How Have Climatic Events Influenced Recent Trends in Global Coral Bleaching?

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 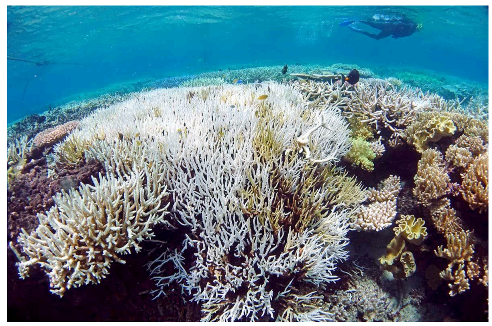

Abstract

This report presents an analysis of the impact of climatic events on coral bleaching using a comprehensive database of over 34,000 coral bleaching records between the years of 1980 and 2020. The study examines the correlations between coral bleaching incidents and the El Niño-Southern Oscillation (ENSO) through the Oceanic Niño Index (ONI), alongside the relationship between coral bleaching and thermal stress anomalies. Further geospatial analysis is also conducted to identify coral bleaching hotspots and their association with sea surface temperatures, revealing connections between El Niño events, increased thermal stress, and more severe coral bleaching. The vulnerability of coral reefs and their critical need for mitigation strategies is highlighted. Additionally, the report explores carbon emissions as a significant contributor to climate change and suggests mitigation measures as transitioning renewable energy sources and promoting sustainable transportation. The study provides valuable insights into the drivers of coral bleaching, emphasizing the importance of proactively protecting our marine ecosystem.

Introduction

Corals are a living colony of invertebrates that can be found in oceanic habitats across the entire globe. While they may seem purely aesthetic with their variety of colors, corals play a significant role for marine and human life alike. Coral reefs provide habitat to a large percentage of marine life, which contributes to the biodiversity of the oceans. Corals also serve the environment as they can absorb carbon dioxide and work to combat erosion. However, due to modern climate threats, corals experience a phenomenon known as "coral bleaching" wherein they lose their color, turning a pale white. This is a result of the algae leaving the coral tissue (NOAA). When coral colonies begin to die out, the reefs suffer tremendously which causes an immense threat to the wildlife that depend on them for survival.

The increasing prevalence of coral bleaching can be linked to climate change since it occurs when the ocean water temperatures rise and the PH levels lower, a process better known as ocean acidification, which is a direct result of elevated levels of CO_2 in Earth's atmosphere. Between the years 2014 and 2017 alone, coral reefs were impacted by global warming temperatures and bleaching occurred in approximately 75% of Earth's reefs (NOAA).

By visualizing the declining health of reefs as well as climatic changes over time, we can better understand the correlations that occur between these variables and develop a plan of action to minimize harm to coral reefs in the coming years.

Methodology

For our analyses we used a database published in Nature that compiled over 34,000 records of coral bleaching globally, with samples taken from 1980-2020. The database provides a variety of relevant information on sample geographics, environmental conditions, and bleaching prevalence across time. We then created additional relations with data concerning climatic events like El Niño and global carbon emissions, collected from the National Oceanic and Atmospheric Association and NASA respectively. To observe what human impacts are most significant to the issue of coral bleaching, we also imported data from Our World in Data regarding which industries contribute the most to global CO2 emissions. From there, we utilized SQL queries that joined and projected applicable data using Python from these relations to create time-series and geospatial analyses.

Analysis

In order to evaluate the impact of seasonal climatic events on trends in coral bleaching, we plotted bleaching incidents over time alongside oceanic niño index, which measures prevalence of the cyclical phenomenon El Niño through difference from average temperature in the tropical Pacific region.

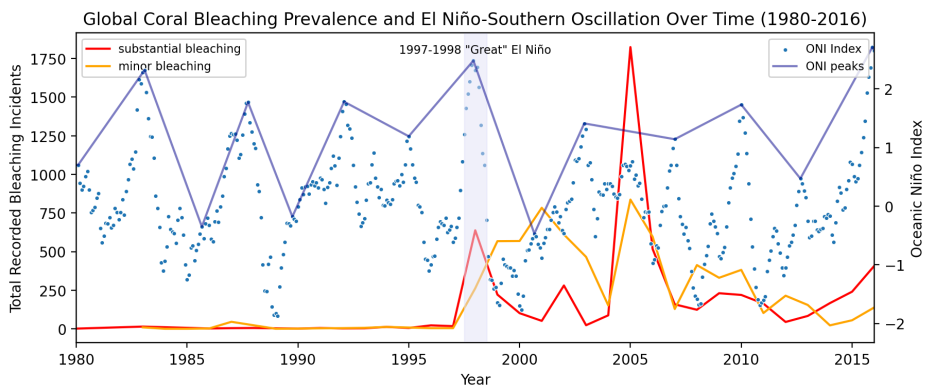

Figure 1. Time-series analysis of coral bleaching incidents and cyclical occurrence of El Niño

