**Executive Summary**

**Introduction**

The Earth is experiencing rapid warming and never-before-seen extreme weather events. NASA scientists explain that the current rate of warming is happening “at a rate not seen in the past 10,000 years,” and the Intergovernmental Panel on Climate Change declares that “scientific evidence for warming of the climate system is unequivocal” (NASA Science).

As the world warms, extreme heat events become more frequent and severe. It is estimated that “human activities have influenced two-thirds of extreme weather events in the past 20 years” (Weiss, Sabrina, et al.).

As discussions of global warming and associated extreme weather events continue to make headlines, our group began to wonder if these patterns were consistent across the earth or if they might affect different regions of the world differently. We elected to conduct research to identify trends across the Northern and Southern Hemispheres and see how they

**Objective**

Climate change is a pressing global concern, and understanding its complexities requires a comprehensive analysis of temperature anomalies across different regions and timeframes. This study analyzes the patterns and trends of temperature anomalies across the Northern and Southern Hemispheres. Through detailed visualizations and statistical analyses, the aim is to assess seasonal variations, identify long-term warming or cooling periods, and determine the reliability of temperature data considering associated uncertainties. The study compares short-term, medium-term, and long-term trends using different moving averages and investigates how temperature anomalies between the hemispheres align or diverge, particularly in global warming.

**Hypothesis:** We suspect long-term (20-year) trends will exhibit similar patterns of climate change in both the Northern and Southern Hemispheres. However, short-term (5 years) and medium-term (5-20 years) trends may differ between the hemispheres due to seasonal variations. We expect seasonal temperature anomalies to be inverted between the hemispheres within a year.

We developed our hypothesis following the assumption that global warming and extreme weather events should exhibit similar effects across the planet. While weather events can take drastically different forms in different regions of the earth, we assume that the lasting effects will appear identical over a large enough area.

It is important to note that seasonality in the Northern and Southern hemispheres is inverted due to the earth’s axis. We expect any trends related to temperature and seasonality to be inverted in these regions within a single year, but we expect the long-term data to show similar trends.

**Questions for Exploration**

Our questions regarding the uniformity of global warming's effects stemmed from understanding how extreme weather events can affect different regions of the United States, even across areas with similar climates and geographic characteristics.

To better understand how climate change affected the planet, we developed a list of questions to guide our analysis:

1. What are the seasonal variations and patterns in temperature anomalies?
2. How do long-term temperature trends manifest, and are there any significant periods of warming or cooling?
3. How reliable are the temperature anomaly estimates considering the associated uncertainties?
4. How do short-term, medium-term, and long-term temperature trends compare when analyzed through different moving averages?
5. How do the Northern and Southern Hemisphere temperature anomalies and trends differ?

**Primary Datasets:**  Southern Hemisphere dataset (contains 1,685 rows and 12 columns):<https://berkeleyearth.org/temperature-region/southern-hemisphere>

**Secondary Datasets:**  Northern Hemisphere dataset (contains 2,172 rows and 12 columns.):<https://berkeleyearth.org/temperature-region/southern-hemisphere>

These datasets represent climate data over time, specifically anomalies in temperature, with various levels of granularity (monthly, annual, five-year, ten-year, and twenty-year) and associated uncertainties for each measurement.

**Data Dictionary (Southern and Northern dataset columns)**

* **Year:** The year of the observation.
* **Month:** The month of the observation.
* **Anomaly:** Monthly temperature deviation from the average.
* **Uncertainty:** Margin of error associated with the anomaly.
* **Annual Anomaly:** The annual temperature anomaly averaged over the year.
* **Annual Uncertainty:** The uncertainty associated with the annual temperature anomaly.
* **Five-year Anomaly:** Average temperature deviation over five years.
* **Five-year Uncertainty:** The error margin for the five-year anomaly.
* **Ten-year Anomaly:** Average temperature deviation over ten years.
* **Ten-year Uncertainty:** The error margin for the ten-year anomaly.
* **Twenty-year Anomaly:** Average temperature deviation over twenty years.
* **Twenty-year Uncertainty:** uncertainty associated with the twenty-year anomaly.

