UNIVERSITY OF LEEDS

Exploring the Use of Climate Data to Assess Climate Change and Its Potential Causes and Effects

Author
Aimi Aqilah Mohd Zulkifli

MATH5747M Learning Skills through Case Studies

School of Mathematics

May 2023

Contents

1 Introduction

Climate change is a serious issue that is being debated around the world. Recently, more and worse natural disasters like hurricanes, floods, wildfires, and droughts have occurred. Scientists, governments, and communities are trying to understand how climate change makes these disasters happen. Due to increased knowledge about the Earth's climate system, it is necessary to study climate data to discover how and why the climate is changing..

Scientists have collected extensive data on global temperatures, greenhouse gas levels, and other relevant factors to gain this understanding. The Intergovernmental Panel on Climate Change (IPCC), a leading international body of climate scientists, has consistently warned about the adverse consequences of climate change caused by human activities [1]. The concentration of greenhouse gases, such as carbon dioxide (CO_2) and methane (CH_4), in the atmosphere, has been rising since the Industrial Revolution. This is due to the combustion of fossil fuels, deforestation, and other human-induced factors. These gases trap heat within the Earth's atmosphere, leading to the greenhouse effect and resulting in global warming.

The impacts of climate change on natural disasters are becoming increasingly apparent. Rising global temperatures affect atmospheric conditions, contributing to the intensification of extreme weather events [1]. For example, warmer ocean temperatures provide the energy necessary for hurricanes to strengthen and become more destructive. Additionally, altered precipitation patterns and shifts in atmospheric circulation can exacerbate flood and drought conditions, affecting vulnerable regions and populations.

In this case study, our objective is to explore the role of data analytics in investigating the effects of climate change on natural disasters. By analysing climate data spanning decades, centuries, and even millions of years, we aim to provide insights into the changing climate patterns and their potential causes. We will also draw insights from several notable sources. These include reports published by the Intergovernmental Panel on Climate Change (IPCC) in 2014 and 2021, as well as studies conducted by Hsiang et al. (2017) and Diffenbaugh and Field (2013). By examining these sources and utilizing data analytics, we aim to deepen our understanding of climate change and its effects on natural disasters. This knowledge is crucial for informing decision-making, policy development, and efforts to enhance our resilience to climate-related challenges.

The following sections will delve into the specific methodologies employed in climate data analytics, investigate historical climate records, and explore the relationships between climate change and natural disasters. Through this analysis, we hope to shed light on the profound impacts of climate change on our environment and emphasise the urgency of collective action to mitigate its effects.

2 Literature Review

In this literature review, we will examine key findings from four notable sources: the Intergovernmental Panel on Climate Change (IPCC) reports from 2014 and 2021, as well as the studies conducted by Hsiang et al. (2017) and Diffenbaugh and Field (2013).

The IPCC is a well-known group of climate scientists who gather and evaluate the latest research on climate change. The 2014 IPCC report, called "Climate Change 2014: Synthesis Report," gave a comprehensive overview of what we know about climate change [1]. It emphasized clear evidence that human activities, like producing greenhouse gases, are causing changes in the climate. The report showed how climate change affects ecosystems, food security, human health, and economies. It stressed the urgent need for global action to reduce greenhouse gas emissions and adapt to the changing climate.

The IPCC's 2021 report, "Climate Change 2021: The Physical Science Basis," built upon the 2014 report and provided an updated understanding of the science behind climate change. It confirmed that burning fossil fuels has been the main cause of global warming since the mid-20th century [4]. The report warned that if we don't significantly reduce greenhouse gas emissions, global temperatures will keep rising, leading to more heatwaves, extreme rainfall, and sea-level rise. It also highlighted the risks of crossing critical thresholds, like irreversible loss of ecosystems and increased threats to food and water security.

Hsiang et al. (2017) conducted a notable study focusing on estimating the economic damage caused by climate change in the United States. They used historical climate data, statistical models, and economic indicators to show that the U.S. has already suffered significant economic losses due to climate change, with projections indicating even greater damages in the future [3]. The study emphasized regional differences in economic vulnerability, particularly in coastal areas and the South. It stressed the importance of implementing measures to adapt to climate change and reduce its economic impacts.

Diffenbaugh and Field (2013) conducted a study examining changes in critical climate conditions for terrestrial ecosystems. They focused on identifying and analyzing key climate variables, like temperature and rainfall patterns, that greatly impact land-based ecosystems. The study highlighted how shifts in these conditions could lead to widespread consequences, such as changes in species distributions, the timing of natural events, productivity, and increased risks of droughts and wildfires [2]. The researchers emphasized the urgent need for strategies to manage ecosystems adaptively, preserving biodiversity, ecosystem services, and human well-being in the face of changing climate conditions.

Overall, these four sources contribute to our understanding of climate change and its impacts. The IPCC reports comprehensively assess the scientific consensus on climate change, emphasizing the urgent need for action. Hsiang et al. (2017) and Diffenbaugh and Field (2013) provide valuable insights into climate change's economic and ecological effects, highlighting the importance of proactive measures to reduce risks and build resilience. Together, these studies underscore the immediate need for action at the global and local levels to address climate change and its consequences.

