AMERICAN METEOROLOGICAL SOCIETY:



Project Atmosphere

Hazardous Weather: Hurricanes

—

TEACHER'S GUIDE

Project Atmosphere

This guide is one of a series produced by Project Atmosphere, a National Oceanic and Atmospheric Administration-sponsored initiative of the American Meteorological Society (AMS). Project Atmosphere is an annual K-12 teacher-focused professional development opportunity offered via hybrid delivery that includes several weeks of online coursework and a one-week residency at the National Weather Service Training Center in Kansas City, MO. The goal of Project Atmosphere is to create and train a diverse network of master teachers prepared to integrate atmospheric and climate science in their classrooms and provide peer training sessions. To support these teachers' educational experiences, Project Atmosphere develops and produces a series of course modules and other educational materials.

For further information, and the names of Project Atmosphere course alumni in your state or region, please contact:

American Meteorological Society
Education Department
45 Beacon Street
Boston, MA 02108
amsedu@ametsoc.org

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Module: Hazardous Weather: Hurricanes
Instructor: Project Atmosphere Instructor or Project Atmosphere Graduate
Audience/Grade Level: K-12 Educators

Standards:

Project Atmosphere Fundamental Understandings

13. Tropical Meteorology:
    a. Describe hurricane structure, life cycle, intensity classification, and typical tracks.
    b. Identify tropical cyclone hazards and impacts, with emphasis on storm surge.
    c. Understand the structure and function of NOAA's National Hurricane Center (NHC) operational units and their roles in forecasting, warning issuance, and decision support.
    d. Theorize reasons for improvements in forecast accuracy, particularly in track and intensity of these systems.

Next Generation Science Standards (NGSS)

Performance Expectations

K-ESS3-2. Ask questions to obtain information about the purpose of weather forecasting to prepare for, and respond to, severe weather.*

4-ESS2-2. Analyze and interpret data from maps to describe patterns of Earth's features.

5-ESS2-1. Develop a model using an example to describe ways the geosphere, biosphere, hydrosphere, and/or atmosphere interact.

MS-ESS2-4. Develop a model to describe the cycling of water through Earth's systems driven by energy from the sun and the force of gravity.

MS-ESS2-6. Develop and use a model to describe how unequal heating and rotation of the Earth cause patterns of atmospheric and oceanic circulation that determine regional climates.

MS-ESS3-2. Analyze and interpret data on natural hazards to forecast future catastrophic events and inform the development of technologies to mitigate their effects.

HS-ESS3-5. Analyze geoscience data and the results from global climate models to make an evidence-based forecast of the current rate of global or regional climate change and associated future impacts to Earth systems.

Science and Engineering Practices

2. Developing and Using Models

4. Analyzing and Interpreting Data

Disciplinary Core Ideas

S2.C: Stability and Instability in Physical System

PS3.C: Relationship Between Energy and Forces

ESS2.A: Earth Materials and Systems

ESS2.C: The Roles of Water in Earth's Surface Processes

Crosscutting Concepts

1. Patterns.

4. Systems and system models.

5. Energy and matter: Flows, cycles, and conservation.

Engage | Tropical Cyclone Hazards

Tropical cyclones are low pressure systems that form over tropical or subtropical ocean regions. They derive their energy from the warm water below and have intense convection surrounding a defined center. Tropical cyclones differ from extratropical cyclones of middle latitudes that form in areas of atmospheric temperature contrast and typically have connected fronts.

Tropical cyclones originate as clusters of clouds over the ocean and can progress from tropical depressions to tropical storms to hurricanes, fueled by the heat drawn from surface waters. They result from convection and the dynamics of rotation. The strongest tropical cyclones in the North Atlantic and Eastern and Central Pacific basins are called **hurricanes**. They are known as typhoons or cyclones in other parts of the world.

Recent hurricanes, such as Helene (2024) and Harvey (2017), caused significant damage to coastal and inland areas. In the cases of these storms and many others, freshwater flooding, along with associated property damage and fatalities, was a major concern. The numerous hazards related to landfalling tropical cyclones include storm surges, freshwater flooding, high winds, rip currents, marine incidents, and tornadoes.

In 2023, AMS highlighted a recent study by NOAA's National Hurricane Center (NHC) in Miami, FL. The NHC study illustrates how direct fatalities from tropical cyclones differed between 1963–2012 and 2013–2022 (**Table 1).**

Table 1. Percentage of fatalities attributed to landfalling tropical cyclone hazards

Hazard	**% (rounded) of direct fatalities from this cause (1963–2012)**	**% (rounded) of direct fatalities from this cause (2013–2022)**
Storm Surge	**49%**	11%
Freshwater Flooding	27%	**57%**
Wind	8%	12%
Surf/Rip Currents	6%	15%
Offshore Marine Incidents	6%	3%
Tornadoes	3%	2%
Other	1%	1%

Group Review and Discussion:

1.) *By what percentage have landfalling tropical cyclone fatalities attributed to freshwater flooding increased between the two periods? Speculate on factors that may have contributed to this increase.*
2.) *Consider the rising percentage of fatalities linked to surf and rip currents. Speculate on where these are more likely to occur with respect to the cyclone center?*
3.) *The storm surge from Hurricane Katrina (2005) caused several hundred fatalities. How might this storm have influenced the percentage of fatalities attributed to storm surge in the two periods noted?*

Explore | Hurricane Helene's Rainfall

Hurricane Helene (2025) was one of the most destructive landfalling tropical cyclones in U.S. history and the deadliest North Atlantic basin storm since Hurricane Maria (2017), which killed nearly 3000 people in Puerto Rico. The majority of Helene's 230 fatalities were due to freshwater flooding, mainly over the Appalachian Mountain Region of western North Carolina and South Carolina.

In a tropical low-pressure system like Helene, strong converging surface winds draw heat and moisture from the warm ocean waters through evaporation. As the air rises and cools, the moisture condenses into clouds, producing precipitation. Tropical cyclones with large circulations, such as Hurricane Helene, can generate high rainfall rates over expansive areas for extended periods. When this broad tropical circulation interacts with a mid-latitude low or front, rainfall can occur well ahead of the cyclone's center. This **predecessor rain event** happened with Hurricane Helene, where a preexisting low-pressure system and accompanying stationary front extended across the Mid-Atlantic and Southeast, and a high-pressure system was located to the east-northeast of the hurricane. Winds spiraling counterclockwise around Helene converged along the stationary front, and air was forced upward by the Appalachian Mountains, enhancing rainfall totals (**Figure 1**).

