	14.0	17.5	5.0		
HFAI	13.3	11.5	11.0	16.2	**9.5**	9.0		
HFBI	12.7	12.5	8.0	25.2	**3.5**	8.0		
DSHP	10.3	13.4	9.7	**8.8**	20.5	3.0		
LGEM	9.9	10.4	8.2	**7.5**	**15.5**	3.0		
ICON	10.8	10.4	9.7	12.8	19.0	4.0		
IVCN	10.9	9.9	9.3	15.0	**15.5**	5.0		
IVDR	11.4	9.4	9.5	16.2	**16.5**	5.0		
CTCI	11.0	10.9	12.5	12.8	19.0	3.0		
GFSI	15.7	13.8	19.8	25.0	29.5	7.0		
EMXI	15.4	20.4	28.0	32.5	39.0	8.0		
HCCA	10.7	11.4	12.0	15.2	**14.0**	7.0		
FSSE	11.6	13.4	10.5	**11.5**	**14.0**	5.0		
Forecasts	10	8	6	4	2	1		

Table 7. Coastal wind watch and warning summary for Hurricane Helene, 24–27 September 2024.

Date/Time (UTC)	Action	Location
23 / 1500	Tropical Storm Warning issued	Tulum to Rio Lagartos, Mexico
23 / 1500	Tropical Storm Warning issued	Cuban provinces of Artemisa, Pinar del Rio and Isle of Youth
23 / 1500	Hurricane Watch issued	Tulum to Cabo Catoche, Mexico
23 / 1500	Hurricane Watch issued	Pinar del Rio, Cuba
23 / 2100	Tropical Storm Watch issued	Florida Keys from Dry Tortugas to Seven Mile Bridge
24 / 0000	Tropical Storm Warning issued	Grand Cayman
24 / 0300	Tropical Storm Watch issued	Bonita Beach to Flamingo, FL
24 / 0900	Hurricane Watch issued	Indian Pass to Englewood, FL
24 / 0900	Tropical Storm Watch issued	Walton/Bay County line to Indian Pass, FL
24 / 0900	Tropical Storm Watch modified to	Englewood to Flamingo, FL
24 / 1500	Tropical Storm Watch changed to Tropical Storm Warning	Dry Tortugas to Seven Mile Bridge, FL
24 / 1500	Tropical Storm Watch issued	Seven Mile Bridge to Channel 5 Bridge, FL
24 / 1800	Tropical Storm Warning discontinued	Grand Cayman
24 / 2100	Hurricane Watch changed to Hurricane Warning	Tulum to Cabo Catoche, Mexico
24 / 2100	Hurricane Warning issued	Mexico Beach to Anclote River, FL
24 / 2100	Tropical Storm Warning modified to	Dry Tortugas to Channel 5 Bridge, FL
24 / 2100	Tropical Storm Warning issued	Anclote River to Flamingo, FL
24 / 2100	Tropical Storm Warning issued	Walton / Bay County Line to Mexico Beach, FL
24 / 2100	Tropical Storm Watch issued	Palm Beach / Martin County Line, FL to Savannah River
25 / 0300	Tropical Storm Warning issued	Palm Beach / Martin County Line to Flagler / Volusia County Line, FL

Date/Time (UTC)	Action	Location
25 / 0300	Tropical Storm Warning issued	Lake Okeechobee, FL
25 / 0900	Tropical Storm Warning modified to	Anclote River, FL to FL / GA border
25 / 0900	Tropical Storm Watch modified to	FL / GA border to South Santee River, SC
25 / 1200	Tropical Storm Warning modified to	Anclote River, FL to Altamaha Sound, GA
25 / 1500	Tropical Storm Warning modified to	Okaloosa / Walton County Line to Mexico Beach, FL
25 / 1500	Tropical Storm Warning modified to	Anclote River, FL to South Santee River, SC
25 / 1500	Tropical Storm Watch issued	South Santee River to SC / NC border
25 / 2100	Tropical Storm Warning modified to	Anclote River, FL to SC / NC border
26 / 0300	All Warnings discontinued	Mexico
26 / 0300	Hurricane Watch discontinued	Pinar del Rio, Cuba
26 / 1800	Tropical Storm Warning discontinued	Cuba
27 / 0600	Tropical Storm Warning discontinued	Florida Keys and Dry Tortugas
27 / 0900	Hurricane Warning discontinued	All
27 / 0900	Hurricane Watch discontinued	All
27 / 0900	Tropical Storm Warning discontinued	Okaloosa / Walton County Line to Mexico Beach, FL
27 / 0900	Tropical Storm Warning discontinued	Suwannee River to Flagler / Volusia County Line, FL
27 / 0900	Tropical Storm Warning discontinued	Lake Okeechobee, FL
27 / 1200	Tropical Storm Warning discontinued	Indian Pass to Suwannee River, FL
27 / 1200	Tropical Storm Warning discontinued	Flagler / Volusia County Line, FL to Altamaha Sound, GA
27 / 1500	Tropical Storm Warning discontinued	Altamaha Sound, GA to Savannah River
27 / 1800	Tropical Storm Warning discontinued	All

Table 8. Storm Surge watch and warning summary for Hurricane Helene, 24–27 September 2024.

Date/Time (UTC)	Action	Location
24 / 0300	Storm Surge Watch issued	Bonita Beach to Flamingo, FL
24 / 0900	Storm Surge Watch issued	Indian Pass to Bonita Beach, FL, including Charlotte Harbor and Tampa Bay
24 / 2100	Storm Surge Warning issued	Indian Pass to Flamingo, FL, including Charlotte Harbor and Tampa Bay
25 / 1500	Storm Surge Watch issued	west of Indian Pass to Mexico Beach, FL
25 / 2100	Storm Surge Warning issued	west of Indian Pass to Mexico Beach, FL
27 / 0900	Storm Surge Warning discontinued	west of Indian Pass to Mexico Beach, FL
27 / 0900	Storm Surge Warning discontinued	south of Bonita Beach to Flamingo, FL
27 / 1200	Storm Surge Warning discontinued	middle of Longboat Key to Bonita Beach, FL, including Charlotte Harbor
27 / 1500	Storm Surge Warning discontinued	all

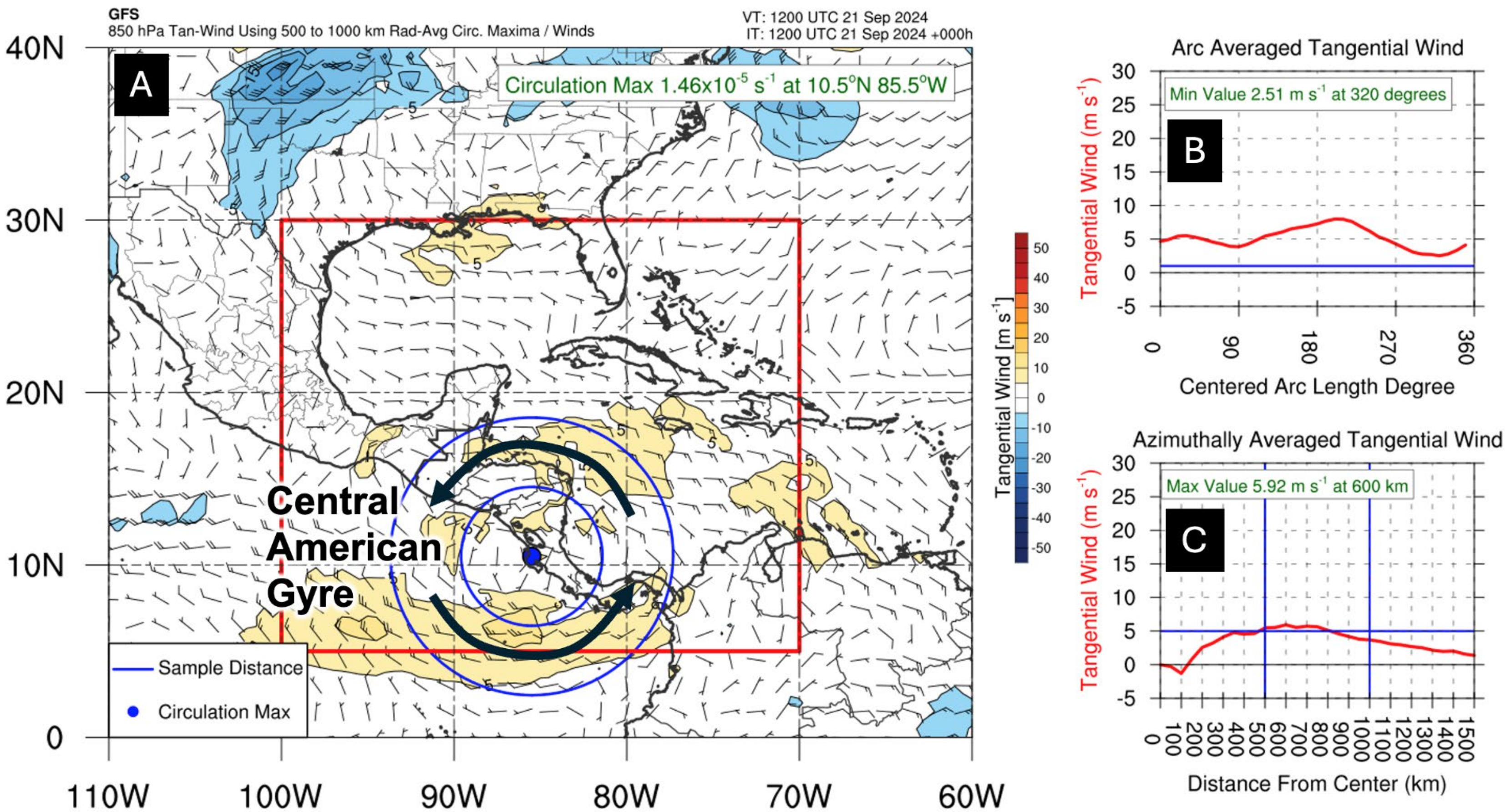

Figure 1. Central American Gyre (CAG) diagnostic plots for the pre-Helene disturbance valid at 1200 UTC 21 September. Panel (a) shows 850 mb tangential wind (shaded, m s^{-1}), and earth relative 850 mb wind (barbs, kt). Tangential wind is calculated based on the large-scale (500–1000 km averaged) circulation max (location denoted by blue dot). Larger blue circles denote the radii of 500 and 1000 km from the circulation max. Panel (b) depicts a line plot of the arc averaged 850 mb tangential wind (red line, m s^{-1}) at all location segments (in degrees) around the circulation max of the CAG candidate. Panel (c) depicts a line plot of 850 mb azimuthally averaged tangential wind (red line, m s^{-1}) extending out in distance from the circulation max of the CAG candidate. For more information on how these criteria verify the presence of a CAG see http://www.pppapin.com/README_CAGs.pdf

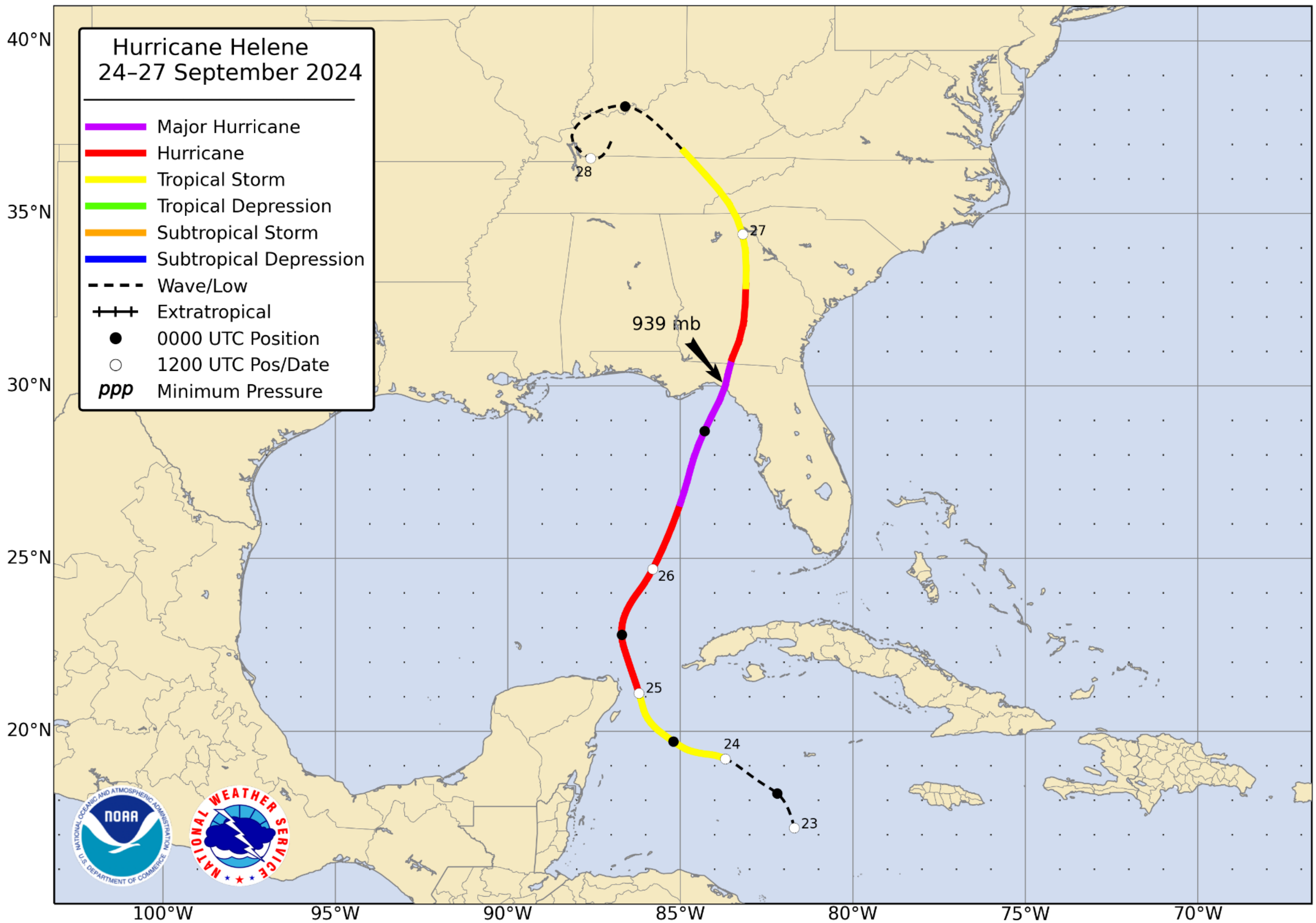

Figure 2. Best track positions for Hurricane Helene, 24–27 September 2024. Tracks over the United States and during the post-tropical stage are partially based on analyses from the NOAA Weather Prediction Center.

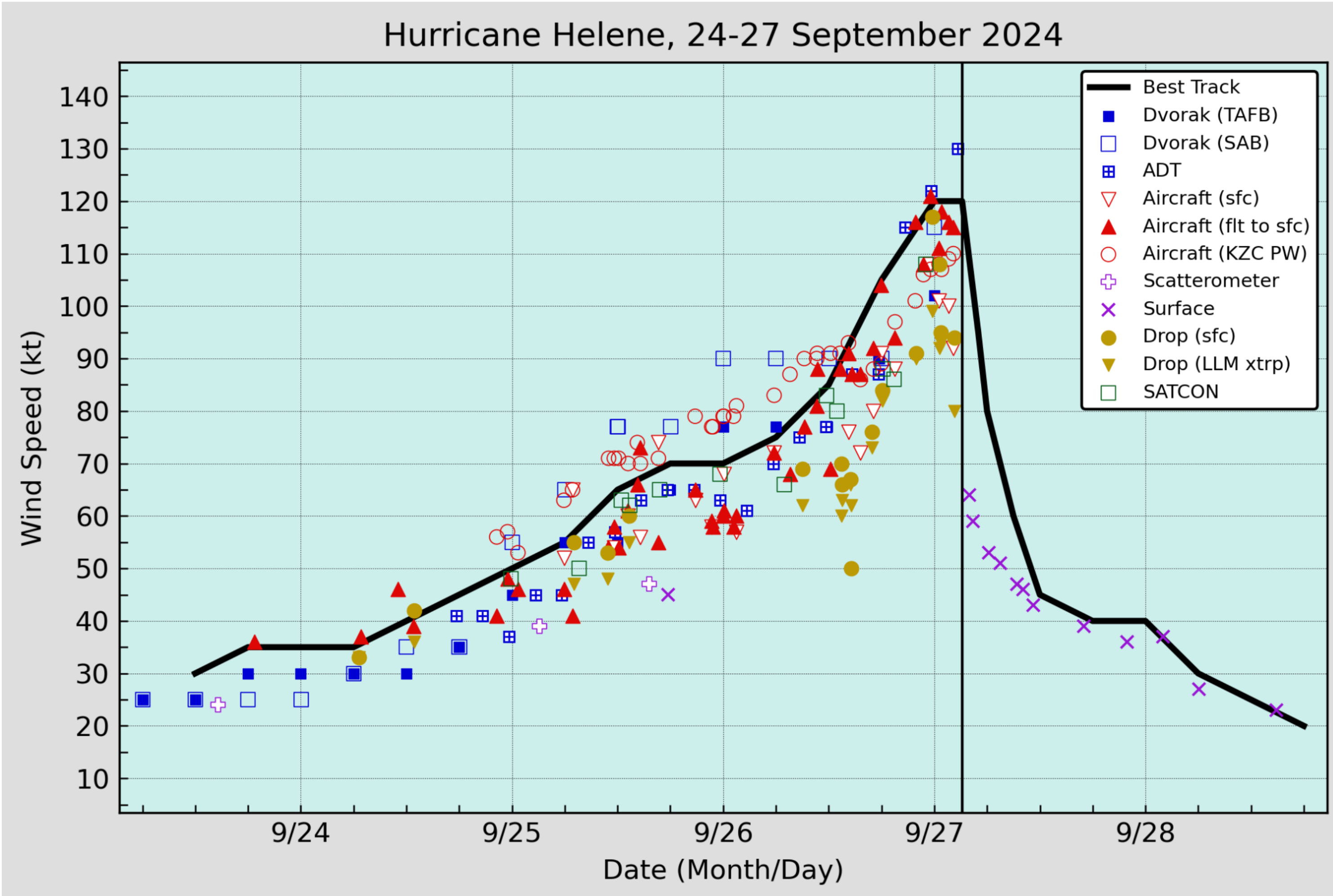

Figure 3. Selected wind observations and best track maximum sustained surface wind speed curve for Hurricane Helene, 24–27 September 2024. Aircraft observations have been adjusted for elevation using 90%, 80%, and 75% adjustment factors for observations from 700 mb, 850 mb, and 925 mb, respectively. Dropwindsonde observations include actual 10 m winds (sfc), as well as surface estimates derived from the mean wind over the lowest 150 m of the wind sounding (LLM). Advanced Dvorak Technique estimates represent the Current Intensity at the nominal observation time. SATCON intensity estimates are from the Cooperative Institute for Meteorological Satellite Studies. Dashed vertical lines correspond to 0000 UTC, and solid vertical lines correspond to landfalls.

