Trends in Heating and Cooling Days in Suburban and Urban Settlements in the U.S. Southwest

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1 Rationale and Research Questions

Climate change, long-term shifts in temperatures and weather patterns, is a naturally-occurring process that has been accelerated by human actions, primarily the burning of fossil fuels. One of the impacts of climate change is rising temperatures, which has negative impacts on Earth's ecosystems, such as melting glaciers, intensifying storms, and worsening drought conditions. Humans are directly impacted by rising temperatures: as the number of hot days and heat waves increase, so do the number of heat-related illnesses.

The U.S. has not escaped these impact. The southwest region of the US which we defined as Arizona, California, and Nevada has witnessed an uptick in droughts. Nevada which utilizes water from Lake Me has seen record lows in recent years cautioning them to adopt water conservation strategies while California has been no stranger to forest fires. We plan to do this by analyzing data from the National Centers for Environmental Information, using max temperature and minimum temperature. Thus, our research questions are:

1. Has there been an increase in the number of heating and cooling days in the U.S. Southwest from 1972 to 2022?
2. Is there a difference in heating and cooling days in urban and rural spaces in the U.S. Southwest over time?
3. How have minimum and maximum temperatures changed over time?

2 Dataset Information

Our datasets were retrieved from NOAA's National Centers for Environmental Information (NCEI), specifically from the GHCN (Global Historical Climatology Network). We selected a total of six stations, encompassing three major cities and each with an associated nearby suburban location. We selected the nearby suburban locations to be within 50 miles of the major city and with a population of less than 50,000 in 2022. The selected locations are as follows:

- Phoenix and Fountain Hills, Arizona
- Las Vegas and Pahrump, Nevada
- San Diego and Ramona, California

We primarily examined the daily data for TMAX = Maximum temperature (Fahrenheit) and TMIN = Minimum temperature (Fahrenheit) for each of the six locations. Our datasets had varying levels of coverage and start dates for each location. All the datasets had high coverage from 1998-2022, and all but Ramona, CA have data from 1980-1998. More information about this data's documentation can be found at https://www.ncei.noaa.gov/pub/data/cdo/documentation/GHCND_documentation.pdf and in the Metadata folder of this project's repository.

3 Data Wrangling

We took several steps in our workflow to clean our datasets. The raw data included both the city and suburb in the same CSV, so we first filtered the data to separate out the locations. For each of the 6 locations, we selected the columns we were interested in exploring, which included NAME, DATE, PRCP, PSUN, TMAX, TMIN, TAVG, TSUN, and created columns for Month, Year, and DayofYear to enable different years to be overlaid on a graph.

The Fountain Hills, Pahrump, and Ramona datasets had some missing data points in the maximum and minimum daily temperatures, so we used linear interpolation to fill in the missing data. The raw data for the 'Average Temperature' column contained many missing values, so we inputted the calculated mean of the daily maximum and minimum for this column.

Heating and Cooling Degree Days Calculations

Having the daily average temperature calculated for each location, we then calculated the heating degree days and cooling degree days. Heating degree days are when people turn their heater on because the average temperature is low, and cooling degree days is when people turn their air conditioner on because the average temperature is warm. The industry standard threshold is 65 degrees F, meaning that anything higher than 65 F would constitute a cooling degree day, and anything lower than 65 would mean it is a heating degree day (US EPA, 2016). The equations to calculate the heating and cooling degree days are as follows:

Heating degree days = 65 - daily average temperature

Cooling degree days = daily average temperature - 65

From these calculations we are able to look at the number of heating and cooling degree days, as well as the intensity, which are two main components examined in the exploratory analysis section.

Describe how you wrangled your dataset in a format similar to a methods section of a journal article.

