Analyzing Weather Station Reliability During Extreme Precipitation Events

HIRES Interns: Mabel Yang, Ihechi Ihesiaba

Mentors: Yuneeb Awan, Aza Derman

Faculty Advisors/Researchers: Professor Nir Krakauer

Address/Affiliation: CUNY CREST High School Initiative in Remote Sensing of Earth System Engineering and Sciences (HIRES) The City College of New York, NY 10031

Background:

The **Global Historical Climatology Network Daily** (GHCNd), maintained by **NOAA's National Centers for Environmental Information** (NCEI), is one of the most intricate networks for collecting daily weather stations. It consists of over 25,000 weather stations across the globe that collect daily climate data, which is recorded and archived to be analyzed in order to better understand climate trends.

Extreme precipitation events, such as hurricanes and intense coastal storms, are significant threats to communities, infrastructure, and emergency response systems. People within areas affected by the harsh weather **rely** on **accurate and complete weather data** for early warning systems and disaster preparedness. However, during extreme events, weather stations can be **disrupted** by power outages, sensor failures, or damage from flooding and wind.

Research Objectives:

Research Question: How reliable are weather stations during extreme precipitation events?

Goals:

1. Determine the reliability of weather stations during major hurricanes in the US through python and QGIS.
2. Evaluate if weather station failures are concentrated in a specific region.
3. Identify patterns in missing or incomplete data in weather stations.

Study Area:

This study focuses on **weather station reliability** through analyzing regions affected by **major hurricanes**, specifically, Southeastern US, Northeastern US, and the Gulf Coast. These regions vary in infrastructure vulnerability and precipitation intensity, allowing them to be case studies.

Case Studies:

Event	Location/Region	Date Range
Hurricane Sandy	NY, NJ, CT, DE	2012-10-25 to 2012-11-05
Hurricane Ida	Louisiana to Northeast (LA, MS, AL, NY, NJ, PA)	2021-08-26 to 2021-09-05
Hurricane Ian	FL, GA, SC, NC	2022-09-25 to 2022-10-05
Hurricane Harvey	TX, LA	2017-08-23 to 2017-09-05
Hurricane Rita	FL, TX, LA	2005-09-18 to 2005-09-26
Hurricane Michael	FL, GA, AL, NC, VA	2018-10-07 to 2018-10-12

How were these hurricanes selected?

1. **Timeframe:** within the past two decades
2. **Impact:** precipitation events that caused significant devastation.
3. **Location:** hurricanes affecting areas to a moderate extent—not too concentrated or broad

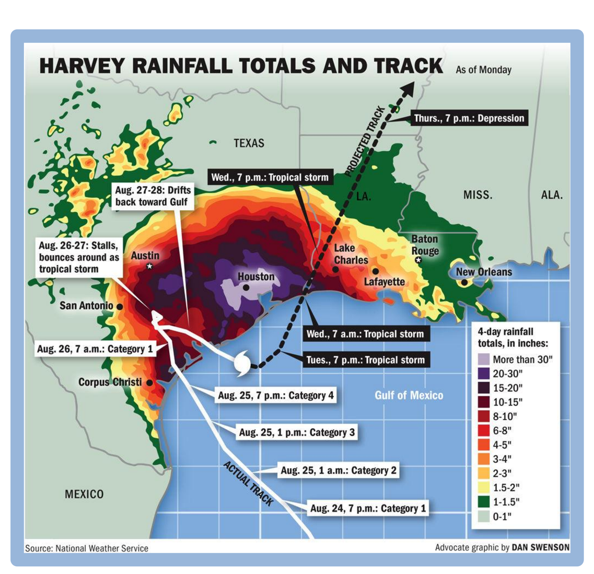
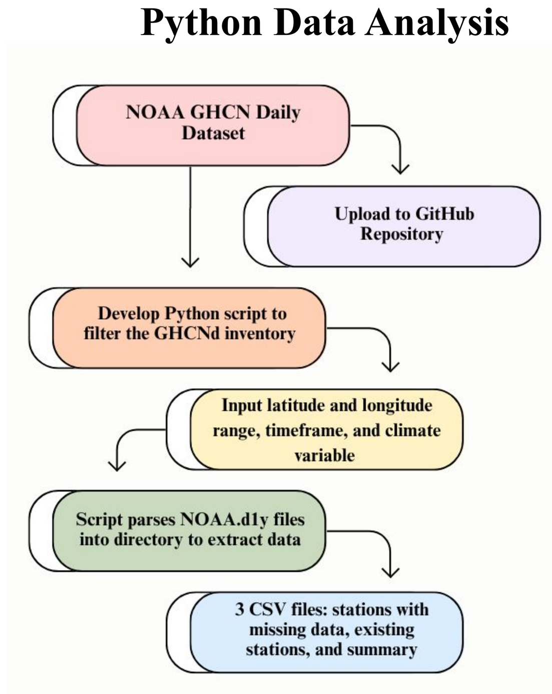