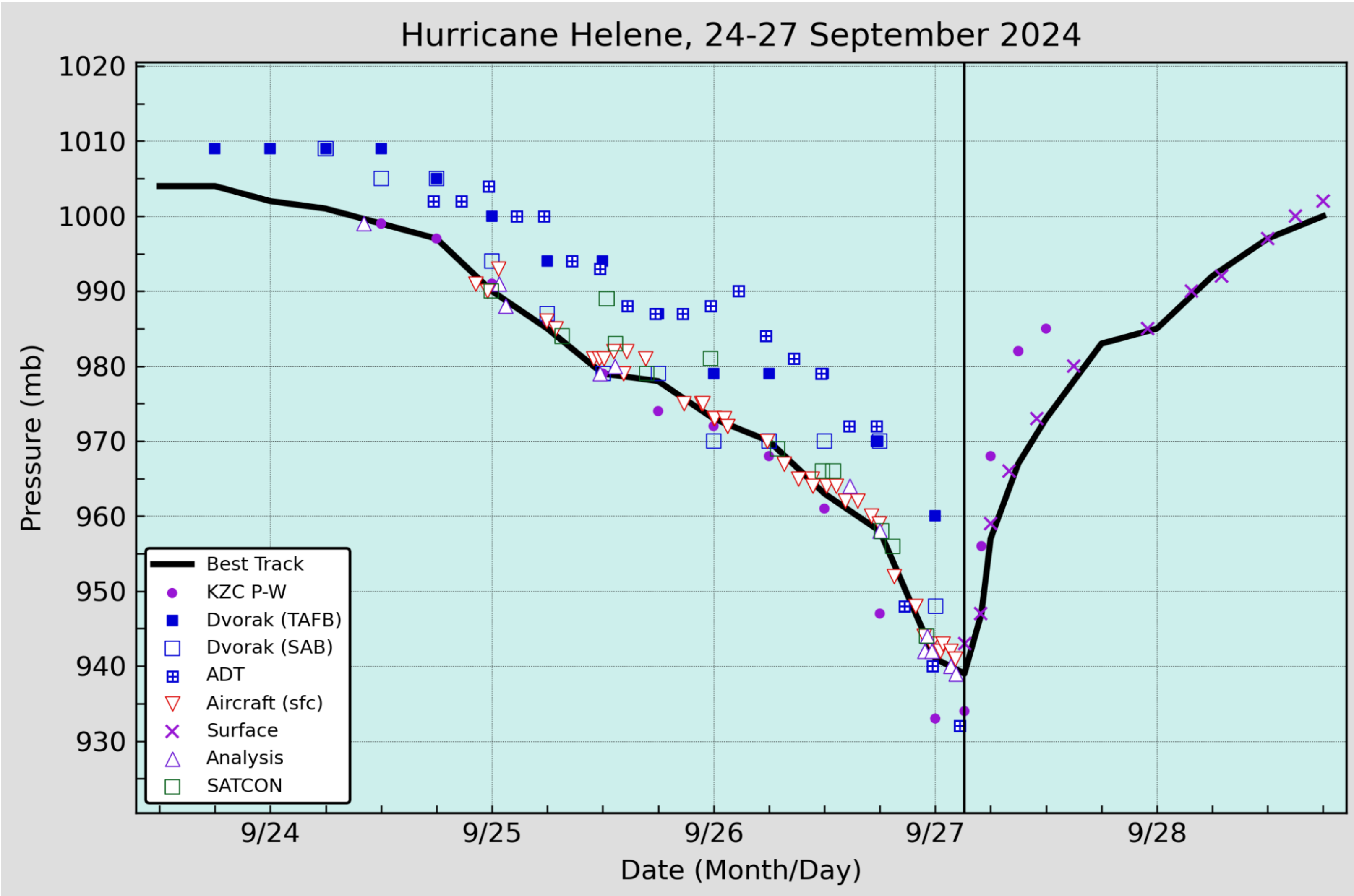

Figure 4. Selected pressure observations and best track minimum central pressure curve for Hurricane Helene, 24–27 September 2024. Advanced Dvorak Technique estimates represent the Current Intensity at the nominal observation time. SATCON intensity estimates are from the Cooperative Institute for Meteorological Satellite Studies. KZC P-W refers to pressure estimates derived using the Knaff-Zehr-Courtney pressure-wind relationship. Dashed vertical lines correspond to 0000 UTC, and solid vertical lines correspond to landfalls.

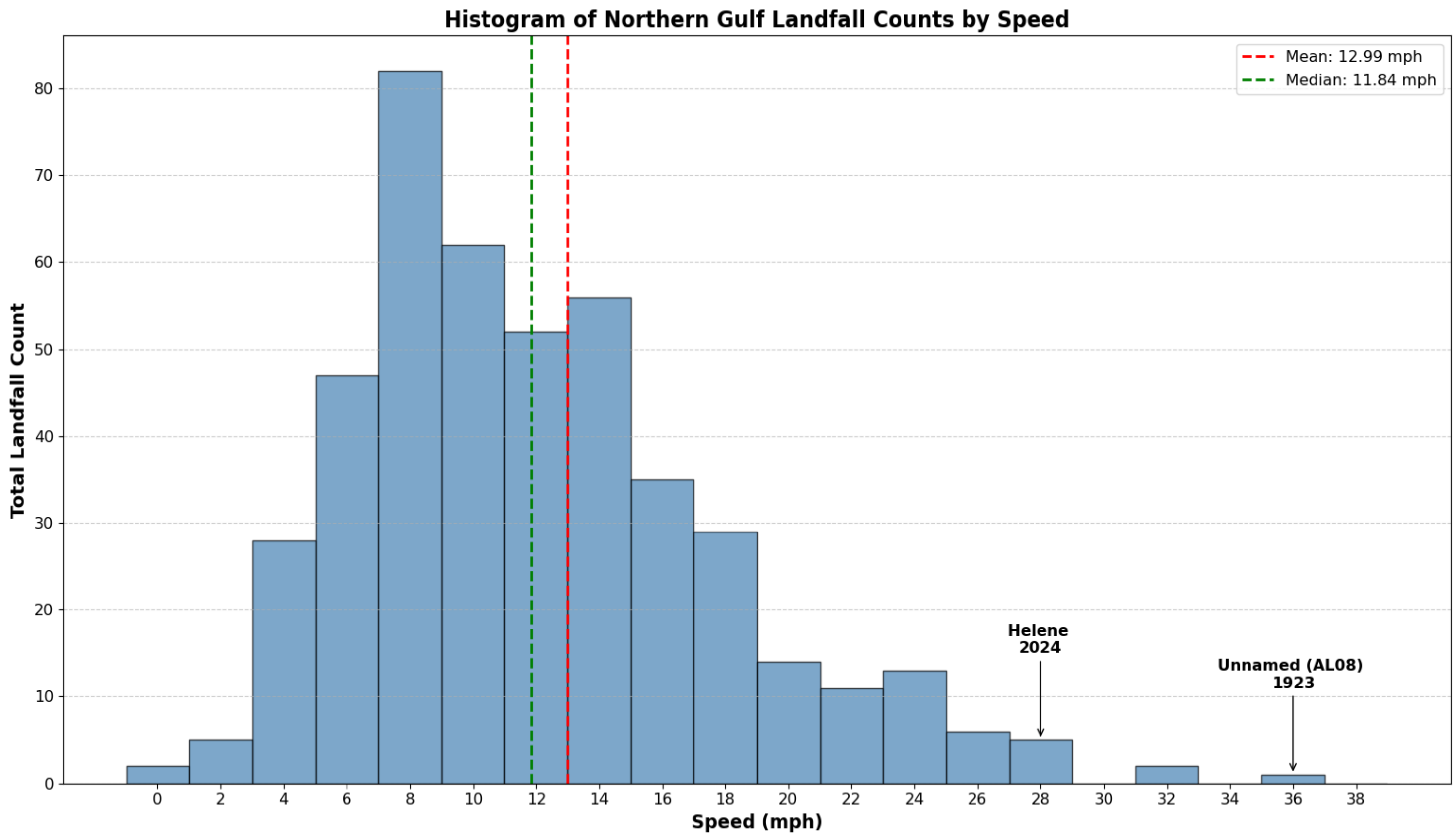

Figure 5. Histogram of tropical cyclone forward speed (mph) at landfall averaged over the 12-h period leading up to landfall for storms making landfall along the coast of the northern half (north of 24°N) of the Gulf of America (1851-2023).

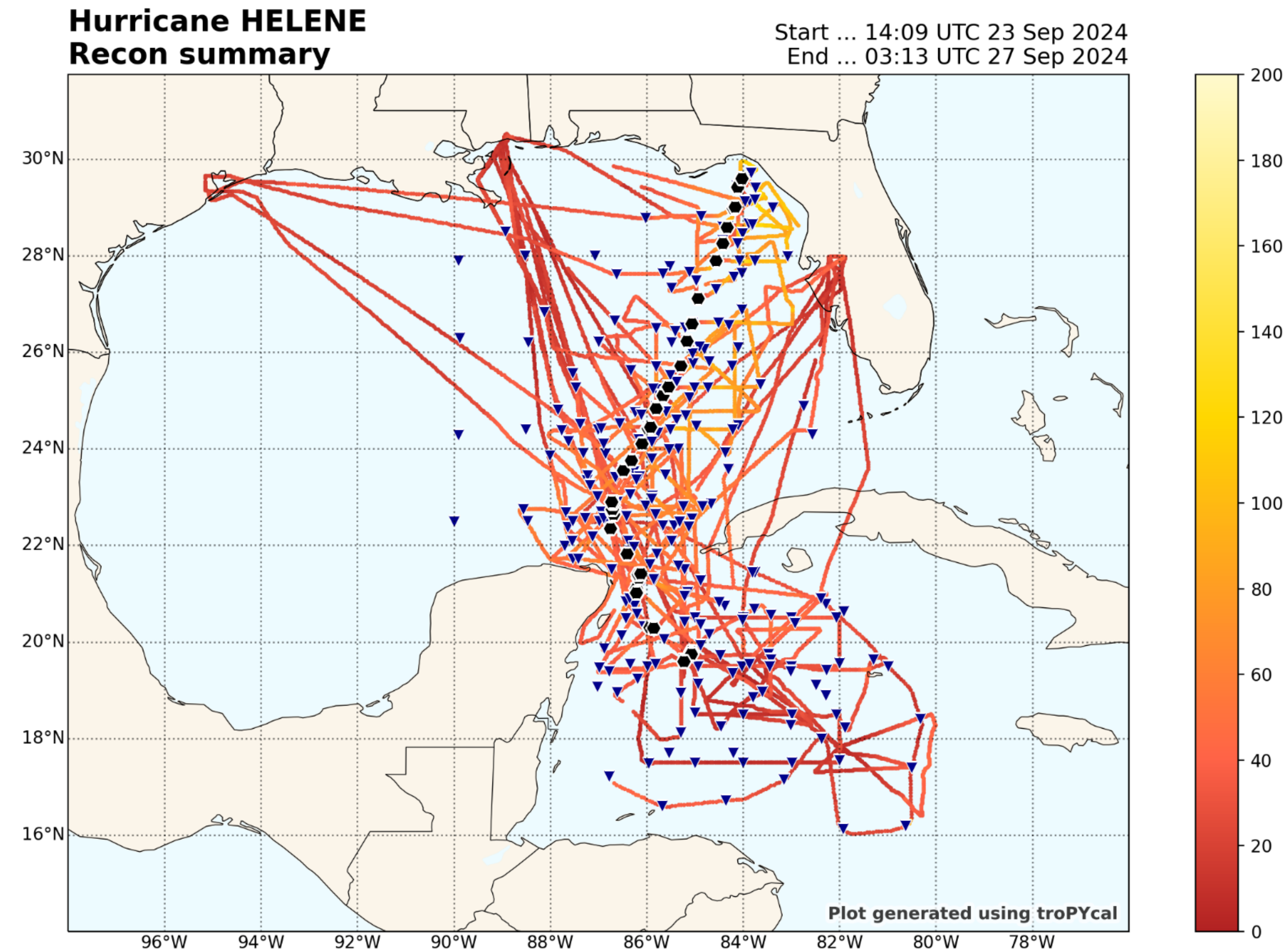

Figure 6. Air Force Reserve and NOAA Hurricane Hunter aircraft flight tracks (red) from reconnaissance missions into Helene. The black markers denote center fixes, and the blue triangles indicate dropsonde locations. The color coding of the flight tracks is based on the observed flight-level wind speed with the color legend to the right of the map representing the color associated with the various wind speeds in knots. Dropsondes with no flight tracks are from the NOAA G-IV aircraft.

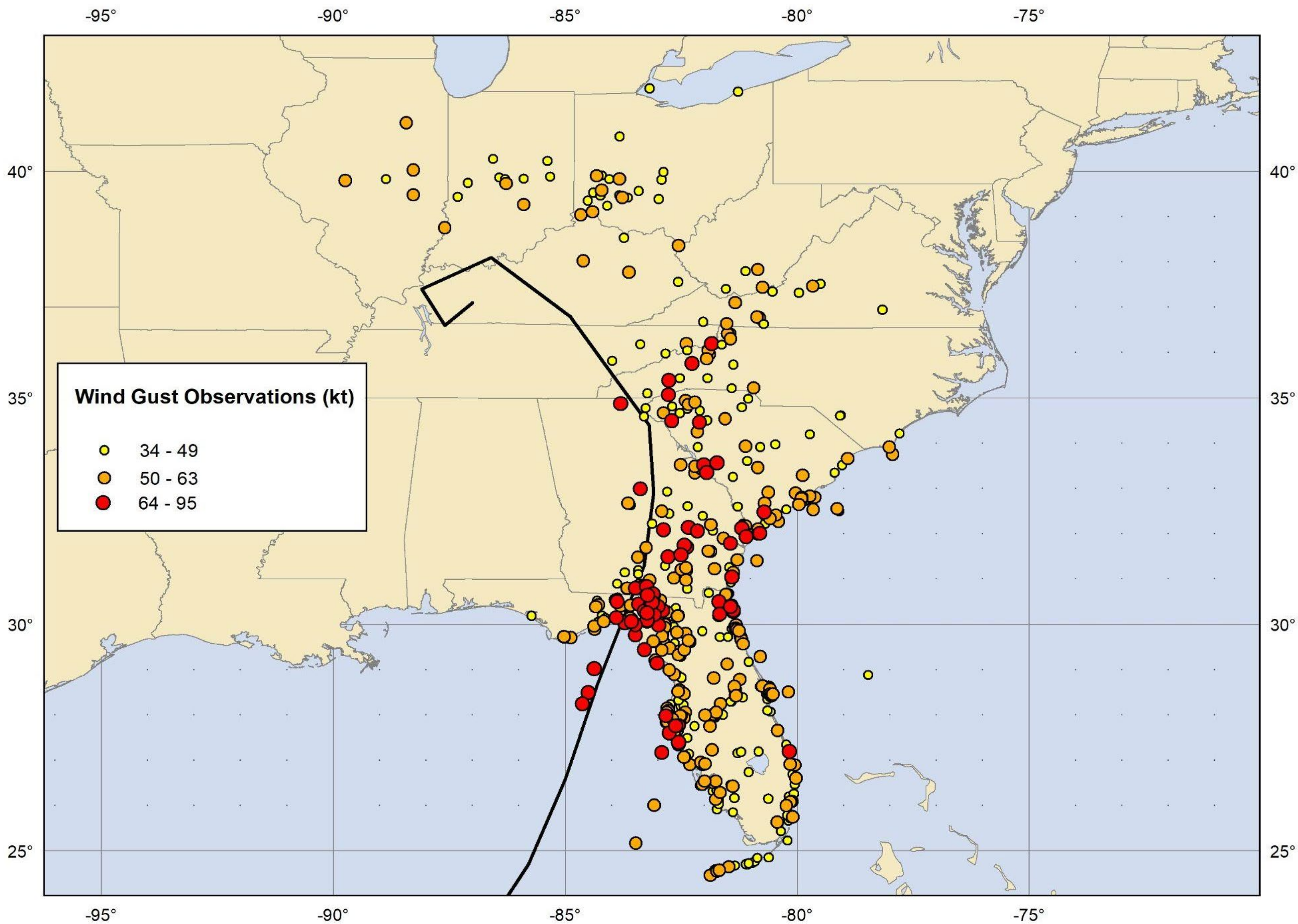

Figure 7. Selected surface or near-surface wind gust observations (kt) associated with Hurricane Helene, 24–27 September 2024. A large number of sites, especially over Georgia and South Carolina, stopped reporting before the peak winds arrived.

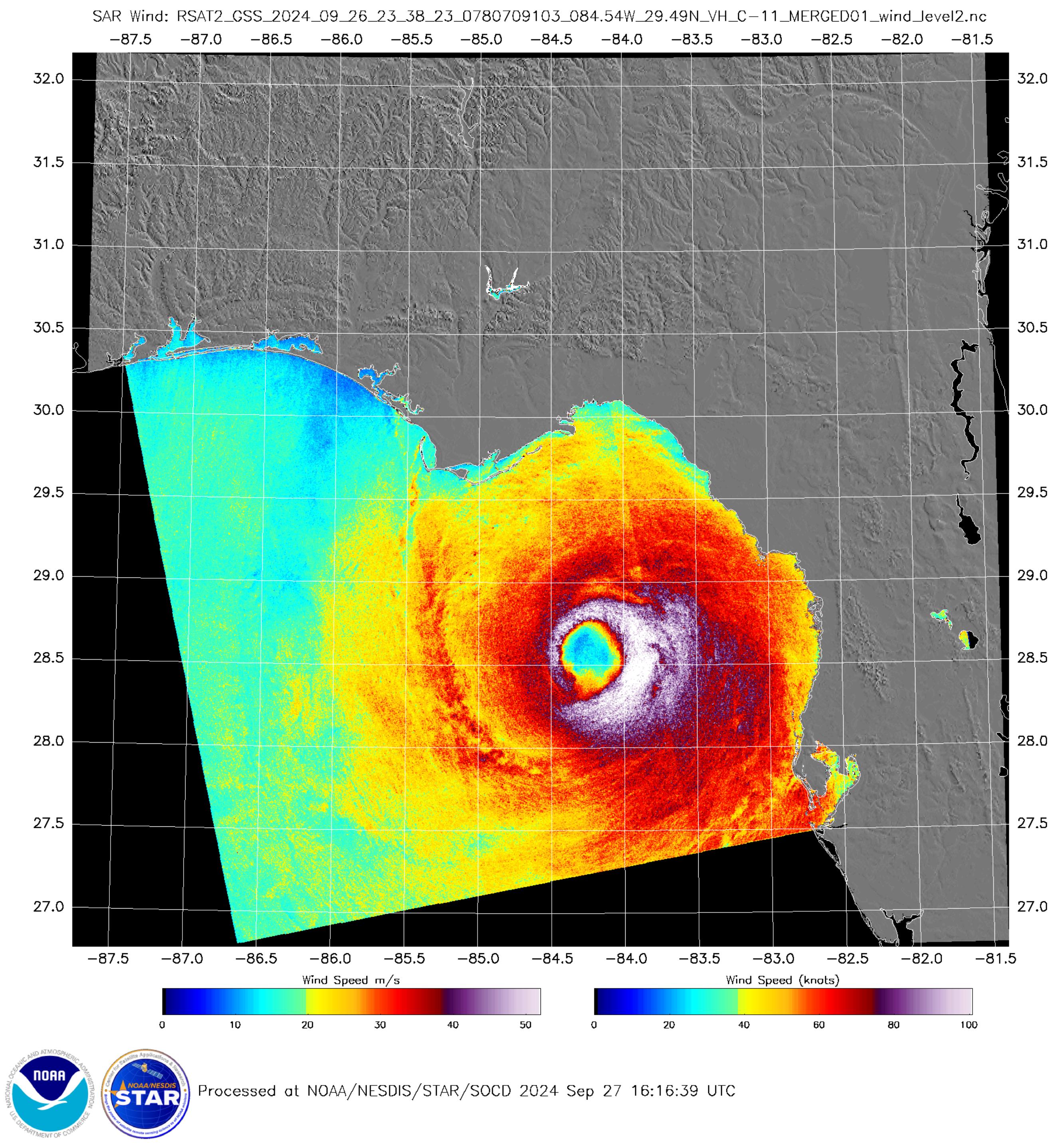

Figure 8. Synthetic aperture radar image showing the estimated surface wind field in Hurricane Helene over the northeastern Gulf. Data is from the Canadian RADARSAT-2 valid at 2338 UTC 26 September 2024.