To wrangle our data, we: * Read in the .csv's * Filtered by location and created new files for each location * Kept certain columns (name, date, precipitation, sun coverage %, max temp, min temp, average tem, total sun) * Format the date column into a date object * Changed the station name to the city name * Created a column for month, year, and day of year by extracting the information from the existing date column * Updated the column names to the full title ** Check the NAs with the summary function * Saw that some cities have NAs in max, min, and average temperature * Interpolate gaps in min and max using linear interpolation in Fountain Hills, Pahrump, and Ramona * Calculate the average daily temperature and fill in the existing column * Created separate columns for heating and cooling degrees and calculated the values ** As we created the two columns, we filled them with 0s ** We calculate heating degrees by indexing the mean temperatures that are below 65F then subtracting the mean temp from 65 ** We calculate cooling degrees by indexing the mean temperatures that are above 65F then subtracting 65 from the mean temp

Add a table that summarizes your data structure (variables, units, ranges and/or central tendencies, data source if multiple are used, etc.). This table can be made in markdown text or inserted as a kable function in an R chunk. If the latter, do not include the code used to generate your table.

3. Exploratory Analysis

For the purposes of exploring our data, we first plotted the three major cities together to get a sense of how their average daily temperatures compared over time, shown in Figure 1. Based on the figure, there are clear seasonal trends throughout the year, and Phoenix has the highest daily average temperature over time, followed by Las Vegas and then San Diego. The trendline for Las Vegas has a noticeable positive slope over time, while the trendline for Phoenix demonstrates only a slight increase and San Diego's trendline remains to be horizontal with no major changes in slope.

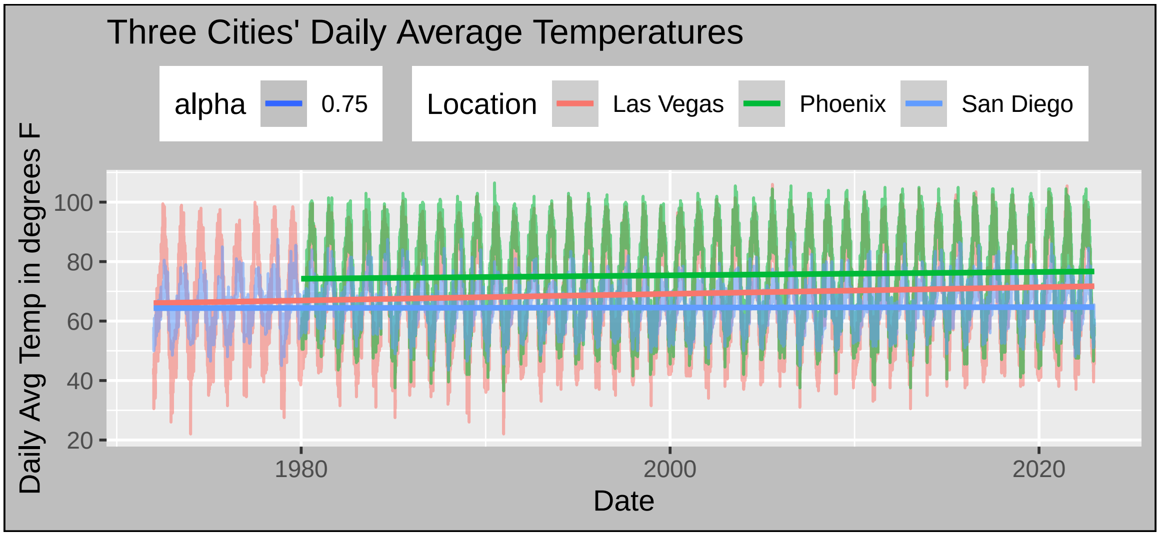


Figure 1: Average Tempearture for Phoenix, Las Vegas, San Diego

For the remainder of the exploratory analysis section, we focused on a single city - Phoenix, Arizona - in order to better understand the data for the statistical analyses. Figure 2 shows Phoenix's maximum and minimum daily temperature from 1980 until 2022. The trendlines for the minimum and maximum temperatures show that there has been a modest increase in both over time. The black horizontal line on Figure 2 marks the 65 F threshold for heating and cooling degrees. Based on the trends in this figure, we would expect there to be more cooling degree days than heating.

