# Climate Change Attribution: Analysis of the Effects of CO2, Solar Irradiance, and Volcanoes on Global Temperature Trends

Farah Abed Zadeh and Sudeep Damodaran

## Abstract

Global warming has been a subject of intense research and debate, with potential causes ranging from natural to anthropogenic factors. This study utilizes an extensive range of global surface temperature data points, covering both land and ocean surfaces, along with atmospheric $CO_2$ content, solar irradiance, and volcanic activity data, to comprehensively analyze the factors influencing global warming. By rigorous data curation, a spatial- temporal behavior was established and the correlation between this trend and the time behavior of $CO_2$ was examined. Then, we investigated if surges in $CO_2$ resonate with volcanic activities and solar irradiance over recent centuries. In doing so, the aim is to provide a holistic view of the influences driving global temperature changes.

## Objectives

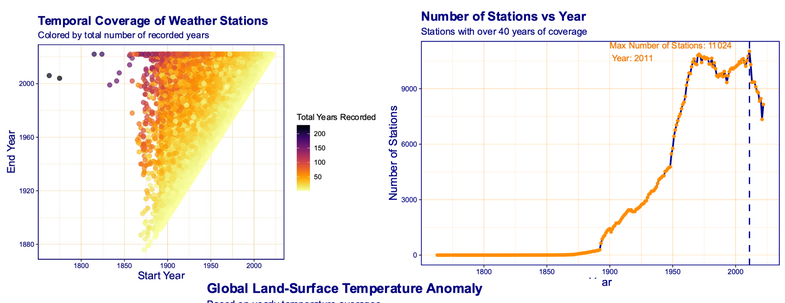
- **Data Compilation:** Gather datasets on global and ocean surface temperatures, atmospheric $CO_2$, solar irradiance, and volcanic activity spanning the last century.
- **Comparative Analysis:** Evaluate the temporal trends of each factor, emphasizing their relative contributions to global warming.
- **Correlation Assessment:** Examine relationships between global surface temperature trends and changes in solar irradiance, volcanic activity, and atmospheric $CO_2$.
- **Human Influence Interpretation:** Determine the extent to which human activities have influenced recent global warming patterns

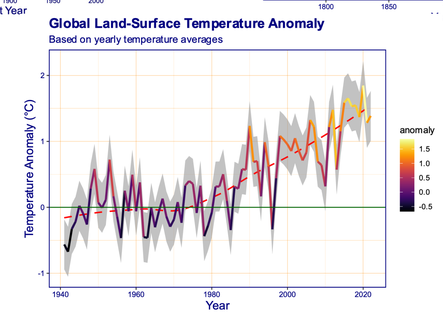
## Data Collection and Curation

### **Land Temperature**:

Data Source is NOAA's GSOY files which offers a summary of meteorological elements, such as average annual temperature.

- Big data consisting of 83,445 files.
- Temporal range spanning from 1763 to 2022
- Removed records of missing average temperature values
- Excluded stations with less than 40 years of data.
- Extracted data for 200 points for years 1950 to 2022.

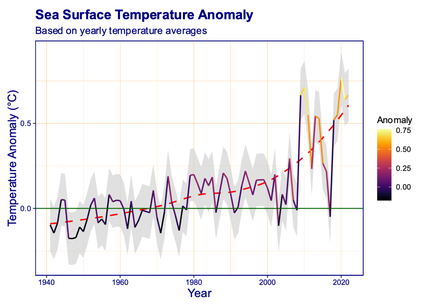



### **Ocean Temperature** :

Data source is Hadley Centre COADS, which has monthly averaged SST values from 1871.

- Imported netCDF files, of resolution 1° x 1°
- Extracted key variables and removed records containing outliers and missing temperature values
- Filtered data by latitude and longitude intervals and assigned a unique identifier for each data combination (station).
- Randomly selected 100 locations for further analysis.




### $CO_2$:

- Sourced from NOAA and supplemented with fossil emission data from the Integrated Carbon Observation System.

### **Volcanic Activity**:

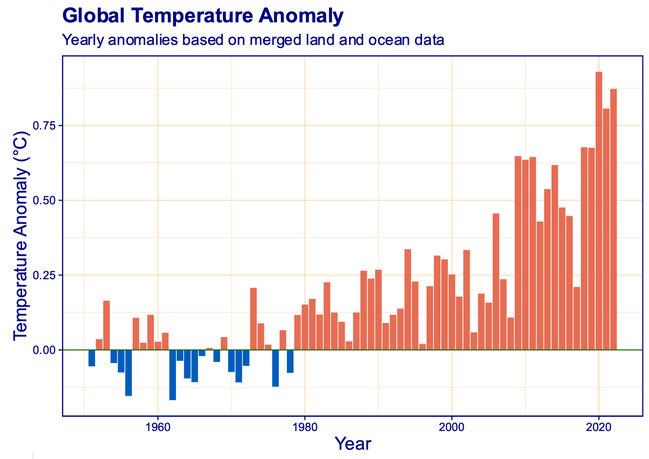
- Derived from Opendatasoft' Significant Volcanic Eruption Database, providing insights of eruptions with a listing of over 500 significant eruptions.

