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Connecting the Relationship Between Climate Change and Intensifying Hurricanes: A Historic Investigation

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Abstract

Hurricanes have been a blight on human civilization since as early as 1625 BC; forming through specific climate conditions,they reign as the terror of the world's oceans, and are only getting stronger. Gathering data from the last 200 years of hurricane seasons, this study analyzed the tropical activity for a 150 year period (1850-2000), with a deeper look into the hurricane season of 1924 and 1932. In addition, this study looked at the climate conditions of the current century, highlighting the growing intensities as a result of climate change and global warming. The aggregation process consisted of Python library Pandas, and the desired metrics were visualized using Tableau Public. As a result of the analysis conducted, the study finds that hurricanes have become more frequent, in some cases doubling in activity (comparing 1870-1900, to 1970-2000), with intensities becoming the standard (with 2015-2019 having 4 category 5s, the longest streak in history), demonstrating the dire need for regulatory change in waste management and fossil fuel consumption to combat climate change. Through agreements like the Paris Climate Agreement or the UN Framework Convention on Climate Change (UNFCCC), the Earth can mitigate and begin to remedy the extreme weather conditions that are becoming the norm.

Key words: hurricane; climate change; temperature; category; wind speed

Introduction

The relationship between climate change and the increasing intensity of hurricanes has emerged as a critical area of study in the 21st century. This study will serve as one of many in the sea of in-depth explorations of climate change by analyzing two centuries of hurricane data to identify trends and key events that illustrate the increasing severity of these storms. With a focus on the 150-year period between 1850 and 2000, alongside case studies of pivotal hurricane seasons in 1924 and 1932, this report juxtaposes historical records with modern observations from the current century to uncover the impact of global warming and human activities on hurricane behavior.

By offering a comprehensive look at how hurricanes have evolved in response to environmental changes, we can begin to decipher the demographic observations of seemingly natural phenomena. The report aims to improve our understanding of the challenges posed by intensifying hurricanes and illustrate the importance of forming strategies for climate resilience.

Understanding Earth's Relationship with Hurricanes

Before being able to understand how hurricanes have evolved over the last couple hundred years, it's pertinent to know the proper climate conditions and reasons for why a hurricane forms. There are 4 primary conditions that can result in a hurricane, these are: warm water, low air pressure, warm and moist air, and a low wind shear.[1, 2]

A storm will take the energy from warm water, typically at around 80 degrees fahrenheit, to promote growth and energy to the storm. This is accompanied with the amount of moisture in, and the temperature of the air, which is directly related to the temperature of the ocean water it resides over; as the temperature of the ocean increases, the temperature of the air also increases, alongside the amount of moisture in that air.[3] The low air pressure refers to the "eye of the storm" where often the storm is the most calm, but this low air pressure allows for air to be pushed up and out in the storm, and due to the Coriolis effect, that air going up will start to rotate based on the hemisphere the storm is in (rotating to the right for the Northern Hemisphere, and to the left for the Southern Hemisphere).[4] This cycle is a rotation of moist air releasing heat and precipitation, and moving air due to low pressure conditions, as visualized in the figure below.

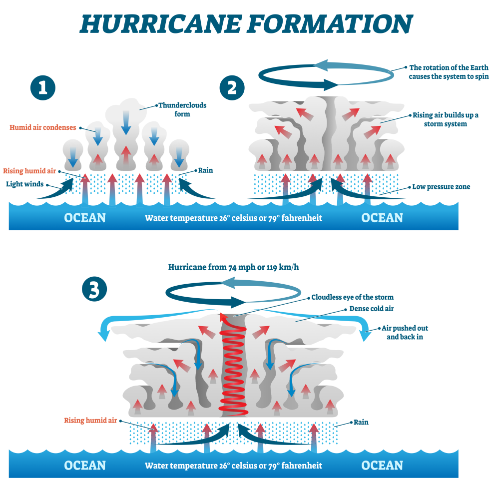

Fig. 1: Tropical storm formation

The final component is a low wind shear, wind shear is the change of wind direction and speed over a vertical or horizontal distance, which in this context of a hurricane translates to a wind intensity outside the storm that is strong enough to steer and move the storm, but weak enough to not disrupt the conditions formulating the storm.[5]