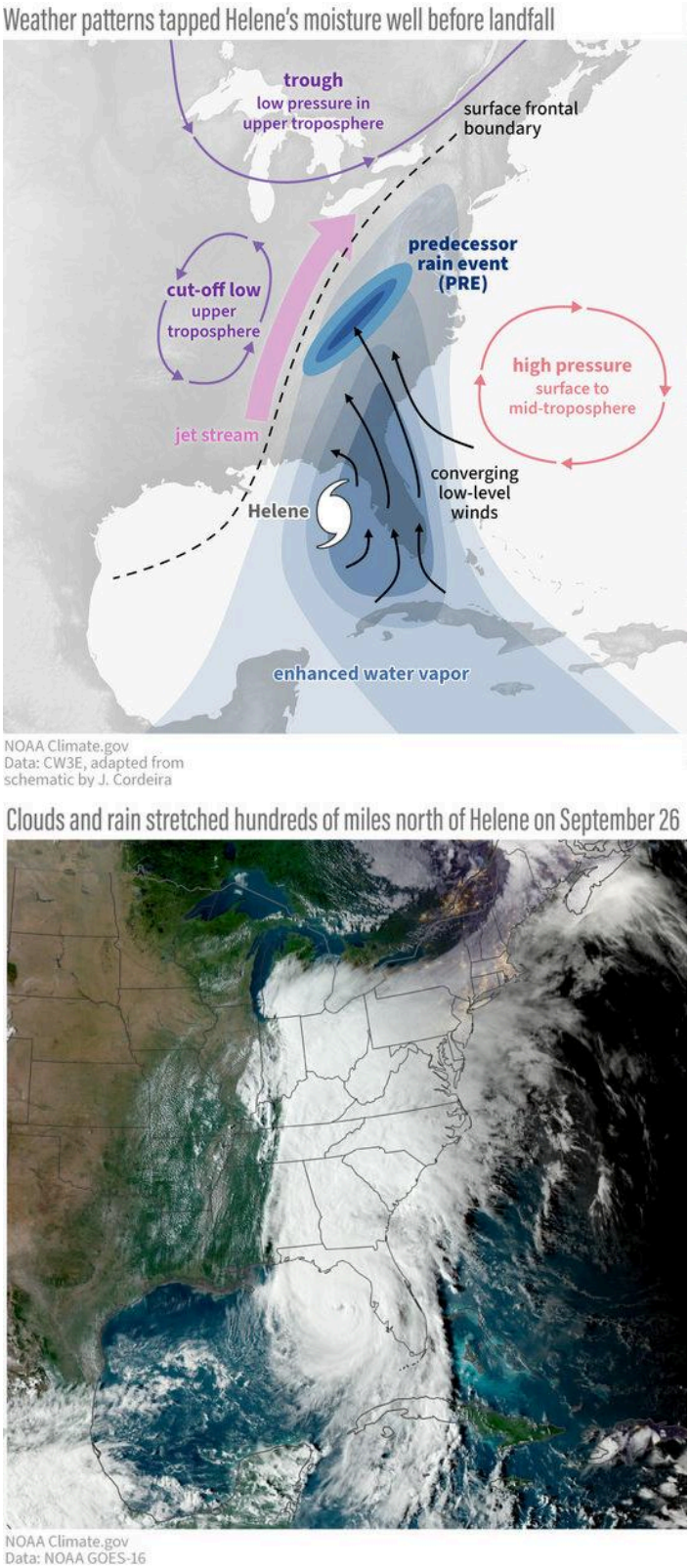


Figure 1. Atmospheric conditions (top) and visible satellite imagery (bottom) as Hurricane Helene crossed the Gulf on 26 SEP 2024. [Thiem, H., and Lindsey, R., 2024]

Asheville, NC, is nestled up against the Appalachian Mountains, which run northeast-southwest through western North Carolina. As Helene approached, winds over the Carolinas blew from the southeast toward the mountains. This caused the air to rise and condense into clouds, causing additional precipitation.

It is estimated that approximately 20 trillion gallons of water fell across Georgia, Florida, Tennessee, North Carolina, and South Carolina during the 5-day period following the passage of these two low-pressure systems. That's 3 million Olympic-sized swimming pools of water! **Figure 2** shows rainfall totals over North Carolina for 25–27 September 2024. This rainfall was a combination of Hurricane Helene's rainfall and the earlier rain.

The highest total rainfall reported in North Carolina was 31.3 in. for Busick, about 42 mi. northeast of Asheville. The tremendous amount of water from Helene, falling on already saturated mountainous terrain, funneled into reservoirs unable to contain the massive inflow. Water also channeled into river basins, causing them to crest well above flood stage, destroying towns along rivers while mudslides added to the damage. Tropical storm-force winds, with reports of hurricane-force winds, across western North Carolina only exacerbated the destruction.

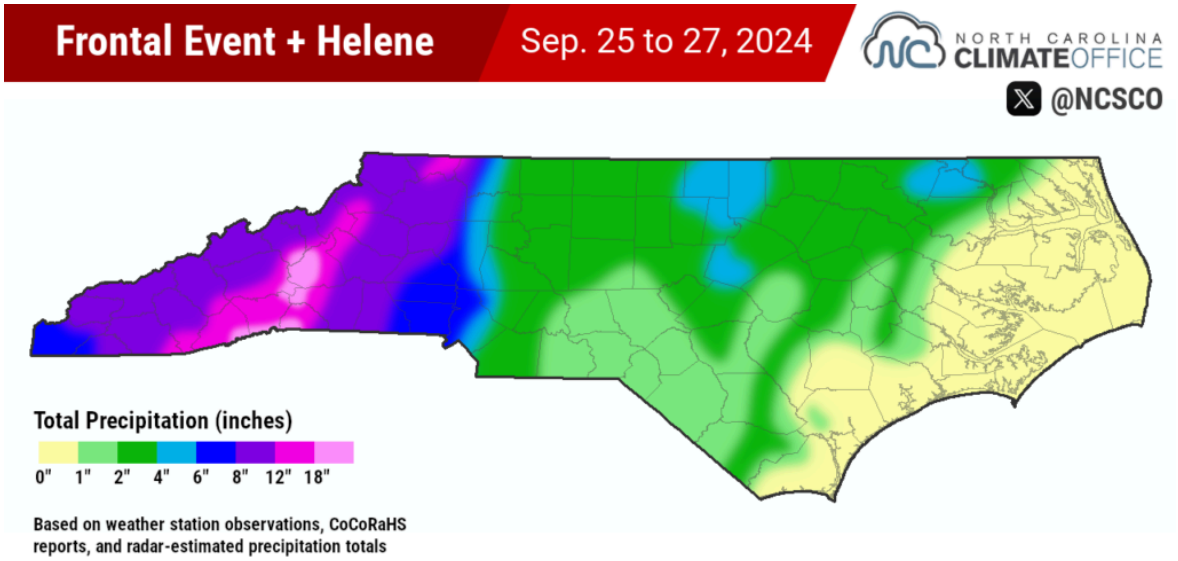


Figure 2. Estimated precipitation in North Carolina from Hurricane Helene and the rainfall that fell before Helene's arrival. [Davis, C., 2024]

Group Review and Discussion:

1.) *To what hurricane hazard were the majority of Hurricane Helene fatalities attributed?*
2.) *What factors came together to cause such high rainfall totals?*
3.) *Speculate on how this situation might have been different over coastal plains vs. a highly mountainous region?*

Explain | Hurricanes

A tropical cyclone begins as a cluster of convective clouds over the ocean associated with a lower-pressure area (such as an easterly wave). It evolves into a larger storm due to the addition of water vapor and latent heat from the surface ocean. The stages of a tropical cyclone are tropical disturbance, tropical depression, tropical storm, and hurricane. In the center of a hurricane, the eye is surrounded by the eyewall and rainbands spiraling counterclockwise and inward. In the North Atlantic Ocean, tropical cyclones are initially steered westward by the trade winds and then turn north and northeast as they are caught up in the prevailing westerlies of middle latitudes. While classified by the speed and damage from their sustained winds, hurricanes also cause significant storm surge flooding, heavy rainfall, and occasionally tornadoes.This section provides more detailed information on the following topics:

- Hurricane Formation
- North Atlantic Hurricane Tracks
- Hurricane Structure
- Wind
- Storm Surge
- Freshwater Flooding
- Tornadoes
- Surf and Rip Currents
- Watches and Warnings

Hurricane Formation

The primary weather features in the tropics include convection associated with the **Intertropical Convergence Zone (ITCZ)**, easterly waves (patterns in the trade winds), and tropical cyclones. A **tropical cyclone** is a warm-core, low-pressure system that develops in a warm and humid air mass. Its formation requires high SSTs, at least 27°C (80°F), in the top 46 m (150 ft.) of the ocean, a sufficient Coriolis Effect, and weak vertical wind shear.

The first stage of a tropical cyclone is a **tropical disturbance**, which is triggered by an easterly wave. Condensation and cloud formation release latent heat into the air, which causes further lifting. Clouds grow vertically, forming a cluster of thunderstorm cells around a central area of low pressure, as seen in **Figure 3**. As the tropical cyclone intensifies, the thunderstorms grow vertically, and more cells are added to the outside of the cyclone.

