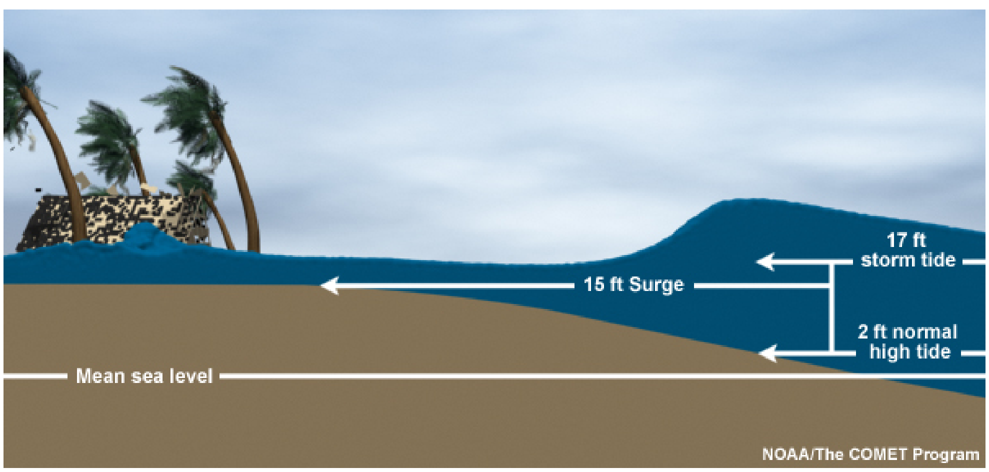
BOLIVAR PENINSULA IN TEXAS AFTER HURRICANE IKE (2008)

Introduction to Storm Surge

What is Storm Surge?

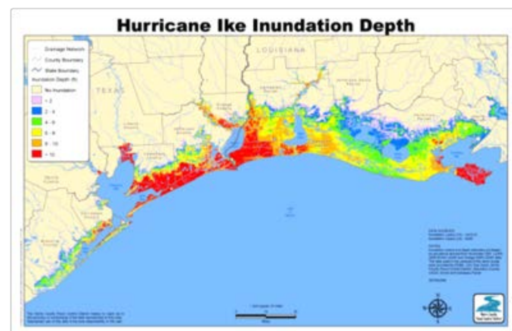


Storm surge is an abnormal rise of water generated by a storm, over and above the predicted astronomical tide.

- It's the change in the water level that is due to the presence of the storm
- Since storm surge is a difference between water levels, it does not have a reference level

Storm tide is the water level rise during a storm due to the combination of storm surge and the astronomical tide.

- Since storm tide is the combination of surge and tide, it *does* require a reference level
- A 15 ft. storm surge on top of a high tide that is 2 ft. above mean sea level produces a 17 ft. storm tide.



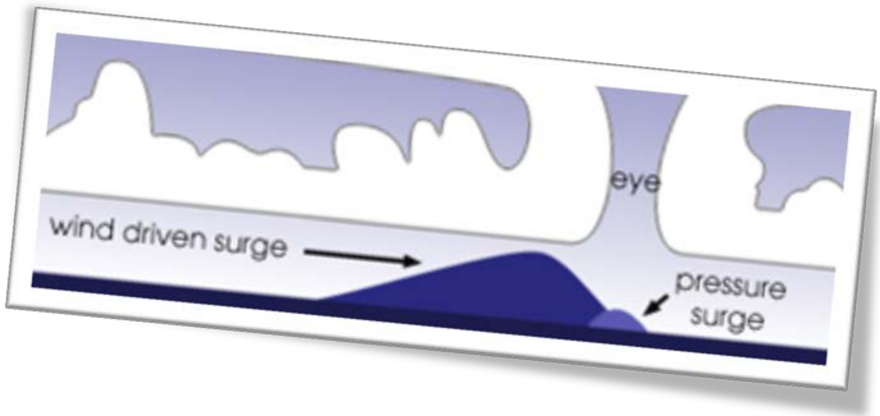
Inland Extent

Storm surge can penetrate well inland from the coastline. During Hurricane Ike, the surge moved inland nearly 30 miles in some locations in southeastern Texas and southwestern Louisiana.

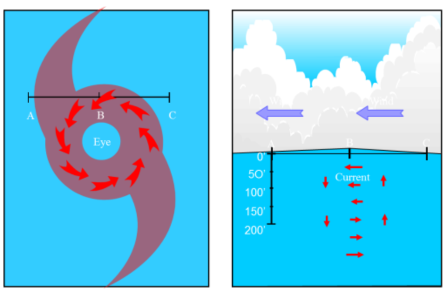
Vulnerability

All locations along the U.S. East and Gulf coasts are vulnerable to storm surge. This figure shows the areas that could be inundated by water in any given category 4 hurricane.

