# The Calm Before the Storm: Tracking the Patterns Behind Hurricane Precipitation and Storm Surge

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**Table of Contents:**

Abstract - page 1
Introduction - page 1
Methodology - page 2
Results - page 3
Discussion - page 5
Conclusion - page 6

**List of Figures and Tables:**

Figure 1: A map of the three hurricane landfall locations selected for analysis - page 3
Figure 2: Hurricane Maria Rainfall for Community Collaborative Rain, Hail and Snow Sites - page 3
Figure 3: Hurricane Harvey Rainfall for Non-Categorized Sites (any individual weather stations not associated with a specific corporation) - page 4
Figure 4: Hurricane Irma Rainfall for ICAO Sites - page 4
Figure 5: Linear regression for storm surge versus sea surface temperature for Hurricane Maria - page 5
Figure 6: Linear regression for storm surge versus sea surface temperature for Hurricane Harvey - page 5
Figure 7: Linear regression for storm surge versus sea surface temperature for Hurricane Irma - page 5

**Abstract**

It is predicted that hurricane intensity will continue to increase due to climate change leading to catastrophic damages. The purpose of this study is to determine if there is a correlation between hurricane precipitation and storm surge, along with their storm tracks and locations. After in-depth research on hurricanes and their parameters, precipitation and storm surge were selected as they are under-represented in hurricane studies. Precipitation, storm surge and location data from Hurricane Harvey, Maria, and Irma, was collected through the National Oceanic and Atmospheric Administration hurricane reports and satellite observations. A linear regression was used to look for correlations between sea surface temperatures and storm surge. As expected, the sea surface temperatures for all storms decreased as the storm continued. A significant correlation between hurricane storm surge and precipitation for Hurricane Imra, but no correlation for Hurricane Harvey and Hurricane Maria. These findings can be used to influence future research for different hurricane parameters, along with innovating solutions for stronger infrastructure to prevent damages.

**Introduction**

Climate change has led to increasing numbers of catastrophic hurricanes over the past few years (Cheng et al., 2021). In 2020 alone, 30 storms were named with 11 making landfall. Seven of these storms were classified as major hurricanes, compared to the average of three storms per hurricane season (NOAA, 2021). With an increase in greenhouse gas emissions such as methane and carbon dioxide, the Earth's atmosphere is warming, along with the adjacent oceans. This resulting rise in ocean sea surface temperatures (SST) leads to lower pressure areas, and additional heat energy, becoming the catalyst to strong hurricanes.

Hurricane formation begins with warm temperatures and low pressure, most commonly found in tropical areas such as the US Atlantic and Gulf coasts. This creates a tropical depression. Throughout this depression, the warm air rises, and surrounding winds and storms cool the air, and force them into the eye of the storm, causing the air to converge and sink. A pressure gradient associated with the Coriolis Effect, along with closed circulation, causes the storm to rotate around the eye and spin. With the continuation of this process, these hurricanes can continue to absorb heat and moisture, increasing in size and wind speed.

Many hurricanes have resulted in devastating damage, from Hurricane Katrina in 2005, Hurricane Sandy in 2013, and to Hurricane Harvey in 2017. These storms have resulted in massive amounts of flooding, storm surge, precipitation, and wind damage, causing power outages, and home destruction. These damages cost millions of dollars to repair, and many coastal cities and countries affected by hurricanes can't afford to repair before the next catastrophic hurricane, leading to additional destruction (Czajkowski et al., 2014).

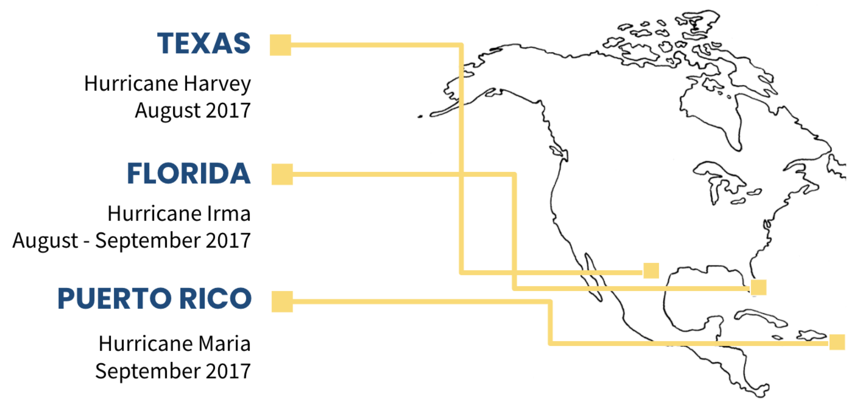
The increase in hurricane strength is predicted to continue, continuing to affect the Southern United States, and increasingly impact the Northern Atlantic region (Mudd et al., 2014). Climate change, among all projected climate patterns, will subject our society to increased hurricane wind damage (Emanuel et al., 2011), along with precipitation (Trenberth, 2011). In addition to increased wind damage, rising sea levels and temperature increases have resulted in higher hurricane storm surges (Marsooli et al., 2019).

