Hurricanes that have Hit the Caribbean: Time Series & Location Analysis

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November 11th, 2022
DA 401: Capstone Project
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Introduction

A hurricane (also known as a tropical cyclone) is a low-pressure system that forms in the Atlantic and rotates around a storm center known as the storm's eye. These storms are known for causing tremendous amounts of damage if they make landfall and have cost countries billions of dollars in repairs and cleanups. For a storm to be categorized as a hurricane it must have a sustained maximum wind speed of 74 mph or 64 knots. If the wind speed is anything less the storm is categorized as a tropical depression or tropical storm. Refer to Figure 1, displayed on page 8, to get a breakdown of the categories/stages of a hurricane. On top of high wind speeds, hurricanes are known for causing increased precipitation rates, flooding storm surges, and even tornadoes (NOAA, 2020). These storms vary in intensity and have a high probability of traveling through the chain of islands in the Caribbean. While not all hurricanes travel through this region, on average there are a total of 12 low-pressure systems that form in the Atlantic each year (NOAA, 2013).

Known Links to Changes in Intensity and Hurricane Occurrences

Many variables have been used for studying hurricanes over time, the one that is most heavily linked to increases in hurricane intensity is the sea surface temperature. This is because hurricanes only form during the warmer months of the year (May through November) which is when the sea surface temperature is the warmest. This variable was taken into consideration as early as 1956 and has continued to be used. Through these studies, they have found that a hurricane is most likely to follow the path of the warmest water and that if a storm moves over colder water the storm will weaken and vice versa (Fisher, 1958). In a study released in 2018, a group of researchers was able to discover that the increased surface temperatures were the main trigger for increased activity in the 2017 hurricane season (Balaguru et al. 2018). Before this many people believed that the change in hurricane occurrences and intensity was due to multidecadal variability meaning that there is a cycle to hurricanes (Gray et al. 1997). Additionally, researchers have also been able to show that multidecadal variability may be a factor influencing increased activity during the hurricane season, and that sea surface temperature is also a major influence (Pielke et al. 2005). With climate change occurring, the sea surface temperatures will continue to gradually rise as well as possibly the intensity of hurricanes.

While climate change is most definitely influencing hurricanes and the weather in general, it may not be affecting hurricanes the way we might think. Naturally one might believe that climate change occurring would increase the number of hurricanes and their intensity. But this may not be the case as some researchers have found other ways in which climate change is affecting hurricanes. This being that with the increase in temperatures and climate change, the total number of hurricanes each year may decrease while the intensity of the hurricanes is increasing (Union of Concerned Scientists, 2019). When thinking of the intensity of a hurricane this would involve weather variables like the pressure, wind speed, precipitation, storm surge, and the speed that the storm is traveling.

Out of the many weather variables that are involved with hurricanes, precipitation has been found to increase gradually every decade. This has been discovered through recent climate change analyses done in the last couple of decades with a focus on multiple locations. While there are locations with decreasing precipitation trends, the number of locations with increasing trends heavily outweighs them (O'Gorman, 2015). Additionally, researchers have also found that with increasing temperatures, precipitation also increased. This is because with rising temperatures more evaporation occurs which results in higher amounts of water vapor being held in the atmosphere (Trenberth, 2011). In locations that are experiencing hurricanes, these low-pressure systems are known for thunderstorms and heavy rain. With more water vapor being readily available for these storms, more precipitation will occur resulting in higher amounts of flooding. This can cause millions of dollars in damage and potentially injure or kill individuals.

Hurricane Data

Hurricanes have been occurring for thousands of years and the advancement of technology has helped individuals track and analyze hurricane data. One of the main administrations that contribute to these types of analyses is the National Hurricane Center and Central Pacific Hurricane Center. These two hurricane centers work with the National Oceanic and Atmospheric Administration and are well known for providing information regarding weather forecasts and storm analyses. With a focus more on hurricanes and weather systems that develop in the Atlantic, the NHC is the place to go for any information regarding past or future hurricanes. Their website provides detailed analyses of each hurricane in the Atlantic dating back to the start of 1995. While these reports are useful, the NHC does not release reports regarding comparisons of hurricanes with this data. In other studies, researchers have compared the effects of two hurricanes on a specific location. While there is mention of the previous data variables, there are many more variables that help analyze hurricanes such as tide, wave height, and storm surge. These variables are extremely helpful for analyzing the destruction done to a location but are not great variables when wanting to analyze hurricanes over time (Dietrich et al. 2010).

Gaps in Knowledge

The first of knowledge gap is that historical analyses of hurricanes were not that prevalent among studies done on hurricanes. Instead, many analyses studies were conducted on single hurricanes or comparing two to one another. While these are helpful to understand each of the hurricanes, looking at this topic at the historical level can allow individuals to see trends amongst all similar hurricanes over time. The second knowledge gap that remains is the improvement of forecasting and predicting a hurricane. As mentioned previously, the increasing rates of precipitation are making it harder for individuals to predict expected rainfall. Additionally, the rising sea surface temperatures are also making it hard for individuals to forecast hurricanes (Balaguru, 2018). By doing more analysis on variables like precipitation and sea surface temperature, individuals can get a better understanding of how they affect hurricanes. Ultimately allowing for better predictions to be made because there is a better understanding of how the changing aspects of our environment affect the outcomes of hurricanes.

Research Questions

1. Comparing the last decade (2012-2021) to the twenty years prior (1992 – 2011), using pressure, wind speed, and yearly totals, have hurricanes increased in intensity within the Caribbean?
2. Has there been a most common track for major hurricanes (Category 3, Category 4, Category 5) within the Caribbean?

Based on the research questions above, the project used most of the observational hurricane data that has been collected. For the first question, I answered this using both time-series analysis and two one-way ANOVA tests. The predictor variables for these are the year that the hurricane occurred or the ten-year group that the hurricane falls in (1992 – 2001, 2002 – 2011, 2012 – 2021). While the response variables are minimum pressure, maximum wind speed, and status. For these analyses, my baseline is the earliest year within my data to see if the intensity of a storm has changed over time compared to this baseline year/group. Time series analysis uses 1992 as the baseline while the ANOVA test uses 1992 – 2001. For the second question, I answer this using point pattern analysis. The variables used here are latitude, longitude, status, and year. When considering causality, the only things that can influence hurricanes are other weather systems. Concerning the data, the instrument used to collect the data can influence the records of that storm. Other than these influences, I do not believe there are any other concerns regarding causality.

Methods

Data

The data that I used to answer my research questions is provided by the National Oceanic & Atmospheric Administration (NOAA). Since this administration is funded by the government this data is public and can be manipulated in any way to conduct analyses. Thankfully, the NOAA has aggregated the reports for hurricanes starting in 1851 through 2015 and published this large data set on Kaggle (NOAA, 2017). This data set includes the following variables: ID, Name, Year, Month, Day/Time, Status, Latitude, Longitude, Maximum Wind Speed, and Minimum Pressure. For the remaining years of available hurricane data (2016 - 2021), manual data collection was necessary, and this was done in Excel version 16.65 (*v16.65*; Microsoft Corporation, 2018).

Data Collection

Since the data for each hurricane is provided in separate reports, I first created a new Excel document with columns for each of the variables listed above. Then I downloaded each of the hurricane PDF reports in the years 2016 through 2021 provided by the NHC and NOAA. All of these reports can be found under the data subheader in the bibliography. For each hurricane report, I then converted the PDF to a Microsoft Word Document so that I could transfer the tables of data into the Excel document. The version of Microsoft Word that was used was version 16.65 (*v16.*65; Microsoft Corporation, 2018). From each report, the table that was downloaded was Table 1, which details the best track for each of the storms with the corresponding data to that date and time. This table includes the following variables: Date/Time, Latitude, Longitude, Pressure, Wind Speed, and Stage. One variable that was not transferred to the Excel document was the Stage variable. This is because I found that it lacks information and has many missing values (this will be addressed in the next section). When copying each table into the Excel file, I then manually entered the ID, Name, Year, and Month corresponding to each row of the tables. These variables can be found on the first page of each hurricane report. The reason for doing this is so that the data collected matches the data that was published by the NOAA. Once all the data was collected, I aggregated the two data sets so that I now have data for hurricanes between the years 1851 and 2021.

Data Cleaning

When cleaning the data that I collected, the first variable that needed cleaning was the Day/Time variable. This is because its original format was for example “28 / 600” (the 28th at 6:00 AM), which I would not be able to use in my analysis since it is in text format. So, I decided it would be best to separate these into two separate variables. As mentioned above the Year and Month variables were made but from the Day/Time column, the specific day and observation time can be recorded. To retrieve the data regarding the day I selected all the data to the left of “ /”. While for the time data, I selected all the data to the right of “/ ”. I then converted the data in these two new columns to numeric data.

The second variable that needed cleaning was Minimum Pressure. This is because a lot of the data provided by the NOAA for this variable is measured at -999 which is an impossible pressure since it cannot be negative. This means that this data is missing and out of the total 52884 rows, 30669 rows do not have valid measurements for minimum pressure. When examining the data, I found that most of the data before and during 1991 did not provide valid measurements for this variable and was not missing at random. Because of this, I am not sure how to deal with this data other than treating them as NAs.

Another variable that had missing data was the Maximum Wind Speed. There are only a total of 338 rows without this measurement. Contrary to the Minimum Pressure variable, this missing data are missing at random. Like the minimum pressure variable, a lot of this data is missing before and including 1991. Because of this, I conducted my analysis of the pressure and wind speed variables in the years 1992 through 2021.

The final variable that I needed to clean/alter was the status variable. I was not a fan of how the NOAA provided data for this column as it did not track the specific categories for the hurricane. Instead, they just categorized the storm either as a tropical depression, tropical storm, or hurricane. Using the Saffir-Simpson hurricane wind scale I redid the values for this column using the maximum wind speed variable (Saffir-Simpson Hurricane Wind Scale. NHC, 2018). In Table 1 below you can see how I broke down each category based on the recorded maximum wind speed.

Category	**Maximum Wind Speed (Knots)**
Tropical Depression	Less than 33
Tropical Storm	34 – 63
1	64 – 82
2	83 – 95
3	96 – 112
4	113 – 136
5	Greater than 137

Table 1. *Saffir-Simpson Hurricane Wind Scale.* This table displays the different hurricane categories broken down by maximum wind speed (kts).