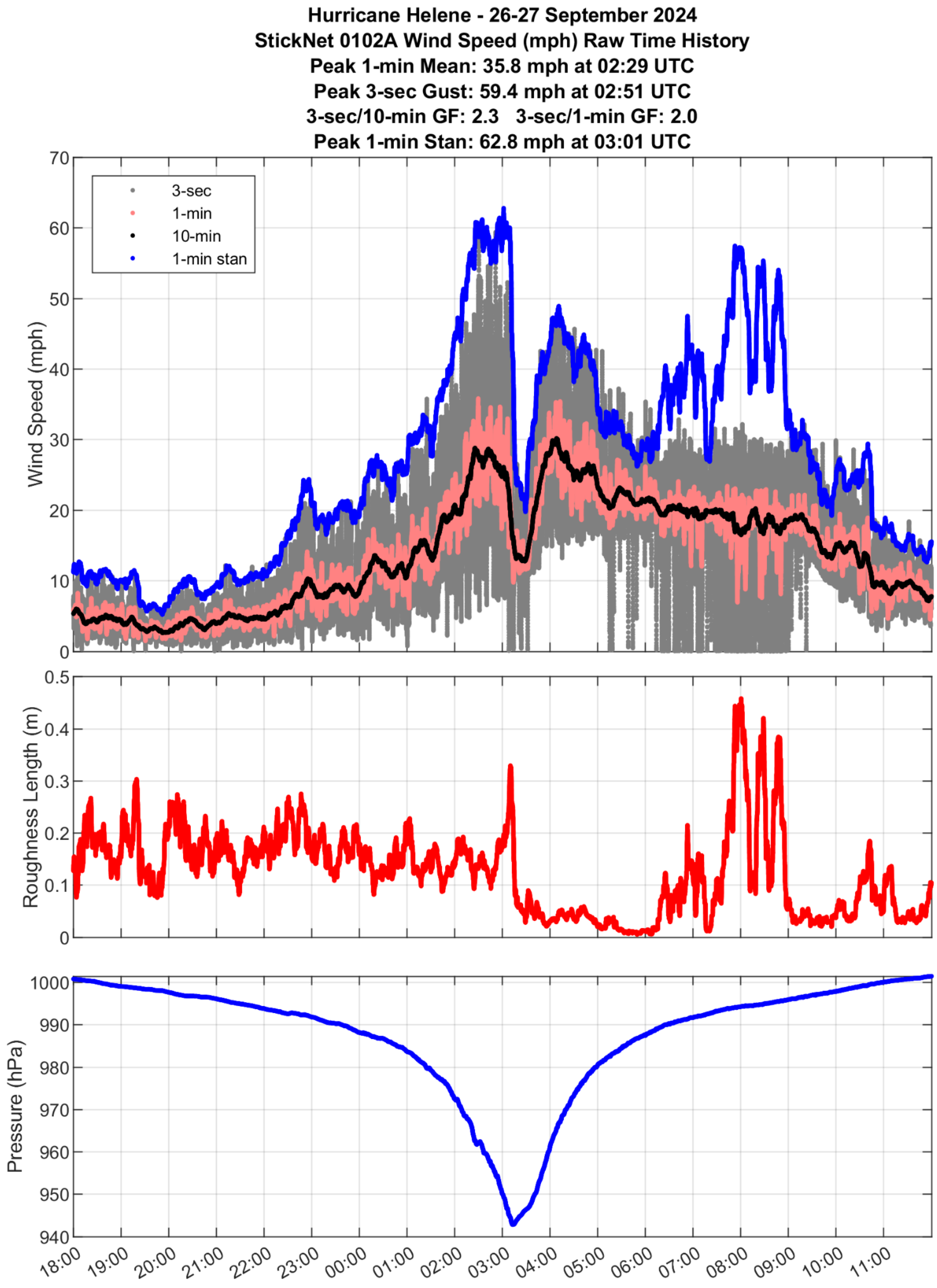

Figure 9. Pressure and wind traces from Texas Tech StickNet observation site 102 placed near Hampton Springs, FL between 1800 UTC 26 September and 1200 UTC 27 September. The grey dots are raw 3-sec gusts, 1-min moving mean (pink dots), and 10-min moving mean (black dots). A local roughness length time history was constructed based on the turbulence intensity derived from the raw 10-Hz measurements. This roughness length was used to standardize the wind speed to 10 m, 1-min, open exposure (roughness length = 0.03 m) as shown by the blue dots in the wind speed trace. Credit: Texas Tech University Hurricane Research Team.

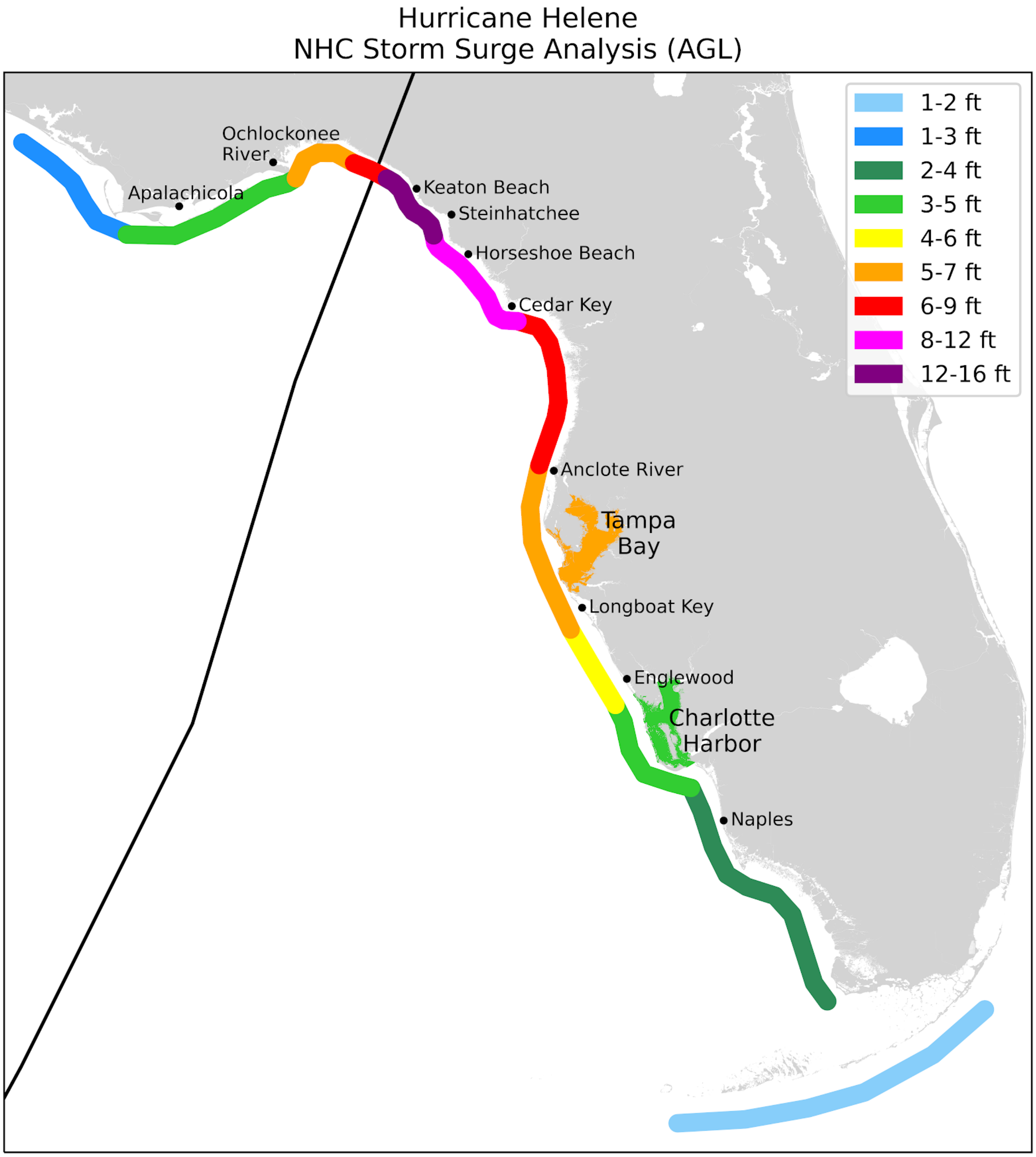

Figure 10. Analyzed storm surge inundation (feet above ground level) along the coast of Florida from Hurricane Helene. Helene's track is overlaid (black line).

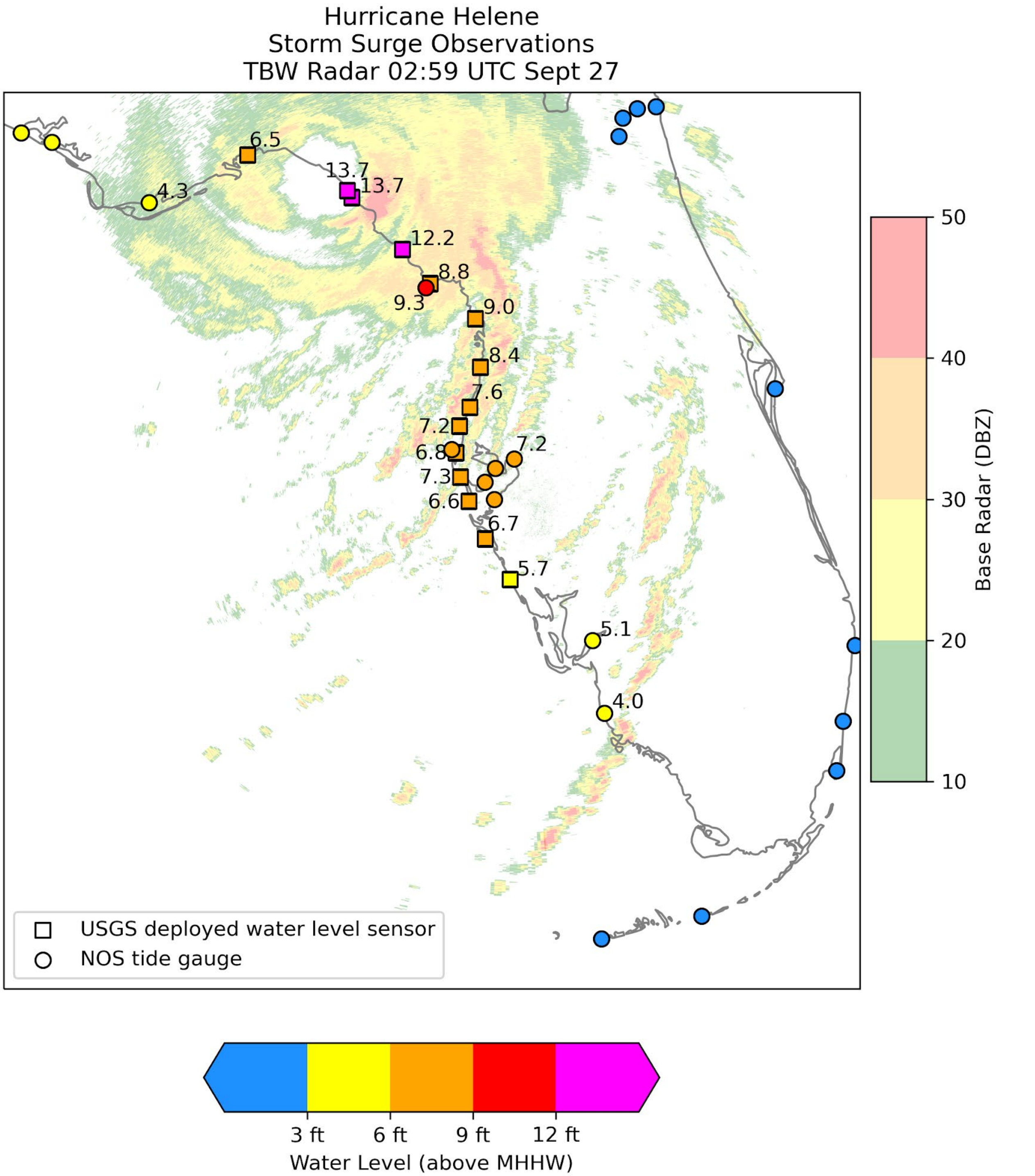

Figure 11. Maximum water levels (ft above MHHW) during Hurricane Helene measured by the NOS tide gauge network and deployed USGS water level sensors, overlaid with TBW radar reflectivity at 0259 UTC 27 September.

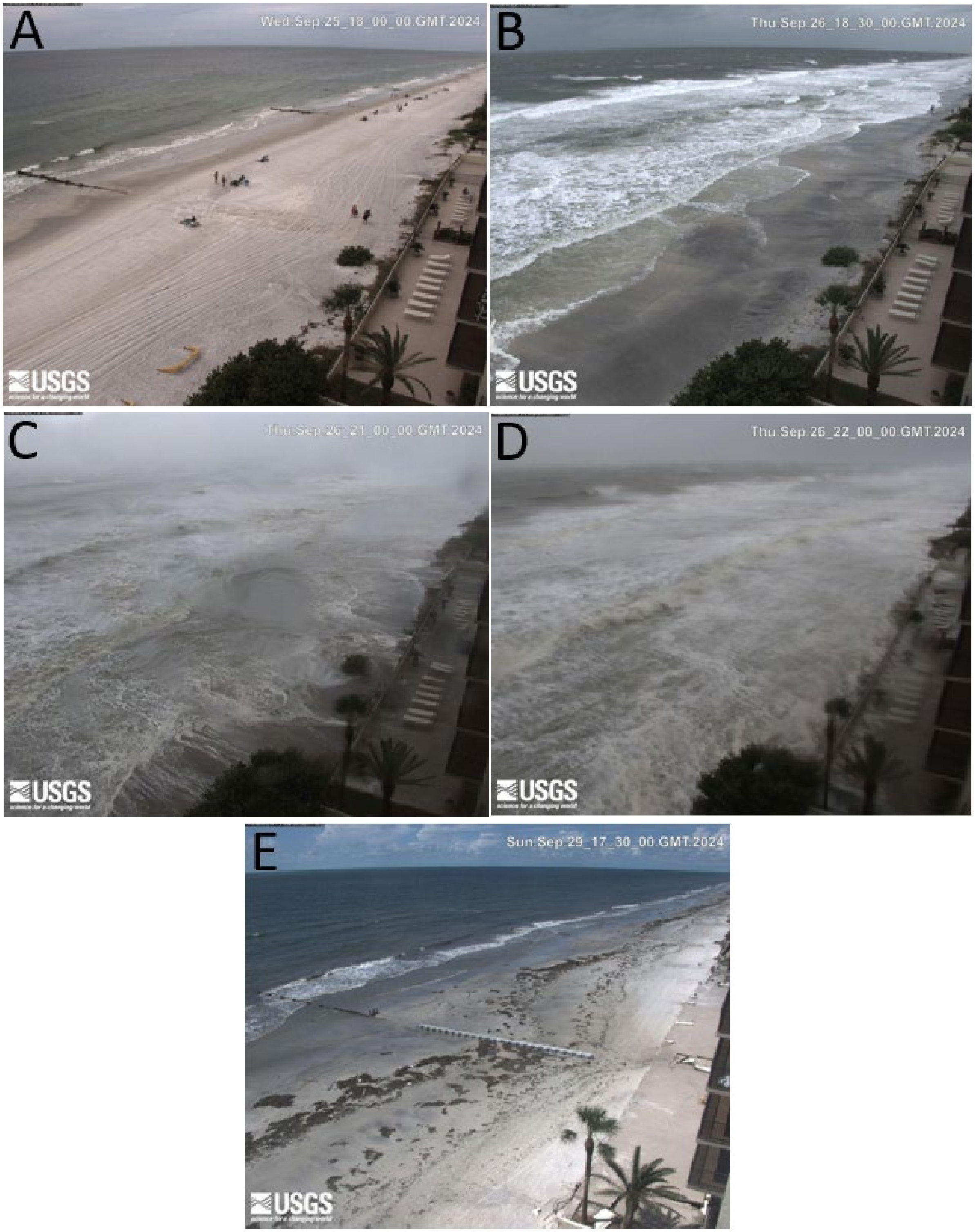

Figure 12. USGS Hydrologic Imagery Visualization and Information System (HIVIS) camera captured the dangerous storm surge at Madeira Beach in coastal Pinellas County.

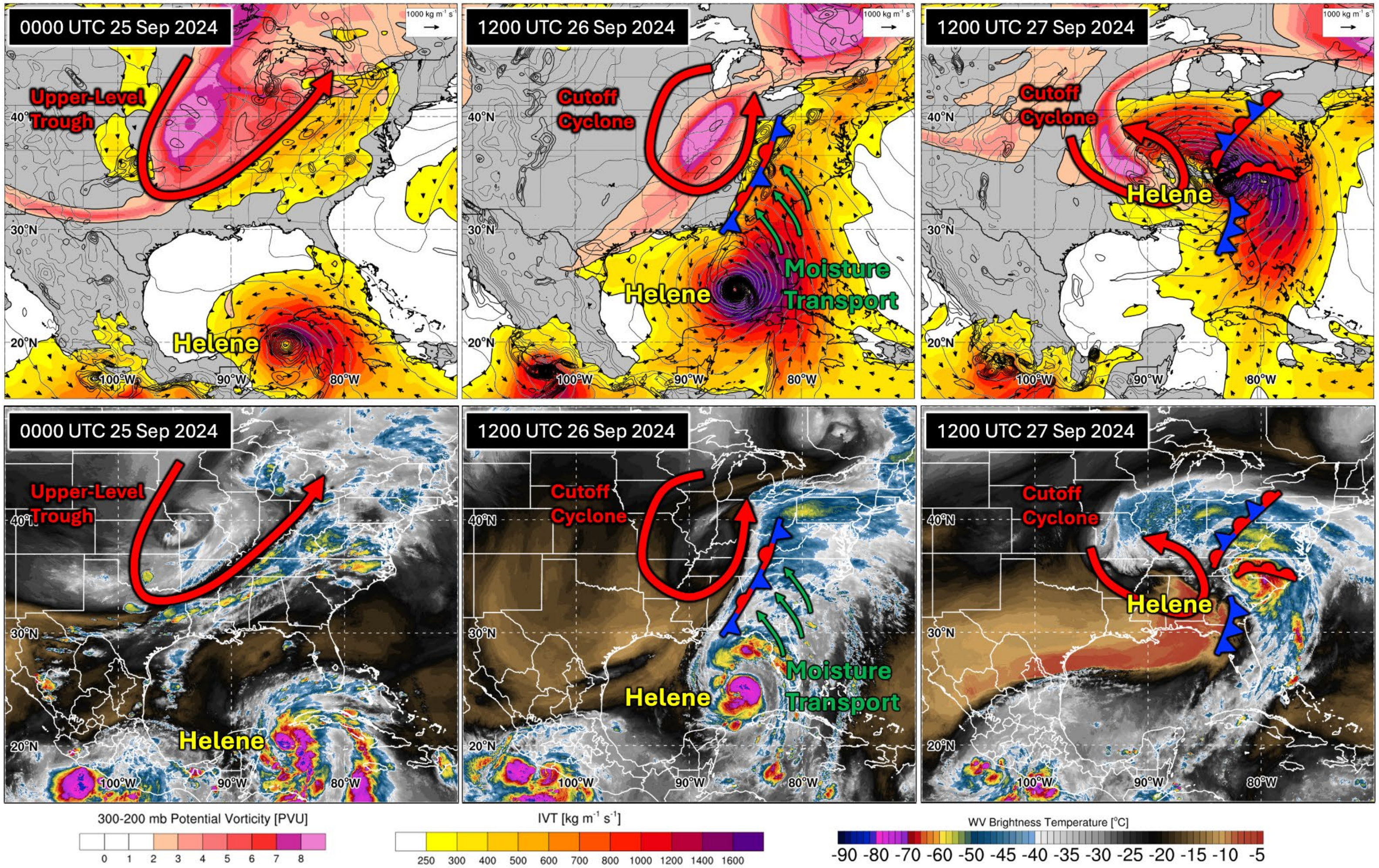

Figure 13. ECMWF Reanalysis v5 (ERA-5) and satellite analysis showing formation of Predecessor Rainfall Event (PRE) prior to Helene's landfall. Top panels show 300–200 mb layer mean Potential Vorticity (shading, PVU), Integrated Vapor Transport (shaded, kg m^{-1} s^{-1}), 850 mb relative vorticity (thick black contours, $>6x10^{-5}$ s^{-1}), and sea level pressure (thin black contours, every 2 mb). Bottom panels show GOES-16 water vapor channel 9 (shaded, °C). Panels ordered by date: (left) 0000 UTC 25 September, (middle) 1200 UTC 26 September, and (right) 1200 UTC 27 September. Frontal features adapted from the WPC surface analysis archive: https://www.wpc.ncep.noaa.gov/html/sfc-zoom.php, and additional features are denoted to highlight trough interaction with Helene and tropical moisture.

