Exploring the Positive Feedback Loop between Anthropogenic Climate Change and Tropical Cyclones

Jaiman Gupta

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The repercussions of climate change on tropical cyclones is a thoroughly researched topic, and a positive correlation between tropical cyclone (TC) intensity and climate change has been widely established in the scientific community. However, a lesser-researched field is the opposite of that: the effect of tropical cyclones on climate change. If there is an effect of hurricanes that exacerbate climate change, this would mean a positive feedback loop exists, which is a very troubling occurrence. This paper aims to investigate how anthropogenic climate change and its relationship to tropical cyclones in the South China Sea plays a part in the positive feedback loop that intensifies the effect of global warming. The primary methodology to research this hypothesis will be analyzing satellite data, including sea surface temperature (SST), total water precipitation (TWP), and tropical cyclone frequency and location. This will be primarily done using statistical, temporal, and spatial analysis. Through these methodologies, we concluded various correlations in the South China Sea. There appeared to be a positive correlation between TWP, SST, and TC events. There was an unclear correlation between the frequency of Cat 4 and 5 events or TC events. Finally, there was a high correlation between TWP and TC events; areas with higher TWP tended to have more TC events. TC events also had an extremely high visual-spatial density in the East and North East of the South China Sea. Furthermore, to validate and compare my results and create a conceptual positive feedback loop model, we focused on-erosion as a middle factor in making the positive feedback loop. The study concluded that a relationship between TCs and climate change forms a continual positive feedback loop which exacerbates anthropogenic effects on the climate.

Introduction

In today's scientific community, the correlation between tropical cyclone intensity and climate change is well-established. Through monumental research works such as Webster et al. (2005), the scientific community eventually reached a consensus on the correlation between climate change and tropical cyclones[1]. This consensus today is helping governments and institutions take steps to help mitigate this dire issue, but the road that led to this involved decades of research, debates, advances in technology, inventions, and much more. The first glimpse of climate change was seen in 1824 when Joseph Fourier calculated that the Earth, at its distance from the Sun, should be much colder. He suggested that there was a substance(s) in the atmosphere that was acting as an insulator, heating the earth. This insulator was discovered in 1856 by Eunice Foote, who showed that carbon dioxide and water vapor in Earth's atmosphere were trapping infrared radiation that was supposed to bounce off the Earth's surface into space, heating the globe. In his paper, Guy Callendar (1938), a small researcher, Guy Callendar (1938) discovered that global temperatures had risen by 0.3°C over the previous 50 years[2]. He did this by collecting records from 147 weather stations worldwide and analyzing the trends. He argued that carbon dioxide emissions were the reason for global warming and was the first to put forth the anthropogenic climate change model that is so well known today. However, this was largely ignored by other scientists who didn't believe that humans could impact such an extensive system as the earth's temperature. This single topic of human linkage to climate change turned out to be 1 of the most heavily debated scientific theories in history. Notable papers such as S. Manabe and R. T. Wetherald (1975) were among the first to use climate models to demonstrate the potential for increased CO2 concentrations to cause global warming[3]. This was opposed by reports such as Reid A. Bryson (1972), who drew conclusions about natural climate variability and increasing temperatures[4].

However, after decades of debate, the Charney Report (1979) marked a point where a general census in the scientific community had been reached: humans are causing climate change[5]. While this marked the soft ending of this debate, the repercussions and effects of climate change were still largely unknown and not profoundly researched. One of the earliest correlations between tropical cyclones and climate change was made in ”Tropical Cyclones and the Climate System” by Kerry Emanuel (1987). In Emanuel's research paper, he used theoretical aspects of tropical cyclones (hurricanes) and their connection to climate change using computer-based climate models[6]. However, search papers like Goldenberg et al. (2001) attributed the increased tropical cyclones to natural climate variability, one of the biggest arguments against climate change and now against climate change's relationship to tropical cyclones[7]. This was all but proven by countless research studies, most notably by papers such as Emanuel (2005), which demonstrated the correlation between tropical cyclone intensity and increasing sea surface temperature[8]. Knutson, T. R., & Tuleya, R. E. (2004) ran extensive simulations of increasing temperatures against factors such as tropical cyclones and precipitation to investigate the relationship between TC intensity and SST[9]. A central argument is the extent to which they were linked. At this time, many sources, such as Goldenberg, S. B. (2001), correlated tropical cyclone frequency with climate change, which resulted in a building discrepancy in the consensus of climate change's effect on tropical cyclones due to the conflicting conclusions drawn by various researchers[7]. Finally, in the Intergovernmental Panel on Climate Change (IPCC) (2007), through an intergovernmental panel, it was established that tropical cyclone intensity was directly increasing because of climate change[10].