3 Data Used for Analysis

3.1 Data for Greenhouse Gas Emissions

For the analysis of greenhouse gas emissions, the data used in this study was obtained from the source "CO_2 and Greenhouse Gas Emissions" by Ritchie, H., Roser, M., and Rosado, P. (2020) published on Our World in Data [7]. This source provides a comprehensive data collection on CO_2 and greenhouse gas emissions from various sectors and countries.

The dataset offers a wide range of information related to greenhouse gas emissions, including historical trends, global and regional comparisons, and sector-specific breakdowns. It covers emissions from sources such as energy production, transportation, industry, agriculture, and land use changes. The dataset also covers multiple greenhouse gases, such as carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and fluorinated gases.

The data presented in this source is based on rigorous research and draws from reputable sources, including international organizations, national reports, and scientific literature. It is regularly updated and undergoes rigorous quality control processes to ensure accuracy and reliability. By utilizing this comprehensive and reliable dataset, the analysis aims to assess the patterns, trends, and drivers of greenhouse gas emissions. It provides valuable insights into understanding the magnitude and composition of greenhouse gas emissions, which is essential for assessing the impact of human activities on climate change and formulating effective mitigation strategies.

3.2 Data for Global Temperature

The data used for analyzing global temperatures in this study was obtained from the NOAA National Centers for Environmental Information. Specifically, the "Climate at a Glance: Global Time Series" dataset was utilized [5]. This dataset provides comprehensive and up-to-date information on global temperature trends over time. This dataset combines information from two comprehensive data collections: the Global Historical Climatology Network-Monthly for land surfaces and the Extended Reconstructed Sea Surface Temperature for ocean surfaces. These datasets cover a period from 1850 to the present, providing a wide range of data for analysis.

This dataset is valuable for assessing the magnitude and direction of global temperature shifts, providing insights into the overall patterns and potential climate impacts. The land and ocean datasets are merged into a single product to calculate the global temperature anomalies, allowing for a combined assessment of global temperature variations. The anomalies, representing deviations from a reference period, are calculated relative to the average temperatures recorded from 1991 to 2020.

Temperature anomalies are used in this analysis instead of absolute temperature measurements for several reasons. Absolute estimates of global average surface temperature face challenges in compilation due to various factors. Some regions have limited temperature measurement stations, resulting in data gaps that require interpolation over large areas. In mountainous areas, observations are predominantly from inhabited valleys, necessitating consideration of elevation's impact on average temperature. For instance, during summer, both a mountaintop

and a nearby valley may experience temperatures below average, but the absolute temperatures at these locations will differ significantly. By using anomalies, it becomes evident that temperatures at both locations were below average.

The NOAA Global Time Series dataset offers a comprehensive and detailed understanding of global temperature patterns and changes over time. By utilizing this dataset, we can assess the extent of temperature anomalies globally and investigate trends and variations in temperature across different regions.

3.3 Data for All Natural Disasters

The dataset used to analyze natural disaster occurrences in this study was obtained from the online resource "Our World in Data" by Hannah Ritchie, Pablo Rosado, and Max Roser (2022) [6]. The dataset provides comprehensive information on the frequency and magnitude of natural disasters. In addition to the occurrence of natural disasters, the dataset also provides valuable metrics related to these events. This includes the frequency at which disasters occur, their intensity or severity, and their impact on human populations and infrastructure. The data may include statistics on the number of affected individuals, fatalities, injuries, and economic damages caused by natural disasters.

This dataset compares and analyzes the trends and relationship between natural disaster occurrences and global temperature anomalies. By integrating the natural disaster occurrence data from "Our World in Data" with global temperature anomaly data, which represents deviations from the average temperature, we aim to investigate the potential connections and patterns between these two variables. The analysis will examine long-term trends in natural disaster occurrences and global temperature anomalies, looking for any similarities, dissimilarities, or potential connections between the two. By exploring this relationship, we aim to gain insights into how changes in global temperature may influence the frequency or intensity of natural disasters.

The findings from this analysis will contribute to our understanding of the potential impacts of climate change on natural hazard occurrences and their subsequent consequences. It will enhance our knowledge of how rising global temperatures may influence the likelihood or severity of different natural disasters. This information is crucial for informing policy and decision-making processes related to climate change adaptation, disaster risk reduction, and developing resilience-building strategies.

4 Increase in Global Temperature

4.1 Greenhouse Gases Emission

Greenhouse gas emissions play a significant role in the rising global temperatures observed in recent decades. The increase in these emissions, primarily caused by human activities, has led to a phenomenon known as the greenhouse effect. This effect traps heat within the Earth's atmosphere, resulting in a gradual warming of the planet. Greenhouse gases consist of carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and fluorinated gases. The standard

greenhouse gas (GHG) emission measurement is called "carbon dioxide-equivalents." It is the metric used by the United Nations Framework Convention on Climate Change (UNFCCC) and many countries and institutions for reporting and setting targets. This metric combines the warming impacts of different gases, like carbon dioxide, methane, and nitrous oxide, into a single measure of total emissions. Figure 1 shows the breakdown of annual greenhouse gas emissions from 1850 until 2022. It shows that the greenhouse gas emission has increased rapidly after 1960 onwards.