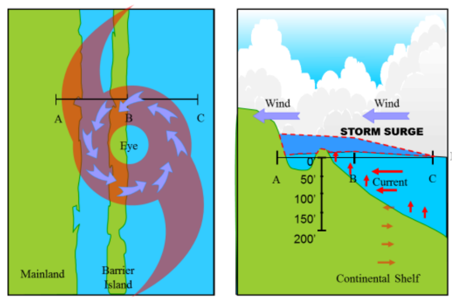
What causes Storm Surge?



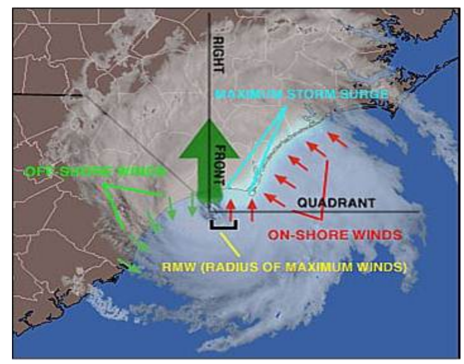
Storm surge is caused primarily by the strong winds in a hurricane or tropical storm. The low pressure of the storm has minimal contribution!



The wind circulation around the eye of a hurricane (left above) blows on the ocean surface and produces a vertical circulation in the ocean (right above). In deep water, there is nothing to disturb this circulation and there is very little indication of storm surge.

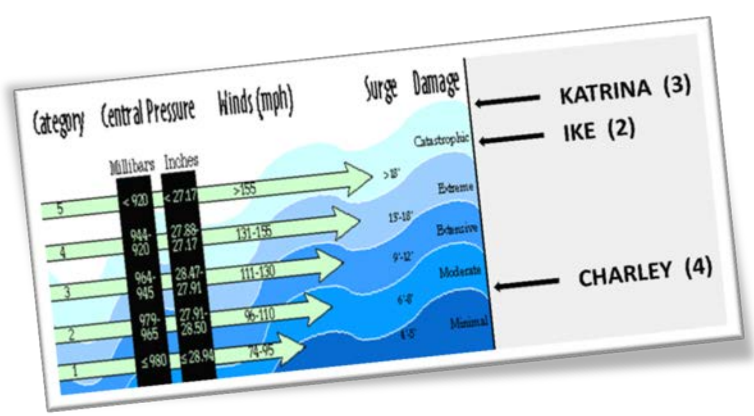


Once the hurricane reaches shallower waters near the coast, the vertical circulation in the ocean becomes disrupted by the ocean bottom. The water can no longer go down, so it has nowhere else to go but up and inland.



In general, storm surge occurs where winds are blowing onshore. The highest surge tends to occur near the "radius of maximum winds," or where the strongest winds of the hurricane occur.

The Saffir-Simpson Hurricane Wind Scale: Surge Not Included



Too many exceptions to fit the scale:

- Hurricane Katrina, a **category 3** at landfall in Louisiana, produced catastrophic damage with a 28-ft. storm surge.
- Hurricane Ike, a **category 2** at landfall in Texas, also produced catastrophic damage with a 20-ft. storm surge.
- Hurricane Charley, a **category 4** hurricane at landfall in Florida, produced a storm surge of 6 to 8 ft.
- Hurricane Irene, a **category 1** hurricane at landfall in North Carolina, produced extensive damage with an 8 to 11 ft. storm surge.

STORM SURGE: BEFORE AND AFTER

Before Hurricane Katrina

After Hurricane Katrina

Images courtesy of David and Kimberly King, Waveland, Mississippi.

FAST FACTS

32%

Population density increase in coastal counties along the Gulf of Mexico coastline from 1990 to 2008.

27%

Percent of major roads in the Gulf region that are at or below 4 ft. elevation.

DID YOU KNOW?

On average, a major hurricane makes landfall in the Gulf Coast region once every 2 years.

Galveston, TX: every 18 years
New Orleans, LA: every 19 years
Mobile, AL: every 23 years
Tampa, FL: every 23 years

Hurricane Ike made landfall at Galveston, Texas, but it still produced significant coastal flooding on the north side of Lake Pontchartrain near Mandeville, Louisiana. Remarkably, the highest sustained wind reported at the lake was only 43 mph!