Higher positive values indicate El Niño, which brings warmer waters to this area every 3-5 years, while lower negative values indicate La Niña, the colder counterpart of this event. One of the highest peaks in substantial bleaching coincides with the 1998 El Niño, which was one of the most intense to date. There is less correlation between these variables observed in the 1980s and early 90s in part due to there being far less data points when compared to the two most recent decades, where there is more concurrence between higher ONI values and increased rates of bleaching. Something to note is that climate change is expected to increase the frequency and severity of this event, which can be observed in more recent years where there is more frequent oscillation and higher ONI values (NOAA). This means that less cool water is being brought to coral habitats during La Niña, putting the health of marine ecosystems at greater risk.

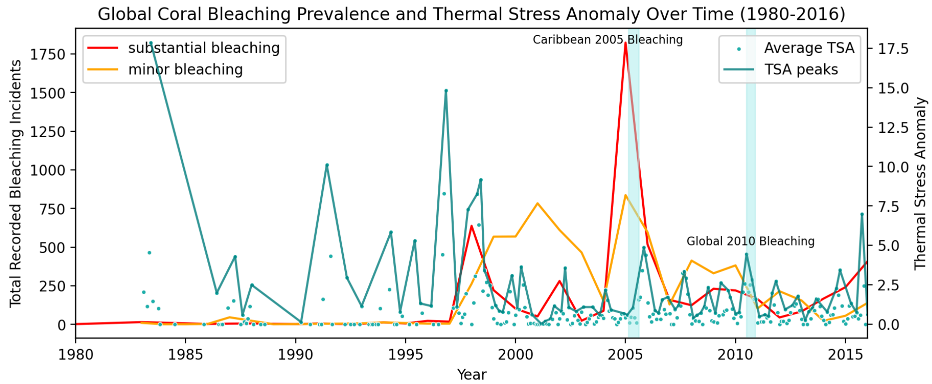

Figure 2. Time-series analysis of coral bleaching incidents and changes in global thermal stress anomaly

In order to delve deeper into the upward rise of warmer water temperatures, we visualized the severity of the coral bleaching – either substantial or minor bleaching – against the thermal stress anomaly, a measure of the thermal stress on corals as a result of being forced to live closer to their upper thermal limit. We found this to be a relevant analysis as thermal stress is not only an indicator, but also the primary cause of coral bleaching leading to the "breakdown of the coral-algal symbiosis, essential for the function of reefs" (Lindsey). Typically thermal stress is attributed to abnormally high ocean temperatures.

Evidently, higher spikes in temperatures can generally be seen occurring with more intense bleaching as is visualized by the red line. The notable peak in the red line correlates to the year 2005 during which a huge coral bleaching incidence took place in the Caribbean where 90% of the coral reefs in the region were victim to bleaching. The thermal stress levels in this region "exceeded 16°C-weeks" which is significantly greater than the levels that cause coral bleaching and death (Lough). In the graph, the temperature indicator likely does not depict as notable of a temperature hike as expected because the overall data is based on a global dataset while this 2005 incident was regional, remaining within the Southern Caribbean.

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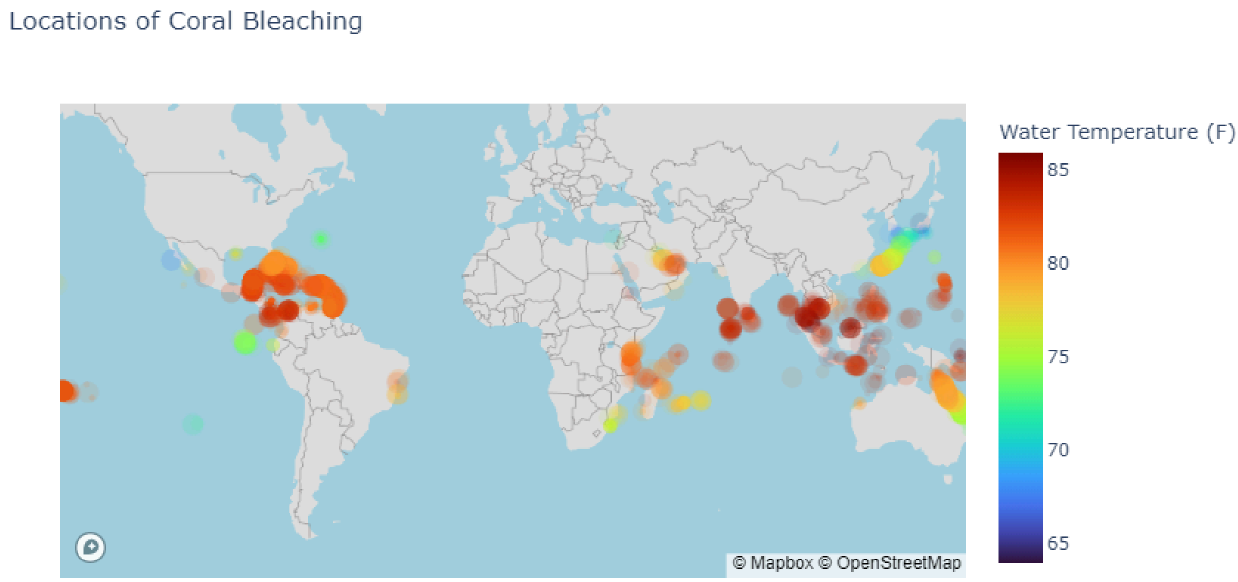