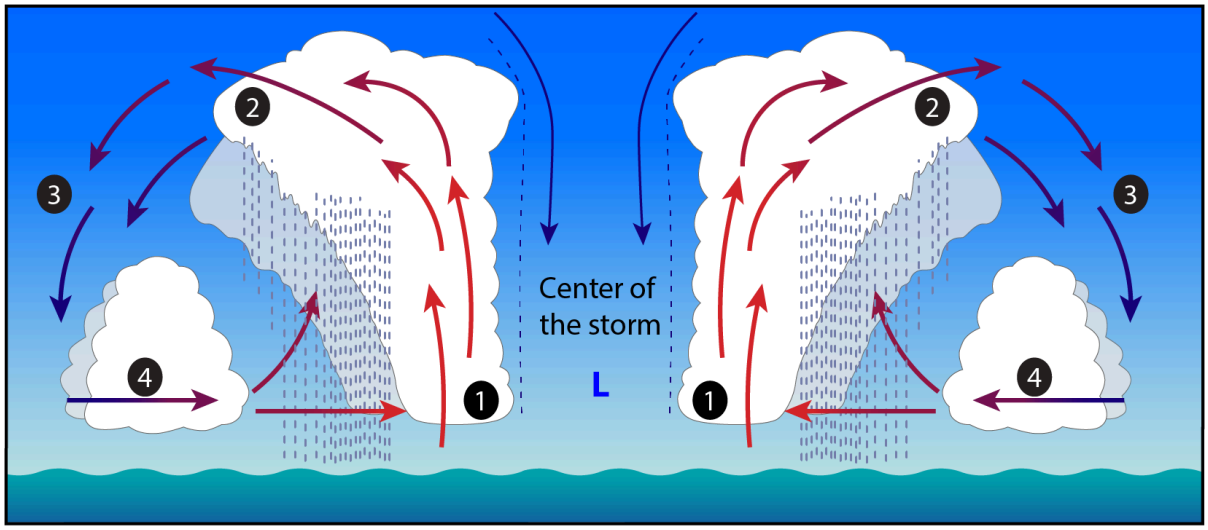


Figure 3. Positive feedback loop of tropical cyclone intensification. (1) Air rises inside the thunderstorm cell. (2) Water vapor condenses into clouds, releasing latent heat into the atmosphere. (3) To compensate for rising air, the air outside the cell sinks and warms adiabatically. (4) Air near the bottom of the storm is heated, expands, and is pulled back into the cell. [AMS - CC BY-SA 4.0]

Thunderstorm cells in a tropical cyclone require warm, humid air from near the ocean's surface to continue intensifying. As saturated air rises in the thunderstorm cell, it cools at the moist adiabatic lapse rate. Condensation releases latent heat into the cloud, causing the air to continue rising. As a tropical cyclone intensifies, the central low is surrounded by the highest cumulonimbus clouds in the cyclone.

The thunderstorm cells organize into bands, and winds accelerate. In the Northern Hemisphere, the winds are deflected by the Coriolis Effect, and the cyclone begins to circulate counterclockwise around the central low pressure. The wind directions near the center of the tropical cyclone result from a balance between the pressure gradient force, Coriolis force (the apparent force that produces the Coriolis Effect), and centripetal (center-seeking) force.

Tropical cyclones do not typically form between 5°N and 5°S due to a lack of the Coriolis Effect. Few systems evolve past a tropical disturbance because the semi-permanent high in the North Atlantic, wind shear, and low humidity aloft inhibit further development. Should the cyclone continue to grow, it becomes a **tropical depression** once wind speeds reach 37 km per hr (23 mph).

As energy is added to the system, the central pressure lowers, and circulation strengthens, leading to a faster inflow of moist air. This leads to more evaporation from the ocean surface, enhanced convection, continued release of latent heat near the center of the system, and further lowering of the central pressure, strengthening the

storm. Once wind speeds exceed 63 km per hr (39 mph), the cyclone becomes a **tropical storm** and is given a name.

A tropical cyclone is classified as a **hurricane** when its maximum sustained surface wind speeds are 119 km per hour (74 mph) or higher. While hurricanes may complete their life cycle in a few days, they can persist for weeks, allowing them to move over new warm water sources that supply additional energy to the system. Hurricanes weaken quickly without ideal environmental conditions.

North Atlantic Hurricane Tracks

Hurricanes of the North Atlantic that threaten the U.S. East Coast and Gulf Coast usually originate over the tropical North Atlantic in three places: off the coast of western Africa, in the Caribbean Sea, or in the Gulf of America (Gulf of Mexico), hereafter known as the Gulf. **Figure 4** shows the paths of North Atlantic hurricanes for 2000–2023. They are shaded according to their strength: a tropical depression is represented in blue, a tropical storm in green, and the five categories of hurricanes are represented in yellow to purple. The color of each path changes as the hurricane forms, intensifies, and dissipates.

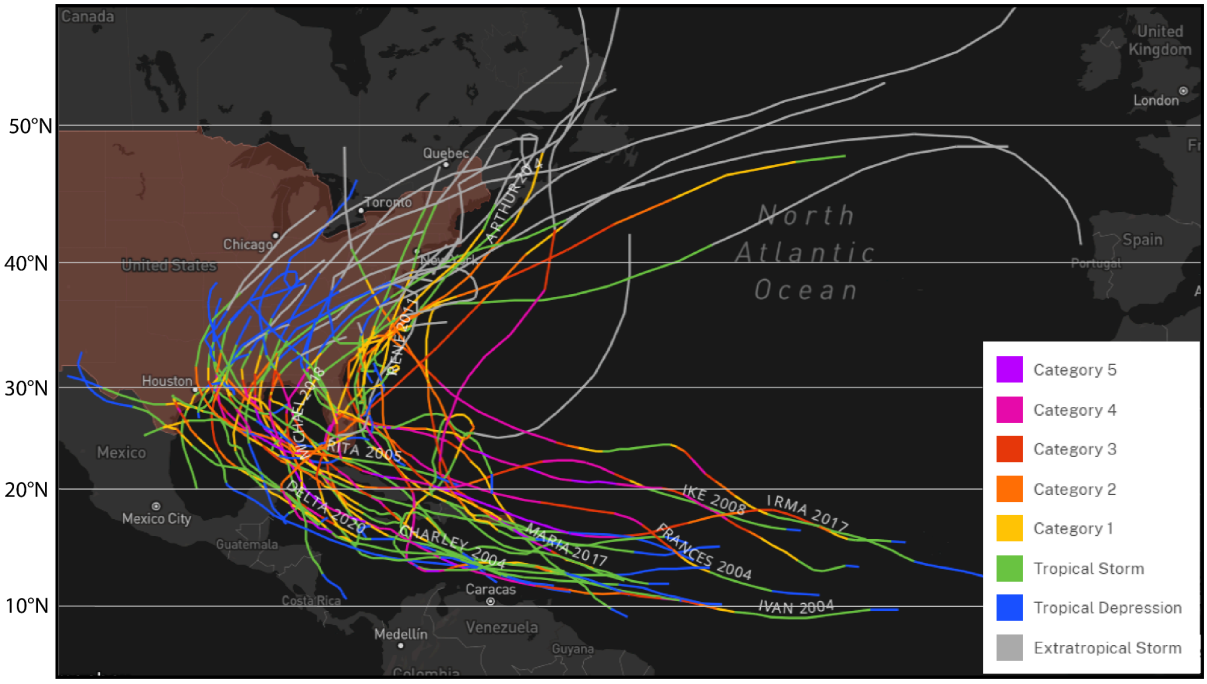


Figure 4. Map of tropical weather system tracks across the North Atlantic Ocean and North America for 2000–2023. [Office for Coastal Management]

Most North Atlantic hurricanes in the Atlantic Ocean and Caribbean Sea form between about 10°N and 20°N, and travel westward at lower latitudes, typically at a forward

speed of up to 15 mph. Hurricanes then curve to the north between about 20°N and 30°N as they approach the belt of prevailing westerly winds. Hurricanes sometimes depart from their expected track, meandering, doubling back, or even moving in figure-eights, making them difficult to forecast accurately. Tropical cyclones, or their remnants, typically accelerate eastward or northeastward after reaching a latitude of approximately 35°N.

Landfalling hurricanes quickly weaken into tropical storms or depressions or, if they travel far enough north, transition into extratropical storms. Hurricanes weaken when they travel over cooler surface waters, encounter a dry air mass, or make landfall, limiting the supply of water vapor and heat. If the hurricane does make landfall, it also encounters greater friction, further slowing the winds. It is important to note that even with this weakening, rainfall totals can still be very high, especially if a weakened system stalls or moves slowly over a particular area.If a storm travels over land but then travels back out over the ocean, it may reintensify.

The official hurricane season in the North Atlantic is from 1 June to 30 November, with peak activity occurring from mid-August to mid-October. However, during some years, warm waters continue to provide ingredients for hurricanes to form outside of those dates.

Hurricane Structure

Hurricanes are organized systems, as seen in **Figure 5**. Once a tropical cyclone reaches hurricane-strength winds, an **eye** typically forms in its center and becomes more defined as the hurricane strengthens. The eye is surrounded by the **eyewall**, which contains the strongest hurricane winds and typically the most intense convection.