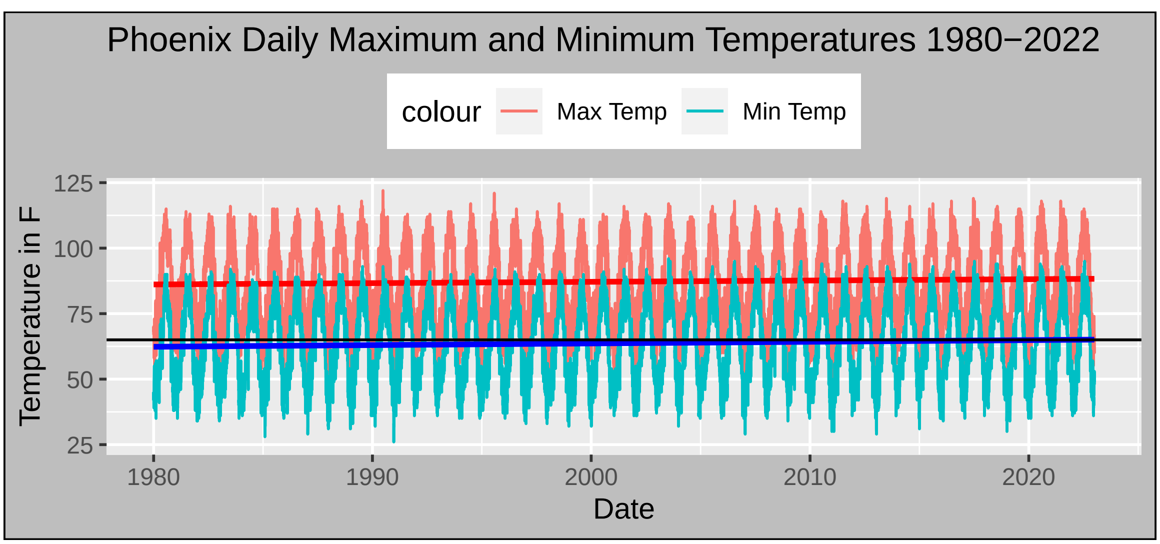


Figure 2: Phoenix Daily Maiximum and Minimum Temperatures

Figures 3 and 4 compare the number of heating and cooling degree days throughout the year for Phoenix in 1980 and 2022. The differences in the two figures demonstrate an increase in the number of cooling days in March, April, and October and a decrease in the number of heating days in February and March.