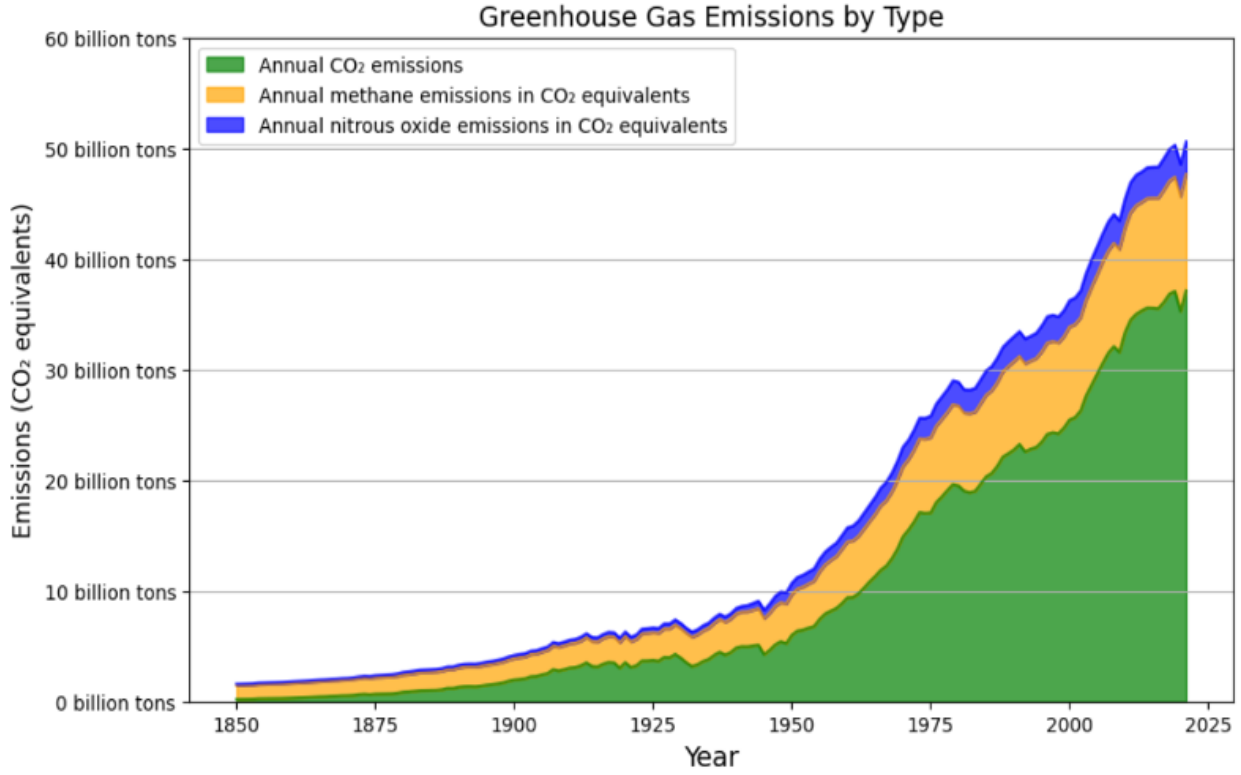


Figure 1: Breakdown of global greenhouse gas emissions [7].

4.2 Global Temperature

Global temperature is crucial in understanding climate change and its impact on the planet. Over the past centuries, scientists have monitored and analyzed global temperature trends to gain insights into the Earth's changing climate. The global temperature trend from 1850 to 2023 reveals a discernible warming pattern. The analysis of global temperature reveals a notable increase since the mid-19th century, accompanied by fluctuations and variations across different regions and time periods. This upward temperature trend has raised concerns about the potential consequences for ecosystems, weather patterns, and human activities worldwide.

One of the potential factors driving the increase in global temperature is the emission of greenhouse gases into the Earth's atmosphere. Greenhouse gases act as a natural "blanket" that traps heat from the sun, preventing it from escaping back into space. This natural greenhouse effect is essential for maintaining Earth's habitable conditions. However, human activities, particularly the burning of fossil fuels, deforestation, and industrial processes, have significantly

increased the concentration of greenhouse gases in the atmosphere. As the concentration of greenhouse gases increases, more heat is trapped, leading to a rise in global temperatures.