Figure 3. Global Sites of Coral Bleaching Occurrence Mapped Alongside Average Sea Surface Temperature

This figure maps the longitude and latitude points of locations where coral was sampled from that have experienced coral bleaching, with a color map overlaid to show the temperature of the water in Fahrenheit in these locations. The size of each point indicates the severity of the bleaching that was observed in each sample, and generally the areas with the highest temperatures also have larger points that denote increased severity. The majority of the points visualized in Figure 3 range from orange to dark red in color, signifying that these are areas where the average surface temperature has remained at or above 80 degrees Fahrenheit over recent decades. While water temperature in the area around the equator is typically higher than other waters around the globe, the average sea surface temperature at the equator is approximately 80 degrees Fahrenheit, so it is abnormally warm for the water to be over 80 degrees. Since even a 2 degree Fahrenheit change in temperature can cause substantial bleaching, it is unsurprising that most of these events occur when temperatures surpass 80 degrees.

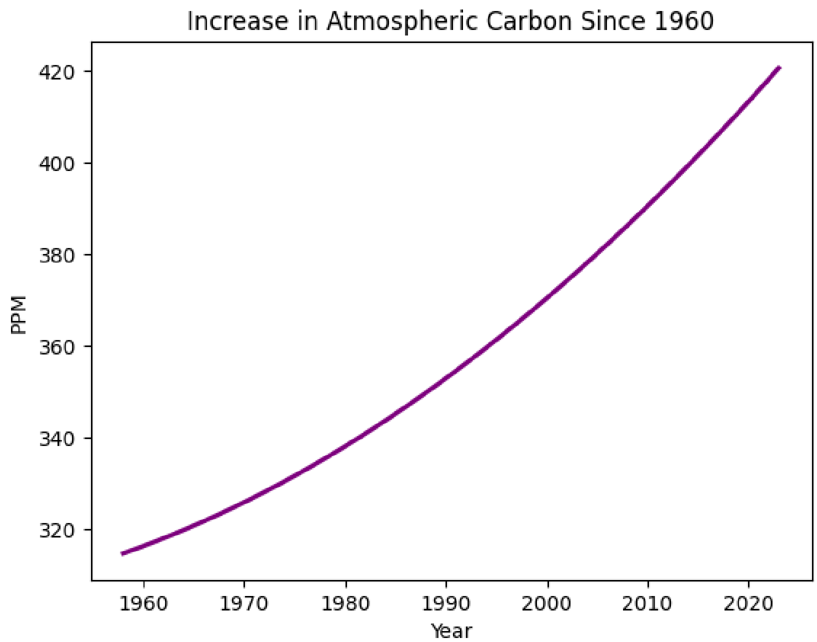

Figure 4. Global Average Carbon Emissions in Parts Per Million Over Recent Decades

This figure plots the global amount of carbon in the atmosphere in parts per million over the years 1958 to 2023. A line of fit was used to help visualize the data due to the method used to indicate the time at which the data was collected. The file used a decimal dating system, which caused dates to be labeled as 1958.2027. If the points were graphed as a scatterplot, the graph would appear to have a slight curve, but the line would look very thick, so simplifying it to the line of fit would preserve the graph's purpose without causing the data to be misinterpreted. From this graph, we can tell that the atmospheric carbon levels have been increasing, but at a faster rate than usual in recent years. This also causes the amount of carbon that the ocean absorbs to increase, leading to a positive association between the ocean acidity and the atmospheric carbon (NOAA).

