Investigating Rising Temperatures in California

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1. Abstract

This study investigates the relationship between temperature trends and carbon dioxide (CO_2) emissions in California, focusing on three distinct cities: San Diego, San Francisco, and Eureka. Using temperature data from 1951 to 2024 (NOAA) and carbon emission data from 2000 onward (California Air Resources Board), we applied linear regression models to identify patterns of warming and emissions over time. Our results show that average and maximum temperatures have risen consistently in all three locations, with the sharpest increase observed in San Francisco. Interestingly, while California's annual carbon emissions have been decreasing in recent years, overall atmospheric CO_2 levels continue to rise. This is due to the long-lived nature of carbon dioxide, which can persist in the atmosphere for centuries. These findings highlight the complexity of climate dynamics and the importance of not only reducing emissions but also addressing the cumulative impact of past emissions through long-term environmental strategies.

2. Introduction

Climate change and global warming are becoming increasingly relevant issues all over the world (U.S. EPA, 2023). California is no exception. This paper investigates how carbon dioxide emissions are affecting California's climate. To narrow things down we are focusing our research on three distinct locations in California: Eureka, San Francisco, and San Diego. These locations were chosen because they are key to California's economy and represent the state's diverse climate regions and unique climate risks. We face problems with increasingly hot summers, heat waves, droughts, and wildfires. This study examines one of the main contributors to climate change: carbon dioxide emissions. The data will reveal how the change in emissions correlates to a rise in temperature.

Greenhouse gases such as carbon dioxide, methane, and nitrous oxide can be found in the Earth's atmosphere (U.S. EPA, 2023). They absorb and hold heat from the sun to keep our planet warm. However, as society continues to emit more carbon dioxide, the atmosphere holds more heat leading to increased temperatures, i.e. global warming. Carbon dioxide is especially problematic because 20–35% of it remains in the atmosphere for centuries, and some can persist for thousands of years, continuing to warm the planet long after it's emitted (Archer et al., 2009). Even if we cut emissions, the amount of carbon dioxide already in the air is only increasing.

Where is all this carbon dioxide coming from? One of the major sources of carbon emissions are the major fossil fuel companies that are responsible for a disproportionately large share of global industrial greenhouse gas (Frumhoff et al., 2015). While some companies have taken steps to reduce emissions, research suggests they should also be held accountable for their historical contributions to climate change.

3. Data and Methods

Yearly Averages:

For each of the three locations, the average temperature for each year in the given time range (1951-2024) was plotted on one graph and the average *maximum* temperatures were plotted on a second graph. We then calculated the trend of each graph to see if these temperatures were generally increasing or decreasing, and the approximate rate of change.

The data for these plots come from NOAA's Global Summary of the Year archives (NOAA, 2024).

Note: Not all years are included in the data set, leading to gaps in the graphs.

Carbon Emission Trends:

The data for our carbon dioxide emissions comes from the California Air Resources Board (CARB, 2024). The time range for this data is the year 2000 onward. Once again we use the data to find the trend line. The code for this calculation looks like this:

```
years = Carbon.iloc[0, :].to_numpy()
coDat = Carbon.iloc[1, :].to_numpy()

slope, intercept = np.polyfit(years, coDat, 1)

trend_line = slope * years + intercept
```

The original data is stored in the Carbon variable with the first row containing years and the second row contains the carbon emission data. Each row is then assigned to a separate variable. Next we use the polyfit function from the NumPy library which uses least squares regression to minimizes the squared difference between the actual data points (coDat) and the values predicted by the line:

$$\text{Error} = \sum (y_i - (mx_i + b))^2$$

It finds the slope (m) and intercept (b) that minimize that total error.