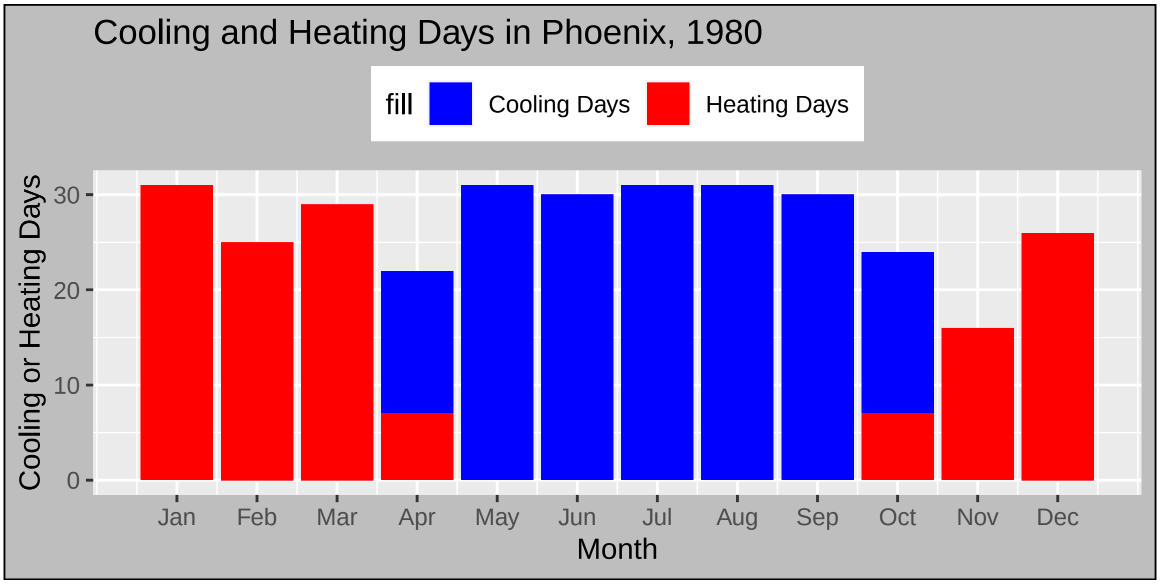


Figure 3: Number of Phoenix's Heating and Cooling Degree Days, 1980

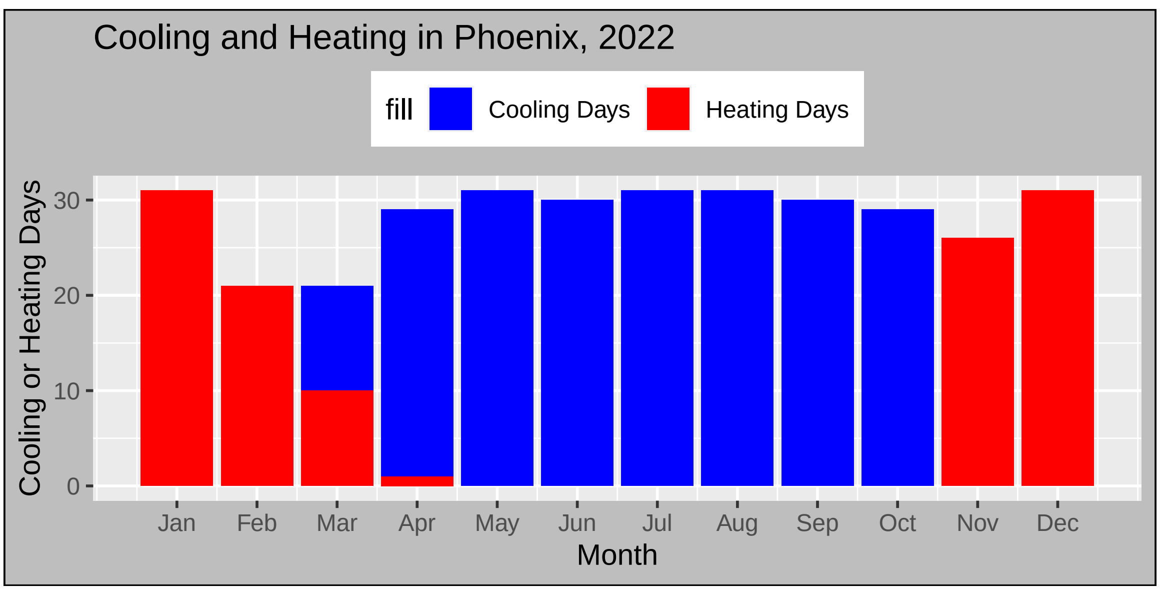


Figure 4: Number of Phoenix's Heating and Cooling Degree Days, 2022

Figures 5 and 6 show the intensity of heating and cooling degree days in Phoenix in 1980 and 2022. In this instance, intensity is the number of degrees over or under 65 F per day. The peaks of the heating degree day intensity is approximately half the intensity of the cooling degree day intensity. Figure 5 shows that there were some higher peaks in 2022 of heating degree days, and March of 2022 saw a much lower intensity of heat degree days than March of 1980. Figure 6 shows the intensity of cooling degree days peaking consistently in the month of July. July 2022 reached 39 degrees F and July 1980 reached 36 degrees F. In 2022 compared to 1980, cooling degree days started earlier in the year, and consistently reached a slightly higher intensity.