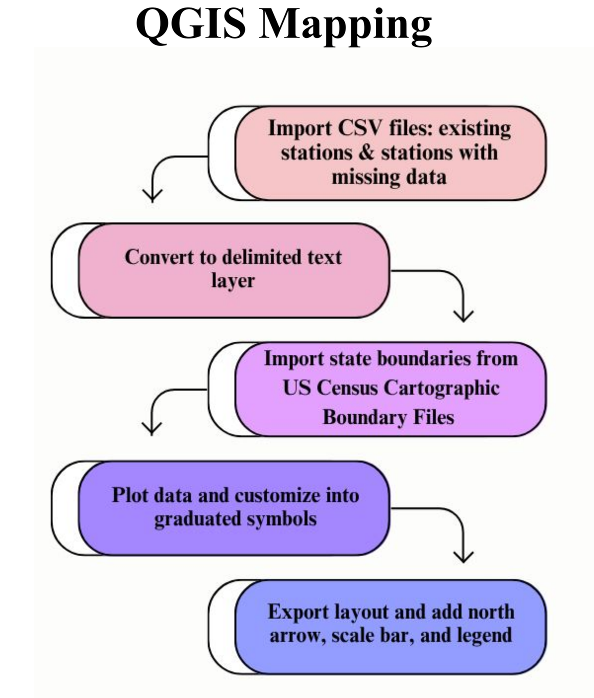
Figure 1: *The total track and rainfall of **Hurricane Harvey** (August 2017). The storm initially made landfall near Corpus Christi and moved towards Houston. Houston received the most rainfall and impact (refer to Figure 4b).*

Methods:

Python Data Analysis



QGIS Mapping



Results and Observations:

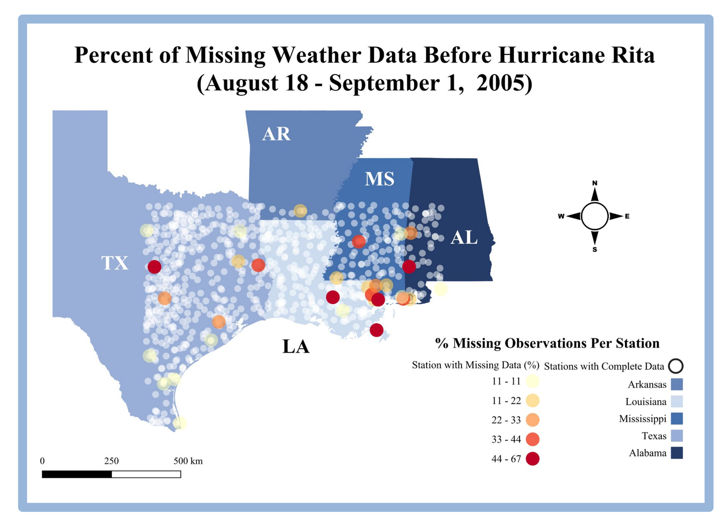


Figure 3a: ***Before Hurricane Rita*** *(2005)—Only a few stations have missing data. These are outliers and mostly caused by station maintenance.*

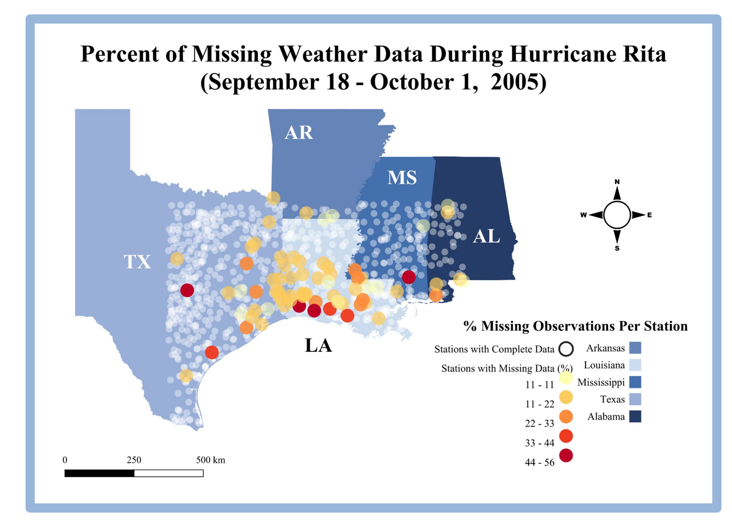


Figure 3b: ***During Hurricane Rita*** *(2005)—Areas near LA's coast and Gulf of Mexico contain the most missing data, which correlates with Rita's landfall zone.*