The IPCC is the foremost authority on such events as it provides an extensive and thorough review of all the literature and has vast teams of top scientists working on synthesizing it and drawing a conclusion on such topics. However, there is undoubtedly progress to be made in the field, and our concept of interest is in the positive feedback loop of climate change, which further intensifies the cycle of TC events. Tropical cyclones have many environmental effects, such as habitat and ecosystem destruction, which have been widely proven to contribute to greenhouse gas release into the atmosphere through plant life loss and other geological cycle disruptions. Furthermore, this academic paper focuses on the South China Sea as this is generally a lesser-studied geographical area compared to the Pacific Ocean. Through this paper, we aim to investigate how anthropogenic climate change and the relationship to tropical cyclones in the South China Sea create a positive feedback loop that intensifies the effect of global warming.

Methodology

The primary general methodology of this research paper was a quantitative analysis of existing satellite data on various variables and factors using a wide assortment of graphs and maps. First, we wanted a way to analyze the relationship between total water participation and tropical cyclones in the South China Sea. The purpose of a graph that could accurately represent this would be helpful in visualizing such a relationship. Therefore, we decided to use a spatial map of tropical cyclones with total water precipitation visible on the graph to identify correlations. Second, we needed to find the correlation between the categories of hurricanes to help support the positive feedback loop mentioned in the research question. Finding the category shifts of hurricanes over time would be instrumental in determining is hurricanes are playing a role in increasing hurricane intensity by contributing to climate change or not. Lastly, we compared TWP to SST, which we later compared to TC frequency and intensity.

Figure 1 in this research paper is a spatial map representing all tropical cyclones of category 1-5, which occurred in the South China Sea from 1850 to the most recent available data from 2024. However, the tropical cyclones alone would not be helpful in drawing conclusions about environmental factors affecting hurricanes. Therefore, we decided to superimpose the total average water precipitation from the same period and geographical location onto the spatial map. The data for TWP had to be hindcasted backward as there were no records of it before 1979. This figure required 2 comprehensive data sets to create the total water precipitation and the tropical cyclone over time with their coordinates and categories. First, we found tropical cyclone data that matched my requirement from a United States government-funded institution named the Nation Center of Atmosphere Research. We found this data set on their official .gov website and used the IBTrACS Version 4r01 dataset for our purposes. The data itself was highly comprehensive and detailed, so extensive filtering and cherry-picking were required. The file included the specific tracks of each hurricane in the form of its exact longitude and latitude coordinates every 1-3 hours of it being active, which is where we can derive the data we need. Another set of data we extracted was the category classification of the hurricane, ranging from Category 1 to Category 5. This was needed to determine the relationship between other factors and the intensity of the hurricane. In the figure itself, we plotted the starting location of the TC events as the point that would provide the most insight into its relationship with the TWP in the area.

The second data set we required for this figure was the average total water precipitation, which we found on the Berkeley Earth website. We found this data on their official website under the Global Monthly Averages (1850 – Recent) for total water precipitation. Berkeley Earth provided total water precipitation data monthly from the same time period of 1850 to 2024. This data was also very comprehensive, with several extra variables related to total water participation, such as data certainty and data anomalies. The Python libraries used to create this graph are as follows: 'Pandas' is used for data manipulation and analysis; 'Matplotlib' and its extension 'Cartopy' for data visualization, specifically for creating maps; 'NumPy' for handling arrays and numerical calculations; and 'Cartopy Gridliner' for adding grid lines and formatting map coordinates. After loading the dataset from CSV files using pandas. The sea surface temperature (SST) data is read and transformed using the pivot function to reshape the data frame to be suitable for contour plotting. This involves creating a grid-like structure where each cell represents the temperature value for a given month and year. Simultaneously, read the Tropical Cyclone (TC) event data. Ensure the latitude