Data

Sourcing and Aggregation

For this analysis, the data collection was split into 2 major parts: historical and modern, this was done to look at a long stretch of time (1850-1999) and pick out key years in hurricane history, as well as looking at the hurricane season for the current century, as these are the most relevant. The sources for both datasets were taken from Kaggle.com, but were curated by different users and collected from different sources. The historical hurricane data was taken from the NHC (National Hurricane Center) as they conduct post-storm analysis in their Hurricane Database. This data was also split by the ocean in which the hurricane was in, Atlantic and Pacific, which was merged during the aggregation process for ease of use. The modern data was compiled from public domains for named hurricanes that have impacted North America, and according to the kaggle.com description, no specific depicted source is listed; these data were cross referenced by NOAA records to ensure accuracy. The data sets can be found as References 6 and 7 in the references.

An interesting yet relevant aspect of the historical data is to question how this data was collected and how we can ensure its accuracy. As we look back in time through the scientific lens, we understand that some of the processes that have been improved upon have existed for centuries, and this is no different for hurricane tracking. A common instrument that measures wind speed and direction, the anemometer, was invented by Italian architect Leon Battista Alberti in 1450; similarly, instruments used to measure air pressure and temperature were invented by Evangelista Torricelli in 1643 (barometer) and by Santorio Santorio in 1612 (thermometers). By the time we get to the era that the historical dataset covers, the understanding of these storm concepts were around for a couple hundred years, continuously refined and improved upon. According to weather.gov, the National Weather Service timelines that by the mid 1800s (specifically 1849), institutions started to communicate real-time weather tracking, forming weather maps and developing weather reports. There is no coincidence that the start of the historical data for this analysis is dated 1851, 2 years after the Smithsonian's major push for weather reporting and data collection. And luckily, these data and these communications were written down for future use, leading to the analysis we have today.[8] It is worth remembering that despite the efforts of the past, we do not have the full context and story of the hurricanes that occurred in early reporting. Such as remote areas, or weaker hurricanes (tropical storms).

In order to present this data in a clean format for analysis, the raw data for both sets was aggregated using python library Pandas. The following covers a basic synopsis of what was done to the data for the final format (example images below). With the initial data loaded in, the first step was to drop columns that were not necessary for the analysis, this included Time, Name, Minimum Pressure, and the various direction winds that were tracked. Then, the format of the Date column was changed to just include the year, after which, the columns were renamed to fit the project properly, changing Date to Year, Status to Category, and Maximum Wind to Highest Wind Speed.

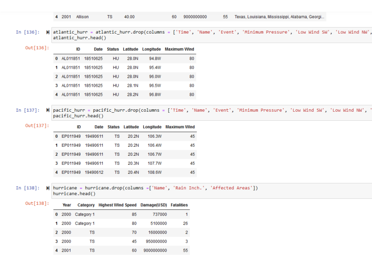

Fig. 2: Dropping unnecessary columns

Fig. 3: Reformatting the date column

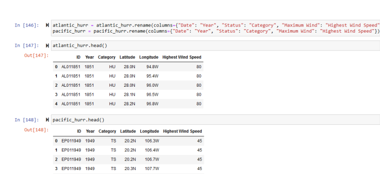

Fig. 4: Renaming the columns

The final step was to correctly label the category of the storms that were recorded historically, (as the data in the Modern dataset were already correctly categorized). Depicted in figure 5, this included creating a function that would go through every record, check the highest wind speed, and change the category appropriately based on the Saffir-Simpson Hurricane Scale.[9]

Before this function, the data in the Category column would be labeled either as TS or HU, with TS referring to Tropical Storms, and HU referring to Hurricanes. Tropical storms are a lower classification of Hurricanes and could have been removed from the analysis altogether, but keeping them retains consistency with classifications from the modern dataset, as well as acknowledging that tropical storms follow the same creation conditions and follow the same trends as hurricanes.

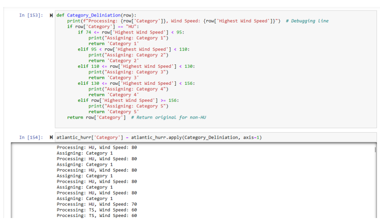

Fig. 5: Writing a function to create categories

While the only pictured application of the function was for the Atlantic ocean portion of the data, this process was also done on the Pacific ocean portion of the data. And to reiterate, the Modern dataset did not need to undergo this process as the data was already categorized accurately, and was the inspiration of the function to be applied to the historical data.