Inclusion/Exclusion Criterion

The first filtering of the data that was done was removing all data that corresponds to a Tropical Storm or a Tropical Depression. This is so I can directly look at hurricanes and not have as big of a variance within my data variables. Secondly, since my research questions are focused specifically on the Caribbean, I needed to filter the data to fit this region. The variables that I used to filter the data were Latitude and Longitude. All the data that was collected and any manipulations of it used for my analysis are provided in a GitHub repository with any other important documents produced during this project (Morley, 2022). Figure 1 shows a map of the boxed region that was used for my analysis with the latitude and longitude cutoffs listed above.

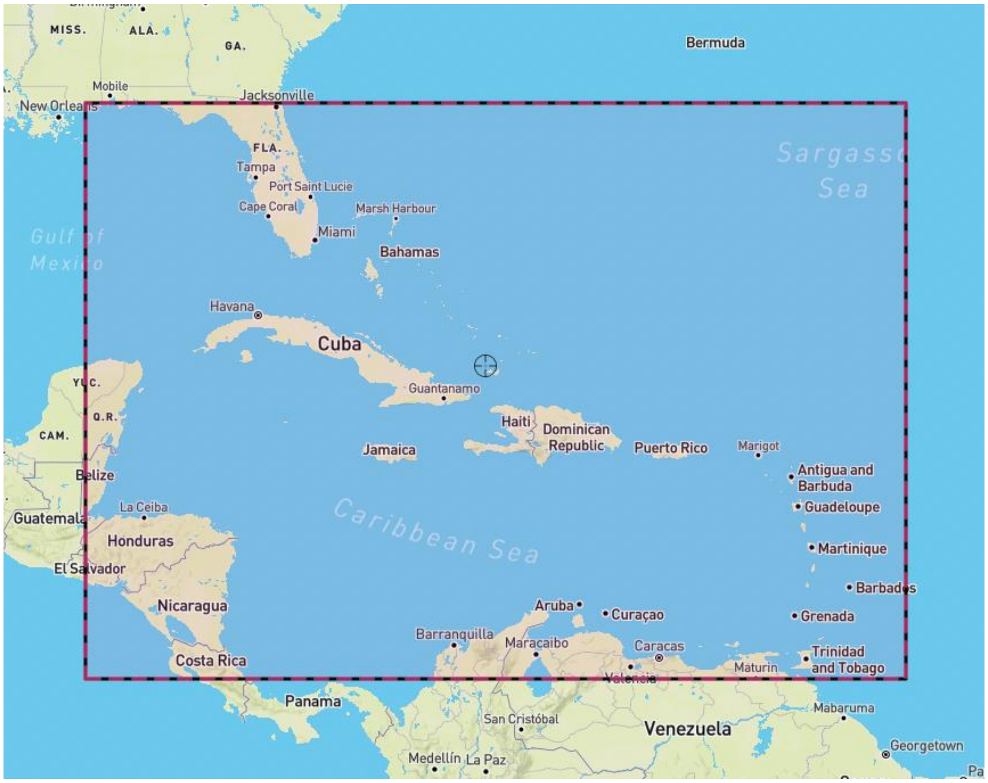

Figure 1. *Map showing the boxed region that is formed based on the inclusion/exclusion criterion.* For the longitude, the western cutoff is -89 and the eastern cutoff is -57.4. For the latitude, the northern cutoff is 30.5 and the southern cutoff is 9.5.

Analytical Approach

The type of analysis that was conducted for these two research questions was descriptive analytics. This is because I looked for trends among hurricanes that have hit the Caribbean whether that be overtime or a cumulative of the years.

Approach for Research Question #1

Time Series Analysis. As stated in the first research question, I looked at hurricanes over time, so time-series analysis was used for this question. The baseline for this analysis is the year 1992 and any hurricanes that occurred in this year. I then compared the observations over time to the year 1992 to see if there was any change. Additionally, with my time series analysis, I introduced an exponential moving average. An exponential moving average is a weighted moving average that considers the user's input of the number of observations to include in the weighted average (Borchers, 2022). By using exponential moving averages with time-series charts the trends within the data become clearer if there are any (Bhaumik et al. 2019). The charts that were created display the date on the x-axis and the pressure, wind speed, and yearly storm count on the y-axis (each y-axis variable being its own chart). The charts displaying the total hurricanes for each year include an exponentially weighted average due to the variability from year to year. The charts displaying wind speed will show the maximum and average maximum wind speed over time. And the remaining charts that display the pressure will show the minimum and average minimum pressure. All these charts were made using the ggplot2 package (Wickham, 2016) in R (*v4.2.*1; R Core Team, 2022).

One-Way ANOVA Tests. Additionally, to help aid my time-series analysis, I used two one-way ANOVA tests. This analysis was done in R (*v4.2.*1; R Core Team, 2022). The groups I compared in these tests were three 10-year groups: 1992 – 2001, 2002 – 2011, and 2012 – 2021. For these groups, a new variable was created putting the hurricanes of each of these years into their corresponding groups. To do this I used the dplyr package in R (Wickham et al. 2022). Any hurricanes in the years prior were not of interest for this test so they were labeled as other. The inputs for the ANOVA models are Minimum Pressure ~ Decade and Wind Speed ~ Decade. The alternative hypothesis is that there will be a difference in the means of each group. The null hypothesis is that there will not be any difference among the groups. For the ANOVA, once the model was made it was plugged into the TukeyHSD() function to allow for interpretability. This function is a part of the stats packages in R (R Core Team, 2022). Additionally, this function allows me to get the confidence intervals and the adjusted p-values for the statistical differences among the groups (Zhu et al. 2021). To reduce the amount of variability within the data, I ran these ANOVA models using only hurricanes with recorded maximum wind speeds of 64 knots or greater. This filtered out any recorded data that was considered a tropical storm or tropical depression.

Approach for Research Question #2

With the second research question, I investigated the location data that was recorded for hurricanes that have hit the Caribbean. This analysis was conducted using the Python 3 computing language (Van Rossum et al. 2009) in a Jupyter Notebook file (*v3.3.2*; Kluyver et al. 2016). When filtering the data to fit the question I found only a total of 11 missing values for the wind speed variable which was used to create the Status variable. The filtering and statistics concerning NAs were done using the Pandas package (McKinney et al. 2010). Because of this, I used the entire data set to answer this question so that I could have as much data as possible. To analyze this data, I decided to use point pattern analysis, specifically quadrat statistics to see if the points are random or follow a trend (Ray et al. 2020). On top of this, I decided to use maps to display the data points of where hurricanes have hit this region. While quadrat statistics are useful, using maps can tell us more about the trends observed regarding the geography of the location (Zhu et al. 2021). To create the plots and maps the packages that were used were Matplotlib (Hunter, 2007), Seaborn (Waskom, 2021), Contextily (Arribas-Bel et al. 2016), and Numpy (Harris et al. 2020). When conducting the quadrat statistics, the PySAL package was used, specifically using the QStatistic function from the pointpats sub-package (Rey et al. 2007). With this analysis, it places a grid over the region of analysis (automatically a 3x3 grid) and counts the total observations within each grid box. For my analysis, I chose to use a grid that is 7x4 so there are a total of 28 grid boxes. With the QStatistic function, it returns a chi-squared p-value that is comparing the likelihood of this distribution if each of the grid box counts is uniform to the true values. If the value is near 0 and less than 0.05 then this value is statistically significant and there is a trend among the location data.

Model Validation

The only model that needs to be validated for model validation would be the ANOVA models used for the first research question. All the validation was done in R (*v4.2.1*; R Core Team, 2022). The first assumption is that each group's observations are normally distributed. For this, I created histograms and Q-Q plots to show if the data among the pressure and wind speed variables are normally distributed. The second assumption is that for each group, the observations have equal variance. To check this, I created boxplots for each group. The final assumption I must validate is that each observation is independent of the observations in the other groups (Salma et al. 2012). While there is no formal test to validate this, since each hurricane is its own weather system, I would say every observation in the data is independent of the others.

Results

Before looking into any of the proposed research questions, I wanted to explore some of the variables within the data. My research on this domain suggests that wind speed and atmospheric pressure are highly correlated, meaning that when pressure decreases, the wind speed will increase. To examine this correlation, I created a scatterplot between the two variables which is shown in Figure 2. As you can see from this plot, these two variables for hurricanes that are Category 1 or stronger have a strong negative correlation of -0.8985.

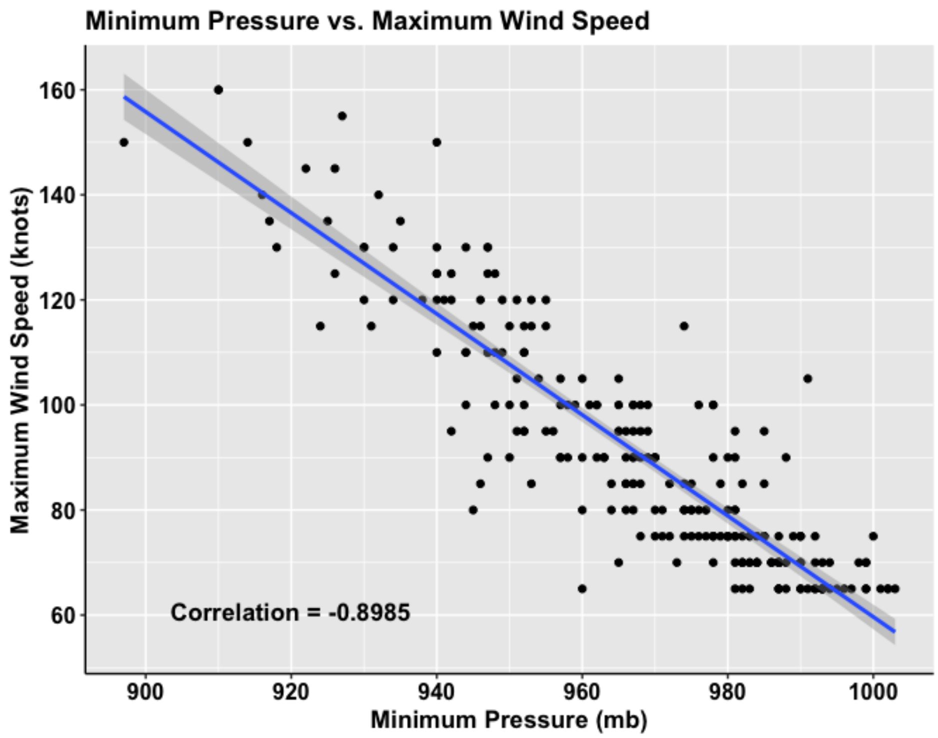

Figure 2. *Scatterplot showing the correlation between minimum pressure and maximum wind speed.* Through the blue index line, we can see that the relationship is linear. Additionally, there is a strong negative correlation between these variables.

