RISING WATERS

Pre-Visit Activity 1: Storm Surge

Directions: Please read the following pages and answer the discussion questions at the end of each section on the provided Answer Sheet on the last page.

Storm surge is the rise in water levels above the normal tide, due to a coastal storm. Storm surge and coastal flooding are responsible for 9 out of 10 deaths during hurricanes, and cause most of the damages to houses and infrastructure. It is important to predict storm surge, to help with evacuation during a storm and with planning between storms.

In this activity, we will learn about the commonly-used models to predict storm surge, and we will develop our own model.

What is Storm Surge?

Hurricanes and other storms can be devastating. As they move over the coast, they bring strong winds that push on the coastal ocean waters, creating large waves and higher water levels. The winds can damage houses, trees, and other items along the coast, but the water is the most dangerous. A few feet of water can float a car and other debris, and several feet of water and waves can knock down a house. The highest water levels that were observed during a hurricane were 28.8 ft -- higher than a two-story house!

Figure 1: Example of how a flood with 9 ft of water above ground will affect a neighborhood. Adapted from The Weather Channel.

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In addition to the water, waves may increase damage to buildings along the coast. Water weighs about 1,700 pounds per cubic yard. This is a large force, and it can be applied repeatedly by dozens or hundreds of waves during a storm. If a structure is not designed to withstand such forces, then it will be demolished.

These two elements (waves and water levels) work together, because the higher water levels allow the waves to extend inland. You have likely seen examples of this devastation. Several storms have affected the U.S. in recent years and damaged our Gulf and Atlantic coasts. Only for the past 10 years in North Carolina, we have lived through Irene, Sandy, Arthur, Matthew, Florence, and Dorian. Each storm was unique in its track and landfall location, but each storm pushed waves and flooding into parts of North Carolina.

Figure 2: Examples of devastation due to waves and flooding during hurricanes. (Left) In 2008, Ike destroyed almost all of the houses on the Bolivar Peninsula, Texas. (Right) In 2012, Sandy destroyed the first few rows of houses in Seaside Heights, New Jersey. Photos courtesy of the Houston Chronicle and Getty Images.

During a storm, the coastal water levels can rise due to several factors. They always rise and fall due to the tides. But on top of the tides, the storm can push the water levels to be higher. This increase in water levels due to the storm is called the **storm surge**. The size of the storm surge at any given location depends on the orientation of the coastline with the storm track; the intensity, size, and speed of the storm; and the local bathymetry.

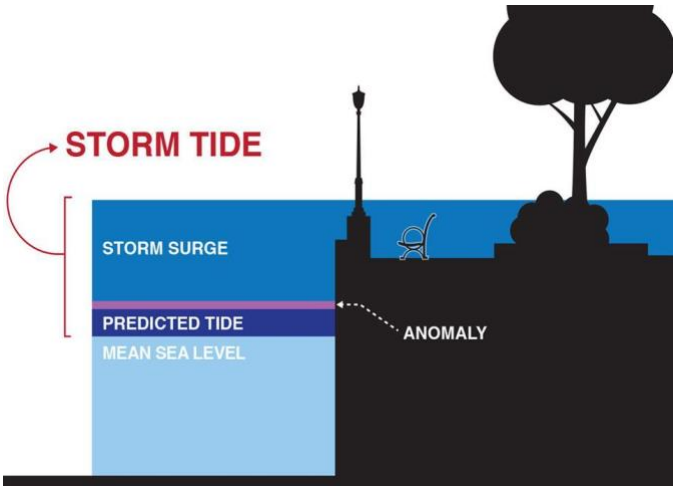

Figure 3: Differences between mean sea level, predicted high tide, and storm surge. Storm surge is the rise in seawater level caused solely by a storm. Storm tide is the total observed seawater level during a storm, which is the combination of storm surge and normal high tide. Adapted from the National Ocean Service.

The combined effect of the tide and storm surge is called the **storm tide**. This is what you see as the total water level, if you are unlucky to be stuck in a storm. And this is what we need to predict. Before the storm arrives, we need to know how high the water will be, what areas will be flooded, and for how long. This information is helpful for evacuation, deployment of resources, and other decisions.

Luckily, it is easy to predict the tides -- people have been doing so for centuries. But it is difficult to predict the storm surge. We need models that include all of the factors that lead to storm surge at a specific location along our coast.

Discussion questions:

1. Which hurricane have you lived through had the largest impact on your community?
2. What were the short-term impacts of the storm on your community?
3. Are there any lingering impacts from the storm?
4. Has storm surge impacted your home? If not, have you seen it impact your community? How?
5. Imagine a hurricane is two days away, and you want to predict how high the water will be at your home. What information do you need for your prediction?

Factors that Influence Storm Surge

Storm surge models are accurate because they consider all of the factors that can influence storm surge. According to the National Hurricane Center, there are several factors that contribute to the amount of surge from a given storm at a given location:

- Wind Speed: Stronger winds will produce a higher surge. This is the primary way that the storm can affect the ocean.
- Atmospheric Pressure: Lower pressure will give a higher surge. However, this is a minimal contributor, compared to the other factors.
- Storm 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.
- 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.
- 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.
- 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.

This is a long list of factors, and it shows the complexity of storm surge. Models for storm surge have to consider all of these factors. But these factors may not be known exactly. For example, during a storm, we may have observations of the wind speeds at a few locations, but we don't know the wind speeds at every point in the storm. These unknowns can lead to errors in the model predictions. Researchers are always trying to remove these errors.

Discussion questions:

6. Which factors are most important for storm surge? Are there other factors not mentioned here that could also impact storm surge?

7. Based on these factors, which parts of the North Carolina coast are most vulnerable to storm surge?