Looking at 150 Years of Hurricanes

There was one major component, and two specific years of data this project was intending to highlight from the historical data, these are the count of tropical activity occurrence over the 150 year period (1850-2000), as well as a dive into the hurricane season of 1924 and 1932.

The following figure observes the count of tropical activity over the 150 year period, including hurricanes, tropical storms, tropical disturbances, etc.

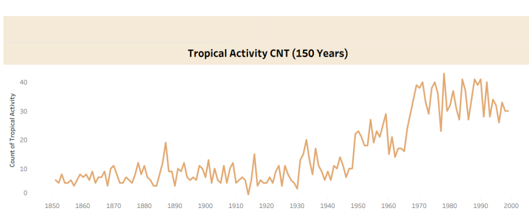

Fig. 6: Count of hurricane activity over the years

Off initial basis, one could argue that the major difference in the first 75 years and the latter 75 years could be a matter of accurate record keeping and tropical activity interpretation, but as described in Data Sourcing, Collection and Aggregation, while the methods have improved over the years, detailed communication and record keeping was solidified in the mid-1800s by the Smithsonian Institution.[8]

To verify the data being displayed in the above figure, we can compare it to a similar analysis presented by the Department of Atmospheric Science from Colorado State University in figure 7. The major difference being the CSU data only includes named hurricanes, and not less intense tropical activity as in the above figure. We can notice major spikes in 1887, 1932, and 1995.[10]

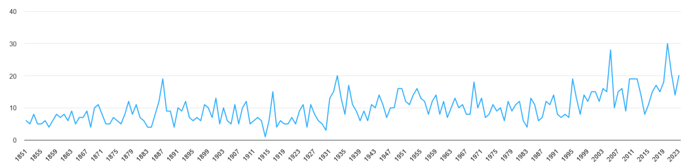

Fig. 7: Colorado State University data on tropical activity

This takes us to the two specific years picked out for the historical analysis, 1924 and 1932. While the choice behind 1932 can be apparent from the noticeable increase in hurricane activity, the choice behind 1924 is less apparent until looking deeper into that year's hurricane season.

Cuba, 1924: Dr. Jose C. Millas, the director of national observation writes:

"I believe that this hurricane is one of the most severe ever experienced in our latitudes."

and later, an account by Captain Burmeister recalls:

"The whole sea was a boiling, seething mass. It was impossible to see any distance. It appeared as if the surface were covered with a mass of turbulent steam...I estimated the wind to be blowing 120 m.p.h. I ordered every pound of steam to be used in keeping her under control."

While Dr. Jose and Captain Burmeister didn't know it at the time, what the Captain experienced and the Dr. documented was the first official category 5 hurricane.[11] This is monumental in hurricane record-keeping as it dates the first hurricane of its kind and provides insight into what the reporters of the time experienced in regards to these conditions. The following figure displays this hurricane, as well as the other 4 most extreme hurricanes of that season.

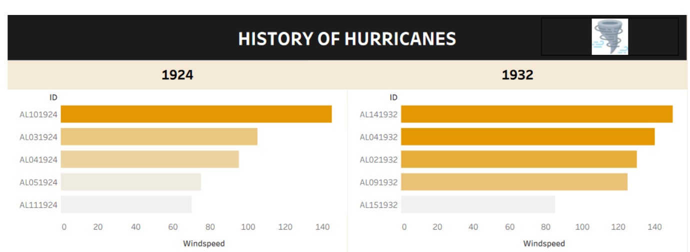

Fig. 8: Top 5 hurricanes (by windspeed) for years 1924 and 1932

On the other hand, 1932s Camagüey hurricane took place in Cuba and was the only recorded Category 5 hurricane to have occurred in November.[12] This phenomenon was observed even then, in the monthly review, US Weather Bureau forecaster C. L. Mitchell writes,

"This storm was remarkable not only for its great intensity so late in the hurricane season... and its moving into the Caribbean Sea at least two weeks later than any other tropical disturbance of hurricane intensity during the last 50 or more years."[13]

However, this isn't the only important metric about this hurricane, which is the length of time that it remained as category 5, totaling to about 78 hours straight of Category 5 intensity from November 6th to November 9th.[12] This is mentioned in the monthly review, with C. L. Mitchell notating,

"During the night of the 8th-9th the storm recurved to the northeast and began to move more rapidly... between 1p.m and 2p.m it passed to sea again near Nuevitas where a barometer reading of 28.85 inches and an estimated wind velocity of 125 miles per hour were reported..."[13]