Research Question #1

Time-Series Analysis

Before creating any of the time-series plots I wanted to inspect the data by using summary statistics. The summary statistics that are of interest are the minimum, median, average/mean, and maximum. These can be found in Table 2 for the minimum pressure and maximum wind speed variables. Instead of looking at the entire data set, I created summary statistics for each of the 10-year groups so that I can begin to see the differences between each of the decades I created. When looking at the maximum wind speed, all the summary statistics tell us that over time there has been a slight increase in this variable. For instance, with the maximum, when comparing the group 1992-2001 to 2012-2021 we can see a total increase of 15 knots. When looking at the minimum pressure, we expect this variable to decrease over time since it is strongly correlated with the maximum wind speed. The summary statistics tell us that when comparing the groups 1992-2001 to 2012-2021 there is a decrease across all statistics other than the maximum. While the group 2002-2011 was the group that experienced the lowest pressures across any of the groups, disregarding the maximum.

Decade/Years	Variable	Minimum	Median	Average	Maximum
1992 – 2001	Minimum Pressure (mb)	922	973	968.4	995
	Maximum Wind Speed (kts)	65	80	88.21	145
2002 – 2011	Minimum Pressure (mb)	897	966	962.7	996
	Maximum Wind Speed (kts)	65	85	91.56	150
2012 – 2021	Minimum Pressure (mb)	910	967	964.1	1001
	Maximum Wind Speed (kts)	65	90	94.09	160

Table 2. *Summary statistics for the two numeric variables used in the time series analysis for each 10-year group of hurricanes.* Using colors, the viewer can easily track differences across groups.

Total Hurricanes Over-Time. The first time-series plot that I created looked at the total number of hurricanes (Category 1 – Category 5) each year. Since I only used wind and pressure data for the years 1992 – 2001 I decided to look at the totals for these years as well. A plot showing the total number of hurricanes from 1851 – 2021 can be found in the appendices. In Figure 3, which is shown below, we can see that from year to year there can be a lot of variability in the total number of hurricanes. While this is the case, looking at the true totals and the exponentially weighted moving average we can see that over the last thirty years there has been a small increase in the total number of hurricanes over time.

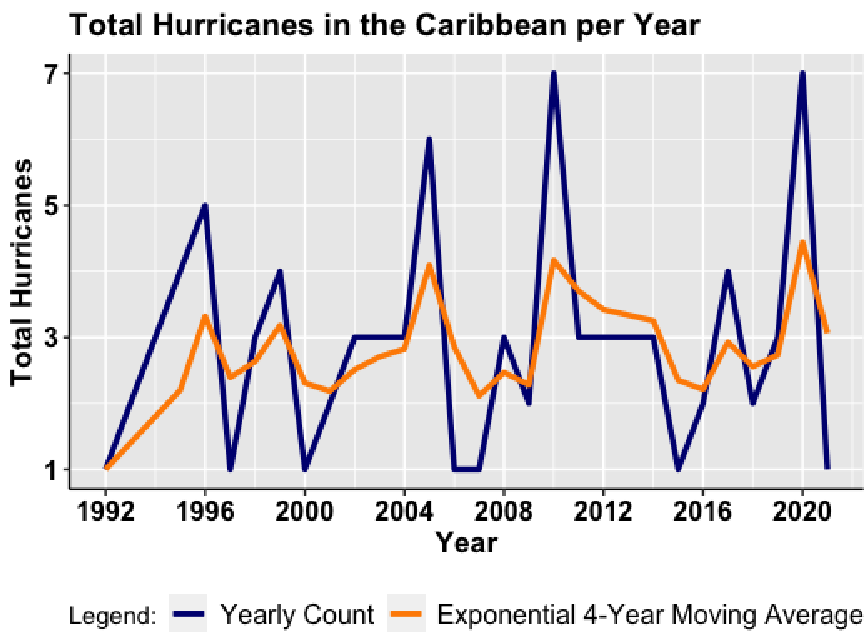

Figure 3. *Time-series plot displaying the total hurricanes for years 1992 through 2021*. In blue, the true totals per year are displayed. In orange, the exponentially 4-day moving average is displayed

Maximum Wind Speed Over-Time. Following the analysis of total hurricanes per year, I investigated the maximum wind speed which is measured in knots (kts). In Figure 4 which is shown to the right, the maximum wind speed and the average maximum wind speed are displayed for the years 1992 through 2021. This plot tells us that there is no real trend for the maximum wind speed over time. The first thing which can be said regarding this data is that in recent years (2012 – 2021) we can see that the Caribbean has been experiencing stronger maximum wind speeds than in prior years. But when considering the average maximum wind speed, from 1994 through 2021 we can see that there has not been a significant increase or decrease in the measured wind speeds of hurricanes in the Caribbean.

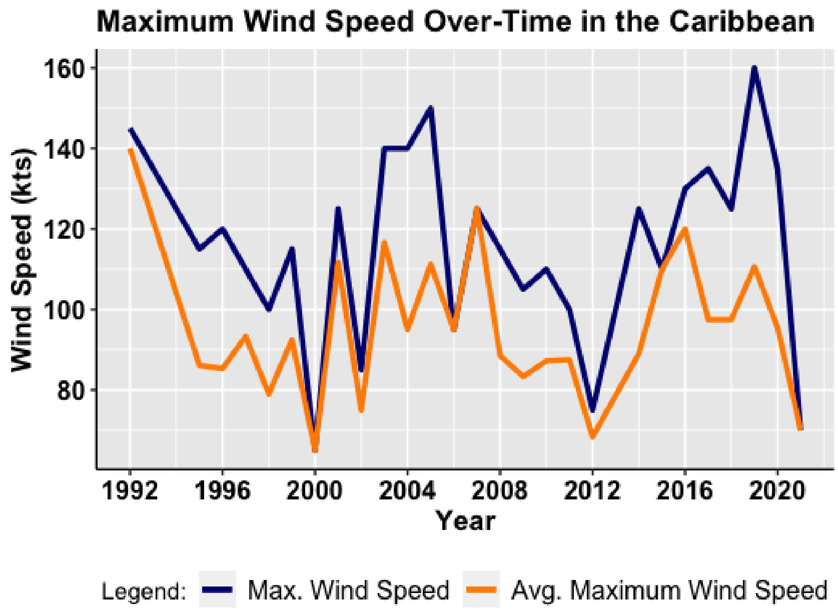

Figure 4. *Time-series plot displaying the maximum & average maximum wind speed (kts) for years 1992 through 2021*. In blue the true maximum wind speed is displayed for each year. In orange the average maximum wind speed is displayed.

Minimum Pressure Over-Time. The final use of time-series plots was used to investigate the minimum and average minimum pressure which is measured in millibars (mb). Shown in Figure 5 below, we can see these two measurements of the minimum pressure variable for the years 1992 through 2021. The first thing which can be seen from this plot is that in the year 2005 there was a tremendous decrease in the lowest minimum pressure recorded. But when looking at the minimum pressure data over time we can see some changes. This being that between the years 2008 through 2018 there was a decreasing trend in the minimum pressure. But as we can see from the average of this variable, there is not a clear trend over time other than that there is a very minimal decreasing trend in average minimum pressure from 2000 through 2021.

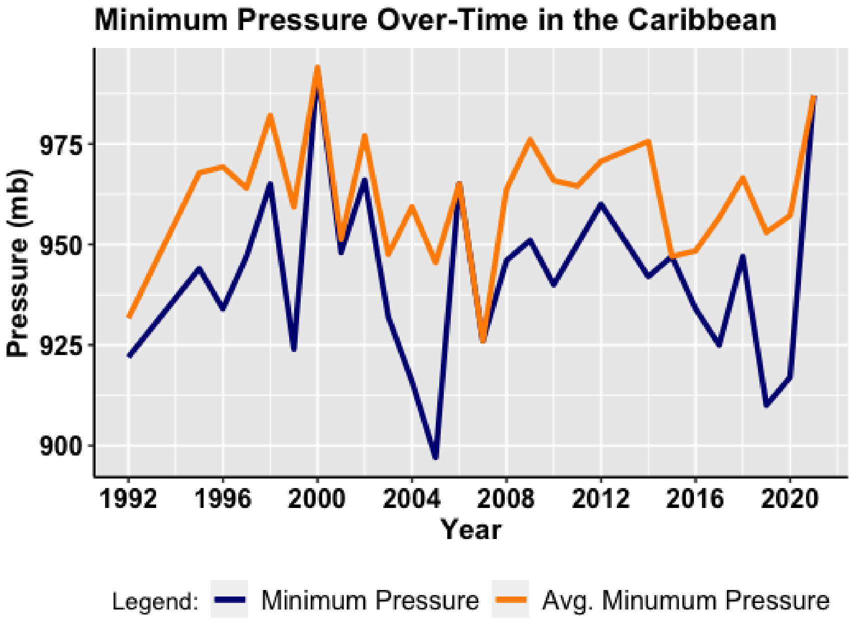

Figure 5. *Time-series plot displaying the minimum & average minimum pressure (mb) for years 1992 through 2021.* In blue the true minimum pressure is displayed for each year. In orange the average minimum pressure is displayed for each year.

One-Way ANOVA Tests

Maximum Wind Speed. To continue the time-series analysis of wind speed, I used a one-way ANOVA to look at the differences between each of the three 10-year-long groups. When looking at the results of the model, the P-Value is 0.282 which is greater than our cutoff value of 0.05 but is smaller than I believed it would be. With this value of 0.282, we would reject the alternative hypothesis and accept the null hypothesis. Looking further into the model using, I was able to look at the differences between each of the groups. These differences are displayed below in Figure 6 where the x-axis shows the difference in mean levels and the y-axis displays each of the three groups. Additionally, this plot tells us the confidence intervals for the difference in means between the pairings of the three groups. These confidence intervals and the rest of the model's statistics can be found in Table 3. Between the groups 2002 – 2011 and 1992 – 2001 the model is 95% confident that there was a difference of 5.5059 knots with an adjusted P-Value of 0.5136. Between the groups 2012 – 2021 and 1992 – 2001 there was a difference of 7.9618 knots with an adjusted P-Value of 0.2696. For the last pair: 2012 – 2021 and 2002 – 2011, there was a difference of 2.4559 knots with an adjusted P-Value of 0.8791.