(‘LAT‘), longitude (‘LON‘), and the Saffir-Simpson Hurricane Wind Scale (‘USA_SSHS‘) columns are in numeric format. Non-numeric entries are coerced to ‘NaN,‘ and entries with missing essential data are removed to maintain data accuracy. Next, we filter the TC dataset to include only significant cyclone events that fall within the SSHS categories 1 through 5. Now, for the actual graph, we need to Initialize a Matplotlib figure and a single subplot with a map projection.‘ccrs.PlateCarree()‘ is specified as the map's projection, which is a simple cylindrical projection appropriate for Earth's latitude and longitude system. The map's geographical extent is then set to encompass the South China Sea region. In order to enhance the map's readability, it is necessary to overlay features such as landmasses, coastlines, national borders, and ocean color, which provide geographical context and visual clarity. Transform and visualize the pivoted SST data as a colored contour plot overlaying the map. A ‘contour‘ function is used to create filled contours, and a color bar is added to the figure to represent the scale of total water precipitation. Next, the TC events filtered by intensity are plotted as a scatter plot on the map. The SSHS value determines the color, from purple to yellow. We also add grid-lines to the map for latitude and longitude, adding appropriate titles and axes.

Figure 2 of this research paper is a graph of the yearly total number of tropical cyclones compared to the yearly total number of category 4 and 5 hurricanes over the same time period of 1850 to 2024, as seen in Figure 1. The data we used for this figure was the same as the tropical cyclone data in Figure 1, but it was implemented very differently. In this graph, we used a yearly number of tropical cyclones of category 4 and 5 hurricanes, respectively, and graphed it over time. To make the graph, we first load the cyclone data into a pandas DataFrame from a CSV file and convert the 'ISO_TIME' column into a datetime object to extract the year, creating a new column, 'Year,' for easier analysis. Next, we need to group the data by the 'SEASON' column to get the total count of cyclones per year. Also, the data can be filtered to identify only severe cyclones (Category 4 and 5) based on the 'USA_SSHS' column. Finally, we plot the total cyclone frequency and the Category 4 and 5 cyclone frequency as line plots with distinct colors and markers for visual distinction. To increase clarity, we also place a legend on the plot to differentiate between the 2 data sets and use ‘tight_layout‘ to automatically adjust subplot params for the figure layout.

Figure 3 of my research paper graphed the total water precipitation and sea surface temperature over time during the time period of 1850 to 2024, the same as the previous 2 figures. For the total water precipitation, we was able to use the same data as Figure 1 but implemented it very differently. As for the sea surface temperature, we found comprehensive data we could use from the website Berkeley Earth, which proved to be enough for our purposes. To create the actual graph, we first import the relevant libraries, ‘pandas‘ for data handling and manipulation, ‘matplotlib.pyplot‘ for creating the graphical output. ‘numpy‘ to assist in numerical calculations and data generation. ‘scipy.stats‘ to use functions to calculate statistical correlations, and ‘matplotlib.lines.Line2D‘ to create custom legend entries. Next, we load the SST dataset from a CSV file into a data frame. This data structure is particularly suited for time series data and allows easy manipulation of columns. After this, we define the period of interest for the analysis and filter the dataset accordingly. This step is crucial for focusing the analysis on a specific time frame.

Subsequently, we need to extract the 'Year' and 'Actual Temperature' columns, which will be used as the x-axis and the y-axis, respectively. For the total water precipitation data, we need to get all the values into a NumPy array for more convenient numerical manipulation later on. For this graph, we will be calculating the different correlations to analyze the data further. To do this, we use the respective functions to compute the Pearson, Spearman, and Kendall correlation coefficients to assess the relationship between SST and TWP quantitatively. On top of this, we add a linear trend line for SST and TWP by fitting a first-degree polynomial. This provides a visual indication of the long-term trends. Finally, we create a new figure with a custom size and plot SST data. Set up a secondary y-axis for the TWP data. This dual-axis plot allows for easy comparison of 2 different scales.