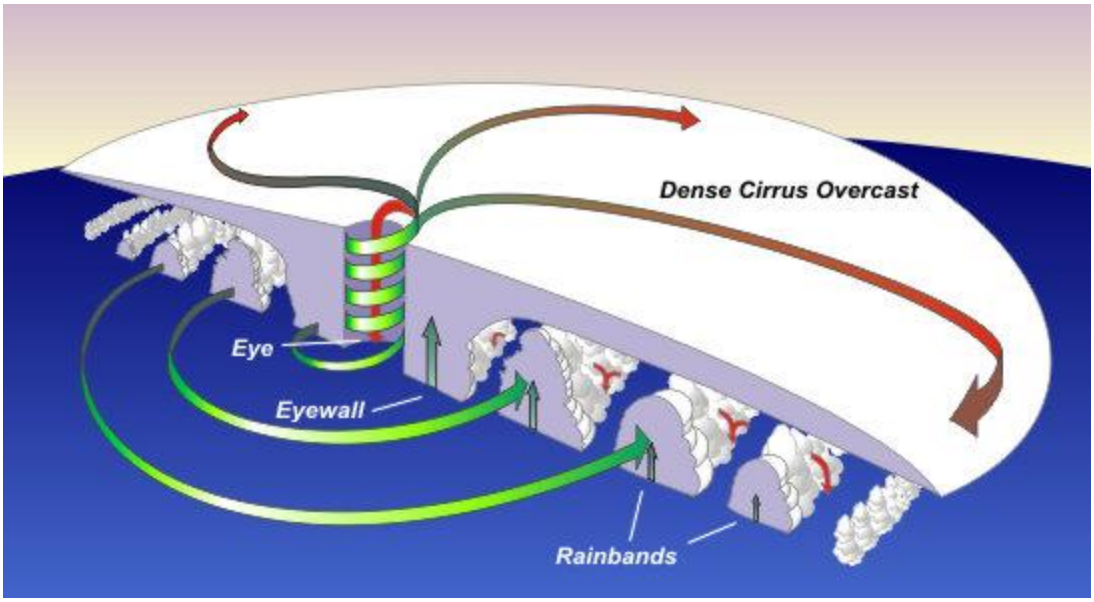


Figure 5. The structure of a hurricane, with red arrows for descending air, especially in the eye, and green arrows for ascending air that spirals counterclockwise and inward with increasing speeds toward the eyewall. [Tropical Cyclone Structure]

The balance of pressure gradient force, centripetal force, and Coriolis Effect, with the principle of conservation of angular momentum, positions the hurricane's maximum winds within the eyewall instead of the eye. The most dangerous and potentially destructive part of a hurricane is the portion of the eyewall where the wind blows in the same direction as the storm's forward motion.

The eye, which ranges from 10–65 km (6–40 mi.) across, features light winds, subsiding air, and near-cloudless skies. The eye often exhibits a "stadium effect" where the eyewall and the eye widen with height due to complex dynamics within the hurricane's inner core (**Figure 6**). The eye of a hurricane is typically formed by the convergence of winds aloft and compressional warming as air descends in the storm's center, causing low pressure. Due to the conservation of angular momentum, air spiraling inward toward the eyewall will accelerate.



Figure 6. Stadium effect inside the eye of Hurricane Dorian in September 2019. [AOML]

Rainbands spiral inward to the eyewall, as seen in Figure 5, and can produce heavy rains, high winds, and tornadoes. Between them, there are sometimes gaps in which little or no rain occurs. As the rainbands spiral inward, they become more vigorous and have a greater vertical extent in that region.

Wind

As a hurricane travels, its rotation and forward motion contribute to the surface wind speeds. In the Northern Hemisphere, the highest rainband wind speeds are to the right of the advancing hurricane's eye. Hurricanes are categorized by their maximum sustained wind speeds, as seen in **Table 2** of the Saffir-Simpson Hurricane Wind Scale, which also estimates property damage for each category of storm. Category 3 and higher hurricanes are known as major hurricanes.

Table 2. Saffir-Simpson Hurricane Wind Scale

Category	Sustained Winds (km per hr)	Sustained Winds (mph)	Damage
1	119–153	74–95	Minimal
2	154–177	96–110	Moderate
3	178–208	111–129	Extensive

4	209–251	130–156	Extreme
5	252 or greater	157 or greater	Catastrophic

*NHC Saffir-Simpson Hurricane Wind Scale

The winds pushing on the outside walls of buildings upon landfall exert a pressure that increases dramatically as winds strengthen. Wind pressure, the force per area caused by air in motion, increases with the square of the wind speed. Hence, tripling the wind speed increases the wind pressure on an external wall by a factor of nine ($3^2 = 9$). Furthermore, debris transported by the wind and hurled against structures adds to the potential damage of strong winds.

Meteorologists had long assumed that strong gusts were responsible for the most serious hurricane wind-related property damage. Following a detailed analysis of the aftermath of Hurricane Andrew (1992), however, T. Theodore Fujita (1920–1998) argued that small but powerful whirlwinds embedded in the hurricane circulation were responsible for the most severe property damage. Whirlwinds combined with the larger-scale hurricane circulation to produce winds estimated at 320 km per hr (200 mph). Based on their mode of origin, Fujita described these whirlwinds as spin-up vortices, small eddies spinning off the eye wall and stretched vertically by powerful convection currents. Stretching accelerates the eddy circulation.

Hurricane winds diminish rapidly once the system makes landfall; most wind damage is confined to within about 200 km (125 mi.) of the coastline. Two factors account for the abrupt drop in wind speed once a hurricane makes landfall. A hurricane over land is no longer in contact with its energy source, warm ocean water. Additionally, the frictional resistance offered by the rougher land surface slows the wind and shifts its direction toward the low-pressure center of the system. This wind shift causes the storm to begin to fill; its central pressure rises, the horizontal air pressure gradient weakens, and winds slacken.

The Saffir-Simpson Hurricane Wind Scale is based on wind speeds. It does not include damage from storm surge, flooding, lightning, tornadoes, or other hazards.

Storm Surge

When a hurricane makes landfall, its strong winds and low pressure create a dome of ocean water, known as a **storm surge**. As a hurricane travels, its rotation and forward motion contribute to the surface wind speeds. In the Northern Hemisphere, because the highest rainband wind speeds are to the right of the advancing hurricane's eye, this is also where the storm surge is the highest. If the storm surge combines with a normal

high tide, it creates an even larger hurricane storm tide. This storm surge, overtopped by high waves, can cause severe flooding in coastal areas. Many U.S. coastal communities are located less than 10 ft. above mean sea level, putting them in great danger from storm surge.

With GIS, the NHC can visualize storm surges on hurricane-prone coasts. **Figure 7** shows the storm surge if a category 5 hurricane made landfall along the coast. An inset of Houston, TX and West Palm Beach, FL shows in detail how much land would be inundated if a Category 5 hurricane made landfall nearby. The map was created with the numerical model **SLOSH** (Sea, Lake, and Overland Surges from Hurricanes). Higher flood levels are shown in red and orange, while lower levels are shown in yellow and blue. A coastline with a shallow continental shelf leads to a larger storm surge than a steep coast. From the storm surge heights shown in the west and east coasts (including the inset of West Palm Beach) of Florida, you can infer that the west coast generally has a shallower continental shelf than the east coast.