Total Water Level

In reality, storm surge only makes up a part of what causes water levels to rise along the coast during a hurricane. Here are the others:

Tides

Water levels rise and fall along the coast every day due to the gravitational pull of the moon and sun. This is the tide. In general, areas along the Gulf of Mexico, except Florida, experience one high and one low tide per day (diurnal tide). Elsewhere along the U.S. East Coast experience two high and two low tides per day (semi-diurnal tide).

When the tide is combined with the storm surge, it is called the storm tide. Unfortunately, we can't time the arrival of a storm within the tidal cycle, so it's safer to assume high tide when making decisions.

Waves

Breaking waves contribute to the water level rise through wave runup and wave setup. **Wave runup** occurs when a wave breaks and the water is propelled onto the beach, as in the picture below.

Wave setup occurs when waves continually break onshore and the water from the runup piles up along the coast because it can't get back out to sea. The water level therefore rises as a hurricane approaches, especially since the waves become larger and more water is pushed onshore. Wave setup caused water levels to rise along the Texas coast nearly a day before Ike made landfall (below).

Freshwater Input

Heavy rainfall ahead of a hurricane can cause river levels to rise well inland from the coast. Once all this water flows downriver and reaches the coast, local water levels especially near deltas and in bays will rise.

Total Water Level =
Storm Surge +
Tides +
Waves +
Freshwater Input

The Many Factors that Influence Storm Surge

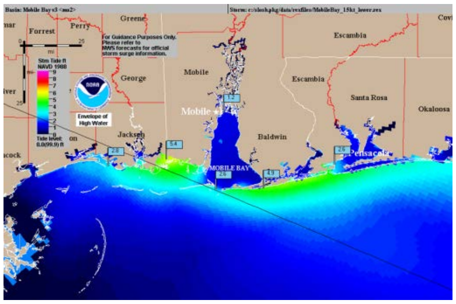
There are several factors that contribute to the amount of surge a given storm produces at a given location:

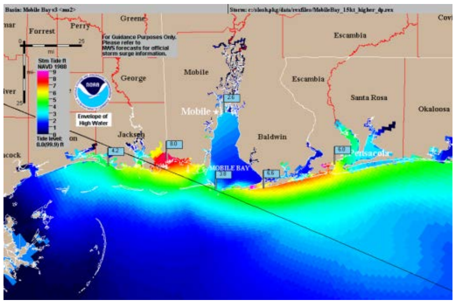
Central Pressure

Lower pressure will produce a higher surge. However, as was shown on page 2, the central pressure is a minimal contributor compared to the other factors.

Storm Intensity

Stronger winds will produce a higher surge. The two images below show how much storm surge is produced by two different storms, the second one having maximum winds that are 15 mph stronger than the first. All other variable are equal.



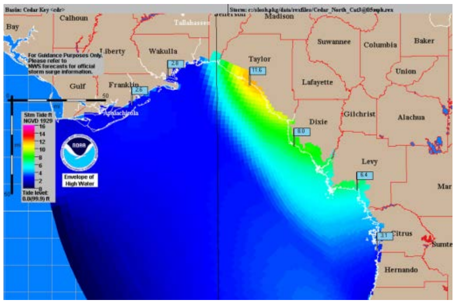


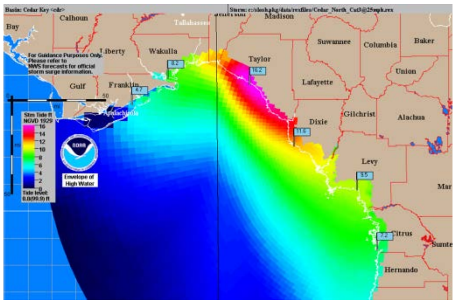
Size

A larger storm will produce higher surge. There are two reasons for this. First, the winds in a larger storm are pushing on a larger area of the ocean. Second, the strong winds in a larger storm will tend to affect an area longer than a smaller storm. Size is a key difference between the surge generated by storms like Katrina and Charley.

Storm Forward Speed

On the open coast, a faster storm will produce a higher surge. However, a higher surge is produced in bays, sounds, and other enclosed bodies of water with a slower storm. The two images below show the surge generated by two hypothetical hurricanes hitting the Florida Panhandle—one moving 5 mph and the other 25 mph.





Angle of Approach to Coast

The angle at which a storm approaches a coastline can affect how much surge is generated. A storm that moves onshore perpendicular to the coast is more likely to produce a higher storm surge than a storm that moves parallel to the coast or moves inland at an oblique angle.