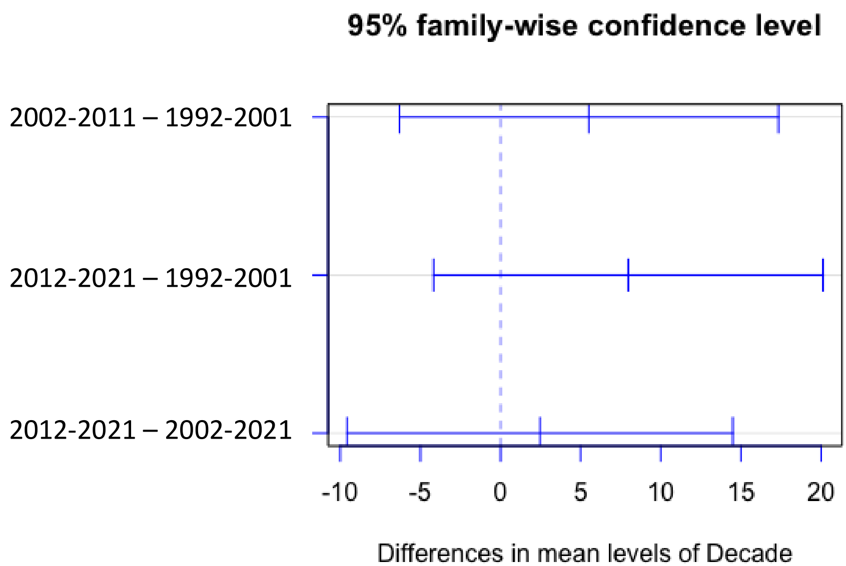

Figure 6. *Plot showing the differences in mean levels across the three groups for maximum wind speed.* These differences are made using the models 95% confidence.

Maximum Wind Speed ANOVA Assumptions. Looking at the assumptions for the data when using ANOVA models, I used boxplots to show the variance between the groups and a Q-Q plot to examine the normality of the data. The boxplot is displayed in Figure 7 where we can see that there are similar variances in maximum wind speed

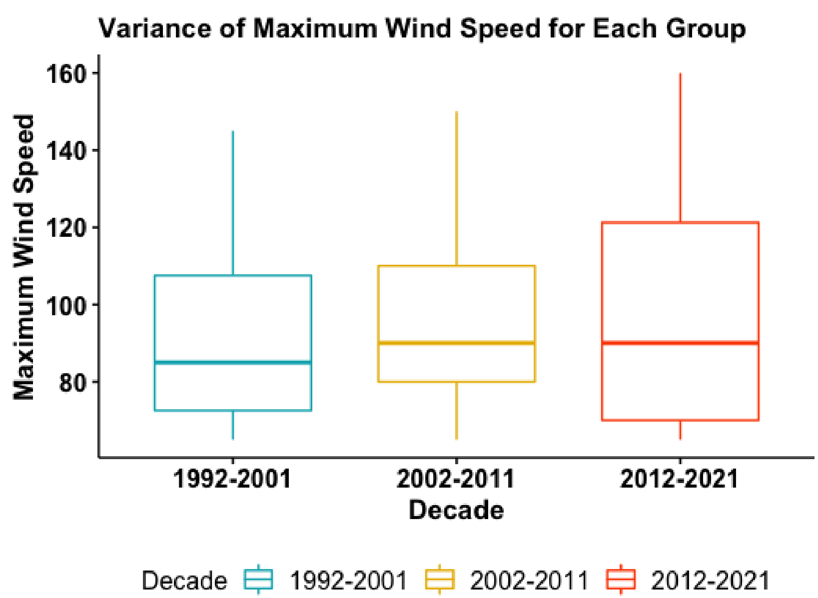

Figure 7. *Boxplot showing the variance in maximum wind speed among each of the groups.* The colors displayed in the plot show the different decade groups. As we can see 2012-2021 has the largest variance while they should be similar.

between the first two groups. But that the group 2012 – 2021 has a larger variance than the other two groups. The Q-Q plot is displayed in Figure 8 and in this plot, we can see if there is univariate normality among the data. Many of the residuals fall along the 45-degree line apart from the tail ends of the residuals (Theoretical Quantiles = +/- 2).

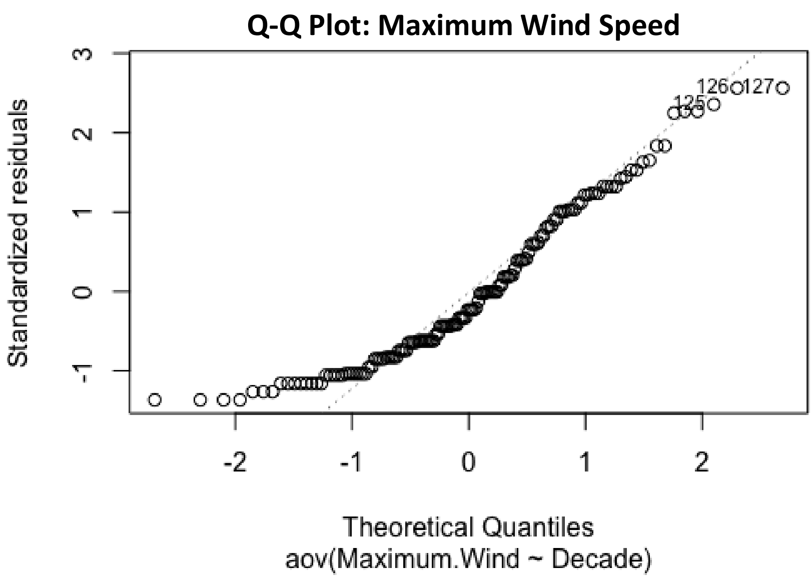

Figure 8. *Q-Q plot for the maximum wind speed in years 1992 through 2021.* This plot helps show the normality of the maximum wind data.

Minimum Pressure. When looking at the results of the one-way ANOVA model, the P-Value is 0.219 which is greater than our cutoff value of 0.05 but is more significant than I thought it would be based on the results found so far. Since the value of 0.219 is greater than 0.05, we would reject the alternative hypothesis and accept the null hypothesis. Examining this model further, I was able to look at the differences between each of the groups. These differences are displayed below in Figure 9. As previously stated, this plot tells us the confidence intervals for the difference in means between the pairings of the three groups. These confidence intervals and the rest of the model's statistics can also be found in Table 3. Between the groups 2002 – 2011 and 1992 – 2001 the model is 95% confident that there was a difference of -6.9904 mb with an adjusted P-Value of 0.2717. Between the groups 2012 – 2021 and 1992 – 2001 there was a difference of -6.8796 mb with an adjusted P-Value of 0.3021. For the last pair: 2012 – 2021 and 2002 – 2011, there was a difference of 0.1109 mb with an adjusted P-Value of 0.9998.

Figure 9. *Plot showing the differences in mean levels across the three groups for minimum pressure.* As we can see most of the difference seen is between the years 2002-2011 and 1992-2001

Minimum Pressure ANOVA Assumptions. As mentioned above under the wind speed ANOVA assumptions, I used boxplots to show the variance between the groups and a Q-Q plot to examine the normality of the data. The boxplot is displayed below in Figure 10 and this plot tells us that the variances for each of the groups are quite similar. Among the three groups,

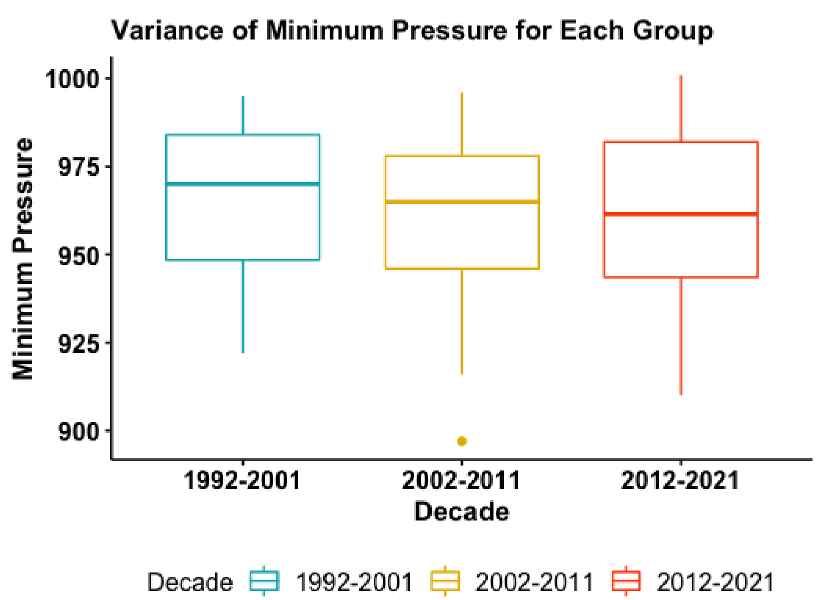

Figure 10. *Boxplot showing the variance in minimum pressure among each of the groups.* The colors displayed in the plot show the different decade groups. As we can see all groups have similar variances among minimum pressure

2002 – 2011 has the smallest variance while the other two are nearly identical. The Q-Q plot is displayed in Figure 11 and in this plot, we can see if that many of the residuals fall along the 45-degree line. The only points that do not fall on this line are points that are greater than the first theoretical quantile.

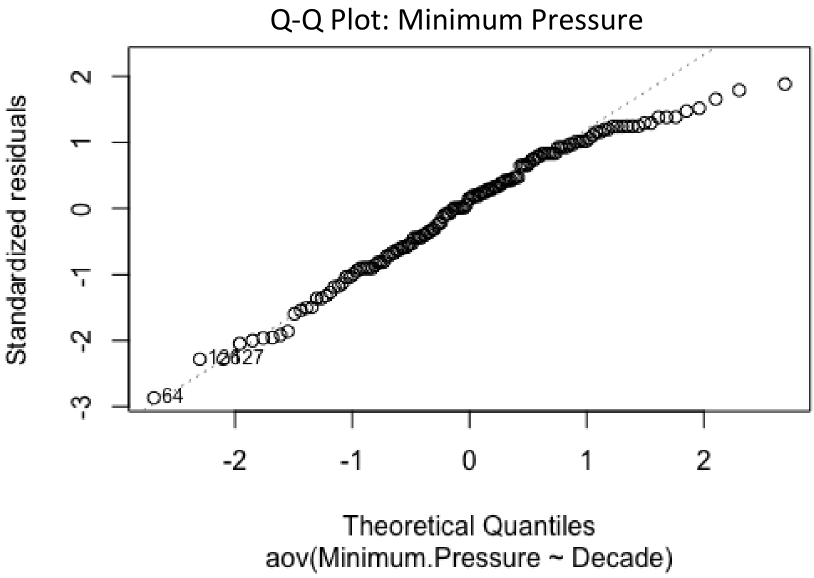

Figure 11. *Q-Q plot for the minimum pressure in years 1992 through 2021.* This plot helps show the normality of the minimum pressure data.