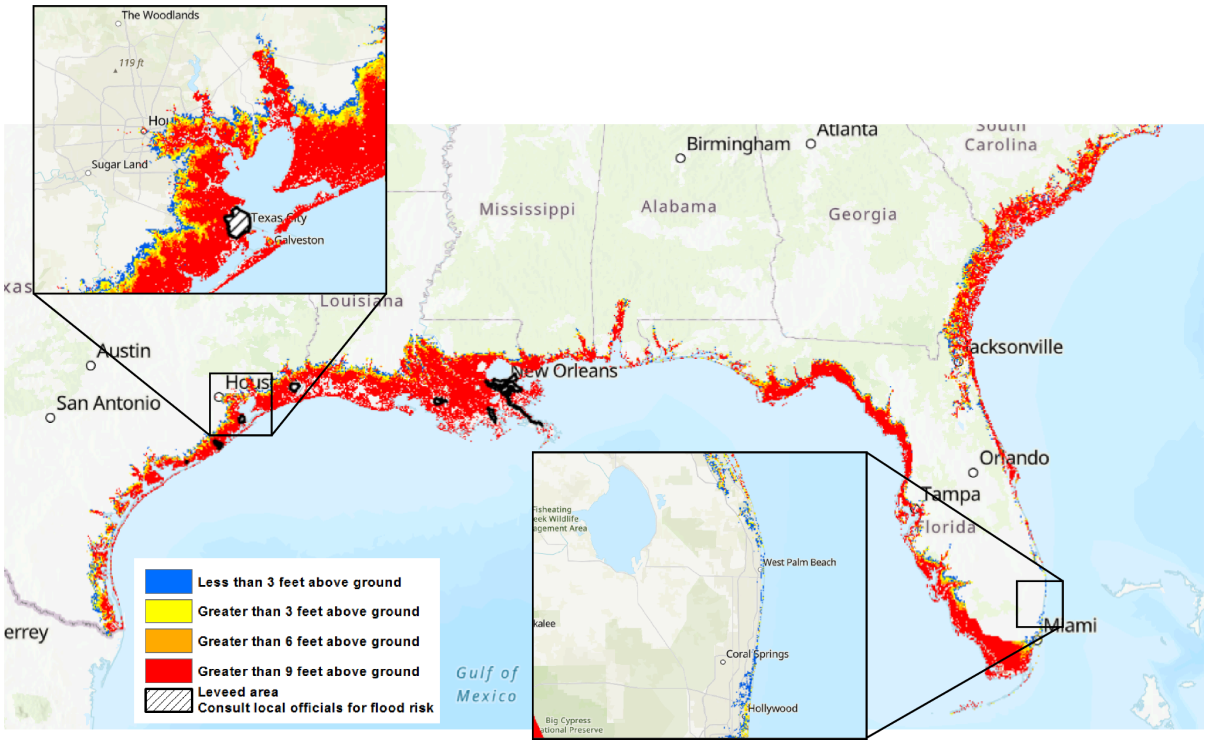


Figure 7. Inundation map for a storm surge from a category 5 hurricane. [NHC]

Louisiana has the most land flooded by the storm surge of a category 5 hurricane in this model. Also, looking at the inset of Houston, TX., storm surge extends into wetlands, bays, and rivers inland from the coastal barrier islands. The potential storm surge flooding in southeastern Louisiana through the Houston region is due to a variety of factors, including a shallow continental shelf, the Mississippi Delta with low land

elevation and a system of wetlands, the position of bays and inlets, and human alterations to the land.

Freshwater Flooding

In addition to storm surge, hurricane hazards include heavy rains and freshwater flooding, strong winds, tornadoes, and waves. Hurricanes and tropical storms produce very heavy rainfall, typically 13–25 cm (5–10 in.). These storm systems draw in tremendous amounts of water through evaporation from the ocean surface and subsequent condensation into clouds. Tropical cyclones typically have very high precipitable water values, meaning the potential for large amounts of rainfall. Hurricane rainfall totals increase with slower storm forward motion, larger size, the presence of a preexisting front, and interaction with mountainous terrain. Even if the system tracks well inland and begins to weaken, heavy rains often persist and may trigger flooding. Two recent examples of hurricanes causing severe inland flooding include Hurricane Harvey (2017) and Hurricane Helene (2024), which was expounded upon in the Engage and Explore section of this module. The catastrophic river flooding event in central Texas in July 2025 was triggered by the remnants of Tropical Storm Barry stalling for many days.

Tornadoes

Although wind speed decreases once a hurricane makes landfall, the system may produce tornadoes. As a storm moves over land its surface winds weaken rapidly while winds aloft remain strong. The wind shear created between horizontal winds at the surface and aloft contributes to tornado development. Usually, only a few tornadoes occur with a hurricane. However there are notable storms, such as Hurricane Milton (2024), that caused 46 tornadoes in Florida, including 3 ranked EF-3.

Surf and Rip Currents

Heavy surf accompanies tropical cyclones at sea and often extends far from the cyclone center. While this increased surf may be appealing to beachgoers and surfers, it can be very dangerous and carries a heightened risk of rip current formation. **Rip currents** are fast, powerful, narrow flows of water moving away from shore. They can sometimes be seen as a seaward-moving channel of water that differs in color from the surrounding water.

Watches and Warnings

As shown in **Table 3**, tropical storm and/or hurricane watches and warnings are issued by the NOAA National Weather Service to indicate threats within particular time periods. NWS may also issue storm surge watches or warnings for a landfalling tropical cyclone.

Table 3. Tropical Cyclone Watch and Warning Definitions [Tropical Definitions]

Tropical Storm Watch	Tropical Storm conditions, including winds of 39-73 mph, pose a possible threat to a specified coastal area within 48 hours
Tropical Storm Warning	Tropical Storm conditions, including winds of 39-73 mph, are expected in a specified coastal area within 36 hours or less.
Hurricane Watch	Sustained winds of 74 mph or higher are possible within the specified area of the Watch. Because hurricane preparedness activities become difficult once winds reach tropical storm force, the Watch is issued 48 hours in advance of the onset of tropical storm force winds
Hurricane Warning	Sustained winds of 74 mph or higher are expected somewhere within the specified area of the Warning. Because hurricane preparedness activities become difficult once winds reach tropical storm force, the Warning is issued 36 hours in advance of the onset of tropical storm force winds. A Hurricane Warning can remain in effect when dangerously high water or a combination of dangerously high water and exceptionally high waves continues...even if the winds have subsided below hurricane intensity.
Extreme Wind Warning (EWW)	Sustained surface winds of 115 mph or greater from a MAJOR Hurricane (Category 3, 4, or 5) are expected within the next hour. This is usually associated with the eyewall of a major hurricane and is considered your final call to shelter in place.
Storm Surge Watch	The possibility of life-threatening inundation from rising water moving inland from the shoreline somewhere within the specified area, generally within 48 hours, in association with an ongoing or potential tropical cyclone, a subtropical cyclone or a post-tropical cyclone.
Storm Surge Warning	The danger of life-threatening inundation from rising water moving inland from the shoreline somewhere within the specified area, generally within 36 hours, in association with an ongoing or potential tropical cyclone, a subtropical cyclone or a post-tropical cyclone. The warning may be issued earlier when other conditions, such as the onset of tropical storm force winds are expected to limit the time available to take protective actions for surge (e.g., evacuations).

Summary

A tropical cyclone begins as a cluster of convective clouds over the ocean associated with a lower pressure area (such as an easterly wave). It evolves into a larger storm due to the addition of water vapor and latent heat from the surface ocean. The stages of a tropical cyclone are tropical disturbance, tropical depression, tropical storm, and hurricane. In the center of a hurricane, the eye is surrounded by the eyewall and rainbands spiraling counterclockwise and inward. In the North Atlantic Ocean, tropical cyclones are initially steered westward by the trade winds and then turn north and northeast as they are caught up in the prevailing westerlies of middle latitudes. While classified by the speed and damage from their sustained winds, hurricanes also cause significant storm surge flooding, heavy rainfall, and occasionally tornadoes.

Group Review and Discussion:

1.) *In which area of a hurricane are the strongest winds found? Where is the hurricane's central pressure measured?*
2.) *Describe the stages of hurricane development.*
3.) *At what latitude band do North Atlantic basin hurricanes typically form? What direction do they initially move?*
4.) *What factors cause storm surge? How do features of the continental shelf and coastline influence storm surge severity?*
5.) *Distinguish between a hurricane watch and a hurricane warning.*

Elaborate | Hurricane Track and Impact Analysis

NOAA's National Hurricane Center issues advisories, including a map of the affected area at least every 6 hr and every 3 hr when there is a tropical storm or hurricane watch or warning in effect. The maps are color-coded along the coasts depending on the nature of the watch or warning.

Figure 8 shows the first advisory issued for Hurricane Helene by the NHC at 11 a.m. EDT, local time, on Monday, 23 September 2024. The center of the system's circulation was in the Caribbean Sea, south of the western tip of Cuba. The panel below the map, under Current Information, describes Helene's maximum sustained wind speed as 30 mph and movement to the north at 6 mph.