4. Results

Yearly Averages

San Diego, CA:

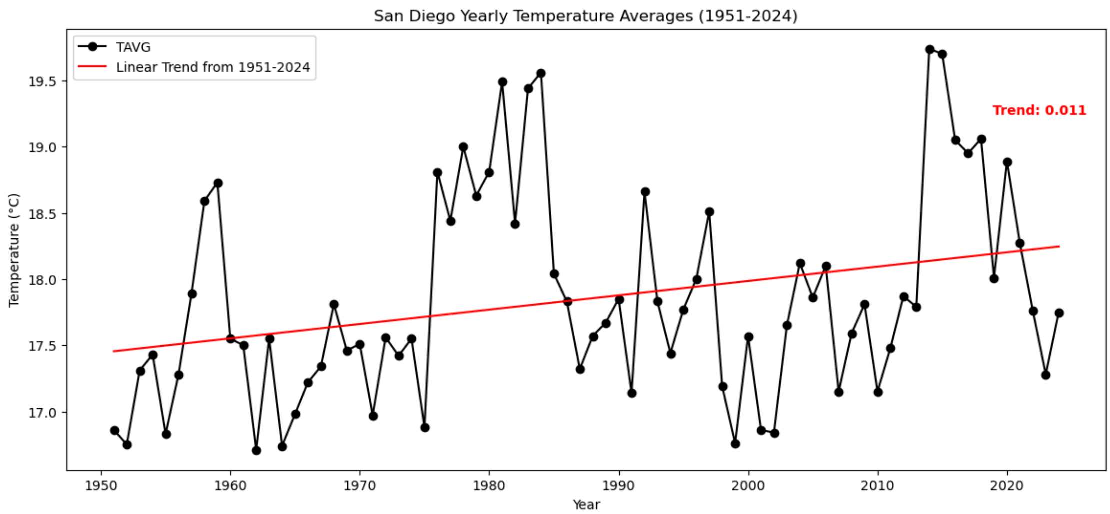


Figure 3.1: *This graph shows the average temperatures in San Diego for each year from 1951 to 2024. The trend line shows a 0.011°C increase per year, or 0.8°C total over the 73 year period.*

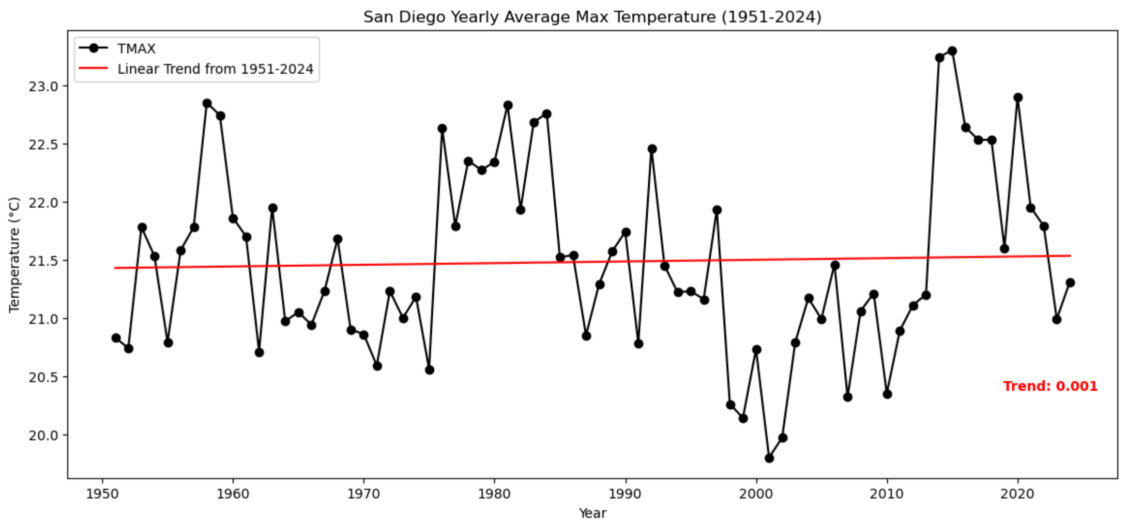


Figure 3.2: *The average maximum temperatures show a less extreme slope, implying that the average temperatures vary more than the maximum temperatures.*

San Francisco, CA:

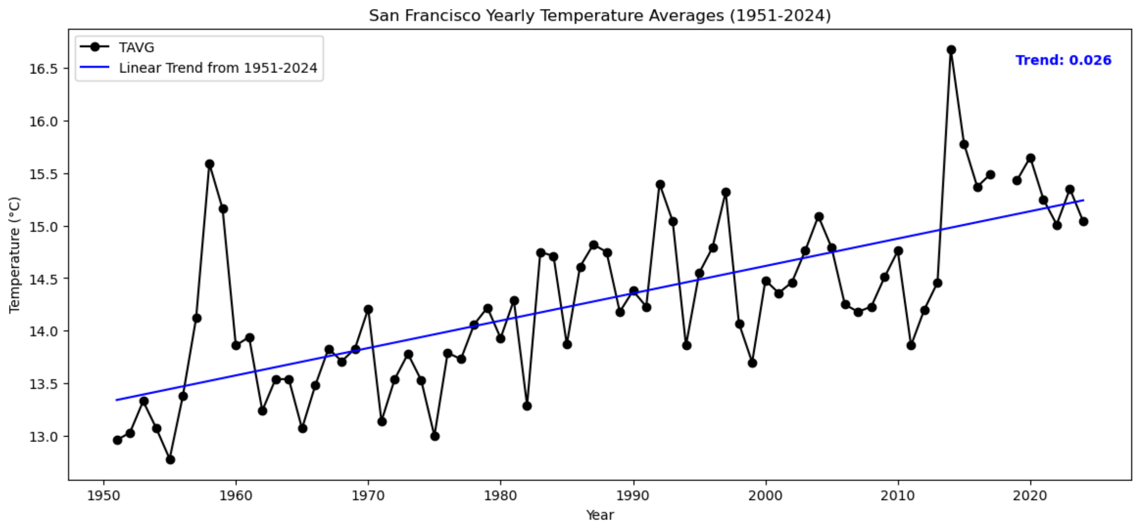


Figure 3.3: *The trend line for yearly average temperature has the largest slope out of any of the other figures in this section.*