Variable	Decade	Difference	Lower 95%	Upper 95%	P Adj.
Maximum Wind Speed	2002-2011 – 1992-2001	5.505862	-6.316367	17.32809	05.135498
	2012-2021 – 1992-2001	7.961799	-4.184841	20.10844	0.2696202
	2012-2021 – 2002-2011	2.455937	-9.570246	14.48212	0.8790593
Minimum Pressure	2002-2011 – 1992-2001	-6.9904472	-17.68679	3.7059	0.2716848
	2012-2021 – 1992-2001	-6.8795938	-17.86946	4.110269	0.302103
	2012-2021 – 2002-2011	0.1108534	-10.77002	10.991731	0.9996788

Table 3. *Table showing both the ANOVA models' statistics for minimum pressure and maximum wind speed.* From this table we can see the differences between the decades, the 95% confidence intervals, as well as the adjusted P-Value.

Research Question #2

Mapping Location Data. When mapping the location data (latitude & longitude) I first wanted to examine this by placing them on a map and seeing if any trends were visually present. This map can be found below in Figure 12, this plot is a joint plot displaying both a scatterplot and a bar plot. This joint plot tells us that most of the occurrences were between the latitude of 22.5 and 30. While for the longitude, most of the occurrences were between the longitude of -80 and -60.

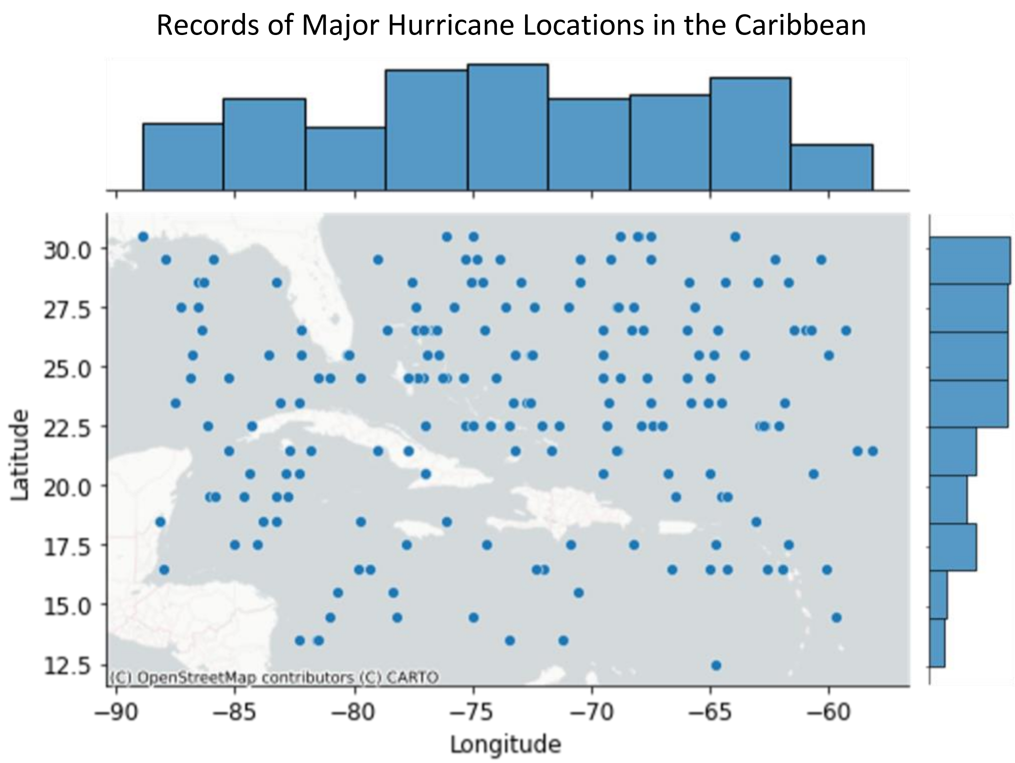

Figure 12. *Joint plot displaying the latitude/longitude data for major hurricane occurrences*. The first plot is a scatter plot displaying the location data. The second plot is displaying the counts for each of the tick marks on the x and y axis.

To further examine the different categories within the group of major hurricanes (Category 3 through Category 5) I created a similar joint plot to what is shown in Figure 12. This joint plot can be seen in Figure 13 it displays the same data that is displayed in Figure 12, but the points are colored based on their status/category. When looking at this plot, there are not any new strong trends that appear. One thing that can be said is that for category 5 hurricanes there is no distinct area in the Caribbean where they occur more than others. Instead, we can see a more even distribution across the latitudes and longitudes for this strength of hurricanes. But we can still see that more hurricanes travel through the same areas previously found in Figure 14.

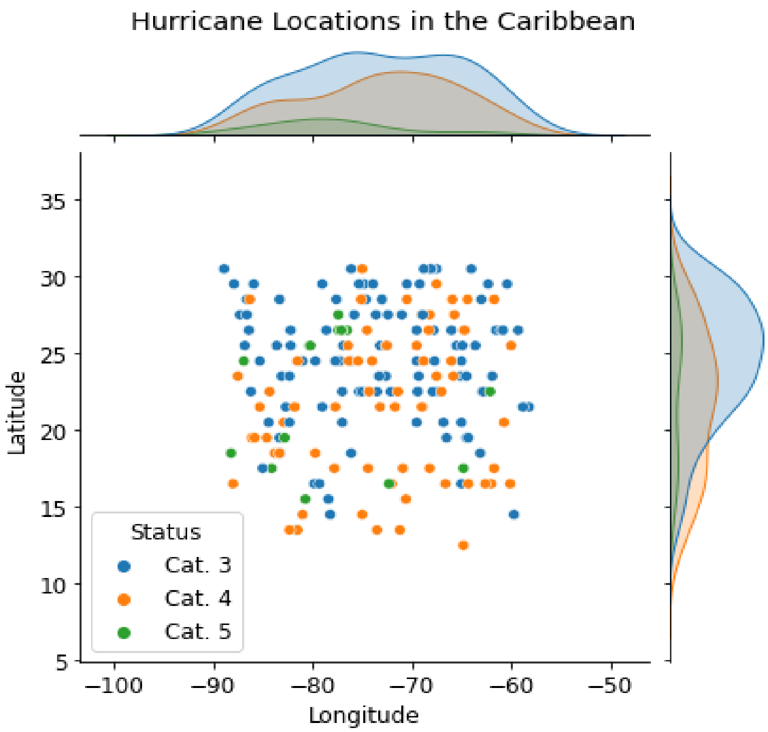

Figure 13. *Joint plot displaying the latitude/longitude data for hurricane occurrences.* The color of the point relates to the storm's category or status. As we can see there is both a scatterplot as well as a distribution plot showing the totals for each tick mark on the x and y axis.

Quadrat Analysis. To see the statistical significance that the location data used in this analysis is different from a random spatial pattern, quadrat analysis was used. The 7x4 gridded plot is displayed in Figure 14. After running this analysis, the computed chi-squared P-Value was 0.0000003447 which is equivalent to 3.447e-07. As this value is less than 0.05, this tells us that the data is different from data that was from a random spatial pattern, otherwise meaning that there is somewhat of a pattern to it.

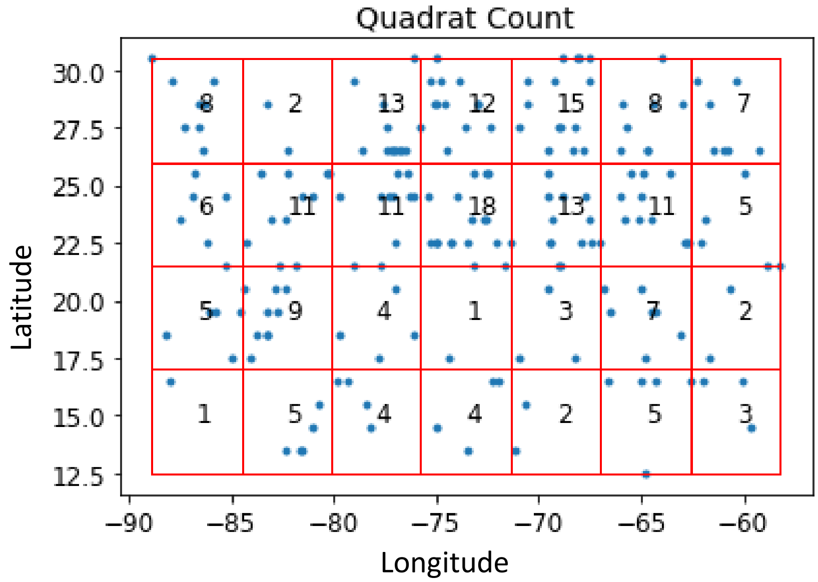

Figure 14. *7x4 Quadrat count plot displaying the total number of occurrences per grid box.* Displayed is a 7x4 grid over my region of choice. Meaning that this area is divided into 28 distinct boxes and the counts within each is displayed inside the box

Discussion

Key Findings

Research Question #1. From the produced results I would say that they suggest that there has been a slight increase in intensity over the last thirty years (1992 – 2021). But if we were to solely use the ANOVA models, the P-Values associated with the model tell us that there has not been a significant change over these past thirty years. While the P-Values may not be statistically significant for the ANOVA models, the differences and confidence intervals between the groups I believe are. This is because these results can still show if there has been a change in the extremes of each of these groups as well as the group's average. When comparing these results to the plots and summary statistics they match up with what is being displayed. That being that while there may not be a lot of change over the last thirty years in hurricane activity, there has been a slight increase in the intensity over time (ie. Lower minimum pressures & stronger maximum winds).

Increases in Intensity. There are many known links to increases in hurricane intensity and much of the results can be explained by these. The first known link is climate change as it is known to cause changes to the weather of a region. With this idea in mind, researchers have been able to link the increase in sea surface temperature to the increase in storm intensity. This is because hurricanes and low-pressure systems are attracted to warmer waters as they allow for more energy to be created within the storm (Cione et al. 2003). But what is important to remember is that climate change and warmer weather may reduce the total number of storms each year and increase the intensity of each of them (Union of Concerned Scientists, 2019). I believe this is why we do not see an increasing trend for the total number of hurricanes in the Caribbean each year (this plot can be found in the appendices). Additionally, I believe this is also why we see that over the three groups minimum pressure is slightly decreasing and maximum wind speed is slightly increasing over the thirty years. While these findings and trends may already be known, I feel that it is useful to conduct analyses like these to get a better understanding of how much these storms are changing over time.