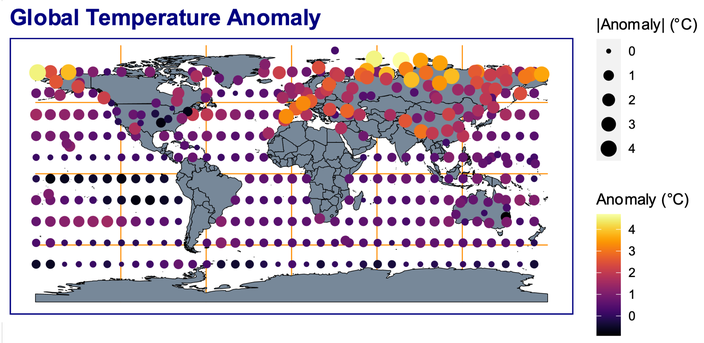
### **Solar Irradiance**:

- Obtained from the NOAA's Total Solar Irradiance Climate Data Record, which details solar energy input to Earth's atmosphere.

## Global Temperature Analysis

- Merged and aggregated land and ocean temperature datasets
- Computed average global temperature for the stations.
- Calculated anomalies using 1951 to 1980 as baseline years
- Established Temperature vs Time for the combined dataset
- Highlighted error bars using standard deviation
- Utilized an ARIMA model to fit and predict the temperature anomaly data

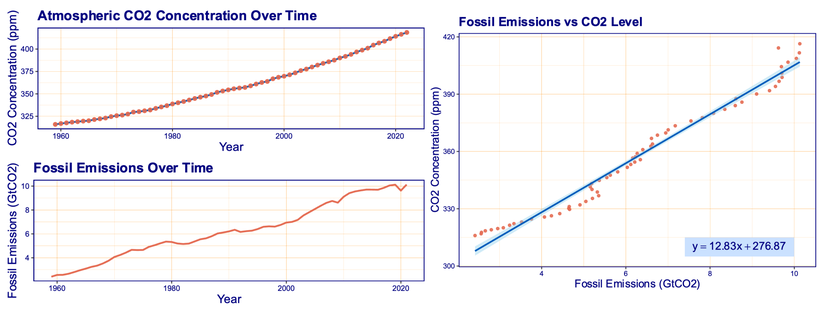



## Correlation Analysis

### $CO_2$ vs. Fossil Emission

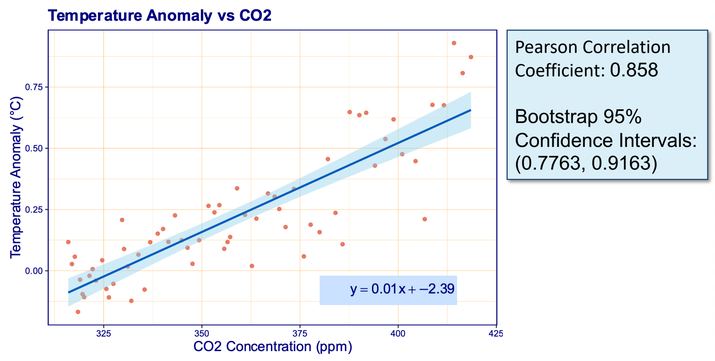
- Quantified the relationship between atmospheric $CO_2$ concentration and fossil emissions




- Pearson correlation coefficient of 0.987 indicates a strong relationship
- Linear regression model shows 97.4% of the variance in $CO_2$ concentration is explained by the fossil emissions.

### $CO_2$ vs. Temperature

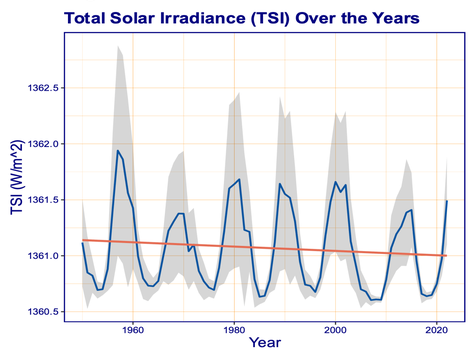
- A Pearson Correlation Coefficient (0.858), bootstrap confidence intervals, Johansen Cointegration Test, Granger Causality Test Granger were implemented.
- Tests showed a strong positive association between atmospheric $CO_2$ levels and global temperatures.
- Regression analysis model underlined $CO_2$'s significant impact on temperature anomalies, with the model's metrics emphasizing its robustness.