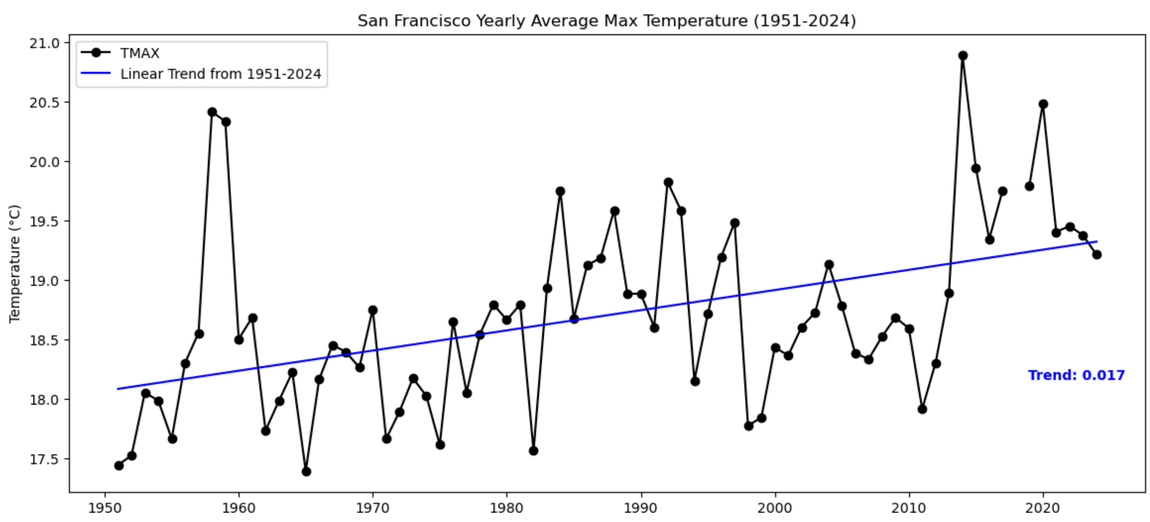
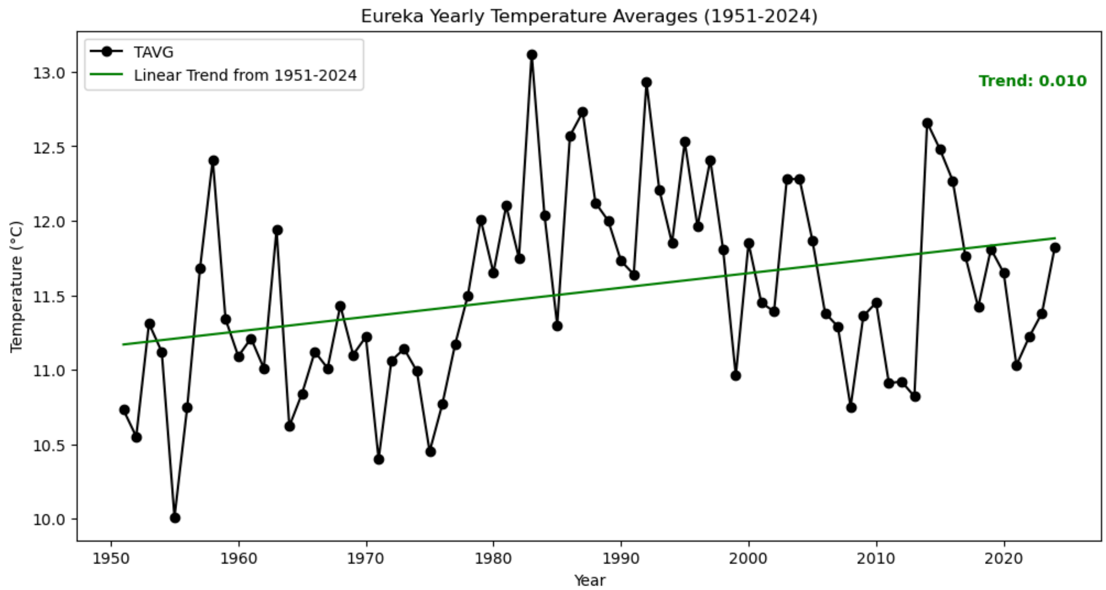


Figure 3.4: *Again we see that the slope of the trend line for the maximum values is smaller than that of the average values.*

Eureka, CA:



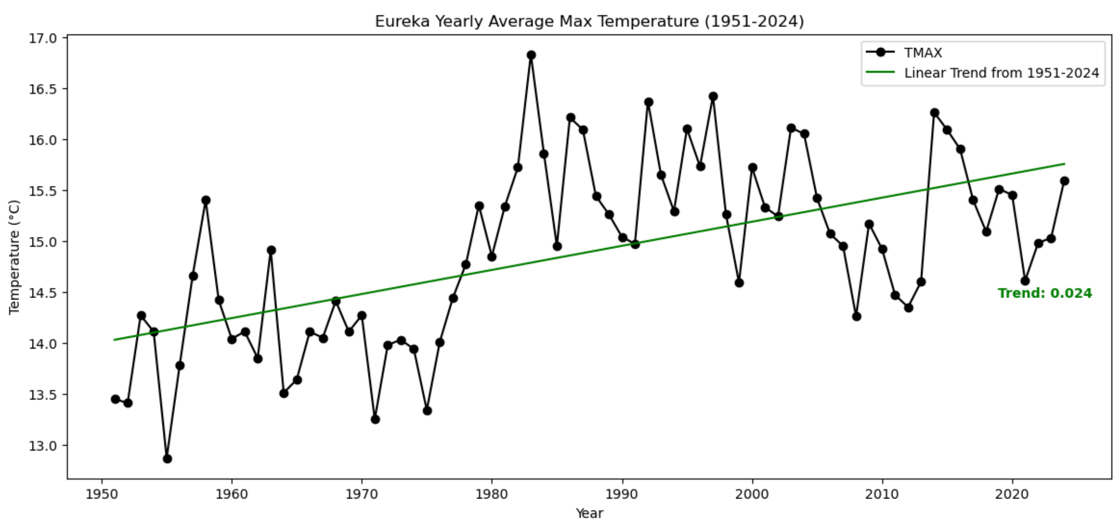


Figure 3.5 & Figure 3.6: *Again the temperatures are generally increasing as the years go by. This time the maximums are increasing faster than the averages. This is why it is important to look at data from more than one location. California is a large state with diverse regions.*