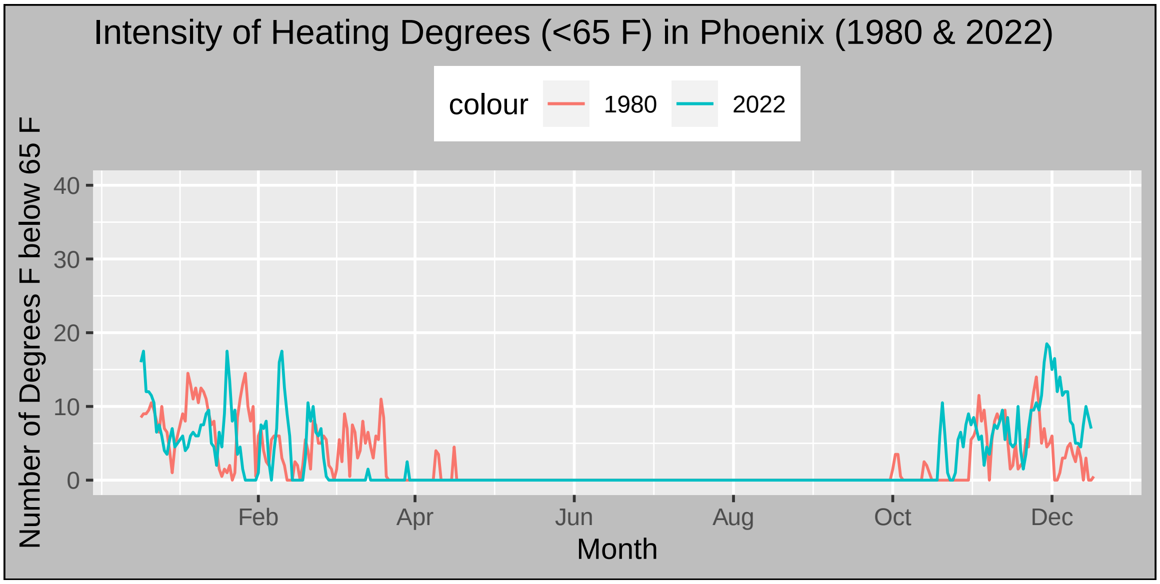


Figure 5: Comparison of Heat Degree Days in Phoenix in 1980 and 2022

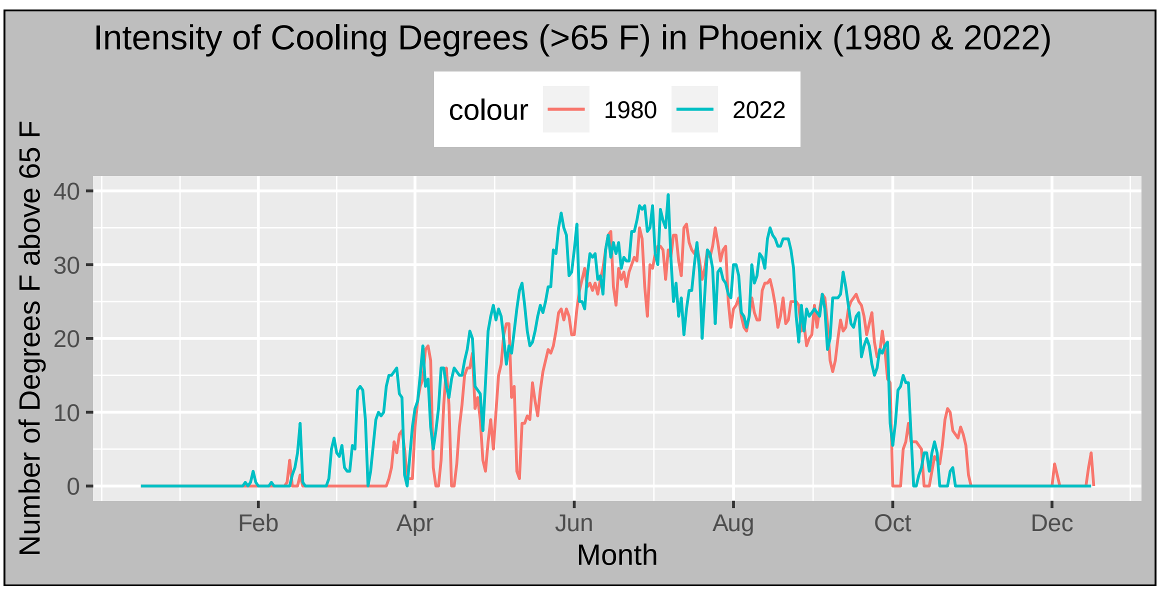


Figure 6: Comparison of Cool Degree Days in Phoenix in 1980 and 2022

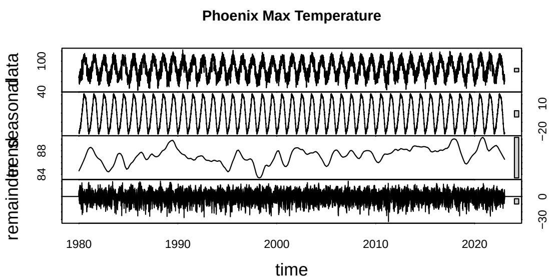
4. Analysis

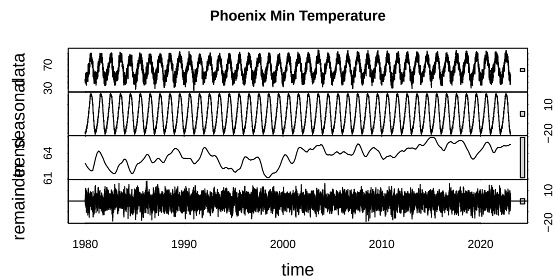
Question 1: Has there been an increase in the number of heating and cooling days in the U.S. Southwest from 1972 to 2022?

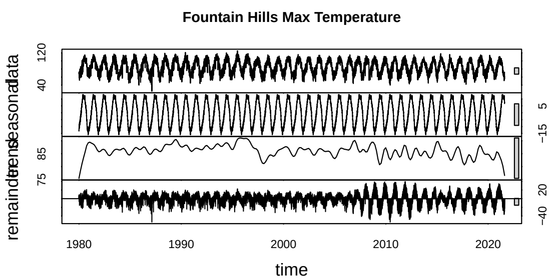