Results

The varied colored dots on the map represent tropical cyclones ranging from category 1 to 5 from the time period of 1850 to 2024. The varying blue shades on the map represent the levels of water precipitation in the South China Sea averaged over the above-mentioned time period. The water precipitation is in ovals, as there is minimal accurate data availability on the total water precipitation in the South China Sea. The figure is very insightful and shows a plethora of trends and correlations. First, a high frequency of tropical cyclones is visible in areas with higher total water precipitations. This indicates that higher total water precipitation leads to better conditions for tropical cyclones to form and intensify. Furthermore, there seemed to be a greater frequency of higher category hurricanes - category 4 and five - in the top right corner of the South China Sea, specifically on the side where the Pacific Ocean is.

The black line represents the total yearly tropical cyclone frequency over the given time period of around 1947 to 2024 in the South China Seas. The purple line represents the yearly total category 4 and 5 hurricanes over the same time period and geographical location. The trend line with the equation is also plotted with corresponding colors – a purple dotted line for cat 4 & 5 hurricanes and a black dotted line for all TCs. There is an increase in both tropical cyclones and category 4 and 5 hurricanes as shown by the trend lines. The total TC frequency seems to increase at 19.33 more TC events per year on average according to the trend line and cat 4 & 5 hurricanes seem to

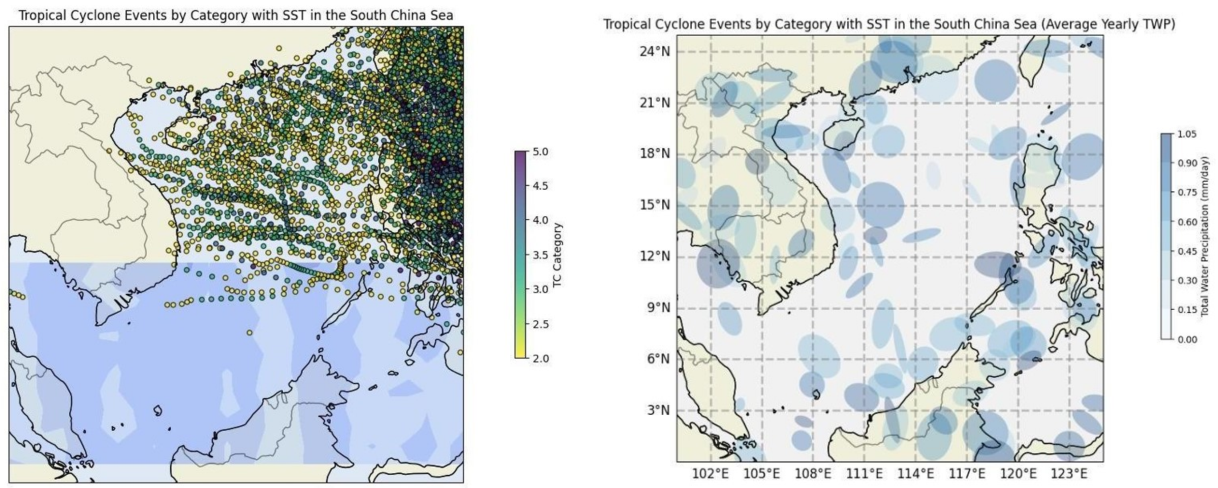

Fig. 1 Tropical Cyclone Events by Category with SST in the South China Sea(Average Yearly Total Water Precipitation)

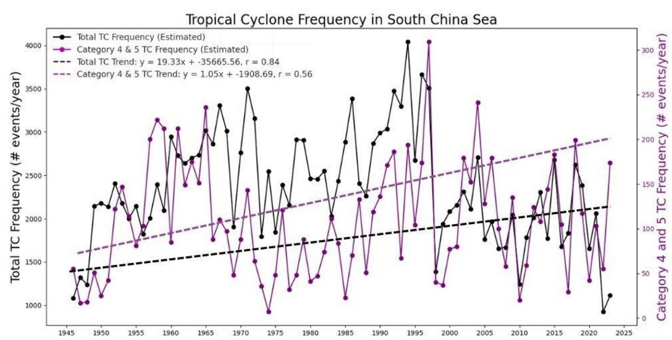

Fig. 2 Tropical Cyclone Frequency in the South China Sea

increase by 1.5 every year on average according to the trend. This would mean that according to this data tropical cyclones have been increasing over time and so have cat 4 & 5 hurricanes. On a side note, it is important to note that these results may not be statistically significant as is discussed later on in this paper.