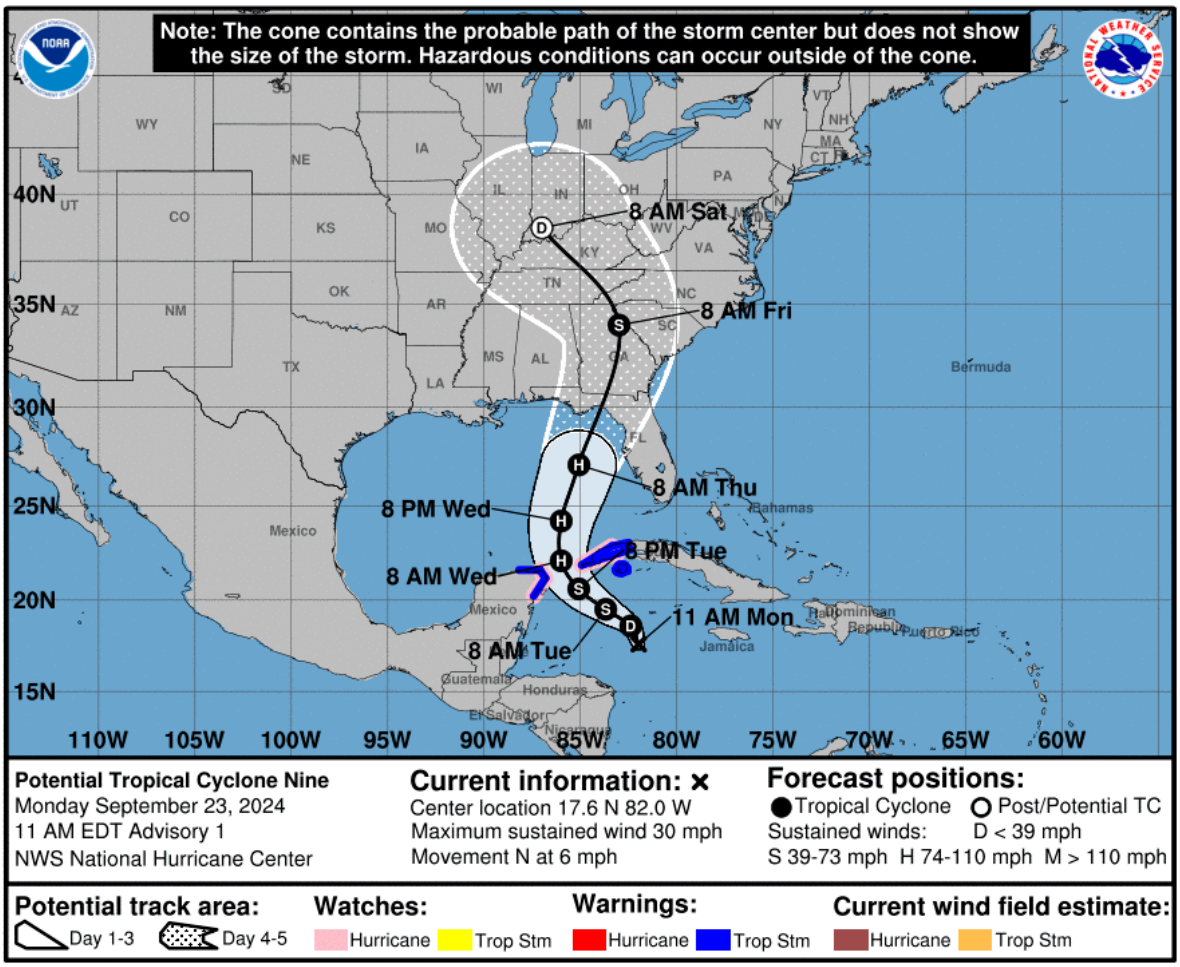


Figure 8. Tropical Storm Helene advisory on 11 a.m. EDT, 23 SEP 2024. [NHC]

For NHC advisories, the cyclone's current position is marked by an X. Large black circles display the forecasted positions and strength, depression (D), tropical storm (S), category 1 or 2 hurricane (H), or major hurricane of category 3 or more (M), with the local time and a white cone of uncertainty for the five days following the current position.

1. Still a tropical storm in Figure 8, Helene was projected to intensify into a hurricane by _____.
   a. 8 a.m. EDT on Tuesday, 24 September
   b. 8 p.m. EDT on Tuesday, 24 September
   c. 8 a.m. EDT on Wednesday, 25 September
   d. 8 p.m. EDT on Wednesday, 25 September

Figure 9 shows Helene's position and forecast advisory at 10 a.m. CDT (11 a.m. EDT) on Wednesday, 25 September, 2 days after Figure 12B-1. With a wind speed of 80 mph, Helene was a category 1 hurricane.

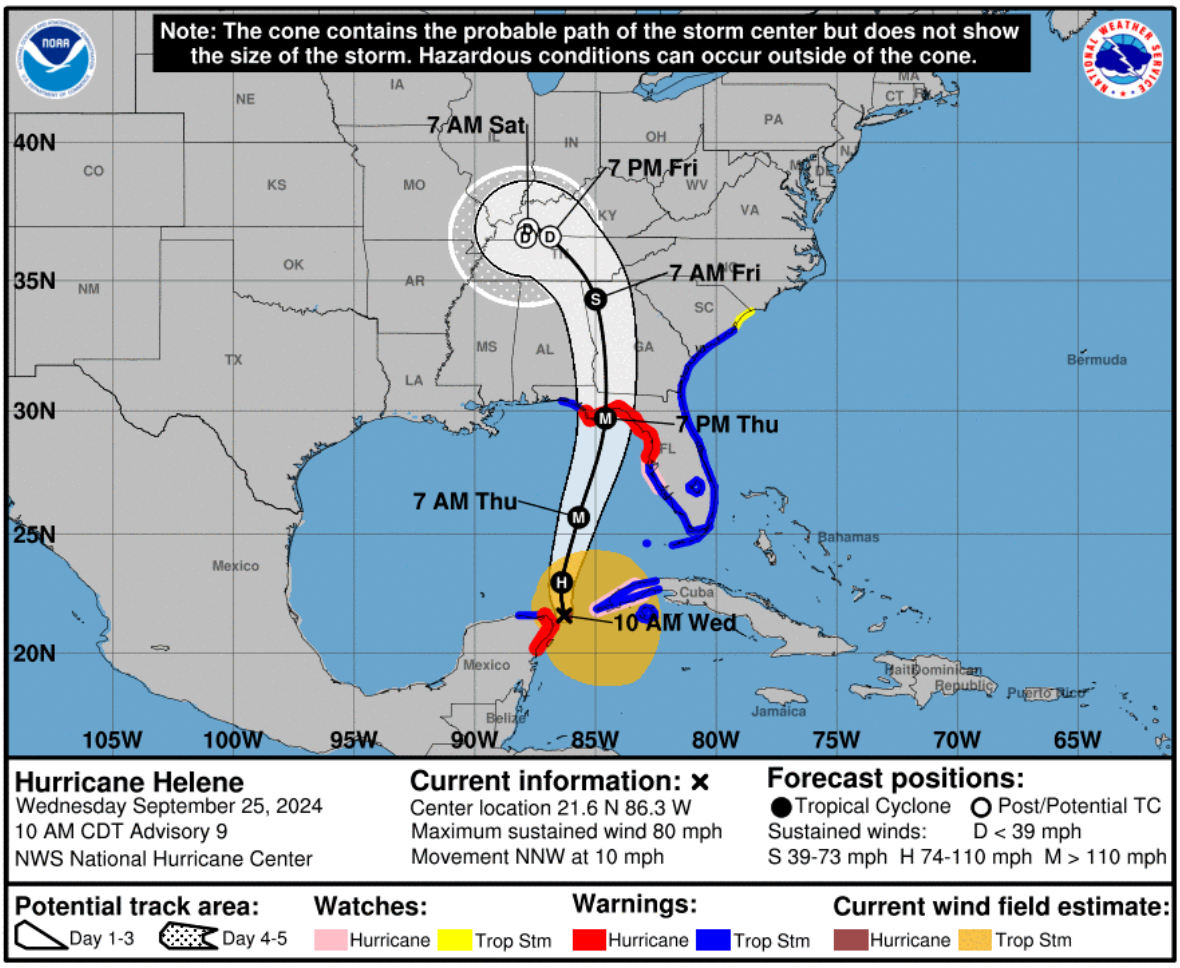


Figure 9. Hurricane Helene advisory on 10 a.m. CDT, 25 SEP 2024. [NHC]

The orange shading around Helene's current location on the map shows the area experiencing tropical storm wind speeds. As Helene grew in size and speed, as seen in later advisories, brown shading indicates hurricane-force winds. Advisories are posted along multiple coasts, showing both watches and warnings for hurricanes and tropical storms.