**Data Cleaning and Assumptions**

We started our data cleaning process by appropriately loading both datasets and examining the data's structure and distribution. The data initially appeared to have formatting issues, possibly due to irregular column delimiters. Considering regular expressions or manual column width specifications, we attempted a refined loading method to address this. We then proceeded to assign column names and examine the data's structure. Upon initial observations, we found missing values.

**Assumptions:** We expected some columns to have missing values due to the nature of the columns. Because the dataset represents climate data over time, precisely anomalies in temperature, with various levels of granularity (monthly, annual, five-year, ten-year, and twenty-year), it would be expected for columns with rolling averages to have missing values. We assumed the number of missing values reflected the amount of time required for the column to accumulate averages. It would explain why the “Twenty-year Anomaly” and “Twenty-year Unc.” columns each had the highest count of missing values in both data sets. This delay is logical because such averages can only be calculated after enough data points are available (e.g., you can't calculate a twenty-year average until you have twenty years of data).

Upon further analysis, we observed a consistent pattern of missing values, which aligns with datasets that calculate rolling averages over time. These missing values may result from historical data unavailability, insufficient data points for calculation, or delays in recording recent data. Specifically, all rolling averages and uncertainties from 2020 onwards were missing, indicating potential incompleteness and or pending updates. Furthermore, the twenty-year anomaly and uncertainty columns were entirely null, possibly indicating initial exclusion or pending inclusion in the dataset.

Given the systemic nature of missing values and the desire to preserve dataset integrity, we opted to drop all missing values instead of imputing them. This decision aimed to avoid bias introduced by imputation and maintain the reliability of visualizations and time series analysis. Dropping missing values reduced the dataset size but ensured data reliability and integrity throughout the analysis; the Southern dataset went from 1685 entries to 1504 entries, and the Northern dataset went from 2172 entries to 1991 entries.

**Summaries from Visualizations**

**Histograms of Temperature Anomalies**

**A graph of different colored lines

Description automatically generated with medium confidence**Both hemispheres exhibit broader spreads in monthly anomalies than annual anomalies, indicating greater monthly variability. In the Southern Hemisphere, distributions center around zero, indicating less extreme temperature deviations on both monthly and annual scales. Conversely, the Northern Hemisphere displays a broader distribution for monthly anomalies and a skewed distribution for annual anomalies, suggesting more frequent warm extremes.

**Time Series Analysis:** Southern Hemisphere vs Northern Hemisphere A graph of a graph

Description automatically generated with medium confidence

The Southern Hemisphere is getting warmer, as shown by the upward trend in the temperature anomalies. The longer the period, the clearer the trend of warming. The Northern Hemisphere is also warming, with a greater variability in annual data points. However, the twenty-year moving average shows a consistent warming trend.

**Box Plots of Seasonal Variability**

A comparison of a graph

Description automatically generated with medium confidence

The box plots illustrate seasonal variability in monthly temperature anomalies for both hemispheres. The Southern Hemisphere displays a narrower range of anomalies, suggesting a more consistent climate, while the Northern Hemisphere exhibits broader variability and higher extremes, especially in the middle of the year. Outliers indicate months with exceptionally high or low anomalies, more prevalent in the Northern Hemisphere, reflecting its greater climate variability. The inverse seasonal patterns between the hemispheres stem from the different timing of seasons.

**Heatmaps of Year-by-Month Anomalies:**

**A comparison of a number of data

Description automatically generated with medium confidence**

The heatmaps for the Southern and Northern Hemispheres display the monthly temperature anomalies across different years, with colors representing the magnitude of anomalies. They show how temperature deviations from the historical average vary monthly and over the years. This allows us to observe consistently warmer or cooler months, shifts towards increasing or decreasing anomalies, and the emergence of warming or cooling trends over time. Patterns of red indicate warmer-than-average temperatures and shades of blue indicate cooler-than-average temperatures.