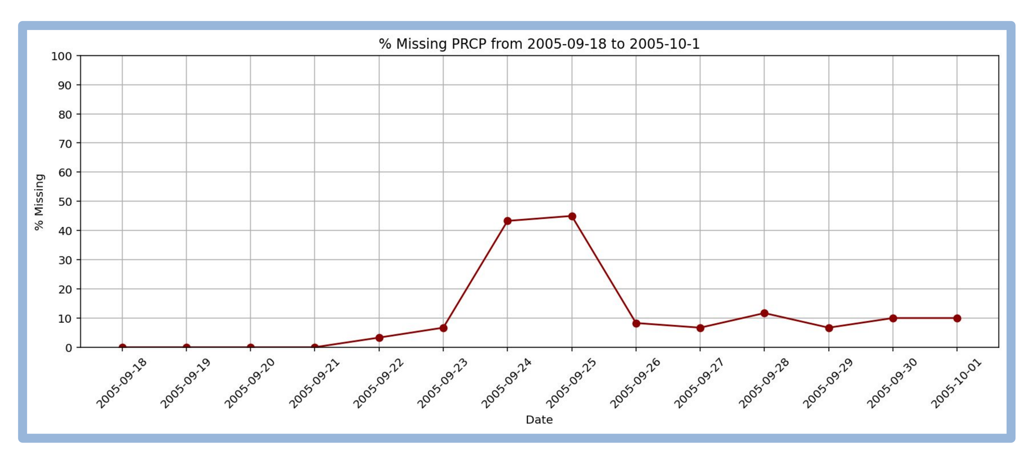


Figure 3c: ***Graph: Hurricane Rita*** *(2005)—The average missing data peaks after the most intense period of the hurricane, reflecting sensor malfunction and damage. The average lingering at 10% after the peak shows lack of repair/maintenance of stations after hurricane.*

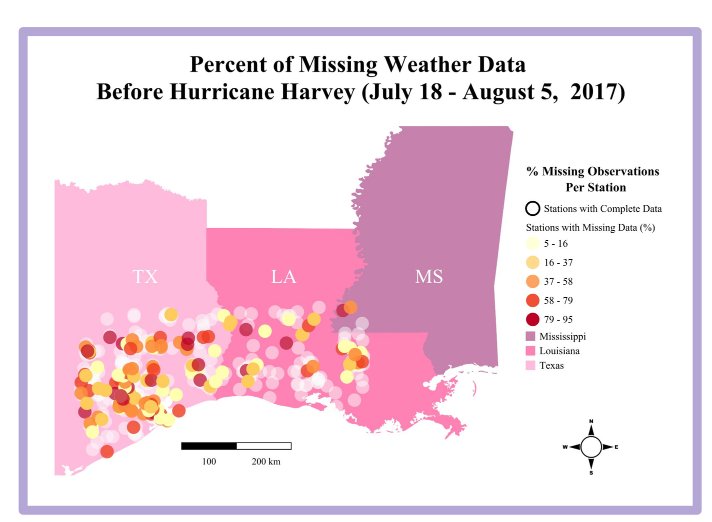


Figure 4a: ***Before Hurricane Harvey (2017)*** *– Stations in Southeastern Texas are missing less values. The stations missing values are scattered rather than concentrated.*