Shape of the Coastline

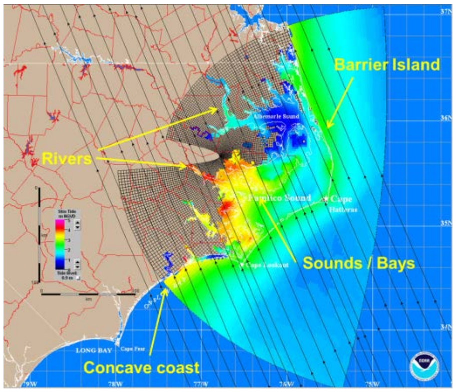
Storm surge will be higher when a hurricane makes landfall on a concave coastline (curved inward, such as Apalachee Bay in Florida) as opposed to a convex coastline (curved outward, such as the Outer Banks of North Carolina).

Width and Slope of the Ocean Bottom

Higher storm surge occurs with wide, gently sloping continental shelves, while lower storm surge occurs with narrow, steeply sloping shelves. Areas along the Gulf Coast, especially Louisiana and Mississippi, are particularly vulnerable to storm surge because the ocean floor gradually deepens offshore. Conversely, areas such as the east coast of Florida have a steeper shelf, and storm surge is not as high.

Local Features

Storm surge is highly dependent on local features and barriers that will affect the flow of water. A good example is the coast of North Carolina, which has the complexities of such features as barrier islands, inlets, sounds, bays, and rivers.



Observing and Measuring Storm Surge

Tide Stations

Tide stations measure the variation in water level along the coast. Since tidal cycles are predictable, storm surge can be calculated by subtracting what the water level would have been in the absence of the storm from the measured water level. NOAA's National Ocean Service (NOS) maintains a network of approximately 175 tide stations throughout the United States, which serve as the foundation for NOAA's tide prediction products. They are generally located in areas that are sheltered from waves. This enables a measurement of the "stillwater" height, or the height of the water when it is not disturbed by waves.

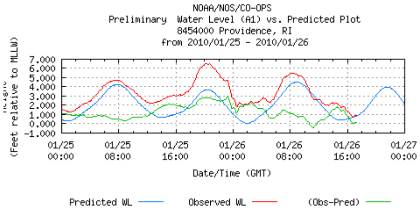
Pros:

- Available in real time
- Generally located in areas sheltered from waves and are able to measure "stillwater"
- Traditionally the most reliable way of measuring surge

Cons:

- Limited number of stations along the coast, so there is often no real-time validation of storm surge in the most vulnerable areas
- Often fail at the height of an event due to loss of electrical power or damage

NOS tide gauge data can be obtained from:
http://tidesonline.noaa.gov
http://tidesandcurrents.noaa.gov



ISSUES WITH STORM SURGE DATA

- Instruments often fail during an event
- Data is often tied to different reference levels, and the conversions are complicated
- Each method has different or even unknown error characteristics
- Data may be measuring different things (stillwater vs. wave runup)

High Water Marks

High water marks are lines found on trees and structures marking the highest elevation of the water surface for a flood event, created by foam, seeds, or other debris. Survey crews are deployed after a storm to locate and record reliable high water marks, usually through GPS methods.

Pros:

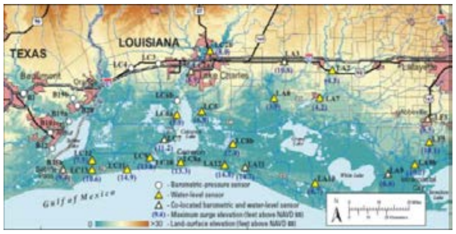
- Traditionally the best method for capturing the *highest* surge from an event

Cons:

- Are not available in real time
- Are perishable, so surveys need to be conducted as soon as possible after a storm
- Can be subjective
- Generally include the effects of wave runup and setup, and only a small percentage represent "stillwater"

Pressure Sensors

Pressure sensors from the United States Geological Survey are temporary barometric pressure sensors that provide information about storm surge duration, times of arrival and retreat, and maximum depths. The sensors are installed around posts and other structures before the arrival of a hurricane.



Pros:

- Are able to provide timing information that cannot be obtained from high water marks
- Can be deployed ahead of a storm at the locations of the highest expected surge

Cons:

- Information from the sensors is not available in real time
- Can include the effects of waves, which will provide an overestimation of the storm surge height
- May be difficult to recover the instruments after a storm