While many researchers have studied hurricanes' increase and wind damage association, many fail to study other effects of hurricanes like precipitation. Precipitation is an important factor when assessing hurricane damage since it poses a threat to humans, and can cause significant damage and flooding. For example, Hurricane Ian recently made landfall in Florida, dumping over 20 inches of rain all over different parts of Florida (NOAA, 2022) Another parameter many studies fail to examine is storm surge. Storm surge can cause heavy flooding, posing threats to humans and causing significant damage in housing property. Therefore, the purpose of this study is to determine the effects of rising sea temperatures on hurricane precipitation and storm surge.

**Methodology**

First, a year with strong hurricanes in the Caribbean, Atlantic, and Gulf Coasts was chosen. Once chosen, three of the strongest storms from 2017 (the year chosen) were selected, making sure each storm focused on a different location (Figure 1). National Oceanic and Atmospheric Administration (NOAA) hurricane reports were then used for data collection. Storm surge data and precipitation levels were recorded for specific locations for each storm (Hurricane Harvey in Texas, Hurricane Maria in Puerto Rico, and Hurricane Irma in Florida). Longitude and latitude points for each specific weather station location were also recorded, using the NOAA/Physical Oceanography Division (PhOD) Ocean Observation Satellite, selecting the OceanWatch Night SST, and recording the longitude and latitude of the storm surge locations for Hurricane Maria. The sea surface temperature data was collected for 5 days before the storm, the day of landfall, and 5 days after the storm. After all data was collected, maps plotting the precipitation and location were created for each hurricane. This was done using Anaconda with an NCL coding language. Each map shows select weather stations, their precipitation rates, along with their longitudinal and latitudinal coordinates. A linear regression was completed for each Hurricane's storm surge versus precipitation to look for significant trends. A p-value was then calculated for each linear regression.

Figure 1: A map of the three hurricane landfall locations selected for analysis

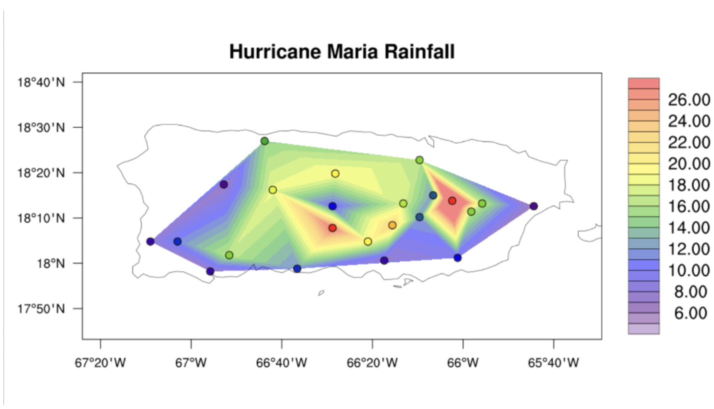



**Results**

Figure 2: Hurricane Maria Rainfall for Community Collaborative Rain, Hail and Snow Sites

Color Side: precipitation in inches

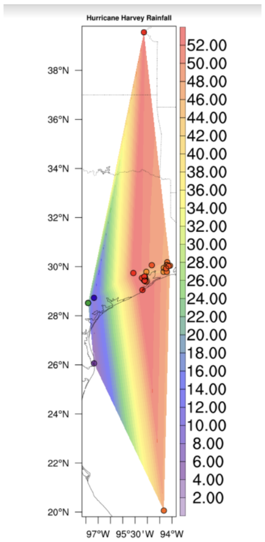
Dots: specific weather sites with their longitude and latitude values



<u>Figure 3: Hurricane Harvey Rainfall for Non-Categorized Sites (any individual weather stations not associated with a specific corporation)</u>