### Solar Irradiance

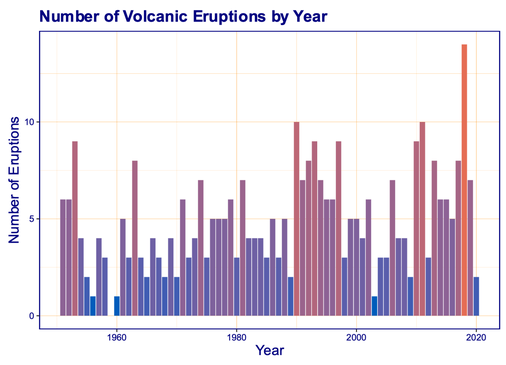
- Using correlation tests, a weak negative correlation was found of -0.0935 between TSI and $CO_2$ levels.
- Conversely, a correlation of -0.0014 suggests no significant relationship between TSI and global temperatures.

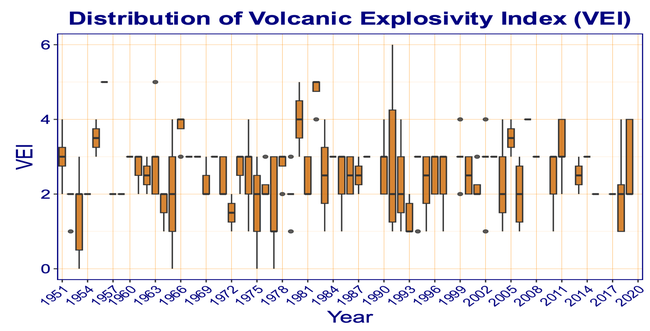
Cyclical variations in TSI values correspond to the solar cycle, with a slight overall decrease observed over the period.




## Volcanic Activity

Years vary in average VEIs, indicating some have more powerful eruptions than others. However, since 1940, there's no consistent trend in eruption magnitude, which has generally remained stable.




- The Granger test indicates volcanic activity has a limited impact on $CO_2$ trends, reinforced by a weak positive correlation.

## Discussion

The data from the last seven decades shows an exponential growth in global temperatures, spanning both terrestrial and marine region. The pronounced anomalies, when contrasted against the 1951-1980 baseline, reveal the accelerated rate of global warming. Such significant anomalies can disrupt ecological balances, alter agricultural productivity, and redefine coastal boundaries due to rising sea levels.

Forecasts derived from the Time series ARIMA model predict a rise in temperatures in coming years. If these trends continue, the planet could approach temperature thresholds that trigger irreversible ecological and climatic shifts, emphasizing the urgency to mitigate $CO_2$ emissions.

While numerous factors contribute to climate change, $CO_2$ stands out as a predominant influence. The temporal alignment of fossil fuel consumption and $CO_2$ emission spikes with the global temperature rise is striking. This synchronization is not just a correlation but hints at a causal relationship, given the well-understood greenhouse effect of $CO_2$.

The analysis underscores a compelling positive correlation of 0.858 between $CO_2$ concentrations and global temperatures. This relationship is further solidified by the confidence interval range of (0.7763, 0.9163) at the 95% level, emphasizing the significant role $CO_2$ plays in shaping temperature dynamics, a critical piece of evidence in the discourse on anthropogenic global warming.

Volcanic emissions, although showing a noteworthy relationship with $CO_2$ concentrations, marked by a correlation of 0.341, exhibit an inconsistent trend over the years. This implies a potentially limited impact on the recent overarching global warming trends. In the realm of solar contributions, the data points toward a marginal decline in solar irradiance. Coupled with its weak correlations (-0.122 with $CO_2$ and -0.012 with temperatures), the evidence indicates that solar variability may not be a predominant factor driving the recent shifts in the planet's climate.

## Conclusion

The analyses confirm that global warming is a significant concern, primarily driven by rising atmospheric $CO_2$ concentrations from human activities like industrial emissions, deforestation, and transportation. While human contributions are dominant, the influence of natural phenomena, such as volcanic activity, cannot be overlooked. Such findings emphasize the need for inclusive research that considers both man-made and natural variables. The repercussions of global warming, from sea level rise to intensified weather events and habitat loss, have far-reaching impacts on human societies and global ecosystems. As Earth's stewards, we must prioritize sustainable practices, including efficient waste management, innovative product development, and the adoption of cleaner energy sources.

## References

1. NOAA's Global Summary of the Year (GSOY).
2. Met Office Hadley Centre observations datasets.
3. NOAA atmospheric CO2 Data.
4. ICOS – Global Carbon Budget 2022.
5. Opendatasoft - Significant Volcanic Eruption Database.
6. NOAA's Total Solar Irradiance Climate Data Record.