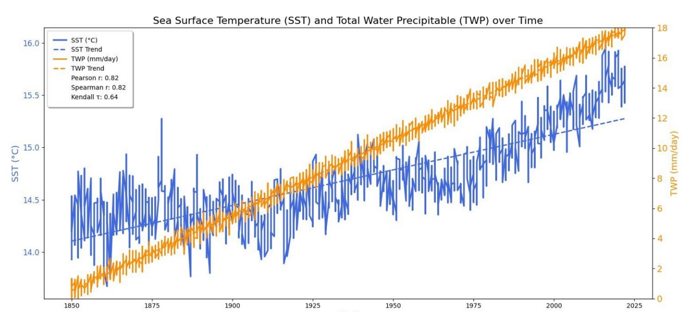

Fig. 3 Sea Surface Temperature and Total Water Precipitation Over Time

The solid blue line represents the average sea surface temperature in the South China Sea over the time period of 1850 to 2024. On the other hand, the solid orange line represents the average total water precipitation over the same time period and geographical location. The blue dashed line and the orange dashed line represents the trend of sea surface temperature and total water participation over time, respectively. As clearly displayed by the orange trend line, over the given time period, total water precipitation has been on a somewhat linear rise. On the other hand, sea surface temperature also exhibits an upward trend but with less of a linear tendency. This suggests that as the surface temperature of the sea has increased over time, so has the amount of water vapor in the atmosphere, which means that the 2 variables have a positive correlation. This could be justified by the chemistry principle of warmer air having the ability to hold more moisture as explained by Sherwood et al. (2010)[11]. The increase in SST could be related to global warming, and a corresponding increase in TWP could suggest more moisture available in the atmosphere for precipitation events, which could lead to changes in weather patterns, such as more intense and frequent storms. The coefficients provided (Pearson, Spearman, and Kendall) are measures of the correlation between SST and TWP over time. First, the Pearson coefficient yielded a value of r: 0.82 - This is a measure of the linear correlation between SST and TWP. The Pearson correlation coefficient can range from -1 to 1, where 1 means there is a perfect positive linear relationship, -1 means there is a perfect negative linear relationship, and 0 means no linear relationship at all. A value of 0.82 suggests a very strong positive linear relationship, meaning that as SST increases, TWP also tends to increase in a linear fashion. Second, the Spearman coefficient resulted in a value of rho (ρ): 0.82 - This is a measure of the monotonic relationship between SST and TWP. Unlike Pearson, which measures linear relationships, the Spearman correlation coefficient can identify any monotonic relationship, meaning it can detect a correlation regardless of whether it is linear or not. A value of 0.82 indicates a strong positive monotonic relationship, suggesting that as 1 variable increases, the other also tends to increase, but not necessarily at a constant rate across the entire range of values. Lastly, the Kendall correlation coefficient showed a value of τ: 0.64 - This is another measure of a monotonic relationship, but it's based on the rank order of the data rather than the actual values. A Kendall τ (tau) of 0.64 suggests a strong positive association between SST and TWP, but it is generally a more conservative measure than Spearman's r, meaning that it is less influenced by outliers. In summary, the graph indicates that over the years, both sea surface temperature and total water precipitation have increased, with strong positive correlations between them, suggesting that as the sea surface warms, the atmosphere's capacity to hold water vapor also increases.

Discussion

TWP, SST, and Tropical Cyclone Frequency

Through this study, many results were obtained, which provided valuable insights into the research question at hand. To restate, the aim of this paper is to explore the existence of a positive feedback loop between tropical cyclones and climate change. To begin, Figure 1 provides deep insight into the positive feedback nature of tropical cyclones.