Research Question #2. When analyzing the results produced regarding major hurricane locations in the Caribbean, while there may not be a most common path there are most common areas. Firstly, using quadrat analysis and its chi-squared P-Value, I was able to show that the data was not randomly distributed and that there is somewhat of a trend in this data. While the maps that are created are useful for understanding the geography of where a hurricane will travel, the quadrat count plot is able to distinguish these trends immediately. From this plot and the other two plots created, we can see that hurricanes are way more likely to occur between latitudes 22 through 30.5 and longitudes -80 through -65. When looking at the map displayed in Figure 14, we can see that the regions of the Caribbean that lie within these coordinates are The Bahamas, and the Greater Antilles (Cuba, Jamaica, Cayman Islands, Haiti, Dominican Republic, and Puerto Rico).

Most Common Hurricane Areas. As mentioned above for the time-series analysis, sea surface temperature has a big impact on hurricanes, and therefore I believe we see the results that we do. While this measurement does affect hurricanes, they do not ultimately decide where a hurricane will travel. The idea behind this is that a hurricane will follow the track of the warmest water because the colder the water the less energy there is in the ocean for the storm to inherent (Fisher, 1958). This idea has been proven as the eye of the storm will increase and become stronger over warmer waters while in colder waters they tend to deteriorate and weaken (Perlroth, 1962). Relating this to the results, with most of the observations occurring between latitudes 22 through 30.5 and longitudes -80 through -65, I believe it relates directly to the sea surface temperature. When looking at the map displayed in Figure 14, we can see that The Bahamas is the main country within these coordinates. Additionally, when looking at a map that shows water depth, we can see that The Bahamas is a country with extremely shallow waters throughout all its islands. Shallower waters allow for warmer waters as there is less water to be warmed between the surface and the ocean bottom. Meaning that based on the research, The Bahamas is almost like a magnet for hurricanes. Also, when looking at the map displayed in Figure 14, we can see that a lot of the occurrences were recorded when the hurricane was over water. I believe this is because, as mentioned previously, a storm needs warm water and flat land to form an intense hurricane. While if a storm’s eye/center travels over land it loses its source of energy and begins to disperse and weaken (Perlroth, 1962).

Limitations

When working with and analyzing this data I found that there were some limitations. The first of these was that there was a small amount of data. Or in my case, a lot of the data was not missing at random, so I was unable to use it. Because of this the groups I used for my ANOVA models also had a small amount of data for each group which I believe is the reason for the high P-Values. Additionally, if there were fewer missing data for the years prior to 1992, I believe a better time-series analysis could be conducted and the models might improve as well. Secondly, with the analysis, the results found can only be applied to the region of the Caribbean. If someone was wanting to look more closely at a specific region of the Caribbean or look at a completely new location/region, they would need to change the inclusion/exclusion criterion. But all the code and visualizations should work with that new location once changing the criterion to fit your needs for analysis. These files will be provided through a GitHub repository which will contain all the data, code, and other important files (Morley, 2022).

The final limitation that I found during my analysis was that I was only using hurricane data regarding weather and location data. Because of this IRB certification was not needed as my research did not involve any human participants. If a person was to want to use other data that did involve human interaction this certification would be needed which might slow down the start of your analysis. But I do believe that other sources of data such as more economic or health-related data sets could be just as useful as the data set that I used for looking at changes in hurricane intensity.

Next Steps and Conclusion

While my models may not have been statistically significant, I believe the results found for each of the questions did a good job of answering them. This is because I was able to show that there is a trend of increasing intensity of hurricanes over time, even if it was extremely small. Additionally, I was able to find areas within the Caribbean that experienced hurricanes more than others which I believe clarifies the behaviors of these storms. But these results can be improved though with the addition of more data or even just improving the currently supplied data. When thinking of the next steps I believe the NOAA and NHC need to first improve or add more data in regarding hurricanes. This is because there are so many different measurements that can be obtained, especially with the technology that is present today. Changing it today allows for the analysis in the future to improve and we hopefully won't have to be as worried about the possibilities of hurricanes. Beyond this type of data, as previously mentioned, I believe more analysis should be done on hurricanes using non-weather data sets. For example, by using an economic type of data set we can start to understand the intensity of hurricanes in a completely different way. And by introducing these new ways of hurricane analysis, we can get a complete understanding of how hurricanes are evolving over time.

Acknowledgments

I would like to acknowledge that without the help of Dr. Supp I would not have the analysis that I have presented. Especially concerning the second research question as she was a great help with developing ideas in different ways to use the location data within the hurricane data set. Additionally, thank you to the NOAA and NHC for providing this data to the public domain so that I was able to complete this analysis.

Appendices

GitHub Repository

As mentioned throughout this paper, all code, data, and important documents can be found in the repository found in the bibliography (Morley, 2022). Under this repository, you will also find a file named README. This should be the first thing that a person reads through before diving into the many files attached to this repository. In this README file, a person can get an understanding of all the files that were created and used in this analysis as well as know the software that was used for each file.

Additional Charts

Since my analysis was focused on the years 1992 through 2021, I did not include the time-series plot shown in Figure 15 within the main text. This was the first plot that I created in my time-series analysis, so I still wanted to include it in my final paper.

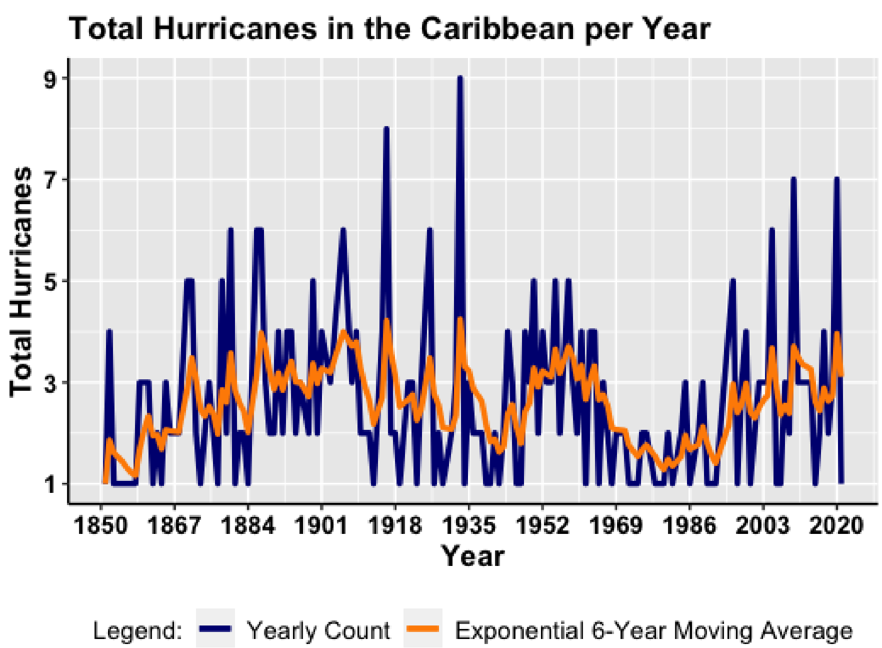

Figure 15. *Time-series plot displaying the total hurricanes for years 1851 through 2021*. The orange line shows the exponentially weight 6-day moving average. The blue line shows the true year to year totals.

References

GitHub Repository

Morley, P. (2022). DA401_Morley Hurricane Analysis. https://github.com/petermorley2023/DA401_Morley. (2022).

Primary Sources

Balaguru, K., Foltz, G. R., & Leung, L. R. (2018). Increasing magnitude of hurricane rapid intensification in the central and eastern tropical Atlantic. *Geophysical Research Letters*, *45*(9), 4238-4247.

Bhaumik, S., & Mukherjee, A. (2019). A statistical analysis on climatic temperature using exponential moving average. In *Innovations in Soft Computing and Information Technology* (pp. 227-240). Springer, Singapore.

Cione, J. J., & Uhlhorn, E. W. (2003). Sea surface temperature variability in hurricanes: Implications with respect to intensity change. *Monthly Weather Review*, *131*(8), 1783-1796.

Dietrich, J. C., Bunya, S., Westerink, J. J., Ebersole, B. A., Smith, J. M., Atkinson, J. H., ... & Roberts, H. J. (2010). A high-resolution coupled riverine flow, tide, wind, wind wave, and storm surge model for southern Louisiana and Mississippi. Part II: Synoptic description and analysis of Hurricanes Katrina and Rita. *Monthly Weather Review*, *138*(2), 378-404.

Fisher, E. L. (1958). *Hurricanes and the sea surface temperature field.* AMETSOC. Retrieved September 21, 2022, from http://journals.ametsoc.org/view/journals/atsc/15/3/1520-0469_1958_015_0328_hatsst_2_0_co_2.xml?tab_body=pdf

Gray, W. M., Sheaffer, J. D., & Landsea, C. W. (1997). Climate trends associated with multidecadal variability of Atlantic hurricane activity. In *Hurricanes* (pp. 15-53). Springer, Berlin, Heidelberg.

NOAA. (2013). *What is a hurricane?* NOAA's National Ocean Service. Retrieved September 20, 2022, from https://oceanservice.noaa.gov/facts/hurricane.html

NOAA. (2020). *Hurricanes*. National Oceanic and Atmospheric Administration. Retrieved November 4, 2022, from https://www.noaa.gov/education/resource-collections/weather atmosphere/hurricanes

O'Gorman, P. A. (2015). Precipitation extremes under climate change. *Current climate change reports*, *1*(2), 49-59.

Perlroth, I. (1962). Relationship of central pressure of hurricane Esther (1961) and the sea surface temperature field. *Tellus*, *14*(4), 403-408.

Pielke, R. A., Landsea, C., Mayfield, M., Layer, J., & Pasch, R. (2005). *Hurricanes and global warming*. AMETSOC. Retrieved September 21, 2022, from https://journals.ametsoc.org/view/journals/bams/86/11/bams-86-11-1571.xml?tab_body=pdf

Saffir-Simpson Hurricane Wind Scale. NHC. (2018). Retrieved October 11, 2022, from https://www.nhc.noaa.gov/aboutsshws.php

Salma, S., Rehman, S., & Shah, M. A. (2012). Rainfall trends in different climate zones of Pakistan. *Pakistan Journal of Meteorology*, *9*(17).

Trenberth, K. E. (2011). Changes in precipitation with climate change. *Climate research*, *47*(1-2), 123-138.