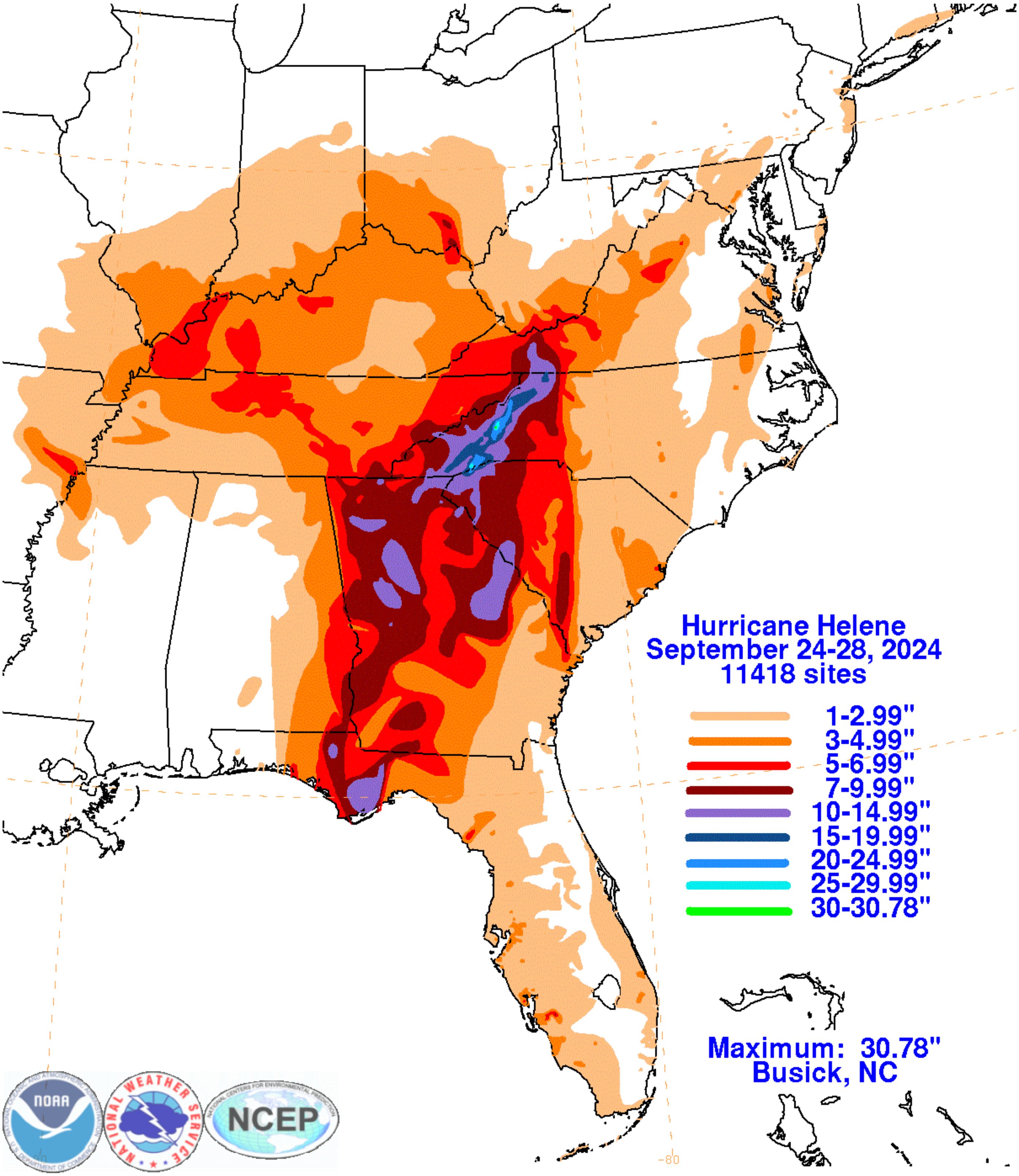

Figure 14. Analysis of storm total rainfall (inches) for Hurricane Helene. Courtesy of David Roth of the NOAA Weather Prediction Center.

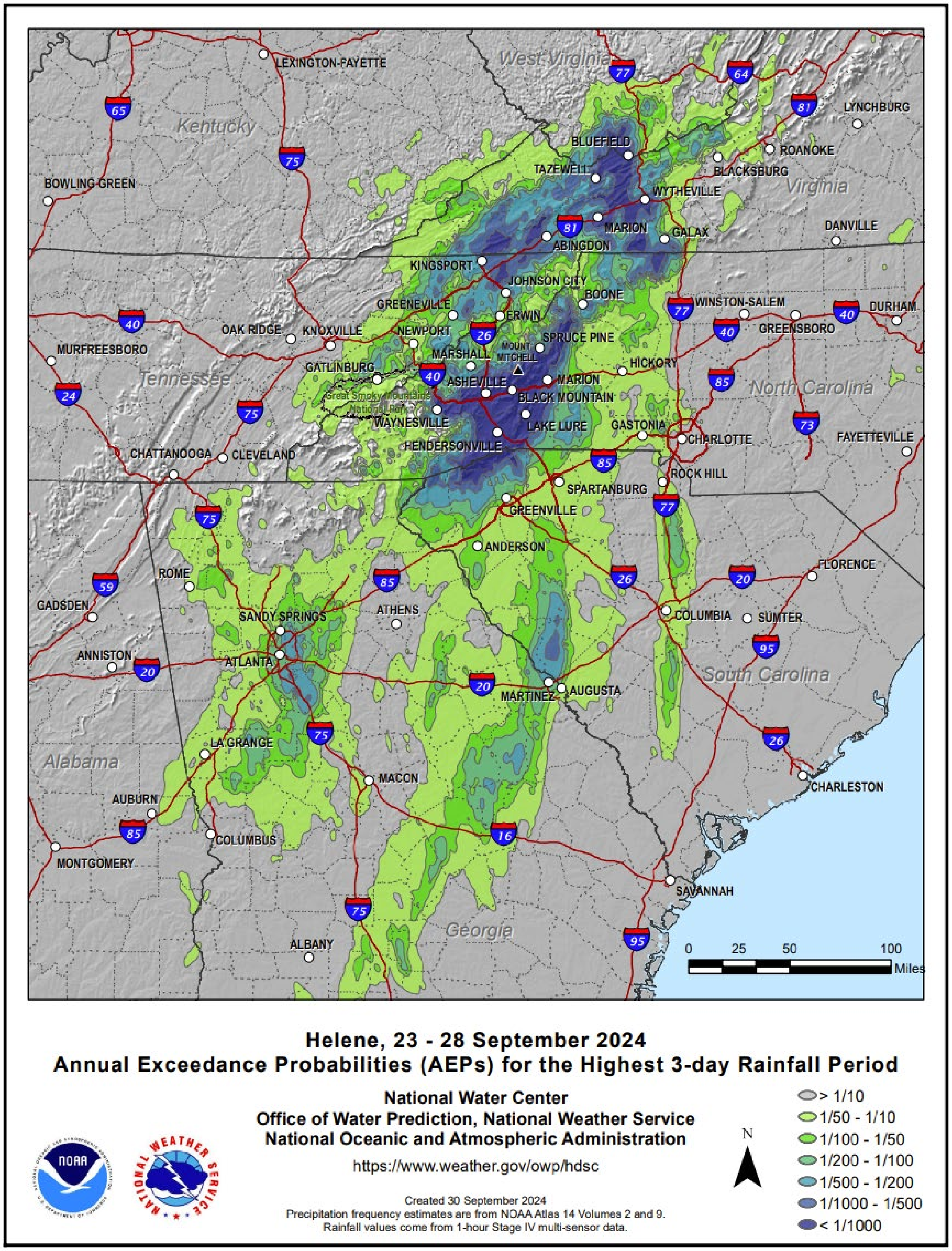

Figure 15. Annual 3 day exceedance probabilities associated with Helene. High resolution image found here: https://www.weather.gov/media/owp/oh/hdsc/docs/202409_Helene.pdf

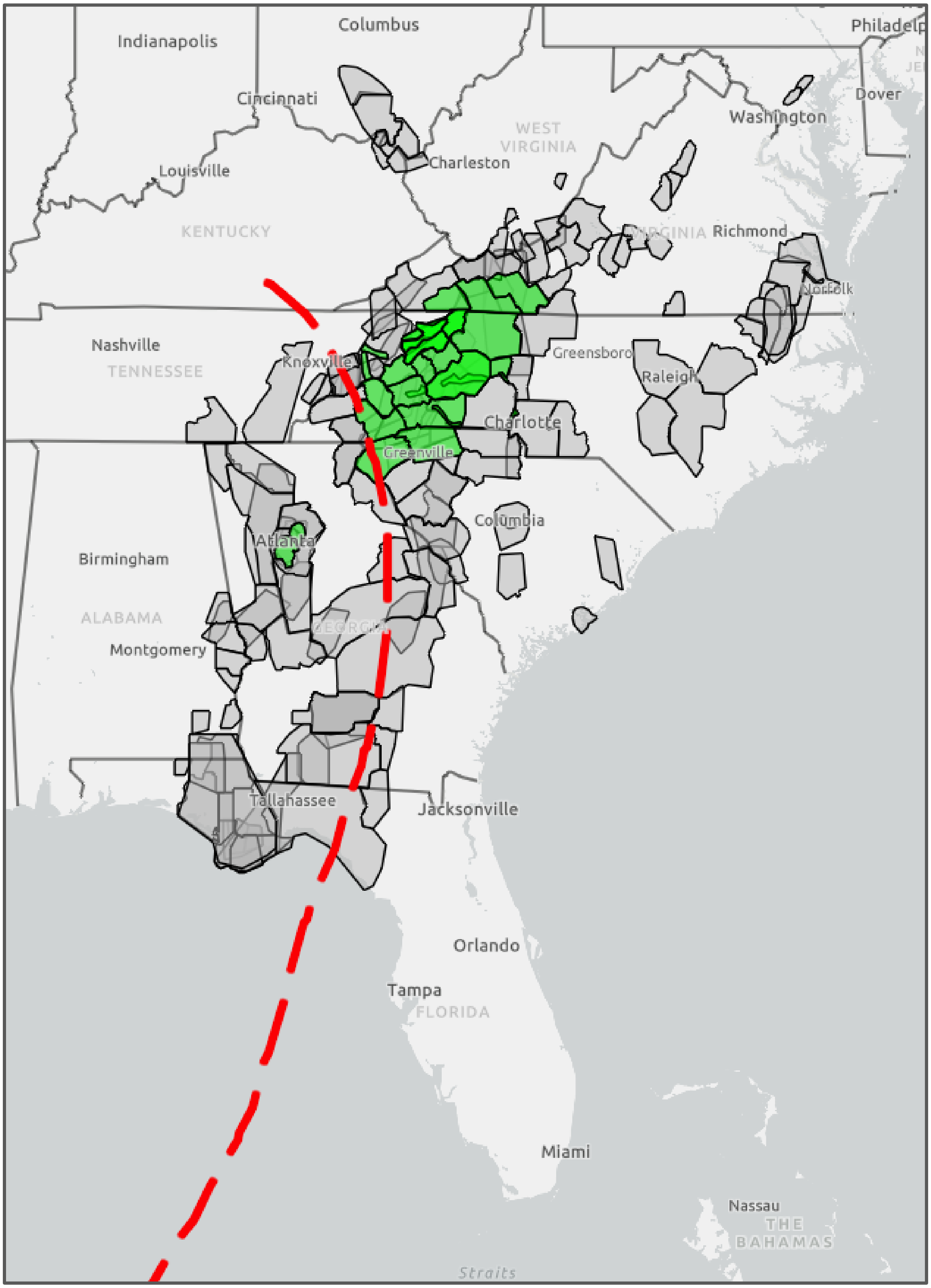

Figure 16. Map of all flash flood warnings issued ahead of and as Helene moved inland. The green polygons represent the 34 Flash Flood Emergencies that were issued. The red line is the track of Helene based on the operational position estimates.

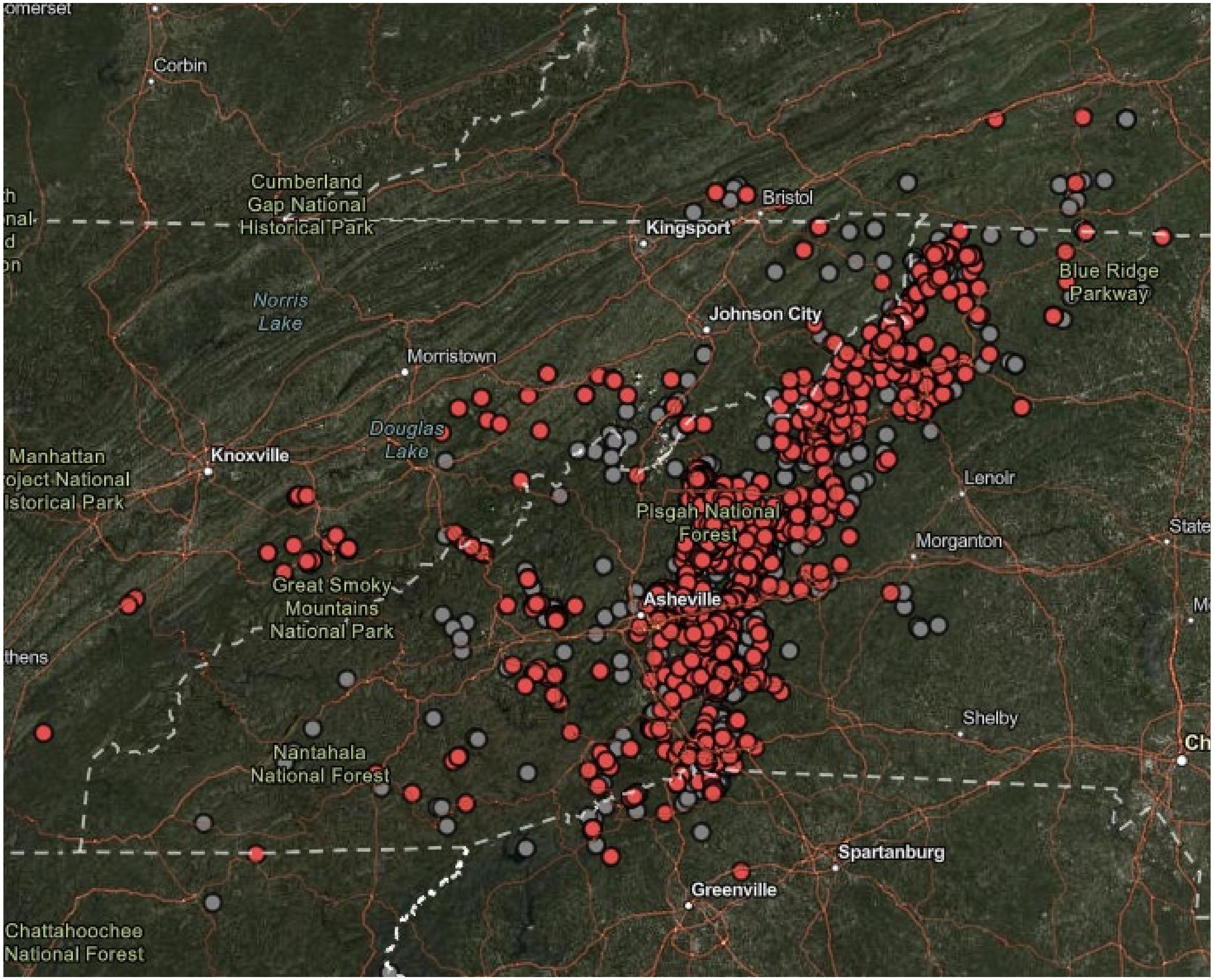

Figure 17. Plot of more than 2,000 landslides associated with Helene as observed by the USGS. The red circles are flagged landslides, which include those that impacted rivers, roads and structures. Interactive image can be found at: https://usgs.maps.arcgis.com/apps/dashboards/01b4f51fc0b64002bf7722a9acfc181d

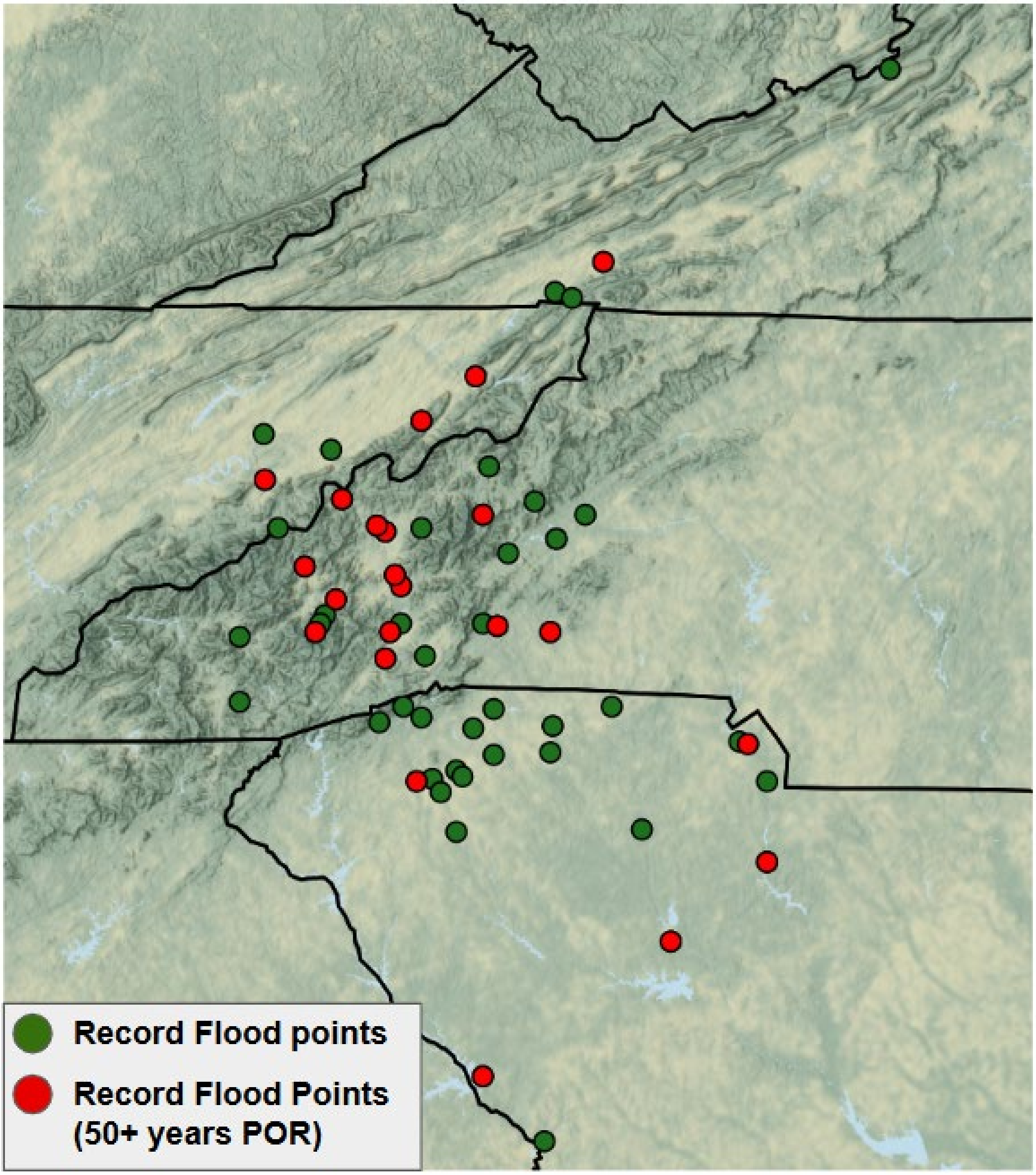

Figure 18. Plot of sites that observed record river flooding during and just after Helene. The red circles indicate the 22 sites that have a period of record of at least 50 years. It should be noted that some of this data is still preliminary and subject to change.