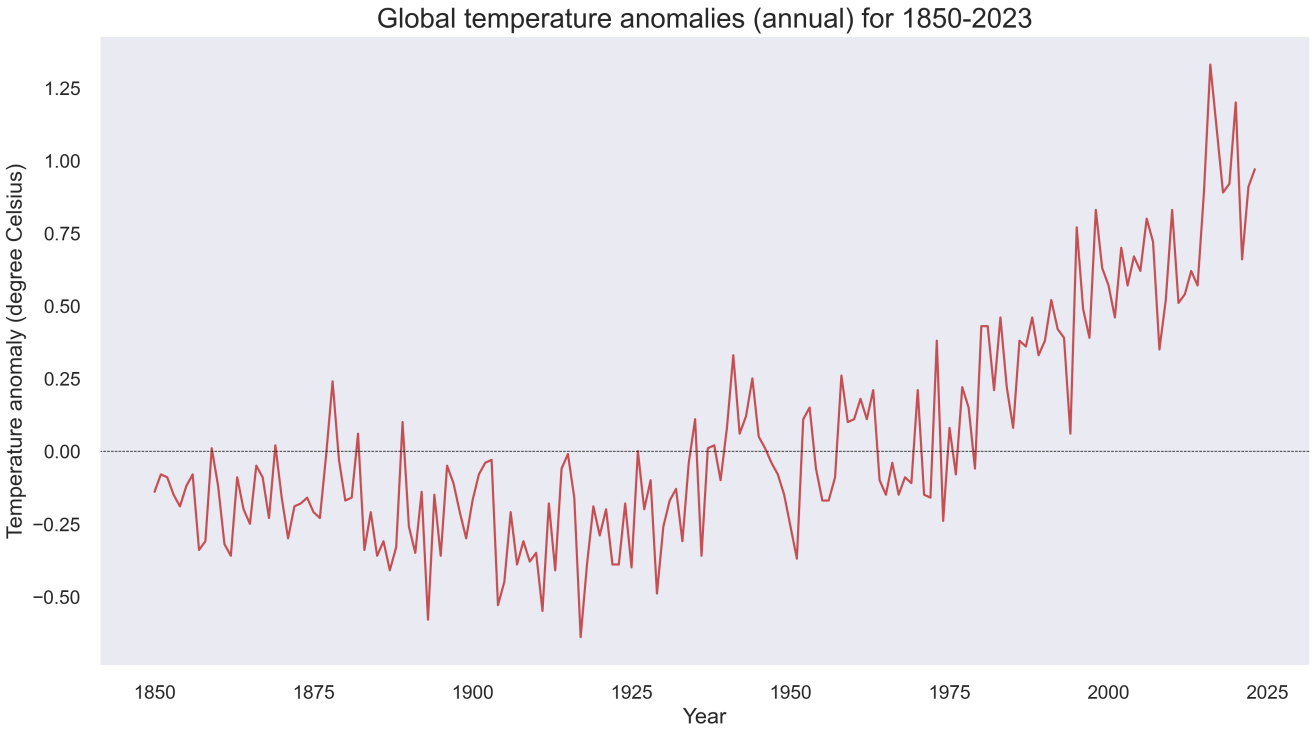


Figure 2: Global Temperature Anomalies from 1850 to 2023

To see how the Earth's temperature has changed over time, let's look at Figure 2. The graph shows the global temperature anomalies relative to the average temperature between 1991 and 2020. Over the past few decades, global temperatures have increased significantly, especially after 1960. If we go back to 1850, temperatures were about 0.4 ℃ colder than our baseline, which is 0.7 ℃. This means that the average temperature has risen by about 1.1 ℃. It is important to note that there are small year-to-year variations in temperature, so the exact increase depends on the starting and ending years we consider. But overall, the temperature rise falls from 1 to 1.2 ℃.

4.3 Relationship between Greenhouse Gas Emissions and Global Temperature

The link between greenhouse gas emissions and the rise in global temperature has been extensively studied and is well-established in the scientific literature. According to the Intergovernmental Panel on Climate Change (IPCC), "it is extremely likely that human activities, particularly emissions of greenhouse (heat-trapping) gases, are the dominant cause of the observed warming since the mid-20th century" [1].

The process of trapping heat from the sun in the Earth's atmosphere is known as the greenhouse effect and is necessary for life on Earth to exist. However, when there are excess greenhouse gases, the Earth's atmosphere becomes overburdened, resulting in a rise in global

temperature. Carbon dioxide is the most significant greenhouse gas and is primarily produced by burning fossil fuels, industrial processes, and land-use changes. The concentration of CO_2 in the atmosphere has increased from pre-industrial levels of about 280 parts per million (ppm) to over 415 ppm in 2021, an increase of nearly 50% [4]. This increase in CO_2 concentration has led to a rise in global temperature, with the Earth's surface temperature has risen by approximately 1.1℃ since the pre-industrial era [5]. Other greenhouse gases, such as methane and nitrous oxide, also contribute to global warming. Agricultural activities, such as livestock farming and rice cultivation, and energy production primarily produce methane. Nitrous oxide is produced mainly by agricultural activities and the burning of fossil fuels. The concentration of methane in the atmosphere has increased by 160% since pre-industrial times, while the concentration of nitrous oxide has increased by 20% [4].