Union of Concerned Scientists. (2019). *Hurricanes and climate change.* Union of Concerned Scientists. Retrieved October 27, 2022, from https://www.ucsusa.org/resources/hurricanes-and-climate-change

Zhu, Z., Wasti, A., Schade, T., & Ray, P. A. (2021). Techniques to evaluate the modifier process of National Weather Service flood forecasts. *Journal of Hydrology X*, *11*, 100073.

Software

Arribas-Bel, D., & Fernandes, F. (2016) contextily: a small Python 3 package to retrieve tile maps from the internet. Retrieved from https://pypi.org/project/contextily/0.9.2/

Borchers, H. (2022). pracma: Practical Numerical Math Functions. R package version 2.4.2, https://CRAN.R-project.org/package=pracma

Harris, C. R., Millman, K. J., van der Walt, S. J., Gommers, R., Virtanen, P., Cournapeau, D., … Oliphant, T. E. (2020). Array programming with NumPy. *Nature*, *585*, 357–362. https://doi.org/10.1038/s41586-020-2649-2

Hunter, J. D. (2007). Matplotlib: A 2D graphics environment. *Computing in Science & amp; Engineering*, 9(3), 90 – 95.

Kluyver, T., Ragan-Kelley, B., Perez, F., Granger, B., Bussonnier, M., Frederic, J., Willing, C. (2016). Jupyter Notebooks – a publishing format for reproducible computational workflows. In F. Loizides & B. Schmidt (Eds.), *Positioning and Power in Academic Publishing: Players, Agents and Agendas* (pp. 87–90).

McKinney, W., & others. (2010). Data structures for statistical computing in python. In

Proceedings of the 9th Python in Science Conference (Vol. 445, pp. 51-56).

Microsoft Corporation. (2018). *Microsoft Excel*. Retrieved from https://office.microsoft.com/excel

Microsoft Corporation. (2018). *Microsoft Word*. Retrieved from https://office.microsoft.com/excel

R Core Team. (2022). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/

Rey, S. J., & Anselin, L. (2007). PySAL: A Python Library of Spatial Analytical Methods. In *The Review of Regional Studies* (Vol. 37, pp. 5-27)

Rey, S. J., Arribas-Bel, D., Wolf, L. J. (2020). Point Pattern Analysis. In *Geographic Data Science with Python.* Retrieved from https://geographicdata.science/book/notebooks/08_point_pattern_analysis.html

Van Rossum, G., & Drake, F. L. (2009). *Python 3 Reference Manual*. Scotts Valley, CA: CreateSpace.

Waskom, M. L. (2021). *seaborn: statistical data visualization.* Journal of Open Source Software, 6(60), 3021, http://doi.org/10.21105/joss.03021

Wickham, H. (2016). *ggplot2: Elegant Graphics for Data Analysis*. Springer-Verlag New York. ISBN 978-3-319-24277-4, https://ggplot2.tidyverse.org.

Wickham, H., François, R,. Henry, L., Müller, K. (2022). *Dplyr: A Grammer of Data Manipulation.* R package version 1.0.10, https://CRAN.R-project.org/package=dplyr

Data

Avila, L.A. (2017). (rep.) *Tropical Depression Four* (pp. 1–9). Miami, FL: National Hurricane Center.

Avila, L.A. (2018). (rep.) *Tropical Depression Eleven* (pp. 1–8). Miami, FL: National Hurricane Center.

Avila, L.A. (2019). (rep.) *Hurricane Katia* (pp. 1–14). Miami, FL: National Hurricane Center.

Avila, L.A. (2019). (rep.) *Tropical Depression Fifteen* (pp. 1–8). Miami, FL: National Hurricane Center.

Avila, L.A. (2019). (rep.) *Tropical Storm Ian* (pp. 1–13). Miami, FL: National Hurricane Center.

Avila, L.A., & Fritz, C.L. (2018). (rep.) *Hurricane Beryl* (pp. 1–16). Miami, FL: National Hurricane Center.

Avila, L.A., Stewart, S.R., Berg, R., & Hagen A.B. (2020). (rep.) *Hurricane Dorian* (pp. 1–74). Miami, FL: National Hurricane Center.

Berg, R. (2017). (rep.) *Hurricane Hermine* (pp. 1–63). Miami, FL: National Hurricane Center.

Berg, R. (2018). (rep.) *Hurricane Jose* (pp. 1–36). Miami, FL: National Hurricane Center.

Berg, R. (2018). (rep.) *Tropical Storm Alberto* (pp. 1–44). Miami, FL: National Hurricane Center.

Berg, R. (2018). (rep.) *Tropical Storm Cindy* (pp. 1–41). Miami, FL: National Hurricane Center.

Berg, R. (2019). (rep.) *Tropical Storm Chantal* (pp. 1–11). Miami, FL: National Hurricane Center.

Berg, R. (2019). (rep.) *Tropical Storm Joyce* (pp. 1–14). Miami, FL: National Hurricane Center.

Berg, R. (2019). (rep.) *Tropical Storm Melissa* (pp. 1–29). Miami, FL: National Hurricane Center.

Berg, R. (2021). (rep.) *Tropical Storm Cristobal* (pp. 1–51). Miami, FL: National Hurricane Center.

Berg, R. (2021). (rep.) *Tropical Storm Fred* (pp. 1–56). Miami, FL: National Hurricane Center.

Berg, R. (2021). (rep.) *Tropical Storm Peter* (pp. 1–18). Miami, FL: National Hurricane Center.

Berg, R., & Reinhart, B.J. (2021). (rep.) *Hurricane Sally* (pp. 1–69). Miami, FL: National Hurricane Center.

Beven, J.L. (2016). (rep.) *Tropical Storm Danielle* (pp. 1–13). Miami, FL: National Hurricane Center.

Beven, J.L., II. (2017). (rep.) *Tropical Storm Lisa* (pp. 1–14). Miami, FL: National Hurricane Center.

Beven, J.L., II. (2018). (rep.) *Hurricane Franklin* (pp. 1–19). Miami, FL: National Hurricane Center.

Beven, J.L., II. (2019). (rep.) *Tropical Storm Ernesto* (pp. 1–13). Miami, FL: National Hurricane Center.

Beven, J.L., II. (2020). (rep.) *Hurricane Pablo* (pp. 1–12). Miami, FL: National Hurricane Center.

Beven, J.L., II. (2020). (rep.) *Tropical Storm Gabrielle* (pp. 1–16). Miami, FL: National Hurricane Center.

Beven, J.L., II. (2021). (rep.) *Tropical Storm Theta* (pp. 1–15). Miami, FL: National Hurricane Center.

Beven, J.L., II. (2022). (rep.) *Subtropical Storm Teresa* (pp. 1–8). Miami, FL: National Hurricane Center.

Beven, J.L., II., & Berg, R. (2018). (rep.) *Hurricane Nate* (pp. 1–45). Miami, FL: National Hurricane Center.

Beven, J.L., II., & Berg, R. (2021). (rep.) *Hurricane Marco* (pp. 1–31). Miami, FL: National Hurricane Center.

Beven, J.L., II., & Berg, R. (2021). (rep.) *Tropical Storm Beta* (pp. 1–). Miami, FL: National Hurricane Center.

Beven, J.L., II., & Berg, R. (2021). (rep.) *Tropical Storm Fay* (pp. 1–38). Miami, FL: National Hurricane Center.

Beven, J.L., II., Berg, R., & Hagen, A. (2019). (rep.) *Hurricane Michael* (pp. 1–86). Miami, FL: National Hurricane Center.

Beven, J.L., II., Hagen, A., & Berg, R. (2022). (rep.) *Hurricane Ida* (pp. 1–163). Miami, FL: National Hurricane Center.

Blake, E. (2021). (rep.) *Tropical Storm Dolly* (pp. 1–8). Miami, FL: National Hurricane Center.

Blake, E. (2021). (rep.) *Tropical Storm Kyle* (pp. 1–9). Miami, FL: National Hurricane Center.

Blake, E. (2021). (rep.) *Tropical Storm Rose* (pp. 1–13). Miami, FL: National Hurricane Center.

Blake, E.S. (2016). (rep.) *Hurricane Alex* (pp. 1–14). Miami, FL: National Hurricane Center.

Blake, E.S. (2017). (rep.) *Tropical Storm Don* (pp. 1–9). Miami, FL: National Hurricane Center.

Blake, E.S. (2017). (rep.) *Tropical Storm Julia* (pp. 1–14). Miami, FL: National Hurricane Center.

Blake, E.S. (2018). (rep.) *Hurricane Chris* (pp. 1–12). Miami, FL: National Hurricane Center.

Blake, E.S. (2018). (rep.) *Hurricane Lee* (pp. 1–16). Miami, FL: National Hurricane Center.

Blake, E.S. (2019). (rep.) *Tropical Storm Eric* (pp. 1–14). Miami, FL: National Hurricane Center.

Blake, E.S. (2019). (rep.) *Tropical Storm Kirk* (pp. 1–15). Miami, FL: National Hurricane Center.

Blake, E.S. (2021). (rep.) *Hurricane Teddy* (pp. 1–25). Miami, FL: National Hurricane Center.

Blake, E., Berg, R., & Hagen, A. (2021). (rep.) *Hurricane Zeta* (pp. 1–56). Miami, FL: National Hurricane Center.

Blake, E.S., & Zelinsky, D.A. (2018). (rep.) *Hurricane Harvey* (pp. 1–77). Miami, FL: National Hurricane Center.

Brennan, M.J. (2016). (rep.) *Tropical Storm Bonnie* (pp. 1–20). Miami, FL: National Hurricane Center.

Brennan, M.J. (2018). (rep.) *Tropical Storm Bret* (pp. 1–12). Miami, FL: National Hurricane Center.

Brown, D.P. (2017). (rep.) *Hurricane Gaston* (pp. 1–19). Miami, FL: National Hurricane Center.

Brown, D.P. (2017). (rep.) *Hurricane Otto* (pp. 1–28). Miami, FL: National Hurricane Center.

Brown, D.P. (2017). (rep.) *Potential Tropical Cyclone Ten* (pp. 1–3). Miami, FL: National Hurricane Center.

Brown, D.P. (2018). (rep.) *Tropical Storm Philippe* (pp. 1–11). Miami, FL: National Hurricane Center.

Brown, D.P. (2019). (rep.) *Hurricane Jerry* (pp. 1–17). Miami, FL: National Hurricane Center.

Brown, D.P. (2019). (rep.) *Hurricane Oscar* (pp. 1–17). Miami, FL: National Hurricane Center.

Brown, D.P. (2020). (rep.) *Hurricane Nana* (pp. 1–18). Miami, FL: National Hurricane Center.