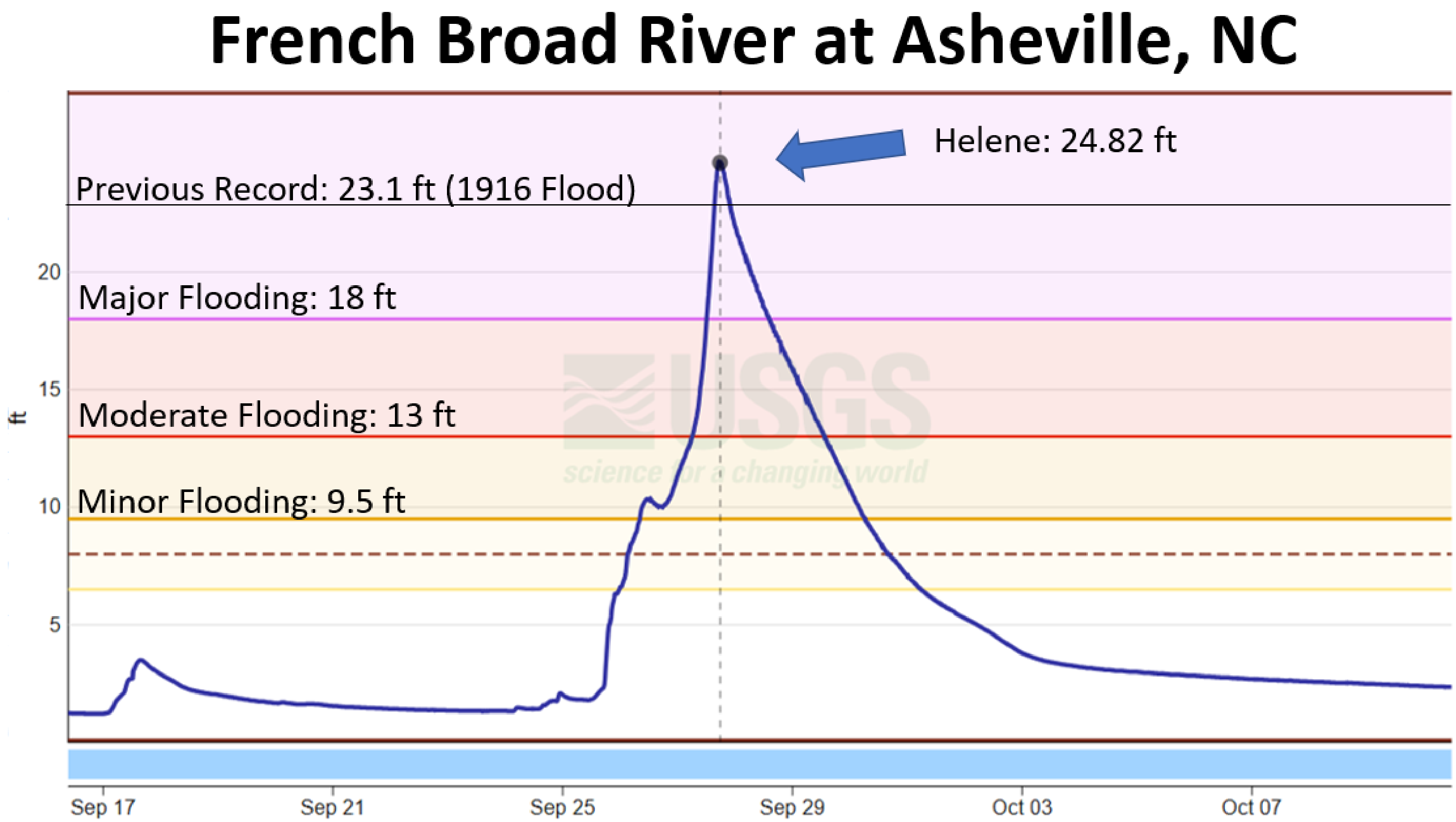

Figure 19. USGS river gauge measurements on the French Broad River at Asheville, NC.

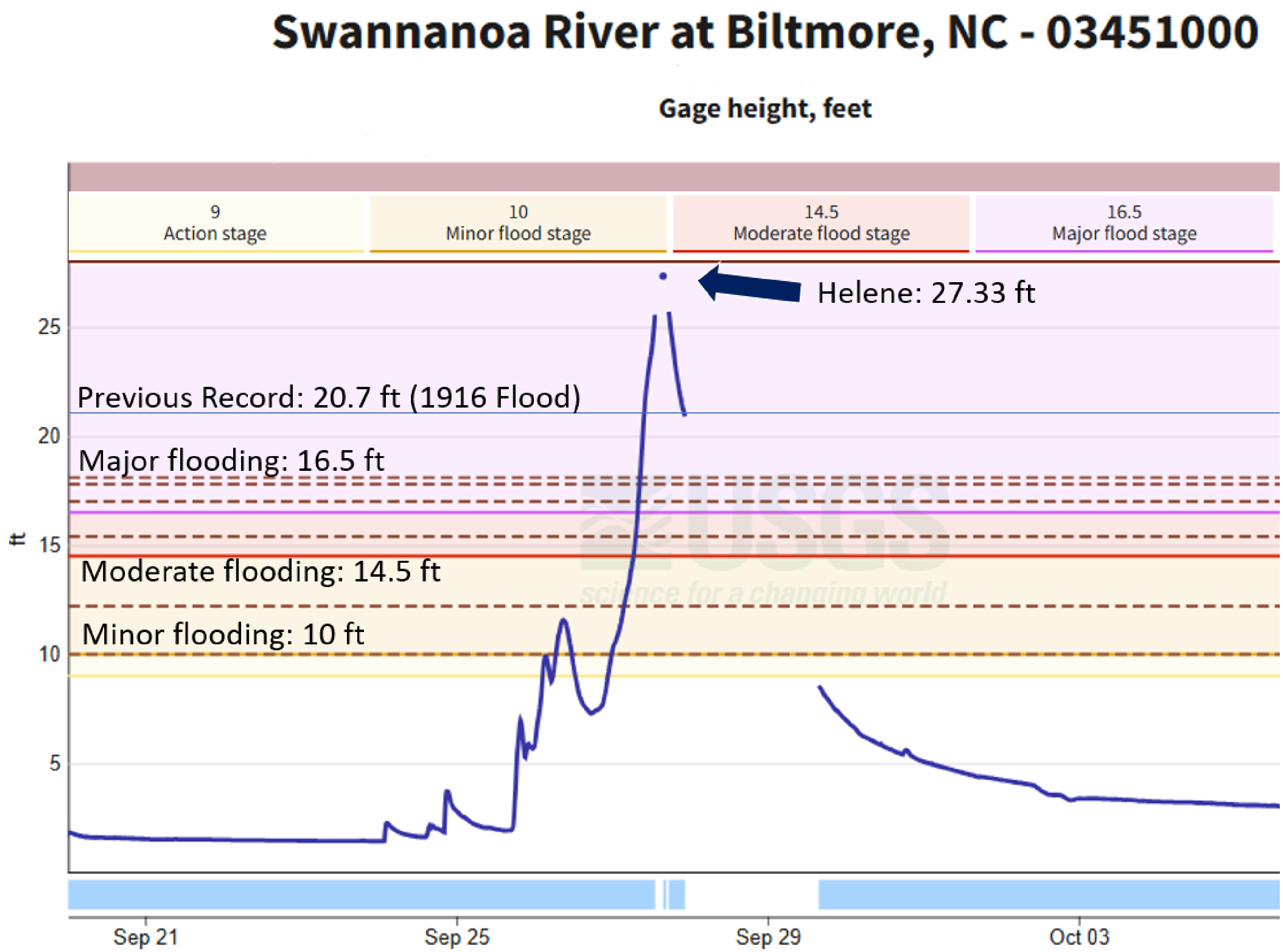

Figure 20. USGS river gauge measurements on the Swannanoa River at Biltmore, NC.

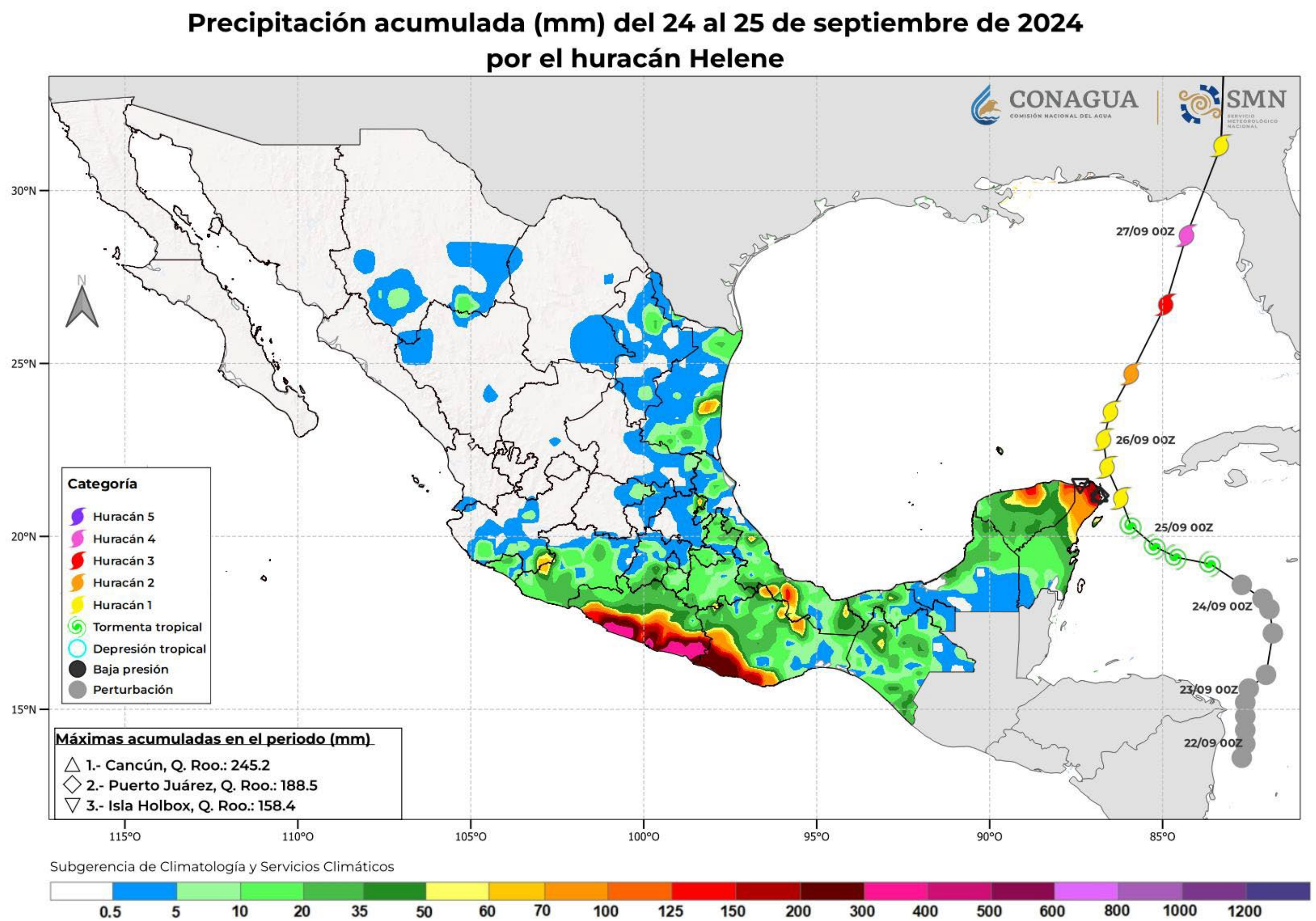

Figure 21. Rainfall accumulations (mm) in Mexico from 24–25 September, including the effects of Helene. Not all of the rainfall shown is directly due to Helene. Helene's track is based on operational location and intensity estimates. Image courtesy of CONAGUA, the national meteorological service of Mexico.

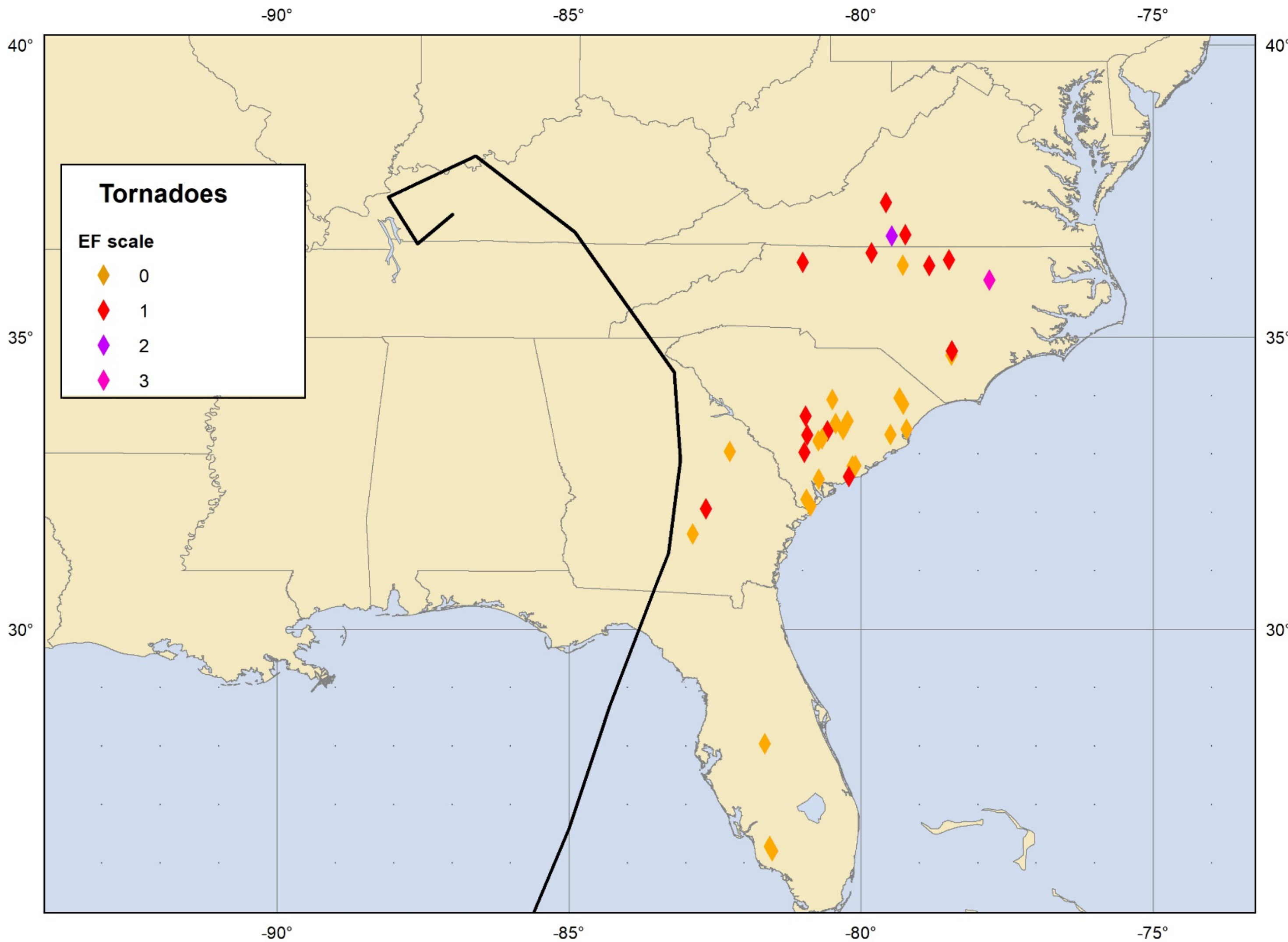

Figure 22. Map of NWS confirmed tornadoes spawned by Hurricane Helene.

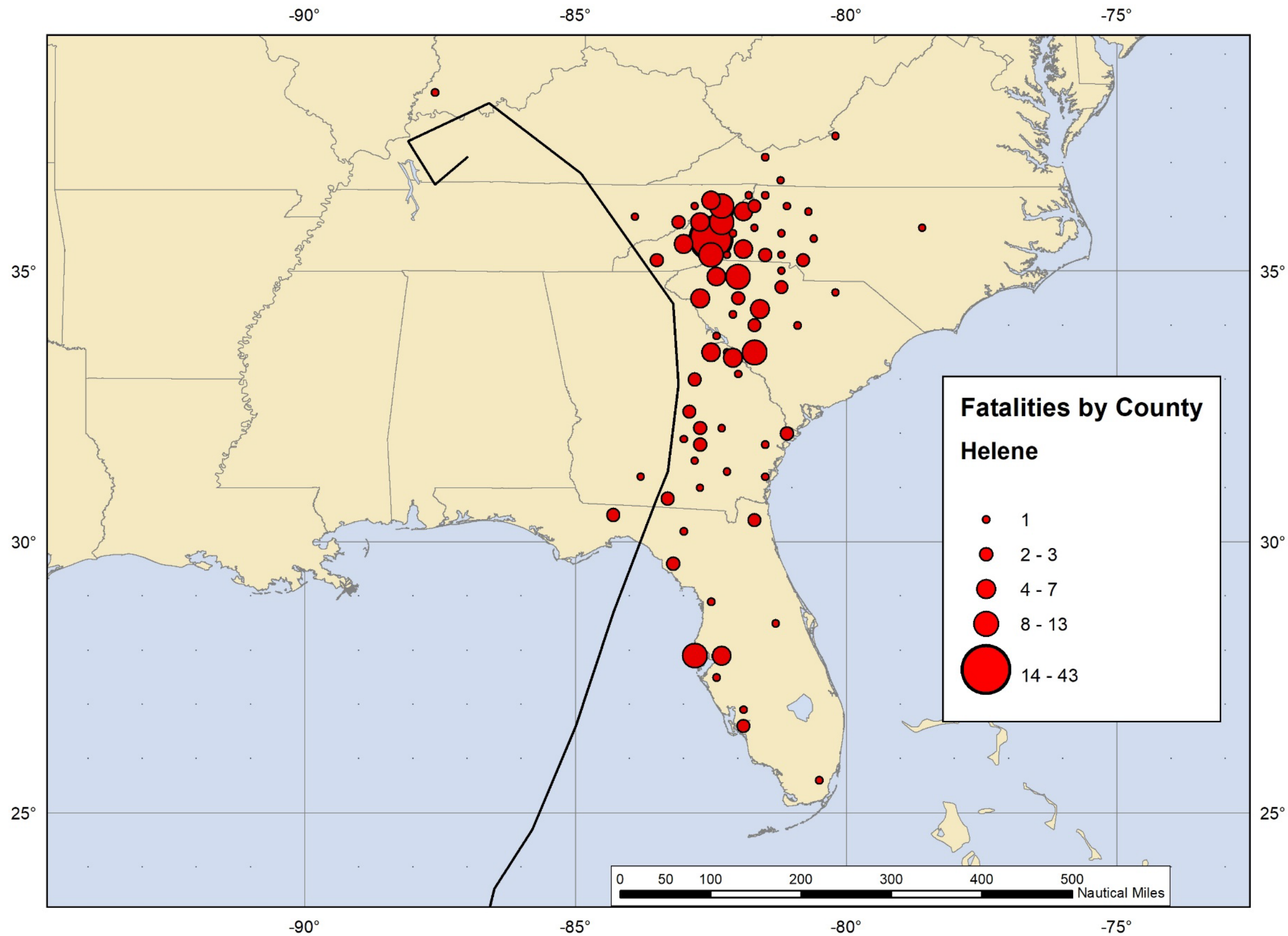

Figure 23. All fatalities (direct and indirect both included) associated with Hurricane Helene, 24–27 September 2024. The size of the dot corresponds with the number of deaths that occurred in that county.