Color Side: precipitation in inches

Dots: specific weather sites with their longitude and latitude values




<u>Figure 4: Hurricane Irma Rainfall for ICAO Sites</u>

Color Side: precipitation in inches

Dots: specific weather sites with their longitude and latitude values

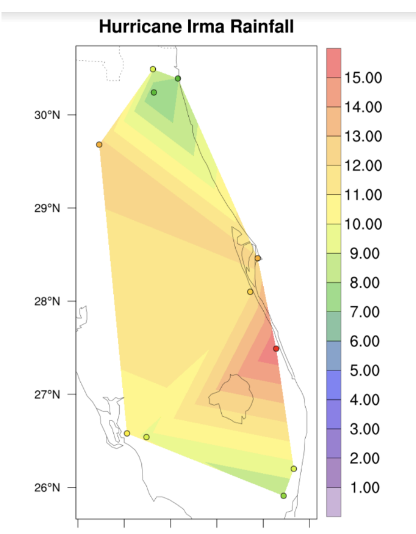


Figure 5: Linear regression for storm surge versus sea surface temperature for Hurricane Maria

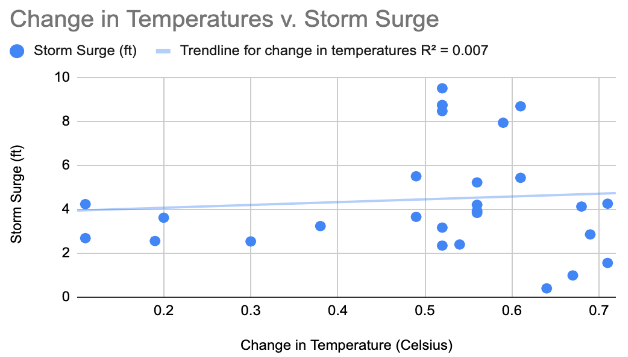



Figure 6: Linear regression for storm surge versus sea surface temperature for Hurricane Harvey

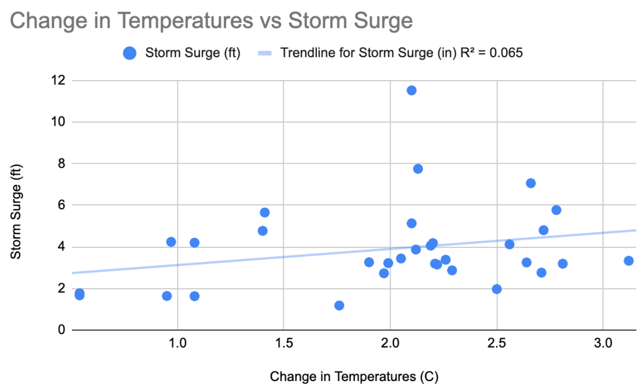
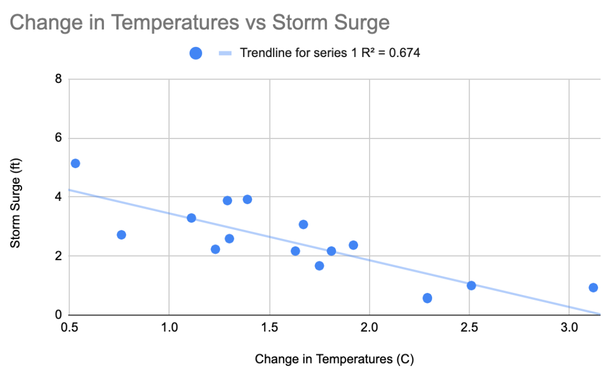



Figure 7: Linear regression for storm surge versus sea surface temperature for Hurricane Irma



As expected, sea surface temperatures generally decreased after a hurricane passed through the area. The sea surface temperatures from 5 days before the storm are higher compared to 5 days after the storm. However, the different storms each had a different trend in rainfall. For Hurricane Harvey, rainfall was heaviest in the eastern part of Texas compared to the western side. Multiple factors could play a role in this, including a more easterly storm track, as well as possible storm surge confounders. An eastern storm track causes more storm building on the coasts, possibly causing more precipitation. For Hurricane Irma, the rainfall trends are a bit more dispersed. Areas on the coast of southern Florida and northern Florida had similar precipitation, but the middle regions of Florida received the most rain. The storm track of Irma itself was more on the western side of Florida. For Hurricane Maria, most of the heavy rainfall was reported in the center parts of the island compared to the coastal areas, which tended to receive less rainfall.