2. Compare the predicted time and location that Helene would intensify into a hurricane in Figure 8 to the actual time and location in Figure 9. Helene became a hurricane _____ the predicted location.
   a. 2 hr earlier and south of
   b. 2 hr earlier and close to
   c. 2 hr later and south of
   d. 2 hr later and close to

Watches are issued where tropical storm or hurricane-strength winds are possible within

48 hr, and warnings are issued where they are expected within 36 hr. Watches and warnings are issued with the expectation that people will secure property and find shelter or evacuate promptly.

3. In Figure 9, Helene was forecasted to make landfall in Florida by 7 p.m. CDT (8 p.m. EDT) on Thursday. At the time of that advisory, all 4 types of watches and warnings were active in the U.S., Mexico, and Cuba. The Florida Keys had an alert of winds _____.
   a. between 39–73 mph possible within 48 hr
   b. between 39–73 mph expected within 36 hr
   c. greater than 74 mph possible within 48 hr
   d. greater than 74 mph expected within 36 hr

Figure 10 shows Helene's position and forecast at 11 p.m. EDT on Thursday, 26 September 2024, 36 hrs after Figure 9.

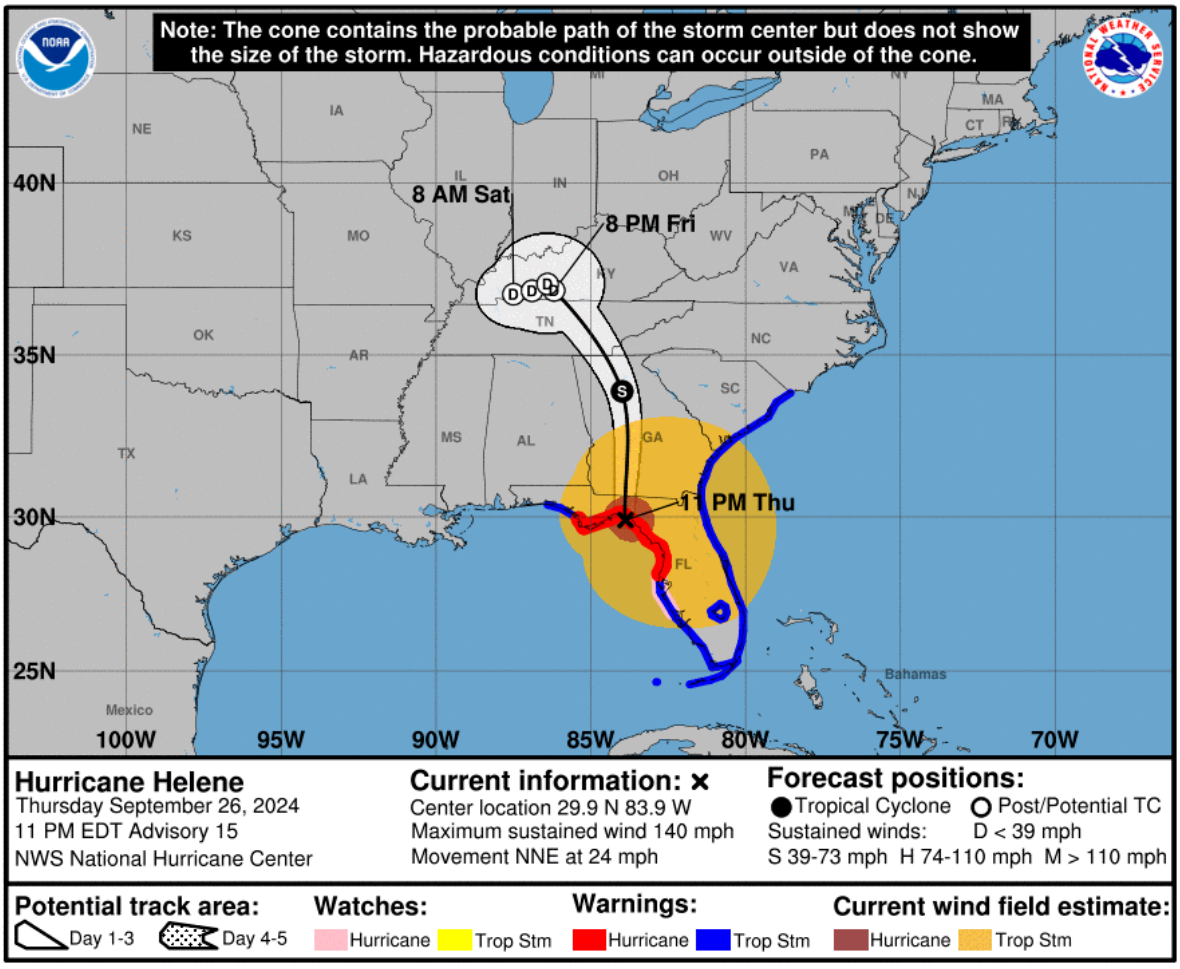


Figure 10. Hurricane Helene advisory on 11 p.m. EDT, 25 SEP 2024. [NHC]

4. With a wind speed of 140 mph, Hurricane Helene was a Category _____ hurricane.
   a. 1
   b. 2
   c. 3
   d. 4
   e. 5

5. In Figure 9, Hurricane Helene was predicted to make landfall in Florida at 7 p.m. CDT (8 p.m. EDT) Thursday, but Figure 10 shows that it made landfall at _____ on Thursday. This means that Hurricane Helene was traveling _____ predicted after passing by Cuba.
   a. 11 a.m. EDT ... faster than
   b. 11 p.m. EDT ... slower than
   c. 8 p.m. EDT ... at about the speed that was

6. After making landfall in Florida, Helene was expected to weaken to a tropical storm, then dissipate in _____.
   a. Alabama
   b. Georgia
   c. South Carolina
   d. Kentucky

Only a month and a half before, Hurricane Debby had made landfall in Florida's Big Bend, and then Helene hit the same region. The NWS Tallahassee Forecast Office reported Helene's impacts on Florida. Cedar Key, FL, recorded a storm surge of about 11 ft. (3.4 m) above mean sea level, approximately 2.4 ft. above the previous record set by Hurricane Idalia in 2023. The flooding inundated at least 15 ft. above normally dry ground, and flooding combined with sustained winds of up to 56 mph with gusts of up to 85 mph caused widespread power outages and tree damage, destroying whole communities. Because Hurricane Helene was moving relatively quickly at 24 mph, catastrophic inland flooding from rainfall was limited in Florida, though Apalachicola, FL received 8.6 in. (21.8 cm) of rain.

Impacts

Helene slowed after landfall and dumped rain over a several hundred-mile-wide swath of the country, including Georgia, South Carolina, North Carolina, Tennessee, Kentucky, and Virginia. A predecessor rain event, with many areas receiving over 3 in. and some mountainous areas with more than 8 in., had already saturated the ground and caused minor flooding. In some mountainous regions, the direct rainfall from the storm added 8–20 in. to these totals.

Figure 11 shows the rainfall totals in the Southeast for 25–28 September 2024, with higher totals in reds and purples and lower totals in green. Asheville, NC, is circled in white.