Question 2: Is there a difference in heating and cooling days in urban and rural spaces in the U.S. Southwest over time?

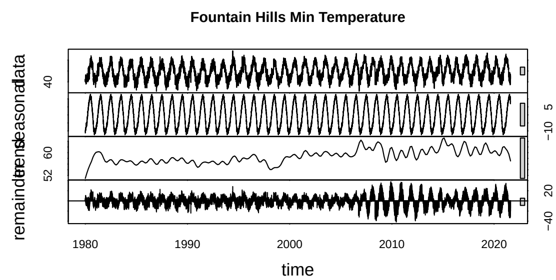
Question 3: How have minimum and maximum temperatures changed over time?

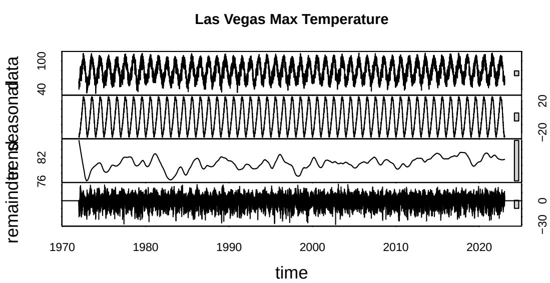
To address the question of whether minimum and maximum temperatures have changed over time, we conducted a time series analysis on every city. We first created univariate time series objects for each measure for each site. We then decomposed each time series to review the trends and seasonality present.

