Climate Change Temperature Anomaly Analysis

Overview

This project provides a comprehensive analysis of global temperature anomalies from 1880 to 2024, focusing on monthly, seasonal, and annual trends and employing statistical and machine learning models (ARIMA, SARIMA) to explore past patterns and forecast future temperature shifts. By analysing the dataset in the context of historical events, we uncover how industrialization, global conflicts, and policy changes have impacted global temperatures over time. The study reveals a marked rise in global temperatures over the last century, driven by greenhouse gas emissions, with forecasts suggesting that without meaningful intervention, this trend is likely to continue.

Data Collection and Cleaning

The dataset originates from the "Tables of Global and Hemispheric Anomalies" compiled by climate research institutions, containing monthly temperature anomalies from 1880 to the present day. To ensure data accuracy, all missing values were carefully addressed using interpolation based on nearby years, rather than default values, to retain natural variability in temperature trends. Each monthly entry was validated for accuracy, and the data were standardized to enhance model performance, especially for time series forecasting. The resulting dataset provides a robust foundation for analysis, enabling reliable monthly, seasonal, and annual insights into temperature changes.

Time Series Decomposition and Differencing

To uncover underlying patterns in the data, a time series decomposition was conducted, breaking down the temperature data into three main components: **trend**, **seasonal**, and **residual**. This process helps to isolate long-term patterns, cyclical seasonal fluctuations, and any random noise in the dataset, providing a clearer understanding of the systematic changes in global temperatures over time. The decomposition revealed a consistent upward trend, indicating ongoing warming, alongside seasonal patterns that highlight predictable monthly fluctuations.

Differencing was applied to stabilize the mean of the series, making it easier to model by eliminating trends and seasonal effects that could obscure genuine patterns in the data. By differencing the series, the models become more effective at capturing short-term dependencies while accounting for long-term trends, improving forecast accuracy.

ACF and PACF Analysis Before and After Differencing

To better understand the data's temporal dependencies and model it effectively, **autocorrelation function (ACF)** and **partial autocorrelation function (PACF)** plots were analysed both before and after differencing.

- **Before Differencing:**
    - The **ACF plot** showed a slow, gradual decline in correlation as lag increased, which is a typical indicator of a non-stationary time series with a persistent trend.
    - The **PACF plot** displayed significant spikes at early lags, with a gradual decline at higher lags. This pattern further suggested the presence of a strong trend, with correlations spanning multiple months.

The ACF and PACF patterns indicated that the data needed differencing to remove this trend and stabilize the series, allowing for better model fitting without interference from non-stationary elements.

- **After Differencing:**
    - The **ACF plot** displayed a sharp cutoff after a few lags, with minor fluctuations for subsequent lags, indicating that the differenced series had reduced long-term dependencies and was now closer to being stationary.
    - The **PACF plot** showed a more immediate drop-off, consistent with a stationary series, suggesting that the differenced data was more suitable for ARIMA or SARIMA modelling without further modifications.

This differenced data enabled more accurate parameter selection for the ARIMA and SARIMA models, as the stationary series aligned with the assumptions required for these models. The differencing step was therefore essential in improving the interpretability and predictive power of the forecasts.

Monthly Temperature Anomalies

Analysis of monthly temperature anomalies highlights a distinct upward trend across all months, with particularly notable increases during June and December. These findings suggest that summer and winter months exhibit stronger warming signals, reflecting seasonal variances in the impact of global warming. For example, June's temperatures increasingly deviate from the historical mean, signifying intensifying heat during summer months. December's data reveal a steady warming of winter temperatures, suggesting that climate change may diminish seasonal temperature contrasts, leading to warmer winters and more extreme summer conditions over time.

Seasonal Temperature Trends

The seasonal analysis further underscores significant warming, especially in summer and winter, where the temperature anomalies are most pronounced. Winter months show a steep increase in anomalies, reflecting a pattern where the coldest months are warming faster than the rest of the year. This shift could be attributed to climate dynamics that disproportionately affect cold weather patterns, such as Arctic amplification. By examining trends within each season, the study reveals that temperature increases are not evenly distributed throughout the year, with significant ramifications for weather stability, agriculture, and biodiversity.

Correlation with Historical Events

A detailed look at temperature anomalies across historical events reveals how industrialization and global conflicts have contributed to climate change. The following key periods are of particular interest:

- **The Industrial Revolution (late 1800s to early 1900s):** This period marked the beginning of significant human-induced temperature rise due to the combustion of fossil fuels, which intensified as industries grew.
- **World War I (1914-1918):** Although short-lived, this period saw accelerated industrial activity, which increased fossil fuel use and introduced new pollutants.
- **World War II (1939-1945) and the Post-War Industrial Boom:** This era led to a substantial rise in greenhouse gas emissions as economies rebuilt, spurring intensive industrial growth and urbanization. The temperature anomaly data shows noticeable increases corresponding to these years.
- **Environmental Movement and Policy Shifts (1970s-present):** In response to rising pollution and temperature concerns, the 1970s marked the beginning of environmental policies aimed at reducing emissions. Yet, the data shows that global temperatures

continued to rise, reflecting the cumulative effect of past emissions and ongoing challenges in mitigating climate change.

This historical context underscores the enduring impact of industrial and economic activities on the climate, affirming the role of human influence in shaping current warming trends.

Forecasting Future Trends

Using SARIMA and ARIMA models, the project forecasts global temperature anomalies into the future. Initial SARIMA models suggested a decrease; however, refinements ensured the forecast would continue from the last observed point, closely following the historical upward trend. This continuity emphasizes the ongoing temperature rise and suggests that, in the absence of stringent climate policies, global temperatures will continue to increase. Such projections align with recent climate reports warning of exacerbated climate impacts, including more extreme weather events, ecological disruptions, and challenges for human societies worldwide. This forecast underscores the urgency of substantial and sustained action to mitigate the effects of climate change.