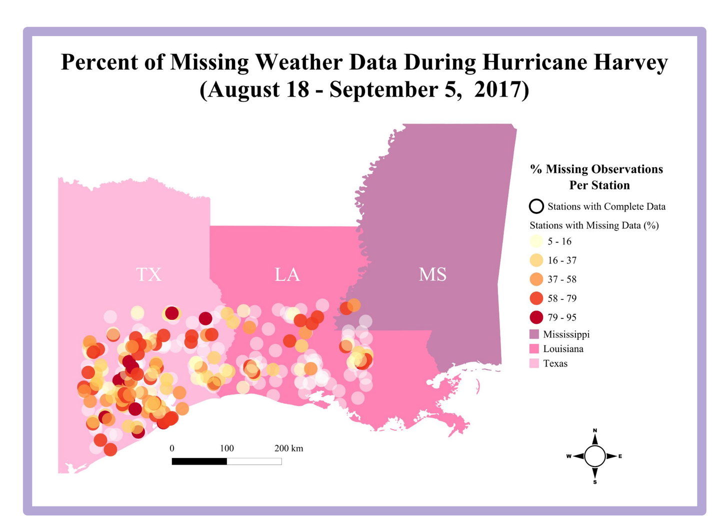
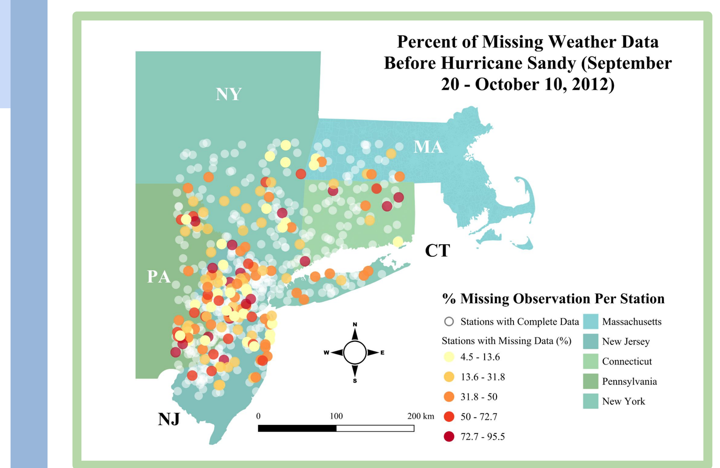


Figure 4b: ***During Hurricane Harvey (2017)****--Stations surrounding the Houston (TX) metro area and the surrounding coastal areas experiencing the most data gaps.*



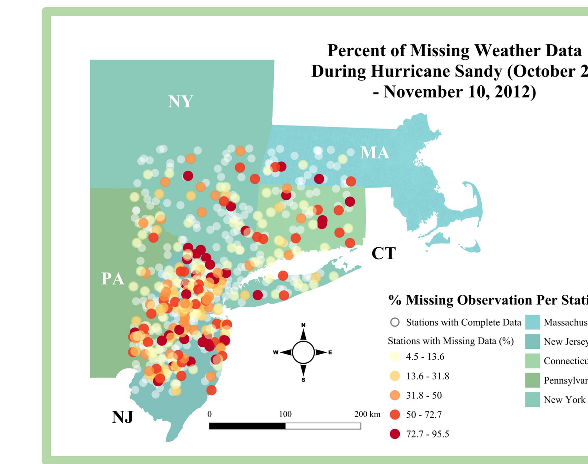


Figure 5b: ***During Hurricane Sandy*** *(2012)—Coastal areas and parts of NJ saw the largest data gaps. NYC also experienced large data gaps, but due to denser station networks, NYC maintained better coverage.*

Figure 5a: ***Before Hurricane Sandy*** *(2012)—Missing data exist, but isn't as intense. Urban areas (NYC), have more stations, thus, higher maintenance and more data gaps.*

Conclusions and Discussion:

Conclusion:

This reveals the **significant disruptions (data gaps)** that weather stations experience during hurricanes.

- Stations near **coastal regions**, where the most impact resides, often display the **highest** amounts of malfunctioning.

This is especially true for **rural areas** as station networks are sparse. This **supports** the initial research question as **reliability varies by region and storm intensity**.

Example:

During **Hurricane Harvey (*Figure 4b*)**, some stations reported over **90%** missing data. This malfunctioning is concentrated towards Houston, where the hurricane impact was the most severe as demonstrated in ***Figure 1***. In contrast, during **Hurricane Sandy (*Figure 5b*)**, New York City experienced data loss, but still maintained function due to the denser network of stations.

Discussion:

This finding has **significant implications** for climate science, general safety, and regional disparities.

- **Without** weather station data, scientists **can't** make correct inferences on storm severity and future trends.

First responders rely on **real-time information** collected from weather stations to issue **relief plans** and **evacuation notices**.

- Without weather station data, they are **forced** to act with **limited data**, which puts people at **risk.**

Reliability varies by region. NYC shows **greater coverage**, the areas around the Gulf appear to have **less**. **Rural stations** face longer outages due to sparse station networks and fewer resources.

- This reflects the **global pattern** that areas highly impacted by weather events may not have adequate resources and funding.

Future Studies:

Improvements and Limitations

Cause of missing data is **not** investigated and is assumed to be hurricane-related. Data gaps could be from **technical and transmission issues.**

- Future studies could cross-reference diagnostics and metadata.

Limited geographic area as only U.S hurricanes were studied. Other rainfall events were not included.

- **Global** and broader cases studies could reveal more station **weaknesses.**

Applications and Impact

Weather station technicians can:

- *Identify* historically vulnerable stations.
- *Prioritize* maintenance and improve durability.

Reliable weather stations allow for:

- Accurate early warning systems.
- Efficient and informed emergency response.
- Better adaptation for climate change.

References:

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