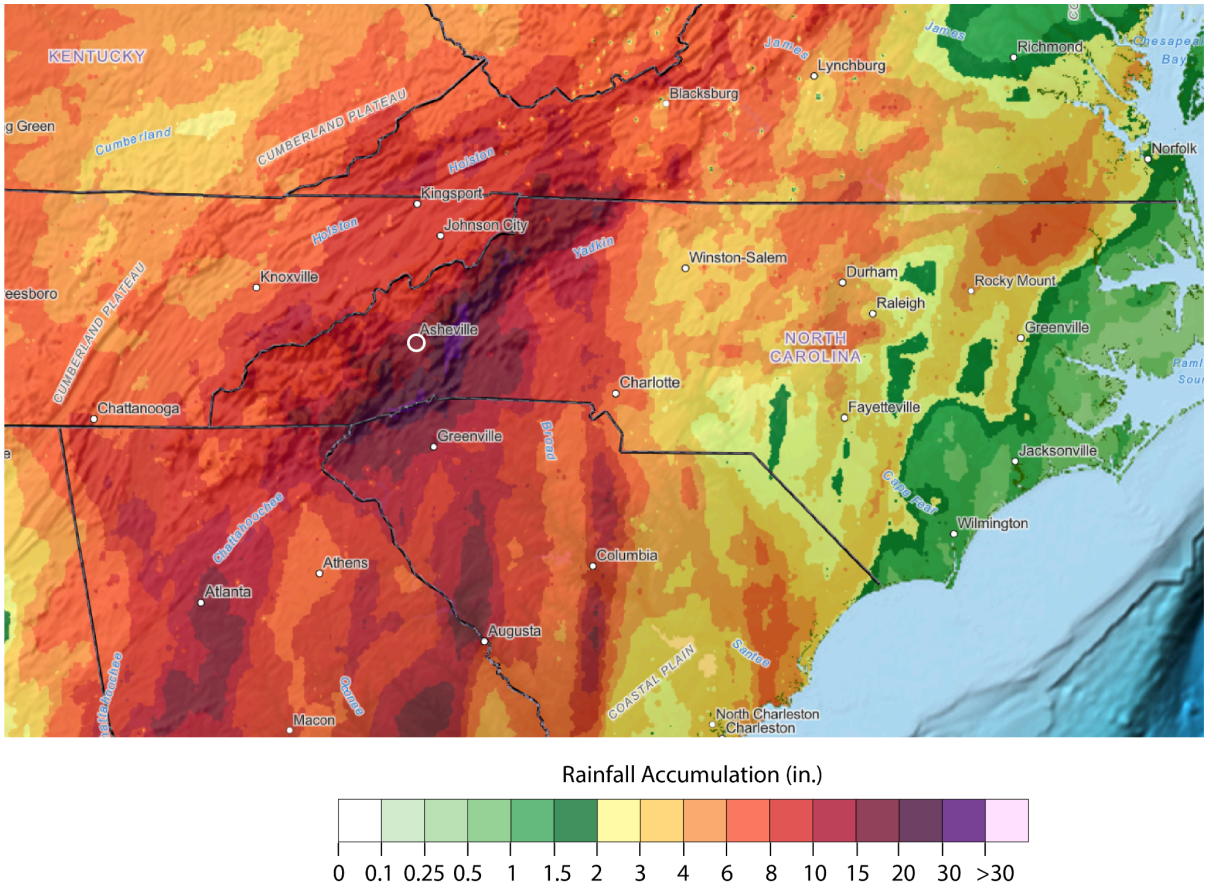


Figure 11. Rainfall accumulation (in.) in the Southeast from 12Z on 24 SEP 2024 to 12Z on 28 SEP 2024. [NWS]

7. Asheville received nearly 8 in. of rain during the predecessor rain event, which combined with another 8 in. of rain as Helene passed over for a total of _____ in. Some higher locations to the east of Asheville received more than _____ in.
   a. 9 ... 15
   b. 11 ... 20
   c. 16 ... 30
   d. 21... 40

This amount of water could not infiltrate into the already saturated ground, so it ran off the surface, swelling rivers and streams over their banks. **Figure 12** shows the stream gauge height at the French Broad River in Asheville from 25 to 30 September 2024. The shading indicates the flood stages.

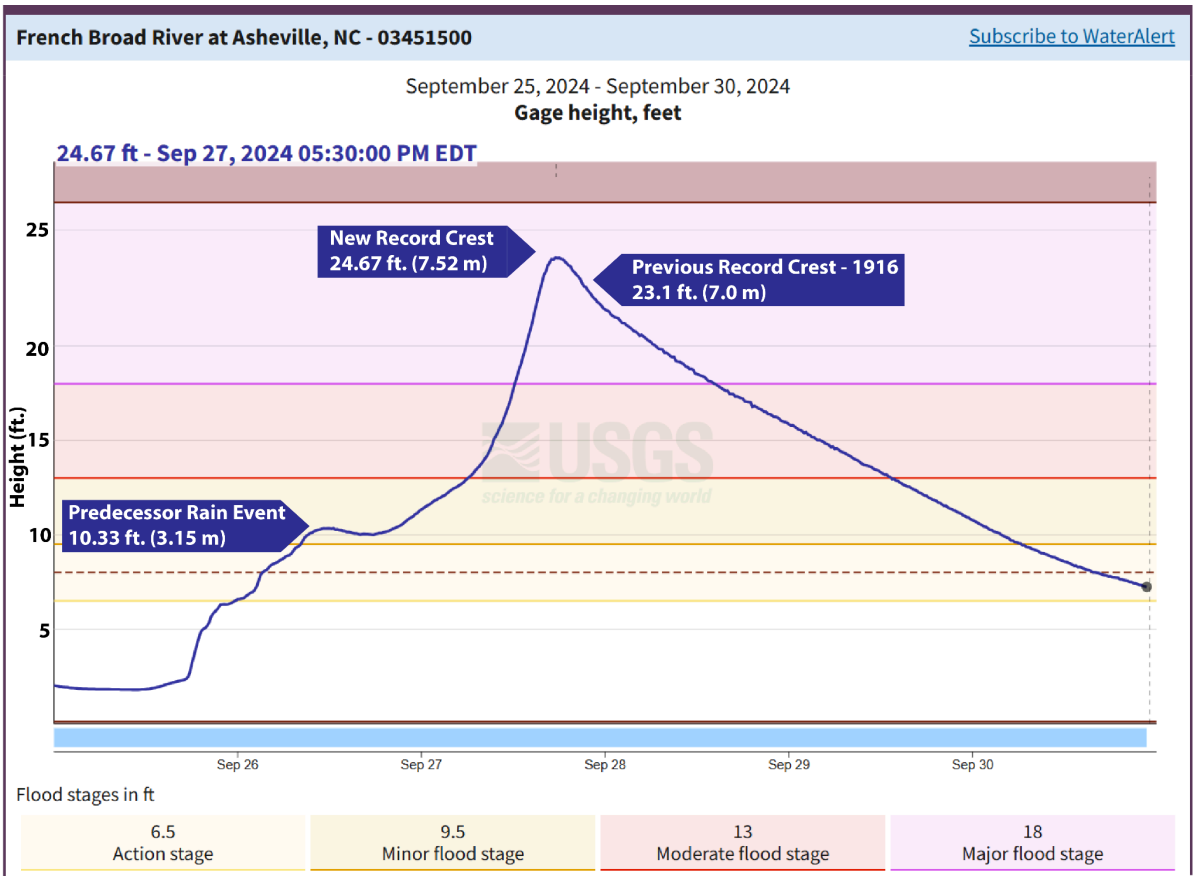


Figure 12. Observed water levels (ft.) in the French Broad River in Asheville, NC for 25–30 SEP 2024. [USGS Water Data]

8. During the predecessor rain event, the river rose to 10.33 ft., _____ above the normal 1.82 ft. at which the river flowed before the storm started. At this point, the river _____.
   a. 4.61 ... had not flooded
   b. 6.41 ... required action
   c. 8.51 ... had a minor flood
   d. 9.31 ... had a moderate flood

9. Before 28 September, the river crested at 24.67 ft., having gained another _____ ft. of water from Helene.
   a. 7.74
   b. 11.27
   c. 14.34
   d. 22.86

Evaluate | Hurricane Understandings

10. North Atlantic basin hurricanes are most likely to form and initially move westward in what latitude band?
    a. 2°N and 10°N
    b. 10°N and 20°N
    c. 20°N and 30°N
    d. 30°N and 40°N

11. The most intense convection is located in the hurricane _____.
    a. eye
    b. eye wall
    c. inner rain bands on the eastern side
    d. outer rain bands

12. A Category 3 hurricane has maximum wind speeds of _____ mph.
    a. 39–73
    b. 74–95
    c. 96–110
    d. 111–129

13. Storm surge is typically highest to the _____ of the advancing hurricane eye.
    a. left
    b. right

14. Which of the following factors does not increase hurricane maximum rainfall totals?
    a. large storm size
    b. fast forward speed
    c. mountainous terrain
    d. presence of front in the storm path

15. Tornadoes are most likely to occur in a hurricane's _____.
    a. eye
    b. eye wall
    c. outer rain bands

16. From 2013 to 2022, the majority of landfalling tropical cyclone fatalities are attributed to _____.
    a. freshwater flooding
    b. storm surge
    c. surf and rip currents

d. wind

Workshop Extensions | Additional Activities

1. When a tropical storm or hurricane is reported, monitor the Internet and TV for information on the storm's progress. Plot the position of the storm's center on a classroom map or tracking chart. Also, mark the coastline along which hurricane watches and warnings have been issued. For more information, see https://www.nhc.noaa.gov/.
2. Invite individuals who have experienced hurricanes to share their stories with the class.
3. What can individuals, families, and communities in coastal areas do to meet the hurricane threat? If you live in a coastal area, what are the preparedness and response plans of your family and community?
4. For more information on hurricane and general severe weather preparedness, see https://www.weather.gov/wrn/.

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