**Discussion**

A p-value of .011 represented the correlation between sea surface temperatures and storm surge, supporting a correlation between those variables. However, for Hurricane Harvey there was a p-value of .1589, and for Hurricane Maria .6616, not supporting a correlation. This suggests that there is no positive correlation between the sea surface temperatures on storm surge, but that there may be a negative correlation between storm surge and change in temperatures. This could be because lower the temperature, the less evaporation, leaving higher water levels which can lead to a higher storm surge. Compared to previous studies, this is surprising since warmer temperatures cause more moisture, sparking stronger storms. This suggests that other hurricane variables need to be studied to find a correlation between a specific variable and hurricane precipitation.

Possible limitations in the methodology include uncontrolled events such as different seasonal weather conditions and patterns. Although 2017 was not an El Nino year, it was the hottest year on record to date. This is significant because it leads to warmer ocean temperatures and higher moisture contents, leading to stronger storms. There were also different pockets of warm waters and cold waters. Different currents controlled the impact and direction of these storms, impacting their paths.

If this study was repeated, it is recommended that multiple storms from varied time periods are assessed. Looking at earlier storms in the 21st century would help decipher the difference in hurricanes with the recent spike in climate change events that affect hurricanes, such as temperature rise, sea temperature rise, different currents, winds, etc. Collecting the sea surface temperatures for more storms and running linear regressions to see if there is a correlation should be performed as well.

**Conclusion**

Hurricanes have always been catastrophic storms, devastating the areas they cross. While conducting this research, the trends between seas surface temperature and storm surge, along with hurricane precipitation and location were traced. There was no significant correlation between sea surface temperature and a hurricane's storm surge. There is however, a relationship between the storm track and its precipitation, along with the location of the storm. Significance for these relationships has yet to be tested.

The importance of this research is that hurricanes are so destructive, and they need to be better understood. It is estimated that since 1981, hurricanes have caused over 2.115 trillion dollars in damages (NOAA Coastal Management, 2022). Many communities affected by hurricanes aren't built to withstand hurricane damage, along with paying for the damages. Knowing the specific cause of hurricane flooding can help engineers target specific problems to create infrastructure and innovative solutions. Different types of housing could be built to withstand flooding, along with other hurricane parameters. With climate change causing more catastrophic hurricanes every year, it is urgent that researchers continue to study hurricanes and the effects they have.

**Bibliography**


Cheng, L. J., and Coauthors, 2021: Upper ocean temperatures hit record high in 2020. Adv. Atmos. Sci., 38(4), 523−530, https://doi.org/10.1007/s00376-021-0447-x.

Czajkowski, J., Villarini, G., Montgomery, M., Michel-kerjan, E., & Goska, R. (2017). Assessing current and future freshwater flood risk from north atlantic tropical cyclones via insurance claims. Scientific Reports, 7(1). https://doi.org/10.1038/srep41609

Emanuel, K. (2011). Global warming effects on U.S. hurricane damage. *Weather, Climate, and Society*, *3*(4), 261-268. https://doi.org/10.1175/WCAS-D-11-00007.1

*Hurricane costs*. NOAA Office for Coastal Management. (n.d.). Retrieved November 2, 2022, from https://coast.noaa.gov/states/fast-facts/hurricane-costs.html#:~:text=%242.155%20trillion,U.S.%20from%201980%20to%202021.

*Hurricane Ian Special Summary: September 2022 National Climate Report*. Hurricane Ian Special Summary | September 2022 National Climate Report | National Centers for Environmental Information (NCEI). (n.d.). Retrieved November 2, 2022, from https://www.ncei.noaa.gov/access/monitoring/monthly-report/national/202209/supplemental/page-5

Marsooli, R., Emanuel, K., & Lin, N. (2019). Climate change exacerbates hurricane flood hazards along US Atlantic and gulf coasts in spatially varying patterns. *Nature Communications*, *10*(3785). https://doi.org/10.1038/s41467-019-11755-z

Mudd, L., Wang, Y., Letchford, C., & Rosowsky, D. (2014). Assessing climate change impact on the U.S. East Coast Hurricane Hazard: Temperature, frequency, and track. Natural Hazards Review, 15(3), 04014001. https://doi.org/10.1061/(asce)nh.1527-6996.0000128

*Record-breaking Atlantic hurricane season draws to an end*. National Oceanic and Atmospheric Administration. (n.d.). Retrieved November 2, 2022, from https://www.noaa.gov/media-release/record-breaking-atlantic-hurricane-season-draws-to-end

Trenberth, K., Dr. (2011). Changes in precipitation with climate change. *Climate Research*, *47*, 123-138. https://doi.org/10.3354/cr00953