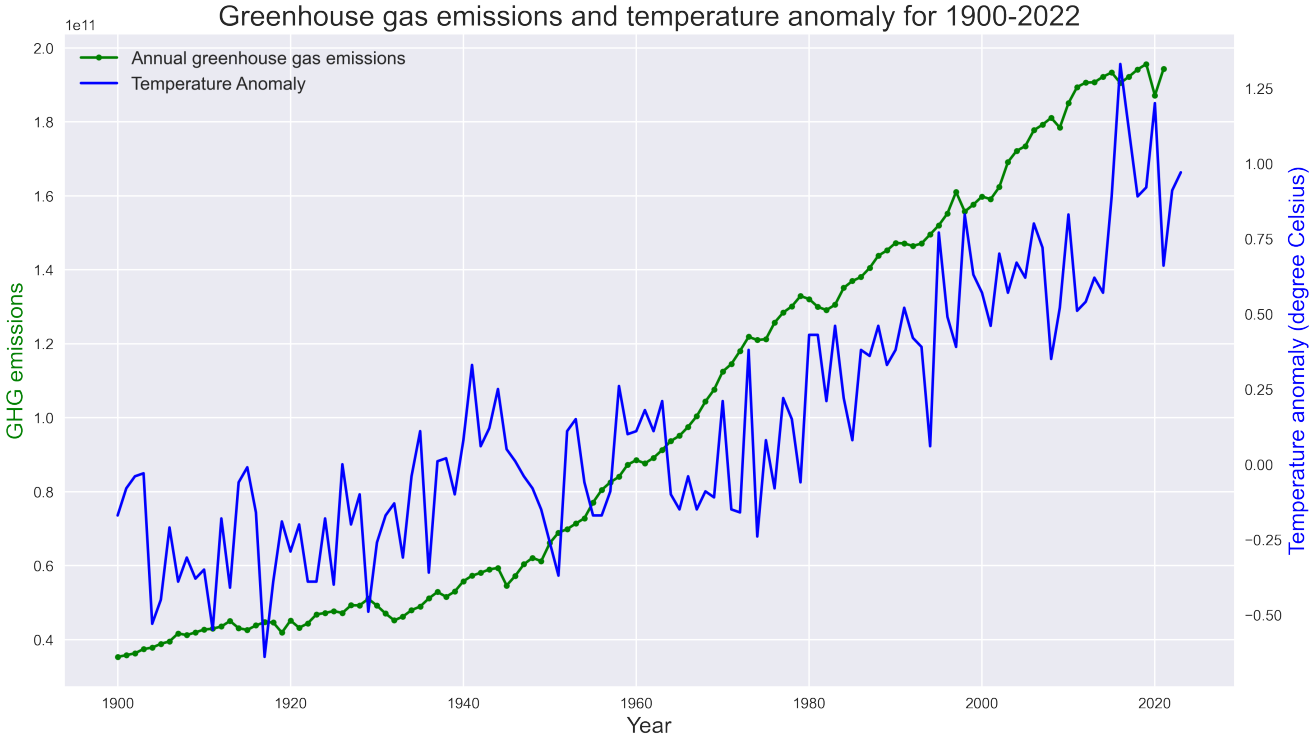


Figure 3: Greenhouse Gas Emissions and Global Temperature from 1900 to 2022.

To see the relationship between global temperature and greenhouse gas emissions, we combined the datasets for global temperature anomaly (1850 until 2023) and global greenhouse gas emissions (1900 until 2022). This allowed us to understand better the similarity of the trend or pattern between greenhouse gas emissions and global temperature. Figure 3 show a clear similar pattern between the increase in greenhouse gas emissions and global temperatures over time. This relationship is particularly evident from 1960 onwards when both graphs show a marked value increase. The period after 1960 is often called the "modern era" or the "contemporary period" in climate change research. This period is characterized by a significant increase in greenhouse gas emissions due to the rapid industrialization and economic growth of many countries worldwide, causing the Earth's temperature to rise drastically.