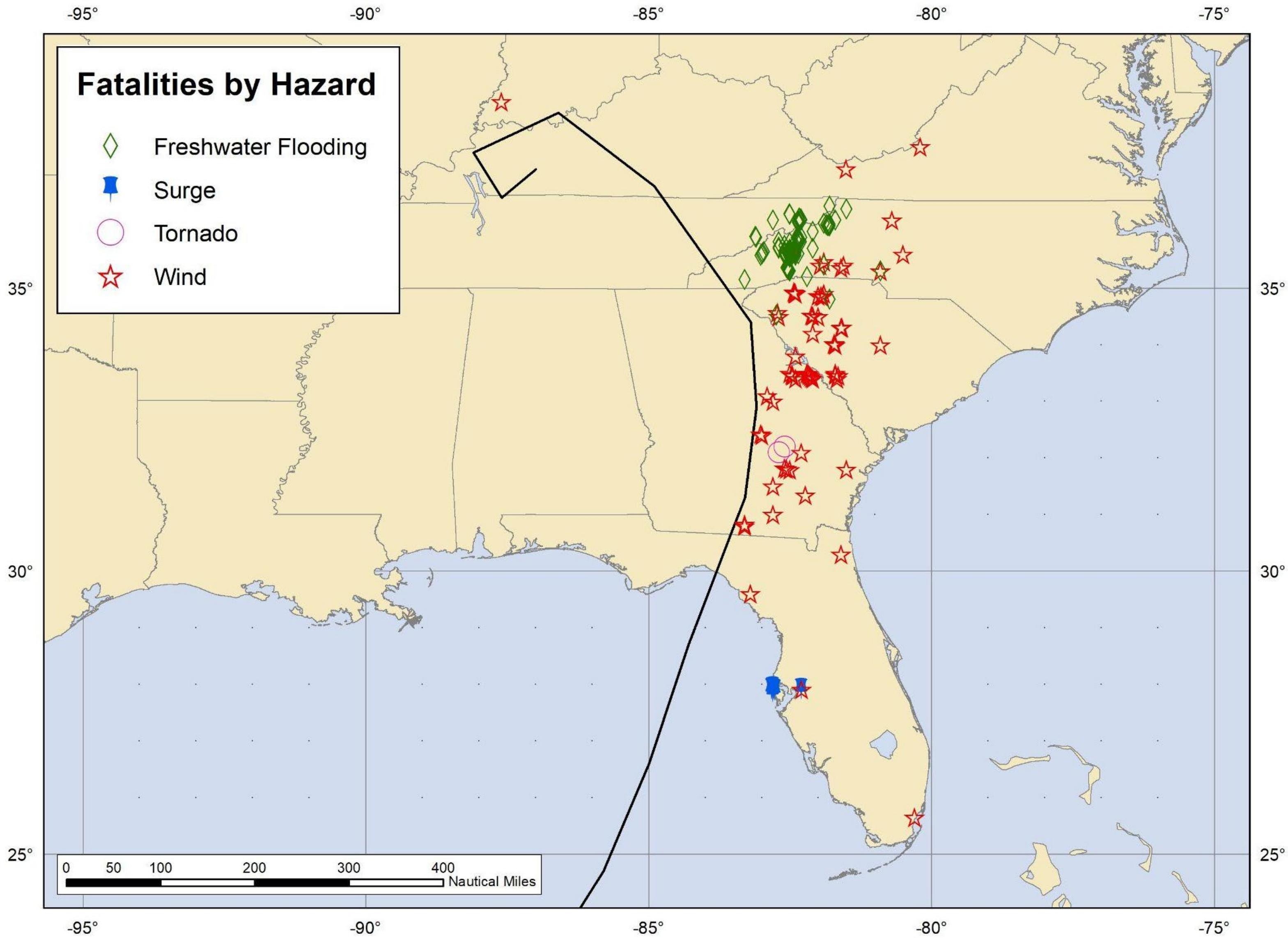

Figure 24. Direct fatalities color-coded by hazard type associated with Hurricane Helene, 24–27 September 2024. (Note: The freshwater flooding category includes deaths that were caused by landslides/debris flows.)

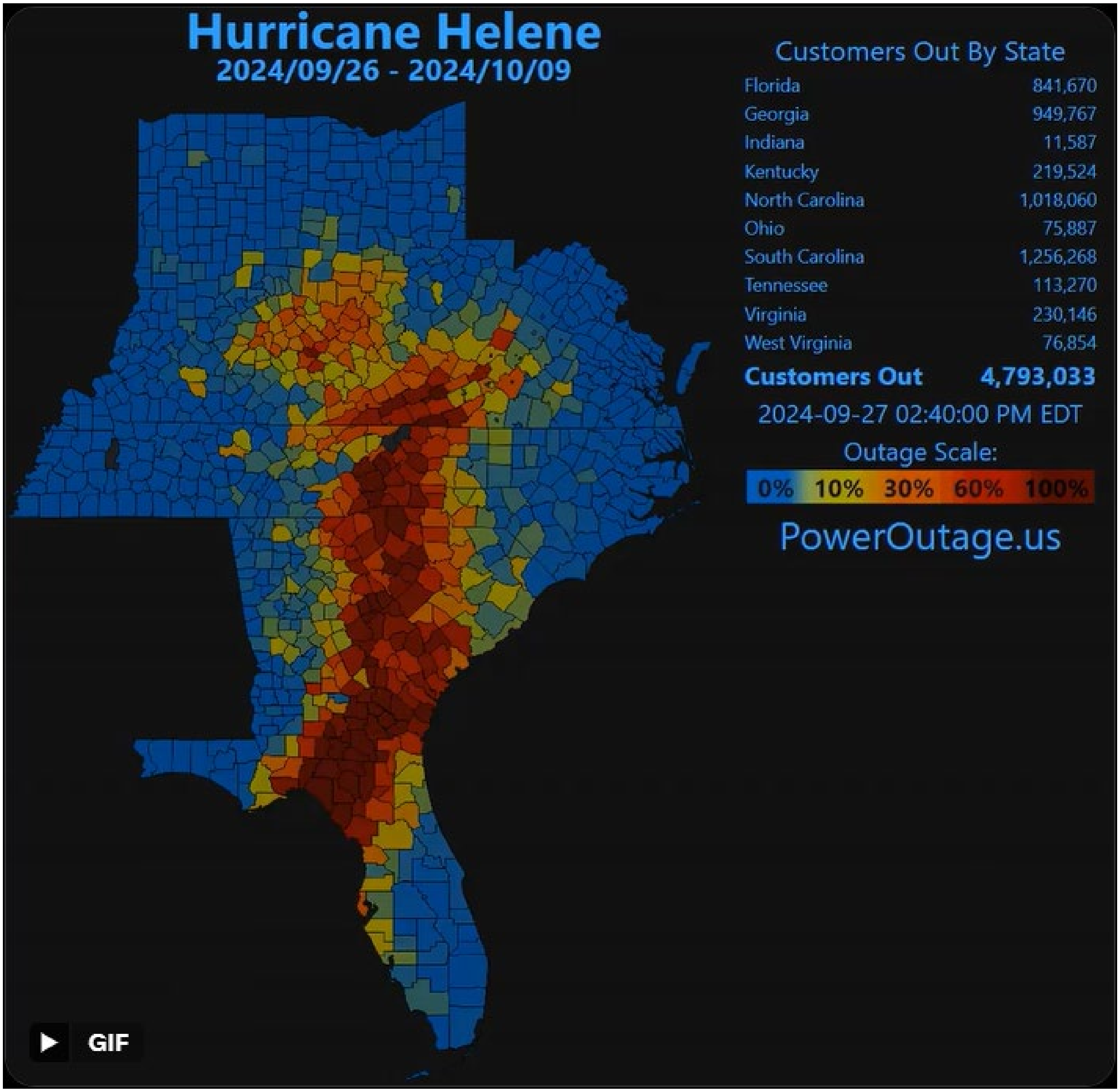

Figure 25. Power outage map for 1840 UTC 27 September. Photo credit: PowerOutage.us

Figure 26. A home in Keaton Beach, FL was gutted due to Helene's 12–16 ft storm surge there. The majority of homes in Keaton Beach were either gutted or washed away. Photo courtesy of Alicia Devine and the Tallahassee Democrat.

Figure 27. A home furniture shop in Valdosta, GA is destroyed by Helene's winds. Photo courtesy of Getty Images and taken from BBC.

Figure 28. A large oak tree that fell on a home in Anderson, SC on 27 September 2024. Photo courtesy of Ken Ruinard and the Anderson Independent Mail via USA Today Network.

Figure 29. Flooding from the Swannanoa and French Broad rivers in Biltmore Village in Asheville, NC after Helene swept through on 27 September 2024. Image courtesy of Colby Rabon and the Carolina Public Press.

Figure 30. Catastrophic flooding from the French Broad River in Asheville's River Arts District in the aftermath of Helene on 27 September 2024. Image courtesy of Colby Rabon and the Carolina Public Press.

Figure 31. Trees from landslides on the surrounding mountains and debris from the cities of Lake Lure and Chimney Rock were carried into Lake Lure on 27 September. Image courtesy of James Broyhill and Fox News.

Figure 32. Cars in a flooded area at a used tire dealer along Business Highway 25 in Hendersonville, NC on 28 September 2024. Photo courtesy of Ken Ruinard and USA Today Network.

Figure 33. Flooding in Downtown Marshall, NC from the French Broad River after Helene. Photo courtesy of Old Marshall Jail Hotel, taken from the North Carolina State Climate Office.

Figure 34. U.S. Route 19 in Yancey County is just one example of hundreds of roads that were washed out and destroyed in western North Carolina. Photo courtesy of Josh Morgan and USA Today.

Figure 35. Dangerous street flooding developed just outside of Boone, NC on 27 September 2024. Photo courtesy of Jonathan Drake and Reuters.

Figure 36. Flood waters from the Nolichucky River rage in Erwin, TN on 27 September 2024 as a helicopter rescues hospital staff and patients from the rooftop of Unicoi County Hospital. Photo courtesy of Alderman Michael Baker and ABC News.

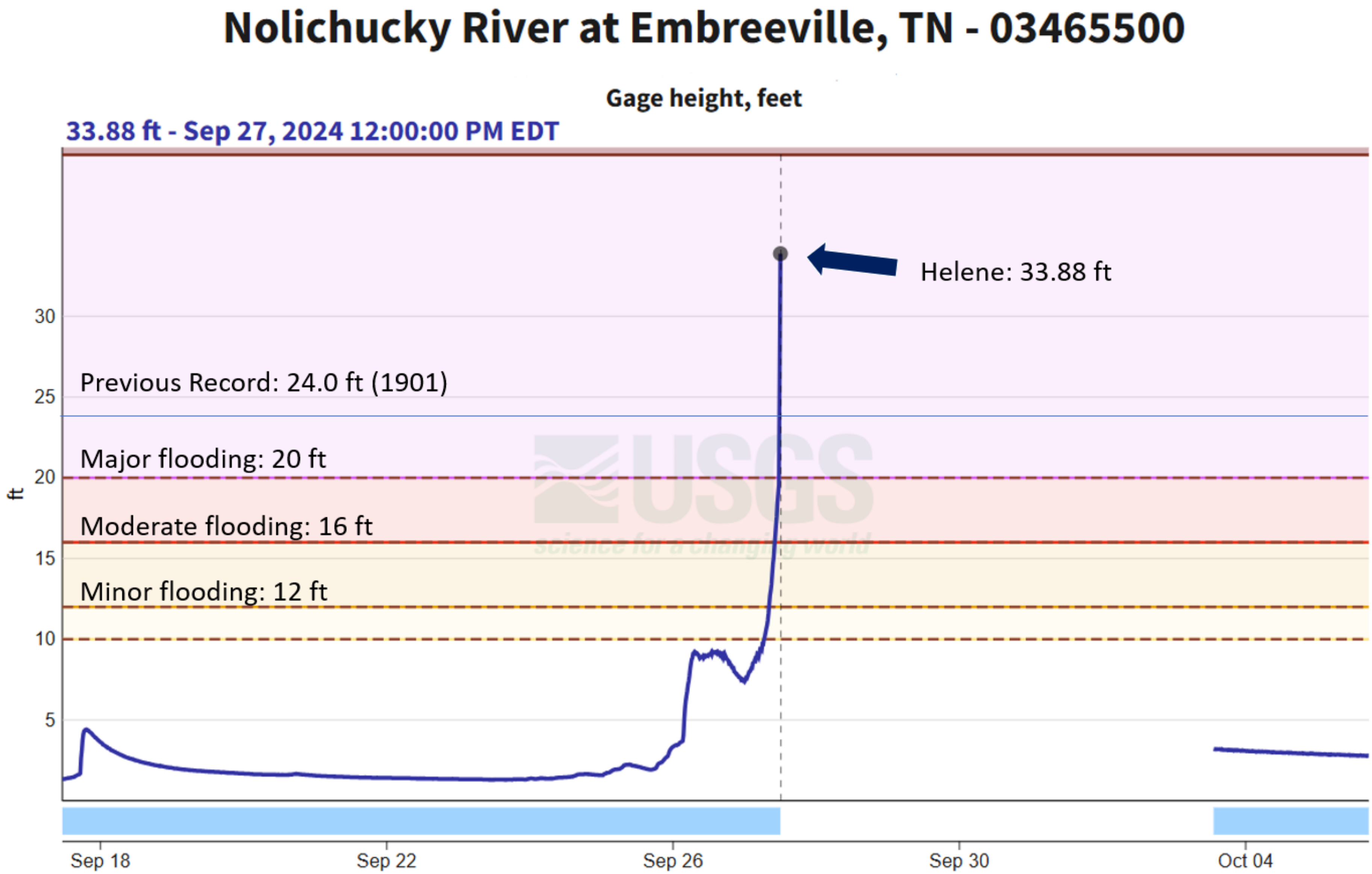

Figure 37. USGS river gauge measurements on the Nolichucky River at Embreeville, TN.

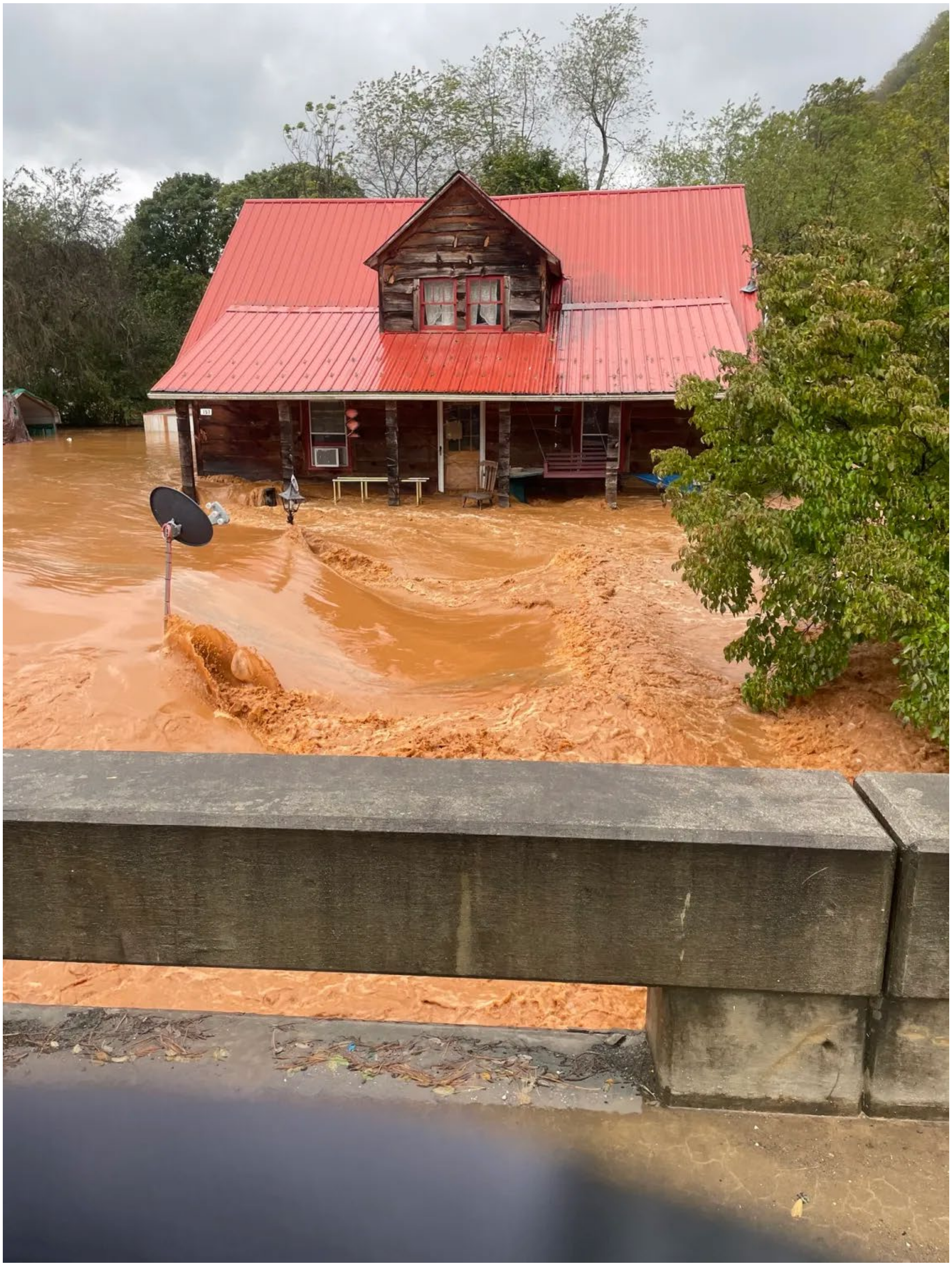

Figure 38. Floodwaters rushing in front of a home in southwest Virginia shortly after Helene passed. Photo courtesy of Virginia Department of Emergency Management.

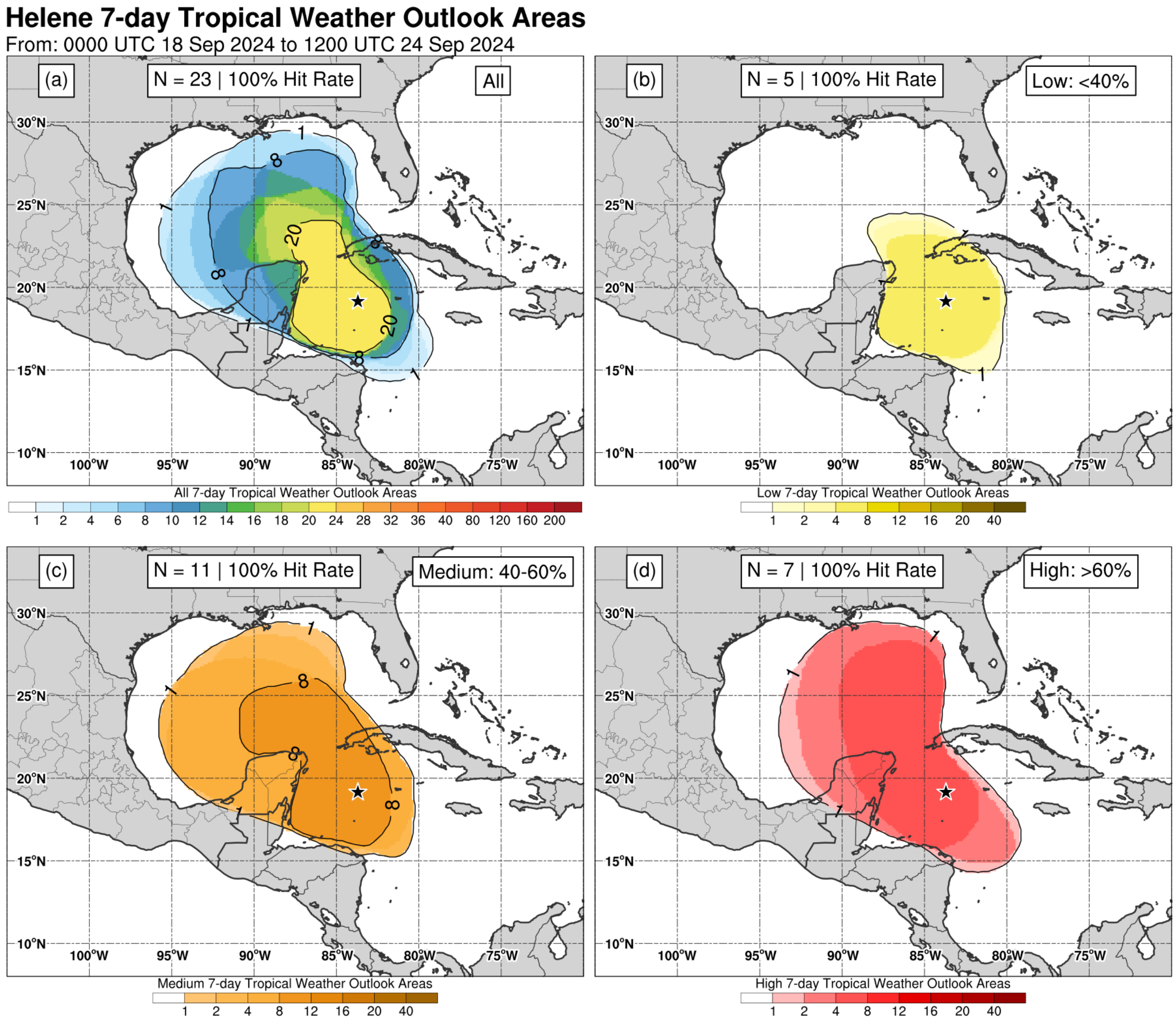

Figure 39. Composites of 7-day tropical cyclone genesis areas depicted in NHC's Tropical Weather Outlooks prior to the formation of Hurricane Helene for (a) all probabilistic genesis categories, (b) the low (<40%) category, (c) medium (40–60%) category, and (d) high (>60%) category. The location of genesis is indicated by the black star.