**Decadal Trends in Temperature Anomalies:**

**A graph of a graph of a graph

Description automatically generated with medium confidence**

The image depicts line graphs showing decadal trends in temperature anomalies for the Southern Northern Hemisphere, with lines representing different moving averages (five-year, ten-year, twenty-year). All three moving averages indicate an increasing trend in temperature anomalies over time, confirming the insights from earlier analyses that both hemispheres are experiencing a warming trend, particularly pronounced in recent decades, especially for the Northern Hemisphere.

**Decadal Trend Summary Table:**

|  |  |  |
| --- | --- | --- |
| **Decade** | **Annual Anomaly Southern** | **Annual Anomaly Northern** |
| **1880** | **-0.388673** | **-0.516817** |
| **1890** | **-0.445167** | **-0.385408** |
| **1900** | **-0.342017** | **-0.276225** |
| **1910** | **-0.261675** | **-0.315042** |
| **1920** | **-0.234625** | **-0.116533** |
| **1930** | **-0.173308** | **0.000442** |
| **1940** | **-0.084717** | **0.091133** |
| **1950** | **-0.113558** | **-0.028908** |
| **1960** | **-0.023275** | **-0.022792** |
| **1970** | **0.067708** | **-0.003067** |
| **1980** | **0.35595** | **0.299217** |
| **1990** | **0.514042** | **0.585575** |
| **2000** | **0.679708** | **0.995533** |
| **2010** | **0.70575** | **1.189583** |

Both hemispheres exhibit a gradual increase in temperature anomalies over the decades, confirming a long-term warming trend. The early decades show negative anomalies, implying cooler temperatures compared to the baseline, while later decades, especially post-1980, show increasingly positive anomalies, indicating warmer temperatures. This decadal trend table affirms the warming trend observed in the previous decadal trend graph and other analyses by quantifying the change in temperature anomalies. It provides numerical evidence of the transition from a cooler climate in the late 19th and early 20th centuries to a warmer climate in recent decades.

**Comparative Plots of Hemisphere Trends:**

A graph of a graph

Description automatically generated with medium confidence

The annual anomalies graph indicates increasing temperature anomalies over time in both hemispheres, with the Northern Hemisphere displaying more pronounced extremes. The seasonal anomalies plot compares average monthly temperature anomalies between hemispheres over a recent decade, revealing varying seasonal patterns. While some months exhibit similar anomalies across hemispheres, others show disparities, particularly with the Northern Hemisphere experiencing higher temperature extremes. Together, these graphs suggest that while both hemispheres are warming, the Northern Hemisphere is warming faster and with more variability, both annually and seasonally.

**Scatter Plots of Anomalies vs. Uncertainties:**

A group of colored maps

Description automatically generated with medium confidence

A group of green and red graphs

Description automatically generated with medium confidence

The scatter plots answer the question of reliability by visually representing the inverse relationship between the magnitude of temperature anomalies and their associated uncertainties, especially over longer time scales. They suggest that while short-term estimates (monthly, annual) have more uncertainty, this uncertainty tends to decrease with longer-term averages (five-year, ten-year, twenty-year), supporting the reliability of observed long-term warming trends as indicators of climate change.

**Linear Regression Graphs:**

A graph of a graph of a graph

Description automatically generated with medium confidence

There's a warming trend in both Hemispheres. The positive slope and low p-value support the idea that climate change is consistent with global warming trends. Both graphs depict a statistically significant upward trend in annual temperature anomalies over time for their respective hemispheres. The trends are consistent with global warming patterns observed worldwide. The visualizations highlight the year-to-year variability, but the regression lines make the long-term trends apparent.

**Correlation Matrices of Anomaly Periods:**

A screenshot of a diagram

Description automatically generated

The correlation matrices provide a quantitative validation of qualitative insights gained from earlier visualizations. They confirm consistent warming trends over the long term, with reduced uncertainties as we look at more extended averaging periods, thus reinforcing the reliability of long-term climate change indications.