This is affirmed by DBpedia, detailing, "On November 6, the tropical cyclone reached its peak intensity as a Category 5 hurricane with maximum sustained winds of 175 mph (280 km/h). The storm weakened to Category 4 intensity while recurving northeast, moving ashore Cuba's Camagüey Province on November 9 with winds of 150 mph (240 km/h)."[14]

Hurricanes in the 21st Century

The two major metrics observed for the modern data consist of the average wind speed for all of the hurricanes of that year, as well as the amount of each category of hurricane for each year. These two metrics work in tandem as wind speed is directly correlated to the category of hurricane, so being able to see a breakdown between the two will provide context to the severity of hurricanes that have formed over the last 20 years.

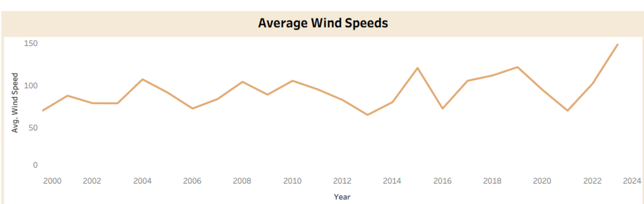

Fig. 9: Average hurricane wind speed since 2000

The average wind speed per year has had a steady increase over the observed 20 year period as the intensity of hurricanes has become more the norm over time, as can be seen in the stacked bar figure. Both figures follow a similar line, with dips in 2006 and 2009, and increases in 2017 and 2019. A glaring data point to note is 2020, where there were the most categorical hurricanes but a fairly low average wind speed, this is due to the lack of that season having intense hurricanes, being 1 of 2 years since 2017 to not have any Category 5 hurricanes.[15] This was a result of the perfect climate conditions coming around altogether and producing a multitude, oftentimes overlapping hurricanes that were fairly weak, these dissipated as the stronger hurricanes started to occur in the latter half of the hurricane season.

Initially, the most intense hurricane of 2020 was classified as a Category 5, however, after a reanalysis, Hurricane Iota was reclassified as Category 4.[16] In an initial 2020 report by the NOAA, the report covers the category 5 status of Hurricane Iota

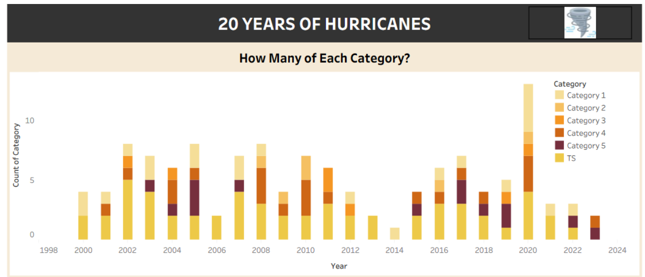

Fig. 10: Category breakdown of named hurricanes since 2000

and the unusually high activity of the hurricane season, claiming, "According to NCEI scientist Jim Kossin, the biggest contributor to the hyperactive 2020 Atlantic hurricane season was by far the much-warmer-than-normal ocean temperatures."[15]

While the conditions observed in 2020 were correct, the categorization of Hurricane Iota was adjusted during its Tropical Cyclone Report, the report stating,

"...its maximum sustained winds to 135 knots (155 mph) – making it a high-end Category 4 hurricane on the Saffir-Simpson Hurricane Wind Scale."

An article by Cyclonic Fury on this report contextualizes this decision, quoting National Hurricane Center Senior Hurricane Specialist Stacy Stewart,

"...ongoing research suggests there is a high bias of SFMR wind speeds in these high wind regimes." Further explaining, "This research has not yet been completed, and could lead to other peak maximum sustained wind estimates being changed of recent intense hurricanes."[16]

To an extent, the classification of hurricanes like Iota comes down to semantics as the winds were reported to be as high as 5 mph below the threshold, which highlights the importance to observe wind speeds, as well as metrics like damage caused or casualties.

What Has Changed Over the Last 200 Years?