Through the spatial map, it is evident that a majority of the typical cyclones occurred in only the top right side of the South China Sea; this was likely a result of the higher total water precipitation in that area, meaning that there is a strong correlation between TWP and optimal conditions for hurricanes to form. This result is concurrent with the consensus in the scientific community about the conditions in which hurricanes can form; high water precipitation is an important factor for hurricanes to be able to form and intensify. This concept is reinforced by works such as Hernandez-Ayala 2023, in which he establishes the trend between higher total water precipitation being present during the hurricane season. Hurricane season in the South China Sea represents the yearly time with increased frequency and intensity of tropical cyclones. The hurricane season occurs mostly from May through October, and there is a shockingly close trend to the spikes in sea surface temperature shown in Figure 3. Figure 3 of this study echoes this pattern very precisely; there is a very clear fluctuation in the sea surface temperature, which occurs almost periodically. The sea surface temperature spikes upward approximately every May and drops back down in around October. Sea surface temperatures' relation to tropical cyclones has been thoroughly researched in geographical regions such as the Pacific Ocean by notable studies such as Hernandez-Ayala 2023, in which a very similar trend is observed for the Pacific Ocean. On top of the effect of water precipitation on a smaller time scale, the water precipitation has been significantly increasing over the past nearly 200 years. Despite sea surface temperature being a key factor in tropical cyclones' formation, tropical cyclone frequency in the South China Sea has seen a general decrease over the same time period. The same is cited on a global scale by Knutson, T. R., et al. (2021)[9]. Specifically, in Knutson et al., a plethora of models were cited, which mostly either stated a slight decrease in tropical cyclone frequency or no observable trend[9].

The Possible Existence of the Positive Feedback Loop

The high concentration of tropical cyclones in the East and North of the South China Sea could be a result of various factors. The nature of tropical cyclones repeatedly forming in a single area certainly hints at a worsening effect that tropical cyclones can have. This could mean that tropical cyclones are creating conditions that will allow future tropical cyclones to form more easily, specifically through certain middle factors such as erosion. Such repercussions of tropical cyclones could be exacerbating climate change which in turn effects the conditions needed for tropical cyclones to form, making them more ideal and thus causing the tropical cyclones to have stronger middle factors such as erosion which again contributes to climate change and as a result tropical cyclone conditions. This in effect, could have been creating an endless cycle or a positive feedback loop.

The abovementioned middle factors are a key to the positive feedback loop model and one of the most prominent ones is erosion. Erosion is a widely researched and an essentially proven contributor to climate change. This correlation can be seen partially in Lal, R. (2003)[12]. In this paper, Lal, R. concluded that erosion can remove topsoil rich in organic carbon and expose deeper, less fertile soil[12]. Eroded organic carbon can be oxidized and released as CO2 into the atmosphere, which directly contributes to climate change.

Also, Lal, R discussed how erosion can redistribute soil carbon by depositing it in aquatic environments where it can be sequestered. Erosion on larger scales, especially when caused by massive events such as cat 4 or 5 tropical cyclones, can have even bigger impacts. 1 part of tropical cyclones that contributes to erosion is the high wind speeds and, by extension, the tornados that often come with higher-category tropical storms. In category(cat) 4 or 5 tropical cyclones, the windspeed can range from 209 to 305 km per hour, and for the tornadoes, up to 177 km per hour, as shown in Knutson et al. (2015) and Wurman et al. (2005) respectively[9,13]. Depending on the specific biome and conditions, this is often enough to erode a large amount of soil, animals, plants, and even trees. Such an occurrence can cause a huge imbalance in the ecosystem that can cause shockwave effects through the food chain, starting with the organisms directly relying on the affected species and causing an ecosystem cascade effect. This could be through an imbalance in predator-prey populations, which causes an overgrowth of a species, which can cause eventual nutrient imbalances in the ecosystem. Such fatal nutrient imbalances can also be caused by erosion of too much soil or nutrient banks. Another way an ecosystem can collapse is through invasive species. Storms with high windspeed often displace organisms to their non-native habitats. If a species has the correct characteristics - being a selected species, having a high tolerance range, having a large range of food consumption, etc. - it can often dominate the ecosystem and out-compete local species. Especially if it has no natural predators, the entire ecosystem could once again experience a collapse due to the ecosystem cascade effect. Essentially, the ecosystems affected by the high wind speeds and tornados from tropical cyclones become very prone to being highly damaged and even completely collapsing. Most ecosystems, when they experience such occurrences, release high amounts of stored carbon in trees and plants that were eroded. In the long term, affected ecosystems fail to act as the carbon sink they were. Previously, the trees and plants in the ecosystem were consistently performing photosynthesis, directly reducing the amount of carbon dioxide in the atmosphere, but with the loss of plants and trees as a result of the causes discussed above, the trees and plant's ability to uptake CO2 becomes extremely reduced due to decreases in population density of the species and even can be stopped altogether if the ecosystem collapses. Natural carbon sinks, such as trees in ecosystems, are an essential way climate change is mitigated. Without these useful carbon sinks, climate change will be further exacerbated. However, high wind speeds are not the only part of tropical cyclones that cause climate change.