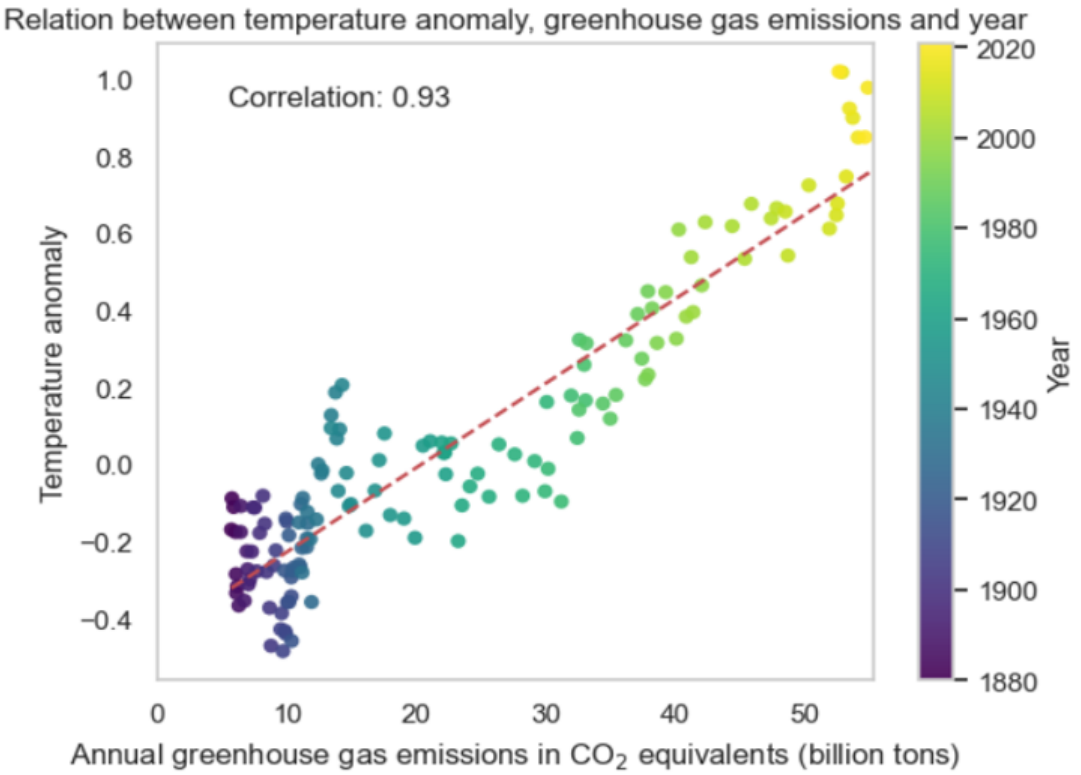


Figure 4: Relationship between Greenhouse Gas Emissions and Global Temperature.

Besides that, we also can see the relationship based on a scatter plot in Figure 4. It shows that greenhouse gas emissions have a strong positive correlation with the global temperature. This indicates that the global temperature will increase as greenhouse gas emissions increase, but this does not imply causation. This is because there are other natural factors such as volcanic activity, solar radiation variations, and natural climate oscillations such as El Niño and La Niña which also can contribute to short-term fluctuations in global temperature.

5 More Frequent and Intense Natural Disasters

Studies have also shown a direct relationship between greenhouse gas emissions and the frequency and severity of natural disasters. For example, a study by Hsiang et al. (2017) found that a 1°C increase in global temperature led to a 5.3% increase in the likelihood of extreme rainfall events and a 2.6% increase in droughts [3]. Another study by Diffenbaugh and Field (2013) found that global warming caused by greenhouse gas emissions has increased the likelihood of extreme heatwaves and wildfires [2].

Using the natural disaster dataset [6], we combined the line graph for global temperature and total natural disasters over time. Based on the graphs in Figure 5, we can see a notable increase in global temperatures after 1960, accompanied by more frequent and severe natural disasters like heatwaves, droughts, wildfires, hurricanes, and floods. This "modern era" is especially significant in climate change research because it signifies a time when the impact of human activities on the Earth's climate became increasingly apparent. To further investigate

the relationship between greenhouse gas emissions, global temperature, and natural disasters, we generated a heatmap to demonstrate the correlation among these variables.

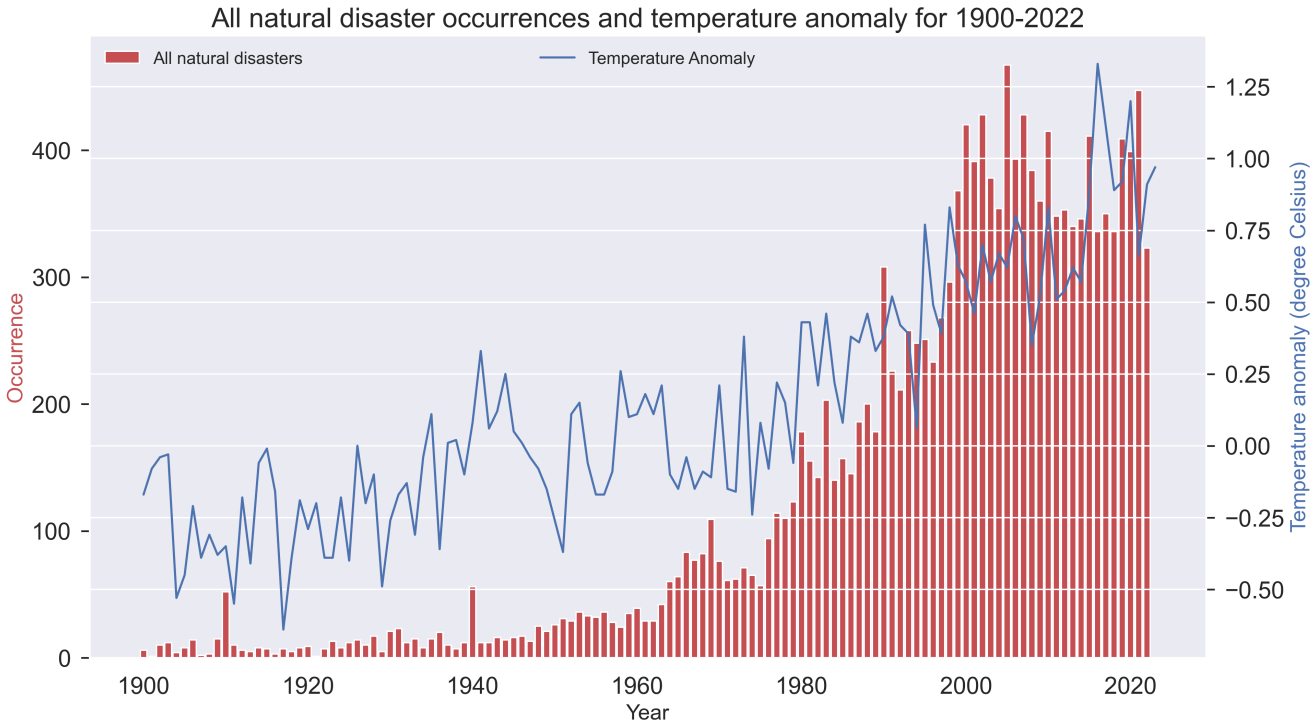


Figure 5: Global Temperature and Natural Disasters Occurence from 1850 to 2022.