**Analysis and Summary of Visualizations**

Analyzing temperature anomalies in the Southern and Northern Hemispheres reveals a long-term warming trend. While the Southern Hemisphere shows a gradual and consistent increase in temperature anomalies, the Northern Hemisphere displays a similar warming pattern but with more significant short-term fluctuations and extreme temperature values. The data suggests that the variability in monthly anomalies is higher in the Northern Hemisphere. This is reflected in the broader spread of data points in scatter plots that relate anomalies to uncertainty. Despite these differences in variability and the occasional cooling periods, both hemispheres show a decrease in the variability and uncertainty of temperature anomalies as the timescale increases from monthly to multi-decade intervals.

In both hemispheres, longer-term analyses—such as those over five, ten, or twenty years—demonstrate decreased variability and heightened reliability in the warming trend. Histograms, heat maps, and box plots all highlight a shift toward warmer temperatures over time, with seasonal variations within this context. In the Southern Hemisphere, the data indicates that although there are slight warming trends monthly, the longer-term trends are more pronounced and reliable. For the Northern Hemisphere, the long-term trends also suggest warming, with short-term data reflecting a complex interplay between periods of cooling and warming.

Comparative analyses of both hemispheres underline that the general trend of rising temperatures is a consistent global phenomenon. Still, the magnitude and intensity of temperature anomalies are more noticeable in the Northern Hemisphere. This could be due to factors such as the distribution of landmasses, which is more prominent in the Northern Hemisphere, potentially influencing climate variability and response to global climate trends.

Seasonal patterns show an expected inverse relationship between the hemispheres, consistent with their respective summer and winter seasons, and the monthly anomaly data support this inverse seasonality. Correlation matrices and comparative annual anomalies confirm the statistical similarity of these trends, particularly over more extended periods. These matrices, alongside the scatter plots and time series graphs, reinforce the conclusion that both hemispheres are experiencing long-term warming, albeit with regional variations in intensity and variability. In the linear regression graph for both hemispheres, the slope of the regression line indicated a positive and statistically significant increase in temperature anomalies, thus supporting a warming trend.

Overall, the evidence from various data visualizations and statistical analyses supports a hypothesis of long-term global warming trends, with both hemispheres reflecting this change despite their geographical and climatic differences. The consistent warming patterns across different timescales and the comparative analysis between the two hemispheres strengthen our understanding of climate dynamics as a shared global characteristic marked by regional specificities.

**Conclusion:**

Our analysis indicates pronounced seasonal variations in temperature anomalies, with distinct patterns emerging in the Northern and Southern Hemispheres. The long-term trends are characterized by a consistent warming pattern, as evident in the multi-year moving averages and decade summaries. These depict significant periods of increased temperatures, especially in recent decades. While more prominent anomalies are associated with higher uncertainties, the strength of the warming trend remains clear and is unlikely to be significantly altered by these uncertainties. When analyzed through short-term, medium-term, and long-term moving averages, the temperature trends consistently illustrate a warming climate, with the long-term trends offering the most robust evidence of this phenomenon. Finally, while both hemispheres exhibit warming trends, the Northern Hemisphere shows more pronounced temperature increases, suggesting differential climate responses that could be attributed to various factors, including landmass distribution and oceanic circulation patterns. These findings contribute to the growing body of evidence that our planet is experiencing substantial and sustained increases in temperature.

**References**

Crimmins, Allison R., and Alexa K. Jay. “Fifth National Climate Assessment.” *Global Change*, 2023, <https://nca2023.globalchange.gov/>

“There is unequivocal evidence that Earth is warming at an unprecedented rate. Human activity is the principal cause.” *NASA Science*, <https://science.nasa.gov/climate-change/evidence/>

Weiss, Sabrina, et al. “10 Facts That Prove the World Is in a Climate Emergency.” *WIRED*, 17 August 2023, <https://www.wired.com/story/climate-change-facts/>