Another part of tropical cyclones is storm surge, a very prominent cause of habitat destruction and coastal erosion. Storm surge refers to aggressive waves of water that surge inland from the ocean during tropical cyclones. These are huge waves that, in category 4 and 5 hurricanes, can be 2-3 stories, moving at speeds of 20-30 mph. Storm surge waves cause large amounts of erosion from their great force and, over time, can decimate habitats they come in contact with, leading to the same climate change exacerbation that occurs as a result of high wind speeds and tornadoes. On a more direct scale, storm surge also often tears pieces of land on the coast off. This is an even more devastating occurrence than regular erosion; the eroded land not only instantly loses all of its stored carbon and carbon sink capabilities but contributes to sea-level rise, which increases the amount of habitat loss and again exacerbates climate change. On top of all this, storm surges can often cause nutrients from human establishments to be drawn back to bodies of water; for example, nitrogen fertilizer from farming establishments can be pulled into bodies of water and can lead to eutrophication. Eutrophication is another occurrence that is heavily linked to exacerbating climate change. The factors mentioned in the last 2 paragraphs clearly contribute to climate change, but this is only 1 part of the positive feedback loop.

Now that we have established that tropical cyclones worsen climate change through the middle factor of erosion, we need to link this back to the initially proposed positive feedback loop model. As discussed above, it logically follows that erosion contributes to climate change, but we need to discuss climate change's connection to erosion. There is a data-driven connection between climate change and coastal erosion that proves this connection. This connection between climate and coastal erosion was highlighted in Jamous, M. et al. 2023[14]. Using the barrier islands of New Jersey as a case study, they predicted that the regionally averaged 100-year eroded volume of beach-dune systems would increase by 58% in the HCC (Hierarchical Condition Categories) scenario, which refers to the projected changes in hurricane climatology due to climate change. It considers factors such as increased storm intensity, frequency, and track patterns. Essentially, it explores how future hurricanes might behave differently under a warmer climate. It also predicted that the regionally averaged 100-year eroded volume of beach-dune systems would increase by 84% in the HCC scenario, with the predicted sea level rise factored in. This evidence clearly shows the correlation between erosion and tropical cyclones, and there is much more evidence that corroborates this point.

Carbon dioxide levels would be a key indicator that would support that erosion was linked to climate change and was therefore causing increasted tropical cyclones. As seen in the accredited figure below, atmopheric CO2 levels have been rising exponentially over the last 100 years. The factors mentioned above have likely partially contributed to this evident rise in CO2 and therefore have certainly been exacerbating climate change.

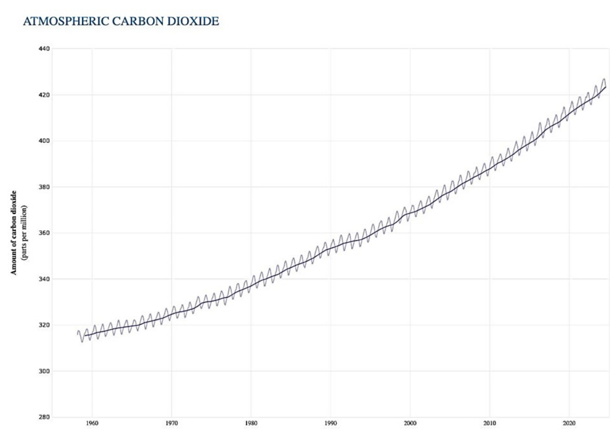

Fig. 4 CO2 levels in the atmosphere over time[15].