The heatmap in Figure 6 showed the strength of the relationship between each variable, with warmer colors indicating a stronger correlation. The heatmap results demonstrated a strong positive correlation between greenhouse gas emissions and global temperature, indicating that global temperature also increases as greenhouse gas emissions increase. Additionally, the heatmap revealed that global temperature is strongly correlated with various natural disasters such as extreme weather, landslide, and floods. This suggests that as global temperatures rise, the frequency and severity of natural disasters may also increase. The heatmap provides a powerful visual representation of the complex relationship between greenhouse gas emissions, global temperature, and natural disasters. However, this correlation does not imply causation. Instead, it suggests that common underlying factors or processes might contribute to these environmental phenomena.

For example, when the planet's temperature rises, it can cause the melting of glaciers and ice caps, increasing the sea levels. This increase in sea level can result in coastal flooding, which can be particularly devastating to low-lying areas and islands. Moreover, higher temperatures can increase the frequency and intensity of extreme weather events, such as heat waves, droughts, and hurricanes. Warmer temperatures can lead to more moisture in the atmosphere, which can cause heavy rainfall and flooding. Additionally, as the atmosphere warms, it can create more substantial and frequent storms, resulting in landslides and flash floods. Furthermore, global warming can also cause changes in weather patterns, such as the Jet Stream. This leads to prolonged extreme weather events occurring more frequently [2].

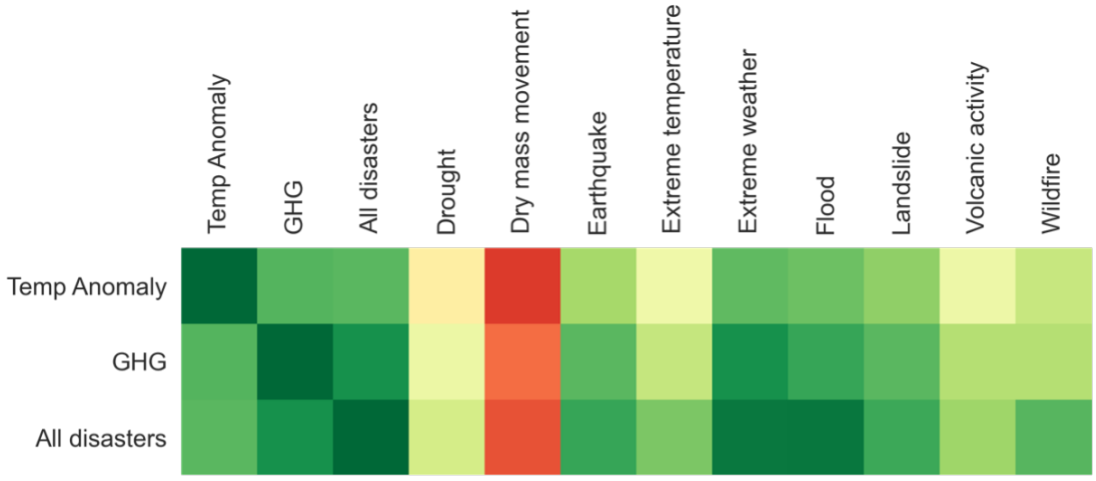


Figure 6: Correlation between Global Temperature, Greenhouse Gas and All Natural Disasters

6 Conclusion

The climate data provides strong evidence that the Earth's climate is changing. The global temperature increase indicates that the planet is getting warmer, which is a critical indicator of climate change. Industrialization has also played a noticeable role in contributing to climate change. The rapid growth of populations, extensive construction, and increased energy use all lead to the release of greenhouse gases, further supporting the evidence of a changing climate. Moreover, extreme weather events have become more frequent and intense, highlighting the influence of climate change on natural disasters. Analyzing climate data and its effects reveals a clear picture of climate change. The causes can be attributed to factors such as greenhouse gas emissions, industrialization, and their impacts on different aspects of the Earth's system.

In conclusion, it is crucial to understand the changing climate and its underlying causes. This understanding enables us to make informed decisions, protect vulnerable communities and ecosystems, grasp the interconnectedness of everything, and work together globally. By taking early action to address climate change, we can create a sustainable and resilient future for both current and future generations, ensuring a better world for all.

7 References

[1] Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.). *Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. IPCC, Geneva, Switzerland, 2014.

[2] Noah S Diffenbaugh and Christopher B Field. Changes in ecologically critical terrestrial climate conditions. *Science*, 341(6145):486–492, 2013.