Carbon Emission Trends

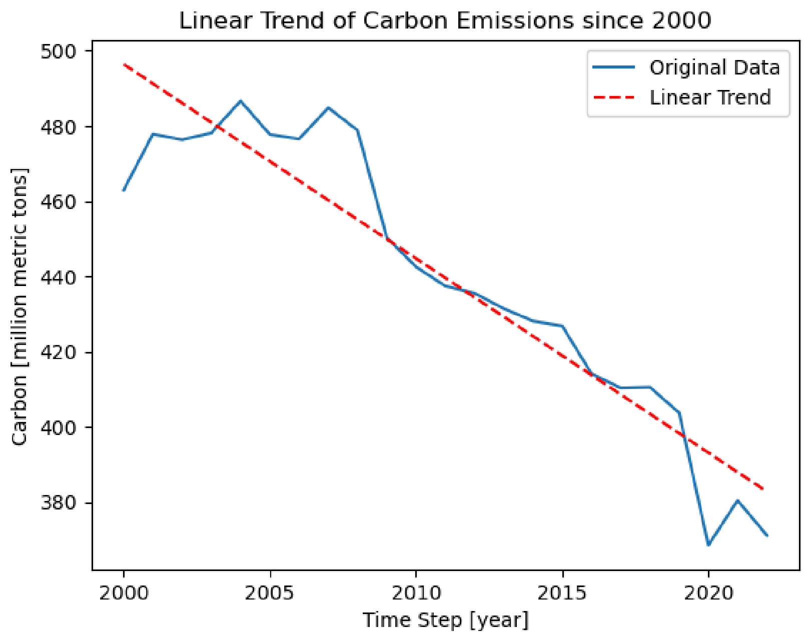


Figure 3.7: *The amount of carbon emissions has dramatically decreased over recent years, presumably due to more research being done and more pressure from the public.*

Note: The temperature figures (3.1–3.6) are based on NOAA's historical temperature data (NOAA, 2024). The emissions graph (Figure 3.7) is according to California's GHG inventory (CARB, 2024).

5. Conclusion

In this project, we looked at how average and maximum temperatures have changed over time in three California cities and compared those trends with carbon dioxide emissions data from the state. What we found was consistent warming across all three locations, though the rate of change varied by region. San Francisco showed the steepest increase in temperature, while Eureka had the most noticeable rise in maximum temperatures.

At the same time, California's carbon emissions have actually been going down since 2000. But because carbon dioxide stays in the atmosphere for a really long time, the total amount in the air is still going up (Archer et al., 2009). This helps explain why temperatures keep rising, even though recent emissions are decreasing. It shows that reducing emissions now is important but it doesn't immediately fix the problem.

Our method used simple linear regression to find trends, which is helpful for spotting long-term patterns and making the data easier to interpret. One downside is that it assumes the trend is linear, which may not always be the case. Climate data can have sudden changes or nonlinear behavior. Other methods, like polynomial regression, time series modeling, or machine learning techniques, could provide more detailed insights but would also require more complex analysis and assumptions.

Overall, our approach gives a clear and accessible way to connect emissions to temperature change. It's a solid starting point, but there's room to expand by looking at more variables, different modeling techniques, or even local factors like urban development and wildfires that also affect regional climate.

6. Data and computer code availability statement

The data sets used for the figures can be found in the NOAA Climate Data Archive and California ARB GHG Inventory.

The file and data files used to generate these graphs can be found on GitHub: https://github.com/isabellaTabrizi/MATH-586-Research-report.

7. References

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8. Peer Review - by ________