This section will cover some of the major reasons as to why we're seeing record breaking hurricane activity and intensity in the 2nd observed time period (2000-2023). A major proponent has been highlighted a couple times throughout this report, being the temperature of the water. As the temperature of water increases, the more intense the hurricanes can become. This phenomenon is explored by the Environmental Defense Fund, the fund explains, "Evaporation intensifies as temperatures rise, and so does the transfer of heat from the oceans to the air. As the storms travel across warm oceans, they pull in more water vapor and heat."[17] What the EDF is explaining is the exact same process introduced in Understanding Earth's Relationship with Hurricanes, the process for creating a hurricane is intensified when the conditions to create the hurricane become more extreme.

Another component is the rising sea level, in just the last 200 years alone (the same observed period as in this analysis), the sea level around the globe has risen 8-9 inches, with around a third of this increase being in the last 30 years alone.[18] As depicted in the following figure by GlobalChange.gov, the change in rising sea level is starting to become exponential, with changes that took

80 years (from 1880-1960), having the same change in 30 years (1993-2023).[19]

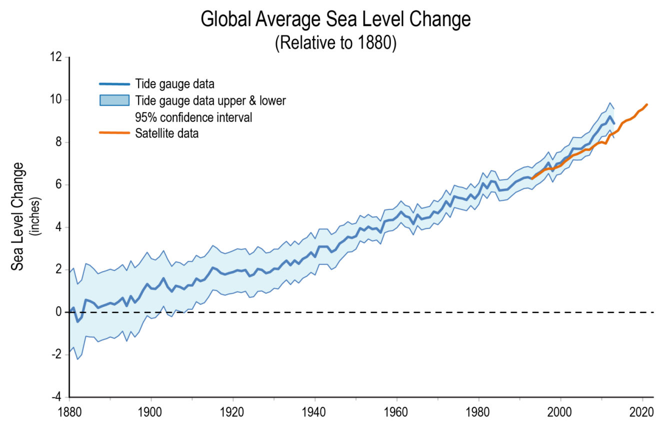

Fig. 11: Average change in sea level over the past 200 years

How does sea level relate to the intensity and occurrence of hurricanes? This is due to the concept of storm surges. According to the National Weather Service, a storm surge is, "an abnormal rise of water generated by a storm, over and above the predicted astronomical tides." further stating, "This rise in water level can cause extreme flooding in coastal areas particularly when storm surge coincides with normal high tide, resulting in storm tides reaching up to 20 feet or more in some cases."[20] Storm surges have been around for major deadly hurricanes, such as Katrina and Sandy, being the reason why intense hurricanes are more destructive than hurricanes of similar category and status in the past, per the Environmental Defense Fund.[17] Using this assessment of the past 20 years, we can look to the future, where NASA predicts: "Due to global warming, global climate models predict hurricanes will likely cause more intense rainfall and have an increased coastal flood risk due to higher storm surge caused by rising seas."[21]

A more immediate effect to be noticed as of just this year (2024) is the rate at which hurricanes are becoming Category 5, with hurricane Milton becoming the fastest recorded hurricane to go from tropical storm → category 5.[22] A quickly intensifying hurricane is harder to prepare for and predict, they're more volatile, with Glorica Dicke and Katy Daigle of Reuters.com citing, "Mexico was surprised last year when a weak tropical storm in the Pacific suddenly became a powerful Category 5 storm called Hurricane Otis, just hours before it slammed into western Mexico…"[23] This can be affirmed by the Environmental Defense Fund, noting, "How fast hurricanes intensify has also increased in the Atlantic since the 1980s, due to climate change. Hurricanes Dorian and Milton are prime examples. Both rapidly intensified close to landfall, making it harder to predict the potential danger."[17]

This is an effect of human-influenced climate change. Within the last 40 years, a staggering 90% of emitted greenhouse gasses have been absorbed by the Earth's oceans, resulting in 2024 to be deemed to have the warmest average global air temperature on record.[23]

Conclusion

Climate change and its effects are a very real and noticeable issue in the modern day ecosystem. Due to rising sea levels and warmer climate conditions, hurricanes have become more frequent and more intense, leading to an increased amount of destruction across at-risk locations. Hurricanes and other natural disasters have a history of being well documented, further exemplifying the accuracy of the change/trends in historical and modern hurricanes. While records of wind speeds and duration of category 5 were set in the last 100-200 years of hurricanes, the last few years of hurricanes are breaking other records like intensification speed, while contending with the historic hurricanes of the past. If the causes of climate change can be heavily reduced in the coming years, humanity may be able to slow and amend the damages to the climate and Earth's health, making these record breaking hurricanes a thing of the past for future generations.

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