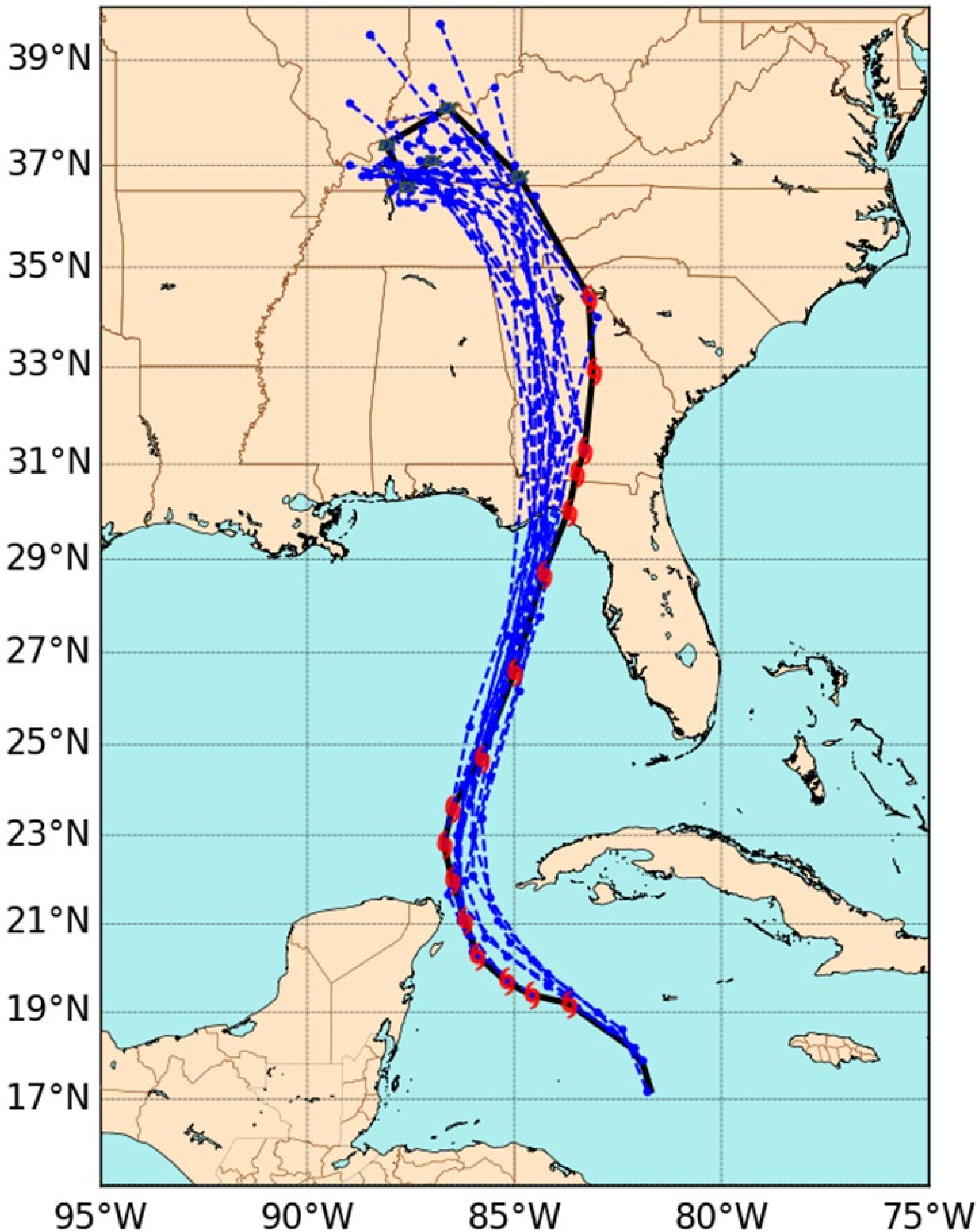

Figure 40. NHC official track forecasts (blue lines) from 1200 UTC 23 August to 1800 UTC 27 August. The best track is depicted by the black line with symbols in red depicting positions typically at 6 h intervals.

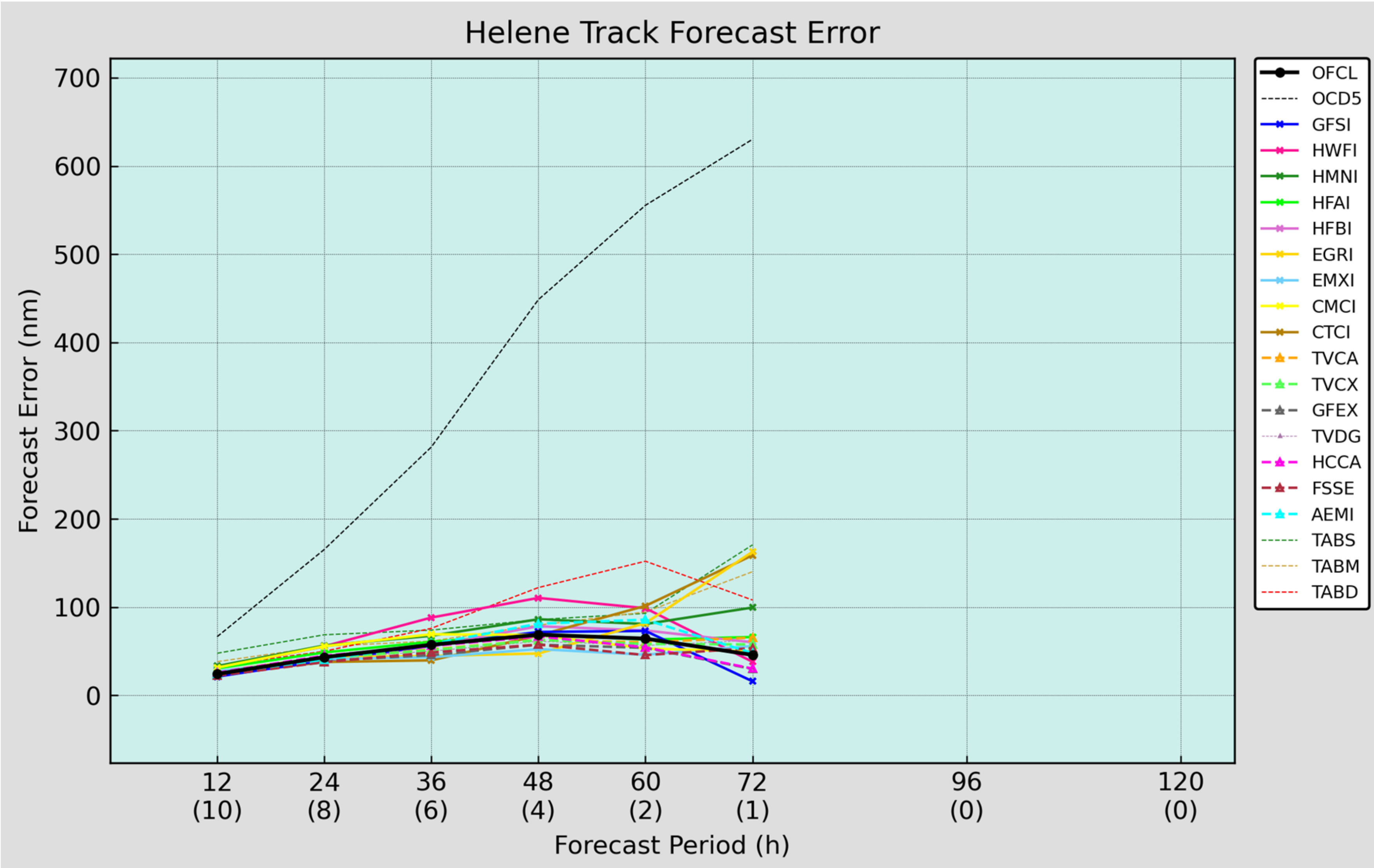

Figure 41. Official forecast (OFCL - black line) and selected model forecast track errors for Hurricane Helene, 24–27 September 2024. The number of forecasts for each verifying forecast time period is in parentheses.

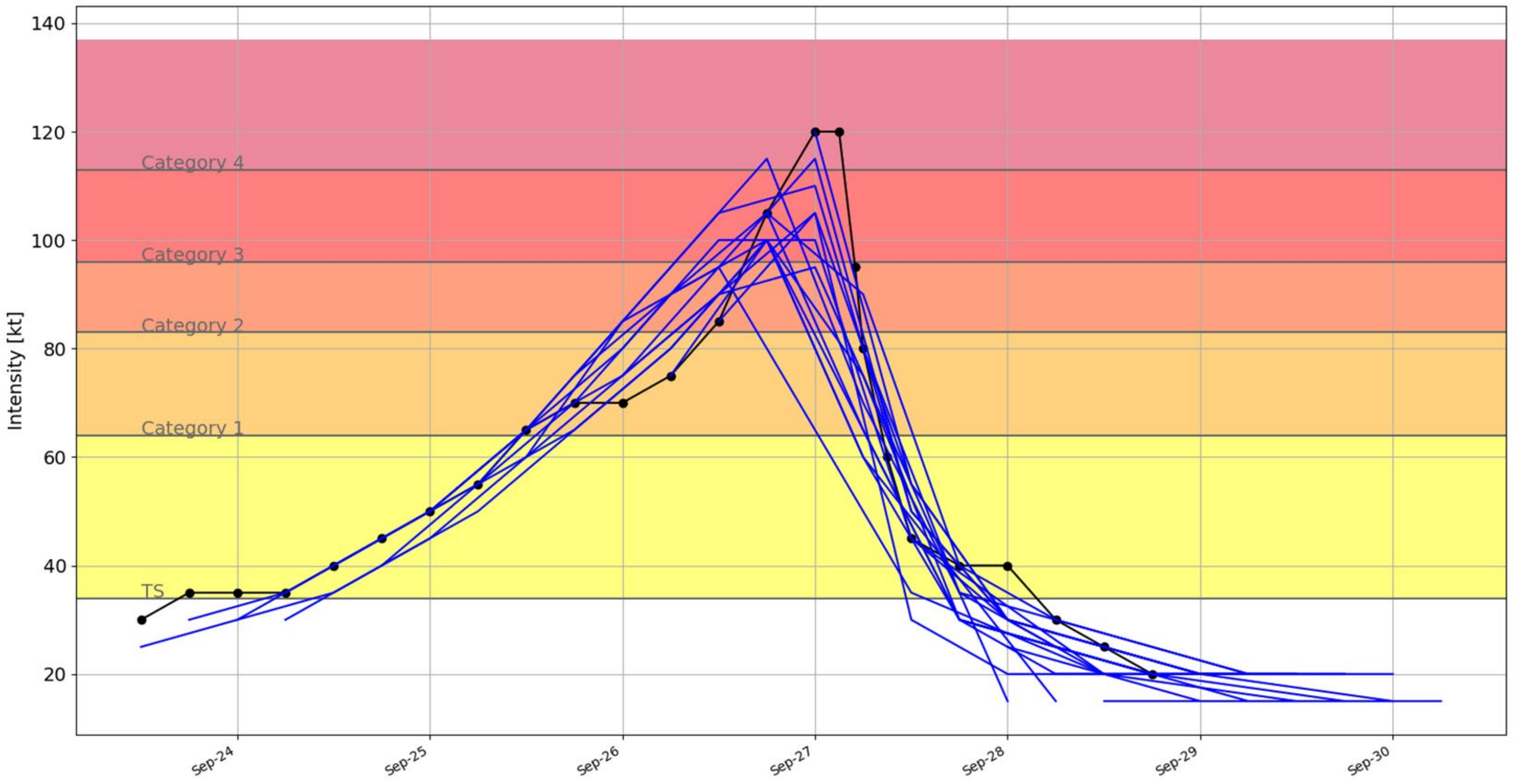

Figure 42. The official intensity forecasts (blue lines) from 1200 UTC 23 August to 1800 UTC 27 August. The best track is depicted by the black line with black dots typically shown every 6 h.

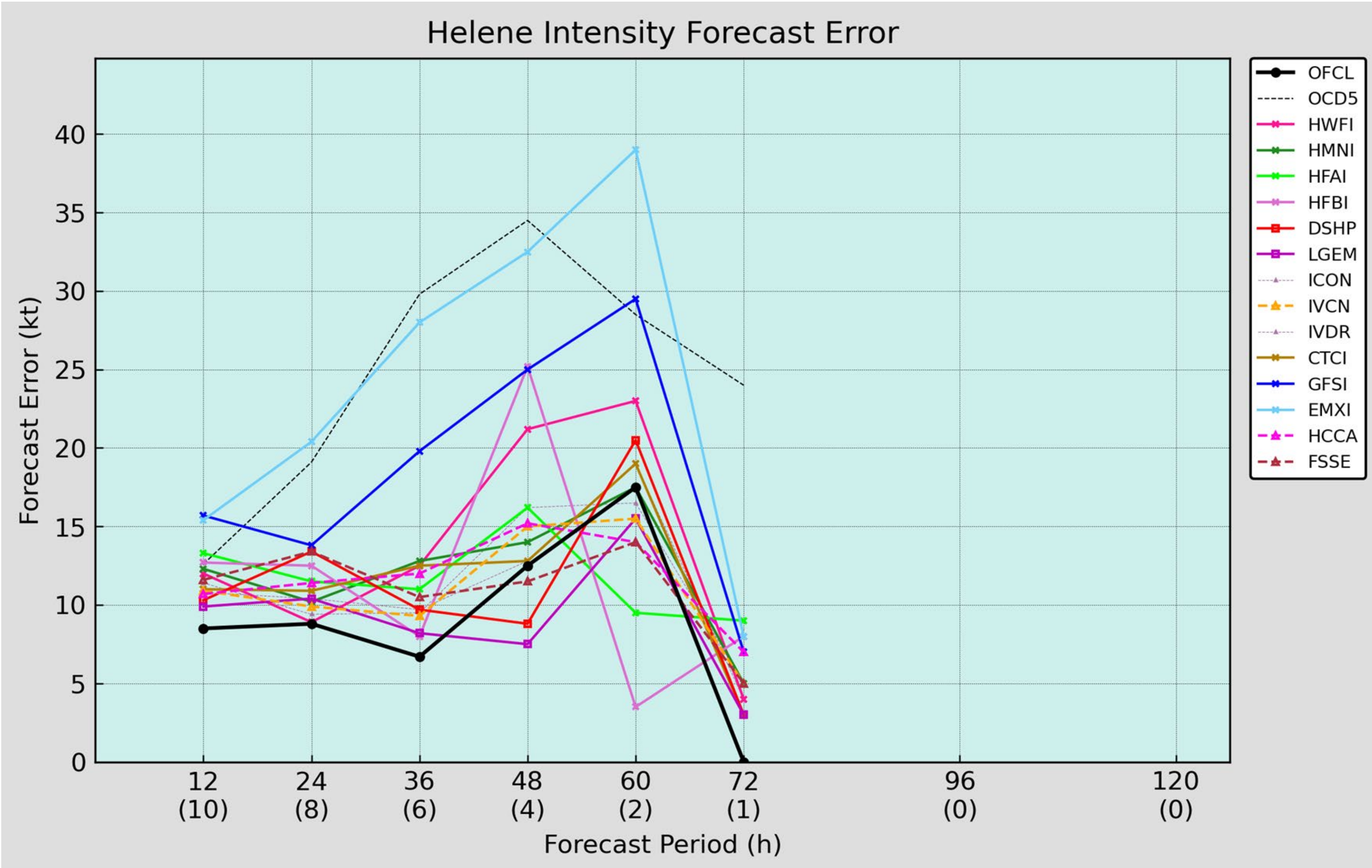

Figure 43. Official forecast (OFCL - black line) and selected model forecast intensity errors for Hurricane Helene, 24–27 September 2024. The number of forecasts for each verifying forecast time period is in parentheses.

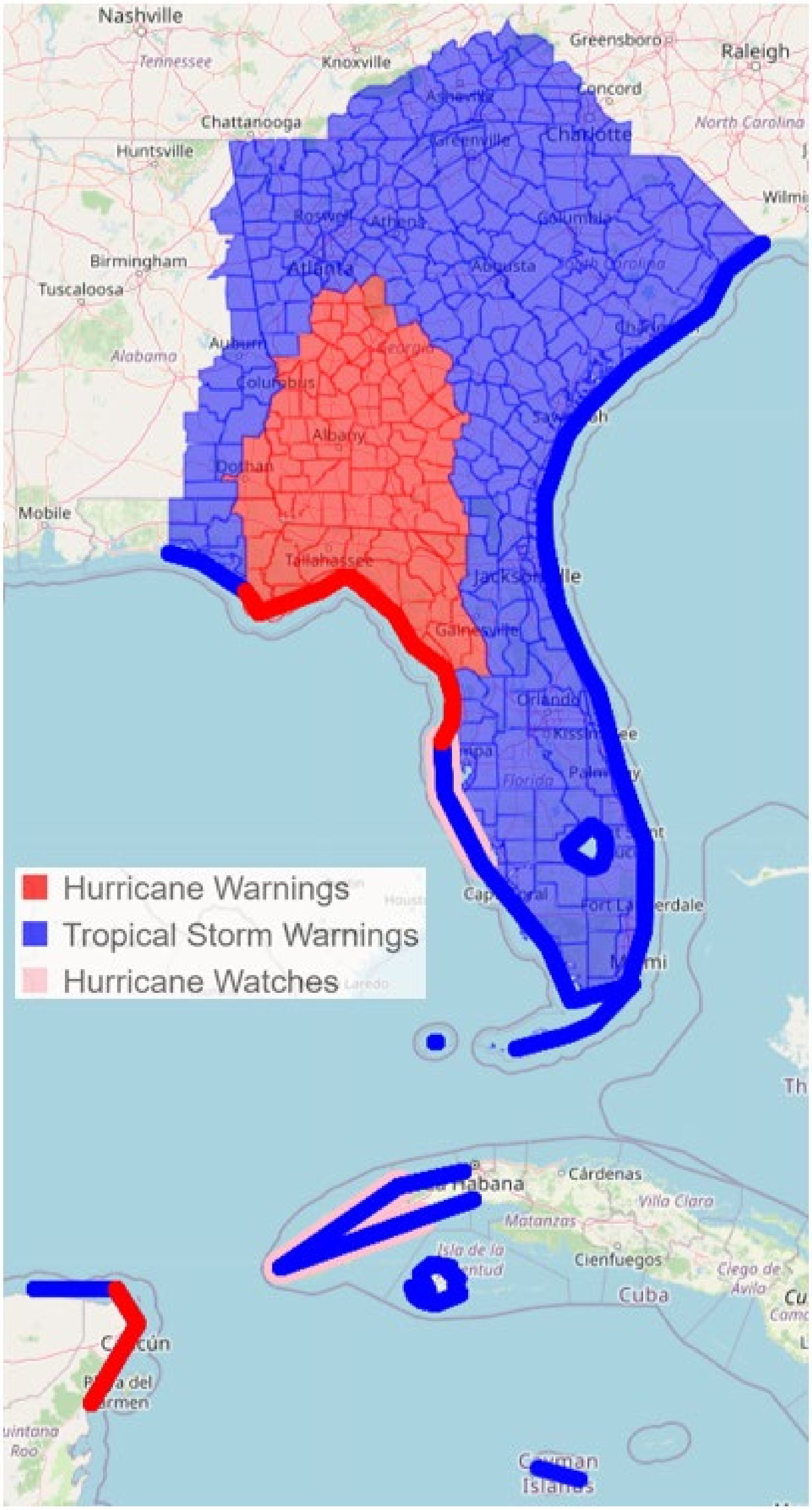

Figure 44. Coastal and inland tropical cyclone wind watches and warnings (only highest severity shown) from Hurricane Helene.