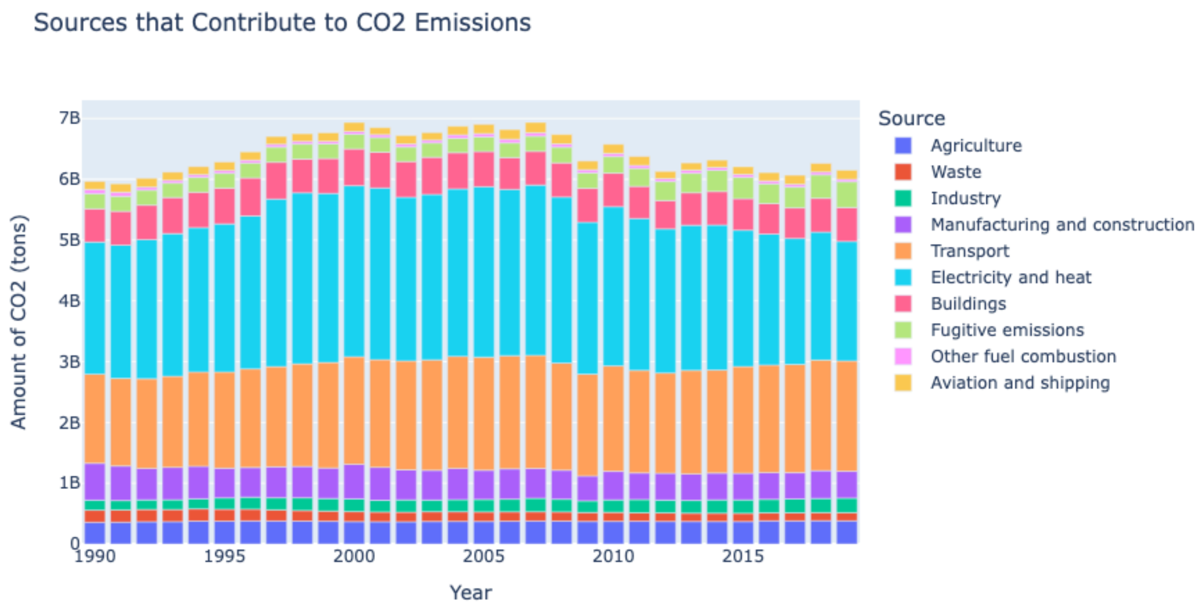

Figure 5. Mitigation Strategies for Climate Change-Induced Temperature Hikes

To provide immediate direction on mitigation strategies, we gathered data on different sources that are contributing to CO_2 emissions and created the visualization above showing the United States' data over the past three decades. The United States is one of the globe's highest producers of CO_2. It is clear when looking at the visualization that electricity and heat are the top two contributors to CO_2 emissions which is consistent with the fact that the US is very reliant on transportation and power generation. In order to cut down on the amount of carbon dioxide that gets put into our atmosphere, we can strive to take use of public transportation or non motorized transportation options as well as powering our homes and industries with renewable energy sources such as solar and wind power. Taking these steps can significantly decrease the CO_2 emissions and in turn save the coral reefs from experiencing bleaching.

Conclusion

In conclusion, this study allowed a deeper investigation of the influence of climatic events on recent trends in global coral bleaching. Through our analysis, we have discovered patterns in more severe coral bleaching and deaths caused by El Niño's ONI Index, a measure of warmer waters cycling into the Pacific Ocean, alongside the resulting increase in thermal stress. These thermal stress anomalies have demonstrated a strong relationship between the rising ocean temperature, such as the 2005 bleaching in the Southern Caribbean, and exceeded coral tolerance thresholds. In order to better understand the patterns in these occurrences, our geospatial analysis led us to conclude that there were a number of hotspots across the globe experiencing severe and higher frequency of coral bleaching than anywhere else. The results of these findings re-emphasize the vulnerability of coral reefs to climate change and temperature increases, and they highlight the urgent need for mitigation strategies. There is no way to quickly eliminate the causes of coral bleaching - there is no technology that can cool large amounts of water in a short amount of time, and doing so can have devastating effects on local ecosystems due to sudden changes. It will be important to find methods that can allow algae to return to coral reefs, or reintroduce new coral species to the area without stressing the environment even further while also preventing any increases in the amount of carbon in the atmosphere.

Author Contributions

Ruby and Annika formulated the project idea and did basic research on the topic. Ruby did more extensive research from multiple sources to write the introduction. Annika developed the visualizations for the time series analyses and compiled data for ONI values. Manvi worked on writing the abstract and conclusion for the report, and both her and Annika contributed to the methodology. Kenichi developed the geospatial and carbon emission visualizations and compiled data for the latter. Ruby sourced data for and created the visualization about CO2 emissions by industry. All the members sourced data for the database and made SQL queries to clean the data and sort it into useful visualizations. Each of the members wrote an analysis of at least one of the visualizations created.

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