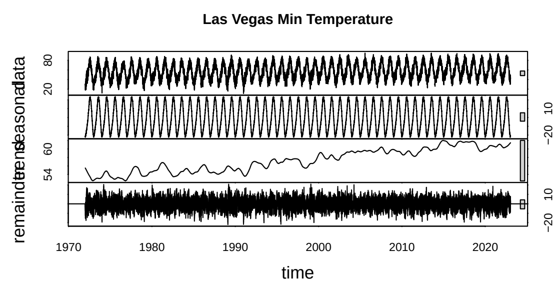


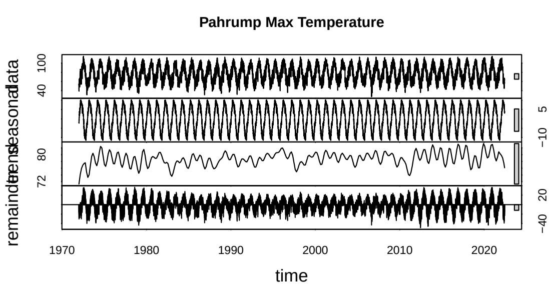


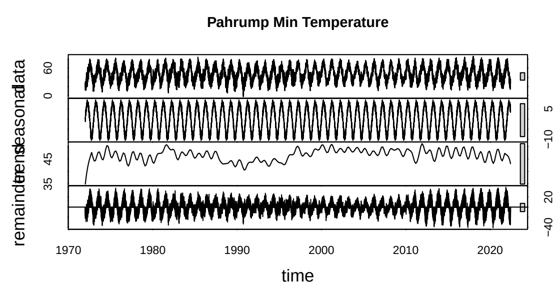


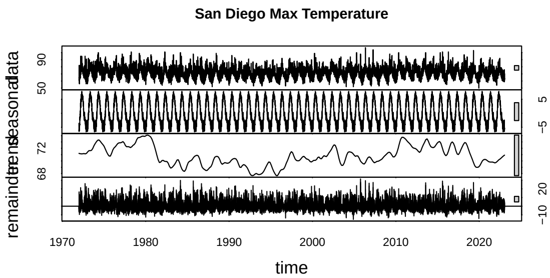


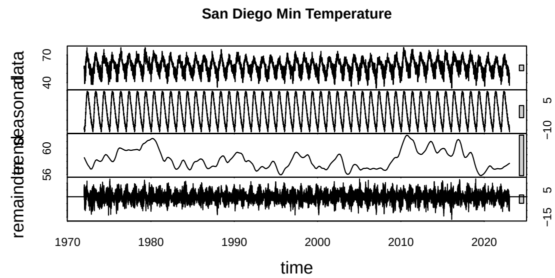


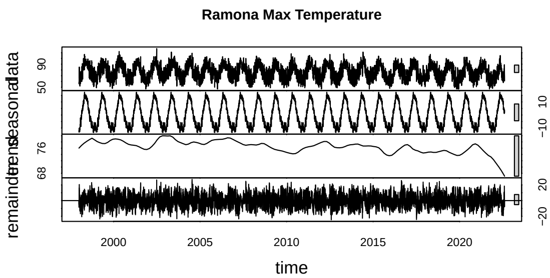


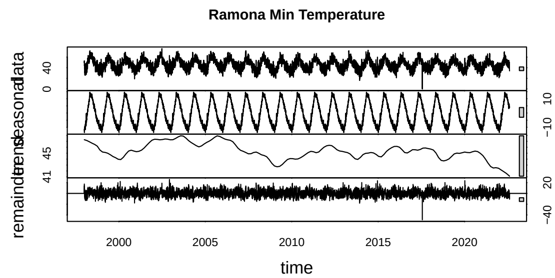










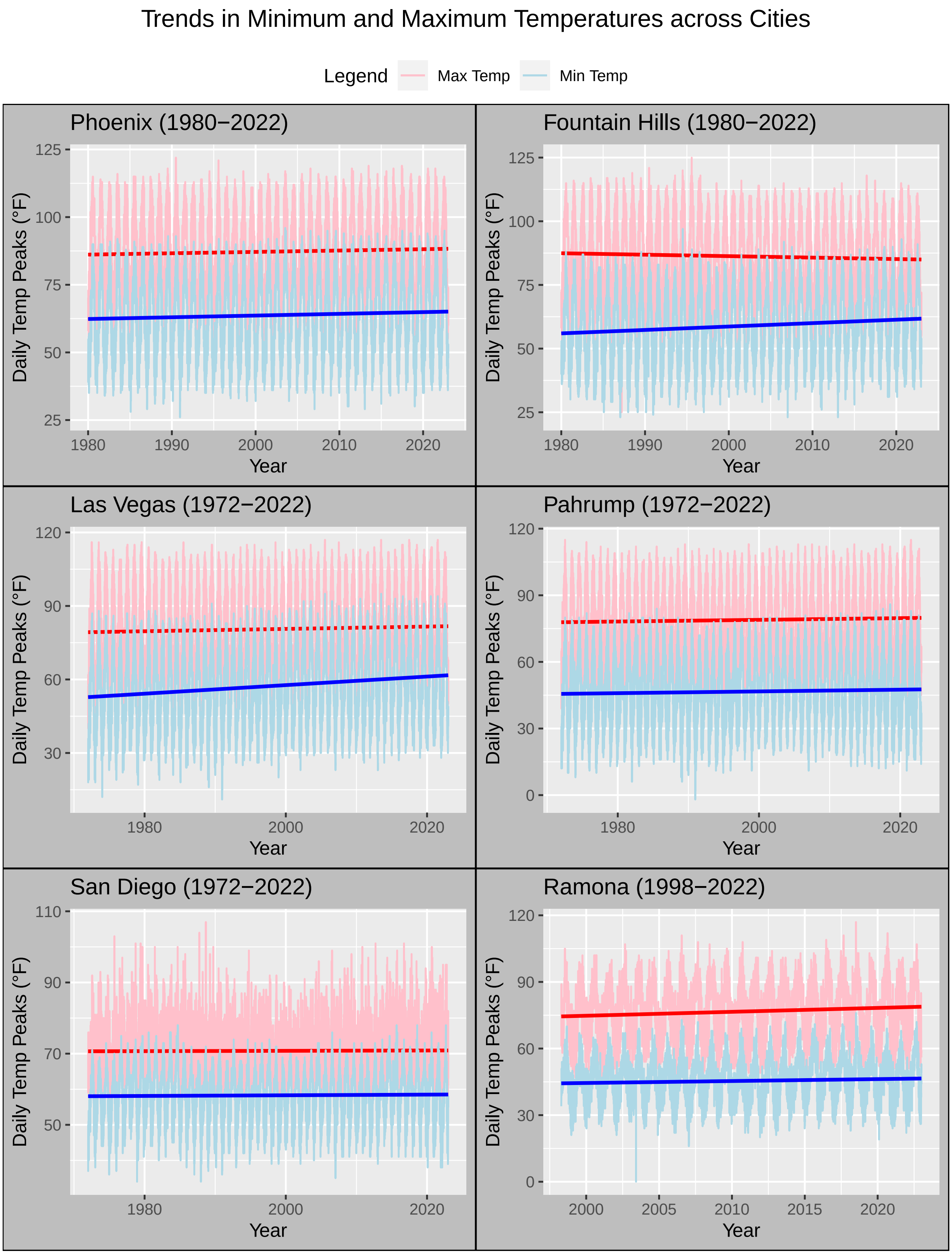


We then conducted a Seasonal Mann Kendall test to test whether the hypothesis that the data is stationary. This would mean that the data exhibit no statistically-significant upward or downward trend over time, meaning that there is no change in the temperature minimum and maximums over time.

The results of the Seasonal Mann Kendall test show us that all trends are statistically significant, so none of the data are stationary. The tau value shows the slope of the trend. Interestingly, Fountain Hill's maximum temperatures, San Diego's minimum temperatures, and Ramona's maximum and minimum temperatures have a downward trend. Every other variable has an upward trend.

Table 1: Results for the Seasonal Mann Kendall test on minimum and maximum temperatures

City	Variable	p-value	tau value
Phoenix	max temperature	<2.22 e-16	0.0617
Phoenix	min temperature	<2.22 e-16	0.0951
Fountain Hills	max temperature	7.66 e-07	-0.0282
Fountain Hills	min temperature	<2.22 e-16	0.0979
Las Vegas	max temperature	<2.22 e-16	0.0671
Las Vegas	min temperature	<2.22 e-16	0.29
Pahrump	max temperature	<2.22 e-16	0.0482
Pahrump	min temperature	<2.22 e-16	0.0678
San Diego	max temperature	8.91 e-4	0.0173
San Diego	min temperature	5.10 e-4	-0.0182
Ramona	max temperature	<2.22 e-16	-0.112
Ramona	min temperature	<2.22 e-16	-0.0912



The graphs above show the trends increasing or slightly decreasing in the case of .

5. Summary and Conclusions

6. References

US EPA, O. (2016, July 1). Climate Change Indicators: Heating and Cooling Degree Days [Reports and Assessments]. https://www.epa.gov/climate-indicators/climate-change-indicators-heating-and-cooling-degree-days