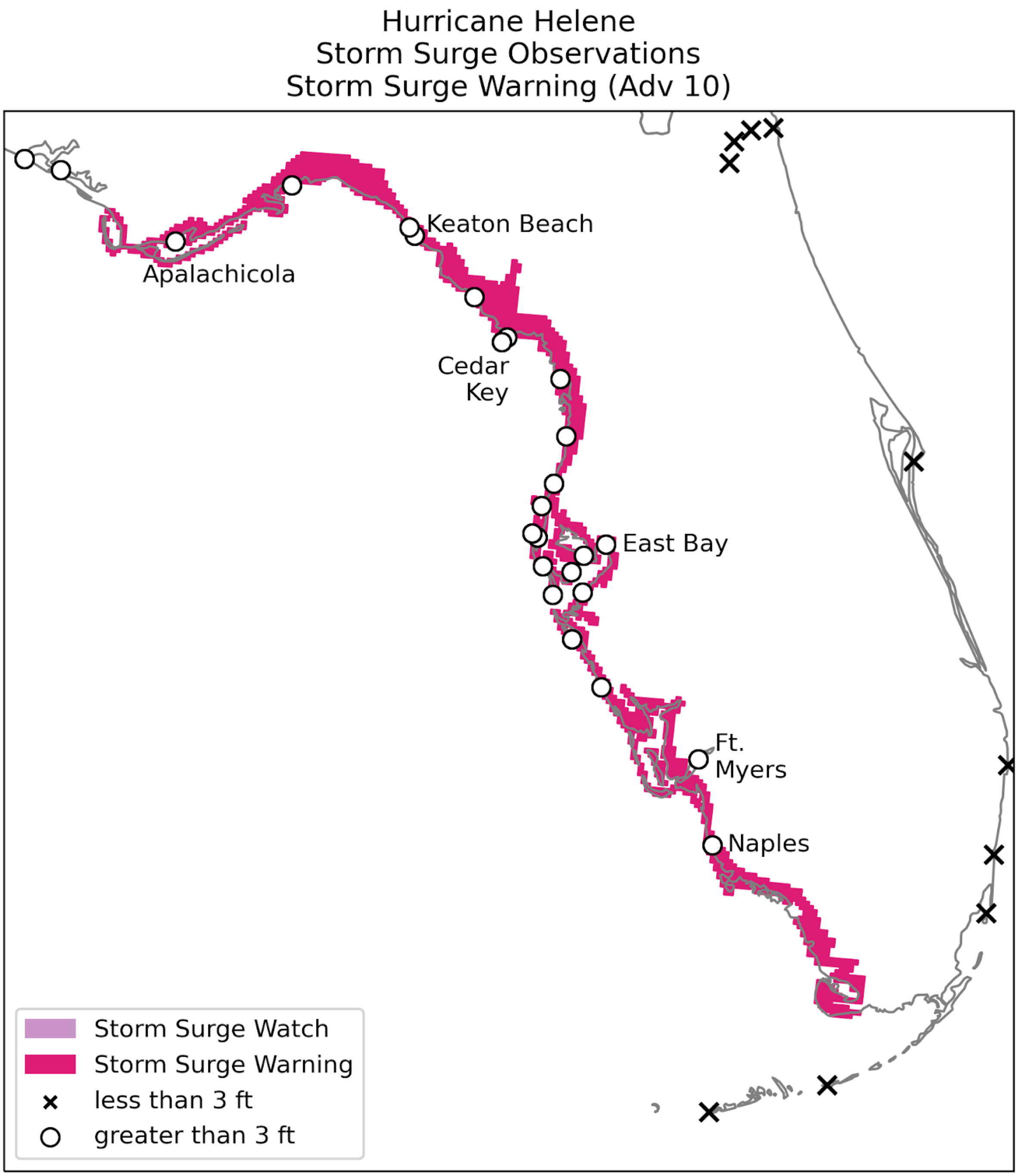

Figure 45. The Storm Surge Warning (magenta) from 2100 UTC 25 September (Adv. 10) and maximum water levels measured from NOS tide gauges and deployed USGS water level sensors. Water levels greater than 3 ft above MHHW are designated as a white "o" and water levels less than 3 ft above MHHW as a black "x".

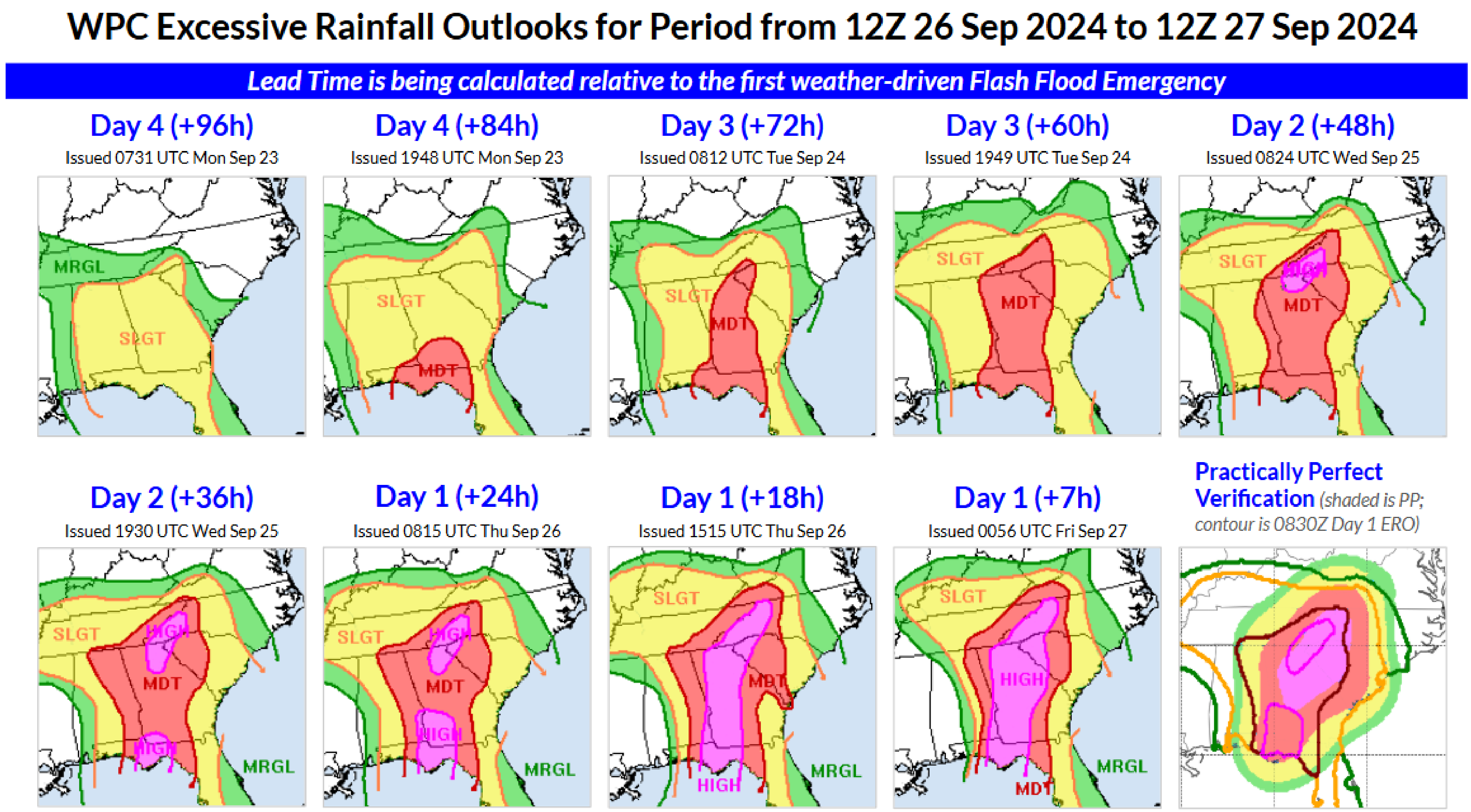

Figure 46. Forecast evolution of the Weather Prediction Center's Excessive Rainfall Outlook valid 1200 UTC 26 September to 1200 UTC 27 September 2024. The "practically perfect verification" is derived from a field of observations and attempts to depict what a perfect WPC Excessive Rainfall Outlook would have looked like. The observations it incorporates include: local storm reports of flooding, flash flood guidance exceedance, annual recurrence interval exceedance and USGS river gauge flooding.

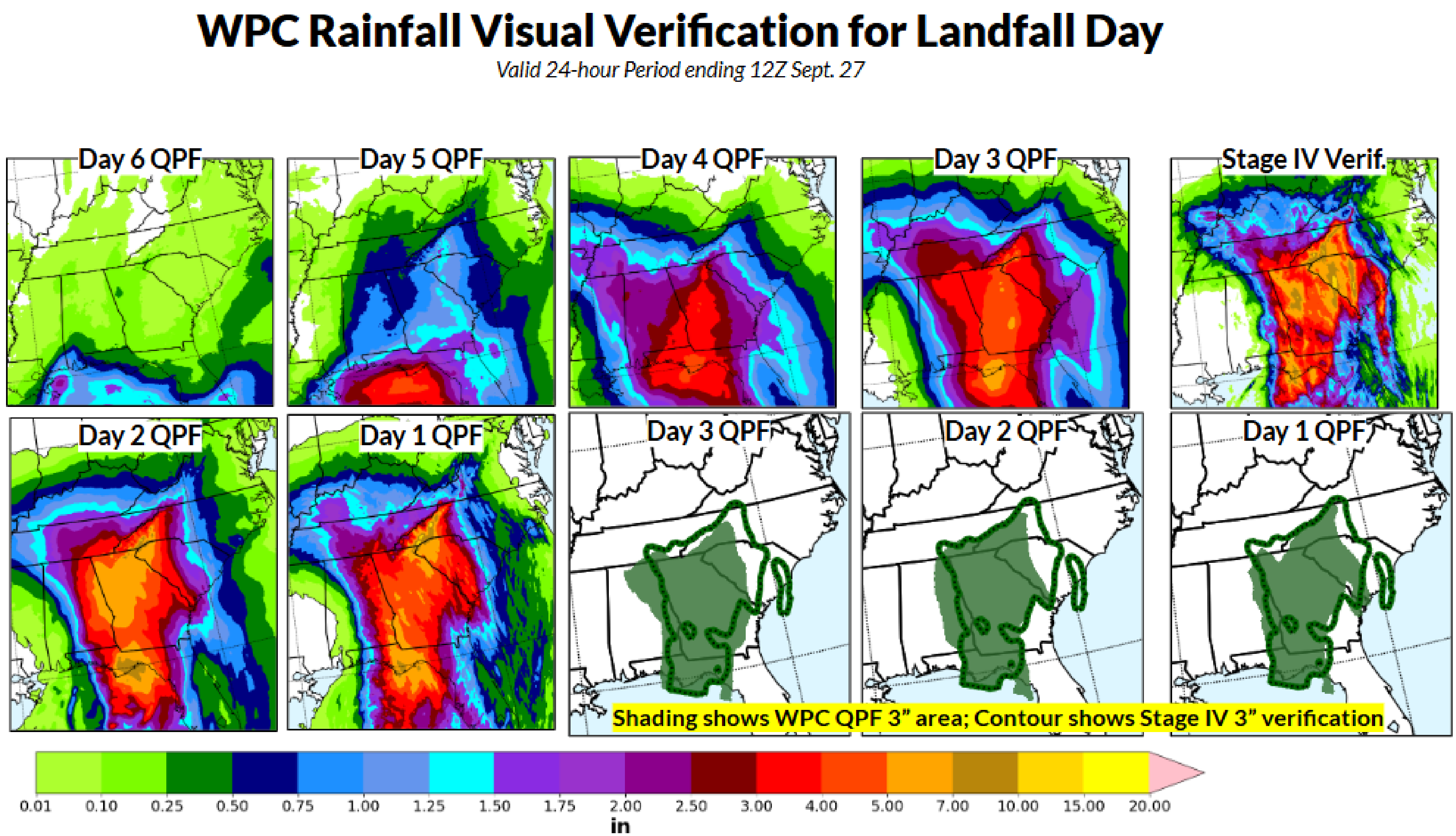

Figure 47. Forecast evolution of the Weather Prediction Center's 24 hour rainfall forecast valid 1200 UTC 26 September to 1200 UTC 27 September 2024.

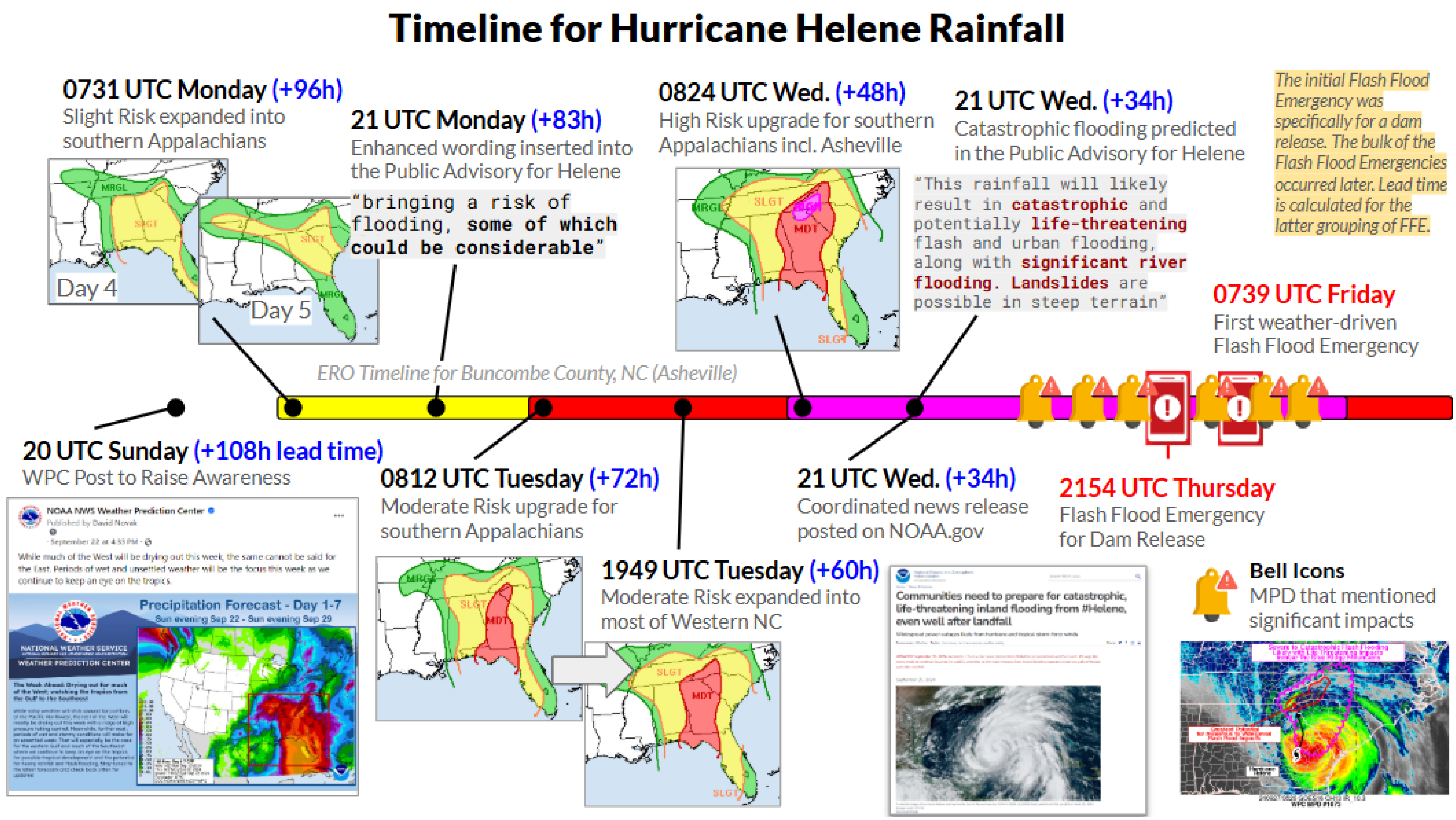

Figure 48. WPC's messaging timeline for Hurricane Helene rainfall.

ADDITIONAL NWS RESOURCES

Note that the storm overviews in these reports were generated using the preliminary Best Track data for Hurricane Helene.

North Carolina State Climate Office article:

https://climate.ncsu.edu/blog/2024/09/rapid-reaction-historic-flooding-follows-helene-in-western-nc/

South Carolina State Climatology Office preliminary report: https://www.dnr.sc.gov/climate/sco/Publications/Helene-OFR.pdf

Tennessee State Climate Office report: https://storymaps.arcgis.com/stories/57af2ac1866f42d58bedb2f3c2154f8b

Blacksburg, VA Weather Forecast Office (WFO) StoryMap: https://storymaps.arcgis.com/stories/c0813e1b36c64563b52ba8f4fd9244b9

Morristown, TN WFO report: https://www.weather.gov/mrx/Hurricane_Helene

Nashville, TN WFO summary: https://www.weather.gov/ohx/hurricanehelene

Charleston, WV WFO Summary: https://www.weather.gov/rlx/2024-September-27-Helene

Wilmington, OH WFO Summary: https://www.weather.gov/iln/20240927

Jacksonville, FL WFO StoryMap: https://storymaps.arcgis.com/stories/44b6406a60c445d49d31d470a8b0f233

Impacts: https://www.weather.gov/media/jax/TropicalEventSummary/PSHJAX_2024AL09_Helene_ImpactNarratives(2).pdf

Summary: https://www.weather.gov/media/jax/TropicalEventSummary/PSHJAX_2024AL09_Helene_Summary.pdf

Tampa Bay, FL WFO Impacts:

https://www.weather.gov/media/tbw/TropicalEventSummary/PSHTBW_2024AL09_Helene_ImpactNarratives.pdf

Summary: https://www.weather.gov/media/tbw/TropicalEventSummary/PSHTBW_2024AL09_Helene_Summary.pdf

Tallahassee, FL WFO Impacts:

https://www.weather.gov/media/tae/TropicalEventSummary/PSHTAE_2024AL09_Helene_ImpactNarratives.pdf

Summary: https://www.weather.gov/media/tae/TropicalEventSummary/PSHTAE_2024AL09_Helene_Summary.pdf

Key West, FL WFO Impacts:
https://www.weather.gov/media/key/TropicalEventSummary/PSHKEY_2024AL09_Helene_ImpactNarratives.pdf

Summary: https://www.weather.gov/media/key/TropicalEventSummary/PSHKEY_2024AL09_Helene_Summary.pdf

Miami, FL WFO Impacts: https://www.weather.gov/media/mfl/TropicalEventSummary/PSHMFL_2024AL09_Helene_ImpactNarratives(1).pdf

Summary: https://www.weather.gov/media/mfl/TropicalEventSummary/PSHMFL_2024AL09_Helene_Summary.pdf

Melbourne, FL WFO Impacts:

https://www.weather.gov/media/mlb/TropicalEventSummary/PSHMLB_2024AL09_Helene_ImpactNarratives.pdf

Summary: https://www.weather.gov/media/mlb/TropicalEventSummary/PSHMLB_2024AL09_Helene_Summary.pdf

Charleston, SC WFO Summary: https://www.weather.gov/chs/HurricaneHelene2024

Impacts: https://www.weather.gov/media/chs/TropicalEventSummary/PSHCHS_2024AL09_Helene_ImpactNarratives.pdf

Summary: https://www.weather.gov/media/chs/TropicalEventSummary/PSHCHS_2024AL09_Helene_Summary.pdf

Columbia, SC WFO Impacts:

https://www.weather.gov/media/cae/TropicalEventSummary/PSHCAE_2024AL09_Helene_ImpactNarratives.pdf

Summary: https://www.weather.gov/media/cae/TropicalEventSummary/PSHCAE_2024AL09_Helene_Summary.pdf

Greenville/Spartanburg, SC WFO impacts:

https://www.weather.gov/media/gsp/TropicalEventSummary/PSHGSP_2024AL09_Helene_ImpactNarratives.docx.pdf

Summary: https://www.weather.gov/media/gsp/TropicalEventSummary/PSHGSP_2024AL09_Helene_Summary.pdf

Wilmington, NC WFO Summary: https://www.weather.gov/ilm/Helene2024

Impacts: https://www.weather.gov/media/ilm/TropicalEventSummary/PSHILM_2024AL09_Helene_ImpactNarratives.pdf

Summary: https://www.weather.gov/media/ilm/TropicalEventSummary/PSHILM_2024AL09_Helene_Summary.pdf

Birmingham, AL WFO Impacts:
https://www.weather.gov/media/bmx/TropicalEventSummary/PSHBMX_2024AL07_Helene_ImpactNarratives.pdf

Summary: https://www.weather.gov/media/bmx/TropicalEventSummary/PSHBMX_2024AL07_Helene_Summary.pdf