Brown, D.P. (2020). (rep.) *Tropical Storm Sebastien* (pp. 1–25). Miami, FL: National Hurricane Center.

Brown, D.P. (2021). (rep.) *Hurricane Larry* (pp. 1–34). Miami, FL: National Hurricane Center.

Brown, D.P. (2021). (rep.) *Subtropical Storm Alpha* (pp. 1–12). Miami, FL: National Hurricane Center.

Brown, D.P. (2021). (rep.) *Tropical Storm Bill* (pp. 1–11). Miami, FL: National Hurricane Center.

Brown, D.P., Berg, R., & Reinhart, B. (2021). (rep.) *Hurricane Hanna* (pp. 1–49). Miami, FL: National Hurricane Center.

Brown, D.P., Latto, A., & Berg, R. (2019). (rep.) *Tropical Storm Gordon* (pp. 1–49). Miami, FL: National Hurricane Center.

Cangialosi, J.P. (2016). (rep.) *Tropical Depression Eight* (pp. 1–15). Miami, FL: National Hurricane Center.

Cangialosi, J.P. (2017). (rep.) *Tropical Storm Arlene* (pp. 1–13). Miami, FL: National Hurricane Center.

Cangialosi, J.P. (2018). (rep.) *Tropical Storm Rina* (pp. 1–12). Miami, FL: National Hurricane Center.

Cangialosi, J.P. (2019). (rep.) *Hurricane Helene* (pp. 1–15). Miami, FL: National Hurricane Center.

Cangialosi, J.P. (2020). (rep.) *Tropical Depression Ten* (pp. 1–8). Miami, FL: National Hurricane Center.

Cangialosi, J.P. (2020). (rep.) *Tropical Storm Bertha* (pp. 1–12). Miami, FL: National Hurricane Center.

Cangialosi, J.P. (2021). (rep.) *Tropical Storm Odette* (pp. 1–11). Miami, FL: National Hurricane Center.

Cangialosi, J.P. (2021). (rep.) *Tropical Storm Rene* (pp. 1–15). Miami, FL: National Hurricane Center.

Cangialosi, J.P., & Berg, R. (2021). (rep.) *Hurricane Delta* (pp. 1–46). Miami, FL: National Hurricane Center.

Cangialosi, J.P., Delgado, S., Berg, R. (2022). (rep.) *Hurricane Elsa* (pp. 1–70). Miami, FL: National Hurricane Center.

Cangialosi, J.P., Latto, A.S., & Berg, R. (2021). (rep.) *Hurricane Irma* (pp. 1–111). Miami, FL: National Hurricane Center.

Cangialosi, J.P., Hagen, A.B., Berg, R. (2019). (rep.) *Hurricane Barry* (pp. 1–31). Miami, FL: National Hurricane Center.

Cangialosi, J.P., & Ramos, N.A. (2019). (rep.) *Tropical Storm Karen* (pp. 1–20). Miami, FL: National Hurricane Center.

Hagen, A.B., Blake, E., & Berg, R. (2020). (rep.) *Tropical Storm Nestor* (pp. 1–26). Miami, FL: National Hurricane Center.

Kimberlain, T.B. (2016). (rep.) *Tropical Storm Fiona* (pp. 1–15). Miami, FL: National Hurricane Center.

Kimberlain, T.B., & Latto, A.S. (2017). (rep.) *Hurricane Nicole* (pp. 1–29). Miami, FL: National Hurricane Center.

Latto, A.S. (2019). (rep.) *Subtropical Storm Andrea* (pp. 1–). Miami, FL: National Hurricane Center.

Latto, A.S. (2020). (rep.) *Hurricane Paulette* (pp. 1–27). Miami, FL: National Hurricane Center.

Latto, A.S. (2020). (rep.) *Tropical Storm Arthur* (pp. 1–19). Miami, FL: National Hurricane Center.

Latto, A.S. (2021). (rep.) *Hurricane Gamma* (pp. 1–20). Miami, FL: National Hurricane Center.

Latto, A.S. (2021). (rep.) *Tropical Storm Danny* (pp. 1–13). Miami, FL: National Hurricane Center.

Latto, A.S., & Berg, R. (2020). (rep.) *Tropical Storm Imelda* (pp. 1–28). Miami, FL: National Hurricane Center.

Latto, A.S., & Berg, R. (2021). (rep.) *Hurricane Nicholas* (pp. 1–50). Miami, FL: National Hurricane Center.

Latto, A.S., Hagen, A., & Berg, R. (2021). (rep.) *Hurricane Isaias* (pp. 1–84). Miami, FL: National Hurricane Center.

NOAA. (2017, January 20). *Hurricanes and typhoons, 1851-2014*. Kaggle. Retrieved October 5, 2022, from https://www.kaggle.com/datasets/noaa/hurricane-database

Papin, P.P. (2021). (rep.) *Hurricane Epsilon* (pp. 1–23). Miami, FL: National Hurricane Center.

Papin, P.P., & Berg, R. (2021). (rep.) *Tropical Storm Claudette* (pp. 1–41). Miami, FL: National Hurricane Center.

Papin, P.P., & Berg, R. (2022). (rep.) *Tropical Storm Mindy* (pp. 1–). Miami, FL: National Hurricane Center.

Pasch, R.J. (2019). (rep.) *Tropical Storm Debby* (pp. 1–14). Miami, FL: National Hurricane Center.

Pasch, R.J. (2020). (rep.) *Tropical Storm Fernand* (pp. 1–13). Miami, FL: National Hurricane

Center.

Pasch, R.J. (2021). (rep.) *Tropical Storm Edouard* (pp. 1–11). Miami, FL: National Hurricane Center.

Pasch, R.J. (2021). (rep.) *Tropical Storm Vicky* (pp. 1–11). Miami, FL: National Hurricane Center.

Pasch, R.J. (2022). (rep.) *Hurricane Sam* (pp. 1–19). Miami, FL: National Hurricane Center.

Pasch, R.J., Berg, R., & Hagen, A.B. (2020). (rep.) *Tropical Storm Olga* (pp. 1–17). Miami, FL: National Hurricane Center.

Pasch, R.J., Berg, R., & Hagen, A.B. (2021). (rep.) *Hurricane Henri* (pp. 1–42). Miami, FL: National Hurricane Center.

Pasch, R.J., Berg, R., Roberts, D.P., & Papin, P.P. (2021). (rep.) *Hurricane Laura* (pp. 1–76). Miami, FL: National Hurricane Center.

Pasch, R.J., Latto, A.S., & Cangialosi, J.P. (2019). (rep.) *Tropical Storm Emily* (pp. 1–15). Miami, FL: National Hurricane Center.

Pasch, R.J., & Penny, A.B. (2017). (rep.) *Tropical Storm Colin* (pp. 1–29). Miami, FL: National Hurricane Center.

Pasch, R.J., Penny, A.B., & Berg, R. (2019). (rep.) *Hurricane Maria* (pp. 1–48). Miami, FL: National Hurricane Center.

Pasch, R.J., Reinhart, B.J., Berg, R., & Roberts, D.P. (2021). (rep.) *Hurricane Eta* (pp. 1–70). Miami, FL: National Hurricane Center.

Pasch, R.J., & Roberts, D.P. (2019). (rep.) *Hurricane Leslie* (pp. 1–18). Miami, FL: National Hurricane Center.

Pasch, R.J., & Zelinsky, D.A. (2017). (rep.) *Tropical Storm Karl* (pp. 1–17). Miami, FL: National Hurricane Center.

Reinhart, B.J. (2021). (rep.) *Tropical Storm Ana* (pp. 1–12). Miami, FL: National Hurricane Center.

Reinhart, B.J. (2021). (rep.) *Tropical Storm Josephine* (pp. 1–12). Miami, FL: National Hurricane Center.

Reinhart, B.J. (2021). (rep.) *Tropical Storm Julian* (pp. 1–10). Miami, FL: National Hurricane Center.

Reinhart, B.J., & Berg, R. (2021). (rep.) *Hurricane Grace* (pp. 1–49). Miami, FL: National Hurricane Center.

Reinhart, B.J., & Berg, R. (2021). (rep.) *Tropical Storm Wanda* (pp. 1–26). Miami, FL: National Hurricane Center.

Stewart, S.R. (2017). (rep.) *Hurricane Earl* (pp. 1–23). Miami, FL: National Hurricane Center.

Stewart, S.R. (2017). (rep.) *Hurricane Matthew* (pp. 1–96). Miami, FL: National Hurricane Center.

Stewart, S.R. (2018). (rep.) *Hurricane Gert* (pp. 1–18). Miami, FL: National Hurricane Center.

Stewart, S.R. (2018). (rep.) *Hurricane Ophelia* (pp. 1–32). Miami, FL: National Hurricane Center.

Stewart, S.R. (2019). (rep.) *Tropical Storm Nadine* (pp. 1–15). Miami, FL: National Hurricane Center.

Stewart, S.R. (2019). (rep.) *Subtropical Storm Rebekah* (pp. 1–10). Miami, FL: National Hurricane Center.

Stewart, S.R. (2020). (rep.) *Hurricane Humberto* (pp. 1–44). Miami, FL: National Hurricane Center.

Stewart, S.R. (2020). (rep.) *Tropical Storm Wilfred* (pp. 1–11). Miami, FL: National Hurricane Center.

Stewart, S.R. (2021). (rep.) *Hurricane Iota* (pp. 1–48). Miami, FL: National Hurricane Center.

Stewart, S.R. (2021). (rep.) *Tropical Storm Gonzalo* (pp. 1–17). Miami, FL: National Hurricane Center.

Stewart, S.C. (2021). (rep.) *Tropical Storm Kate* (pp. 1–14). Miami, FL: National Hurricane Center.

Stewart, S.R. (2021). (rep.) *Tropical Storm Omar* (pp. 1–12). Miami, FL: National Hurricane Center.

Stewart, S.R. (2021). (rep.) *Tropical Storm Victor* (pp. 1–16). Miami, FL: National Hurricane Center.

Stewart, S.R., & Berg, R. (2019). (rep.) *Hurricane Florence* (pp. 1–98). Miami, FL: National Hurricane Center.

Zelinsky, D.A. (2019). (rep.) *Hurricane Isaac* (pp. 1–21). Miami, FL: National Hurricane

Center.

Zelinsky, D.A. (2019). (rep.) *Hurricane Lorenzo* (pp. 1–22). Miami, FL: National Hurricane Center.

Zelinsky, D.A. (2019). (rep.) *Tropical Depression Three* (pp. 1–8). Miami, FL: National Hurricane Center.