[3] Solomon M Hsiang, Marshall Burke, and Edward Miguel. Estimating economic damage from climate change in the united states. *Science*, 356(6345):1362–1369, 2017.

[4] IPCC. *Climate Change 2021: The Physical Science Basis*. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 2021. In press.

[5] NOAA National Centers for Environmental Information. Climate at a Glance: Global Time Series. Retrieved on May 2, 2023 from https://www.ncei.noaa.gov/access/monitoring/climate-at-a-glance/global/time-series, April 2023.

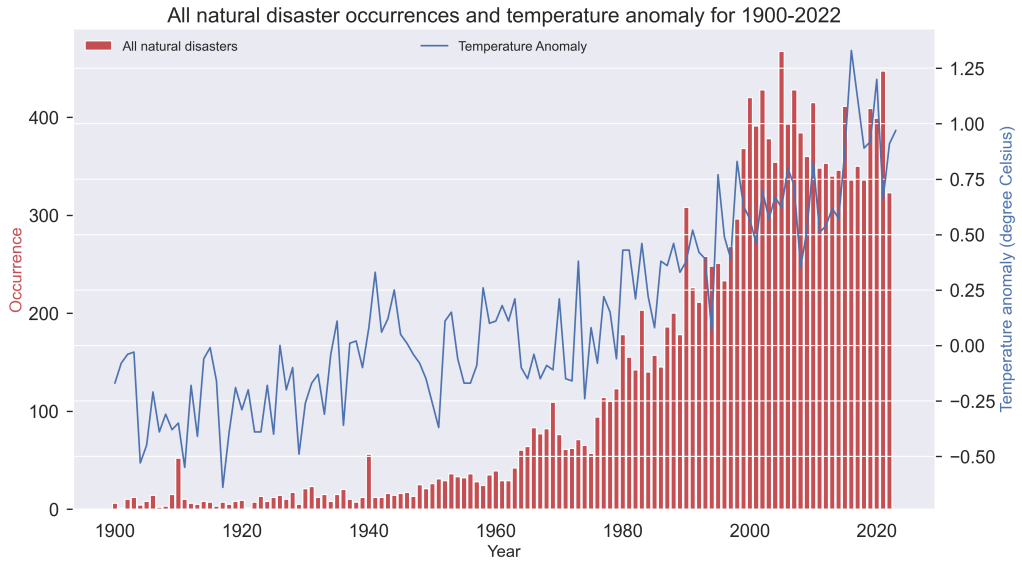
[6] Hannah Ritchie, Pablo Rosado, and Max Roser. Natural disasters. *Our World in Data*, 2022. https://ourworldindata.org/natural-disasters.

[7] Hannah Ritchie, Max Roser, and Pablo Rosado. CO_2 and Greenhouse Gas Emissions. *Our World in Data*, 2020. https://ourworldindata.org/co2-and-greenhouse-gas-emissions.

8 Appendices

1. Example of plotting a graph using `matplotlib` package in Python:

```
import matplotlib.pyplot as plt

# Plot all natural disasters occurrences
fig, ax1 = plt.subplots(figsize = (14, 8))

ax1.bar(nat_disaster_df.index, nat_disaster_df['All disasters'],
        label = 'All natural disasters', color='r', alpha=1)
ax1.set_xlabel('Year', fontsize = 15)
ax1.set_ylabel('Occurrence', fontsize = 15, color = 'r')

# Plot temperature anomaly
ax2 = ax1.twinx()

ax2.plot(global_temp_df.loc[1900:, 'Temp Anomaly'], 'b-', label = '
    Temperature Anomaly')
ax2.set_ylabel('Temperature anomaly (degree Celsius)', fontsize = 15,
    color = 'b')

# Set title and legend
plt.title('All natural disaster occurrences and temperature anomaly for
    1900-2022', fontsize = 19)
ax1.legend(loc = 0, prop = {'size': 12})
ax2.legend(loc = 9, prop = {'size': 12})

# Remove the grid lines
ax1.grid(b=False)

# Save the plot as a PNG file
plt.savefig('natural_disaster_and_temperature_anomaly.png', dpi=300,
    bbox_inches='tight')

plt.show()
```



2. Example of plotting a heatmap in Python:

```
# Plot correlation heatmap
fig, ax = plt.subplots(figsize = (10, 10))

# Get the column labels
labels = [name for name in correlation_table.columns]

# Create the heatmap
cax = ax.matshow(correlation_table, cmap = 'RdYlGn')

# Add colorbar
cbar = fig.colorbar(cax, shrink = 0.82)

# Set the x and y ticks
ax.set_xticks(np.arange(len(labels)))
ax.set_yticks(np.arange(len(labels)))

# Set the x and y tick labels
ax.set_xticklabels(labels, fontsize = 12, rotation = 'vertical')
ax.set_yticklabels(labels, fontsize = 12)

# Disable grid lines
ax.grid(False)

# Save the plot as a PNG file
plt.savefig('all correlation.png', dpi=300, bbox_inches='tight')

# Show the plot
plt.show()
```