At its heart, climate change is essentially categorized as a warming of the planet's temperature. We can see in Figure 3 there is a clear relationship between sea surface temperature, total water precipitation, and time. The sea surface temperate (SST) and total water precipitation (TWP) are generally increasing over time; this is important because SST and TWP are essential parts of tropical cyclone formation. As discussed in Patricola et al. (2018), high sea surface temperatures are required for tropical cyclones to form. They analyzed historical tropical cyclone track data from the National Hurricane Center's best track dataset, Atmospheric reanalysis data (e.g., wind, temperature, humidity) from the European Centre for Medium-Range Weather Forecasts (ECMWF), and a satellite-derived sea surface temperature dataset. The researchers used statistical analysis, numerical modeling, and observations to conclude that warmer SST means more ideal conditions for tropical cyclone formation. Despite this, as shown in Figure 2, there is no statistically significant correlation between frequency and time. This puzzling occurrence is a thoroughly discussed, debated, and researched topic. For this paper, we shall use the most popular consensus in the scientific community so far. Knutson et al. (2020) stated that there is no visible increase in hurricane frequency or intensity because the effects of climate change on TC frequency have not yet been clearly detected in the historical hurricane/TC record[9]. They also mentioned there have been various simulations run to determine future trends, and many predict a decrease in TC frequency while some predict an increase, but there is no widely accepted single simulated prediction. With this being said it is important to note that methodologies in climate data collection have significantly and rapidly changed over the last two hundred so especially older data could be misleading in that regard. It is also important to note that natural climate variability could be masking the actual effect of climate change on tropical cyclones. As discussed by the EPA tropical cyclone formation is heavily influenced by natural climate variability, such as the El Niño-Southern Oscillation and the Atlantic Multidecadal Oscillation - this natural variability can mask or even counteract any long-term trends driven by human-caused climate change. This would mean that we should actually be at a lower amount of tropical cyclones than we are following the natural flow of life but anthropogenic climate change is counteracting this natural decrease. If this is true the possibility of a positive feedback loop would be renewed and further proven.

Conclusion

Climate change is a multi-layered, highly complex problem faced by all humanity.

Understanding this worldwide problem is essential to combating it. This paper aims to add to the plethora of climate change research, specifically tropical cyclones' relationship to climate change. Instead of the linear relationship generally focused on by mainstream research, this paper takes that linear relationship and elucidates its true nature, a positive feedback loop. Specifically, this paper examined how climate change, through tropical cyclones, exacerbates climate change, thus creating a positive feedback loop. We focused on the middle factor of erosion to connect the positive feedback loop from tropical cyclones to climate change. Tropical cyclones caused erosion in a plethora of ways, from high wind speeds to storm surges to mini tornadoes produced by larger-scale tropical cyclones. The primary methodology to research this hypothesis will be analyzing satellite data, including sea surface temperature (SST), total water precipitation (TWP), and tropical cyclone frequency and location. This was using statistical, temporal, and spatial analysis. Through these methodologies, we concluded various correlations in the South China Sea. There appeared to be a positive correlation between total water precipitation, sea surface temperature, and tc events. There was an unclear correlation between the

frequency of Cat 4 and 5 events or TC events. Finally, there was a high correlation between TWP and TC even location. TC events have the visual-spatial density in the East and North East of the South China Sea. Through these connections, we concluded cyclones and climate change. This positive feedback loop shows the spiraling effect of climate change and how hard it is to mitigate, much less stop climate change. Since climate change worsens itself, this could mean that even stopping all anthropogenic climate change sources might not be enough. We might be so far gone in this cycle that the only way to stop or even start to reverse any damage would be human interference in reverting climate change. This could be humans restoring biomes and habitats manually or even implementing newer technologies such as direct carbon capture from the atmosphere. The positive feedback loop model is not a well-enough discussed area in the environmental science field, and erosion, being the middle factor of the positive feedback loop, is just 1 avenue. There could be many more middle factors that contribute to the positive feedback loop effect, and we need a greater understanding of how exactly this takes place. The middle factors between hurricanes and climate change are essential to understanding this complex phenomenon further and are a very important area for further research on this topic. Knowledge of the positive feedback loop of climate change is very important as it can be used to mitigate the positive feedback loop through human intervention or the intervention lack thereof.

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