College of Integrative Sciences and Arts
ARIZONA STATE UNIVERSITY

Dynamic Patterns on Temperature Across Different Climate Regions

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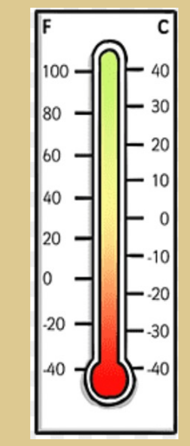


Introduction and Objectives

Much existing data has been collected concerning global surface temperatures and how they have begun to increase over time.

- Global average surface temperature has increased by about one degree Celsius (roughly two degrees Fahrenheit) since the pre-industrial era (1880-1900).
- Although this increase in temperature is small, it is the result of a significant accumulation of heat, and has had significant consequences.
- It has resulted in increased rainfall, reduced snow cover and sea ice, and seasonal temperature extremes—all of which affect plant and animal habitats.

Fig 1[1]

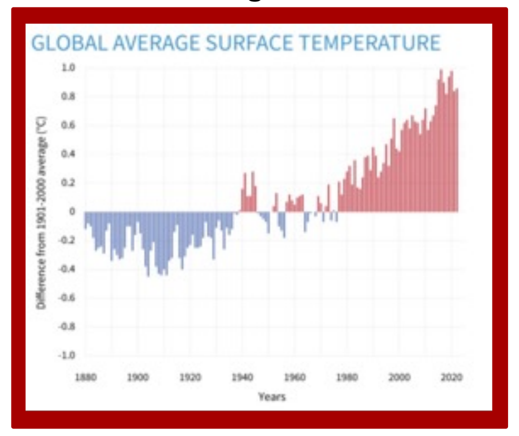
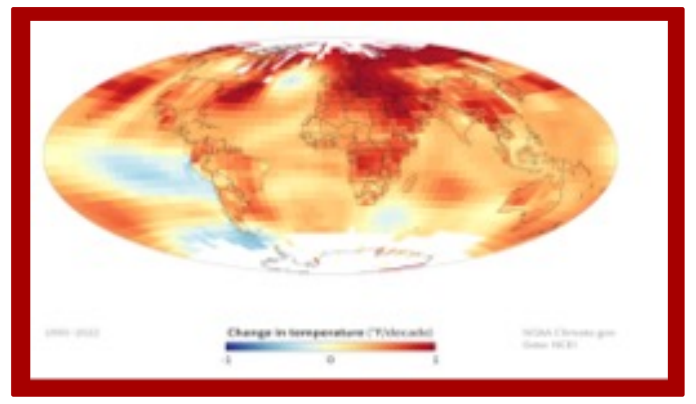


Fig 2[1]



This project analyzes daily temperature data from three different US cities from three different states with diverse climates: Juneau, Alaska; Aberdeen, Washington; Apache Junction, Arizona. The data sets were obtained from NOAA Climate.gov and contain for each of these three cities daily maximum and minimum temperatures (spanning roughly twenty years, ranging from 1995-2022). Periodic analysis of the data will reveal whether there has been a gradual increase of temperature in each of these cities over time.

Research Questions:
1. How has the mean temperature for these three cities changed across the roughly twenty year time period (1995-2022)?
2. How does the period of the periodic fit of the data for these cities change as time progressed?
3. What patterns are presented by the three climate regions' mean temperatures, periods, and temperature differences?

Data and Analysis Approaches

Code is used to fit the data (for each city) to the following periodic function for each year (i) of data:

- A_i: Amplitude
- ω_i: Period/2pi
- ϕ_i : Phase Shift
- C_i : Vertical Shift

$$y_i(t) = A_i sin(\omega_i t + \phi_i) + C_i$$

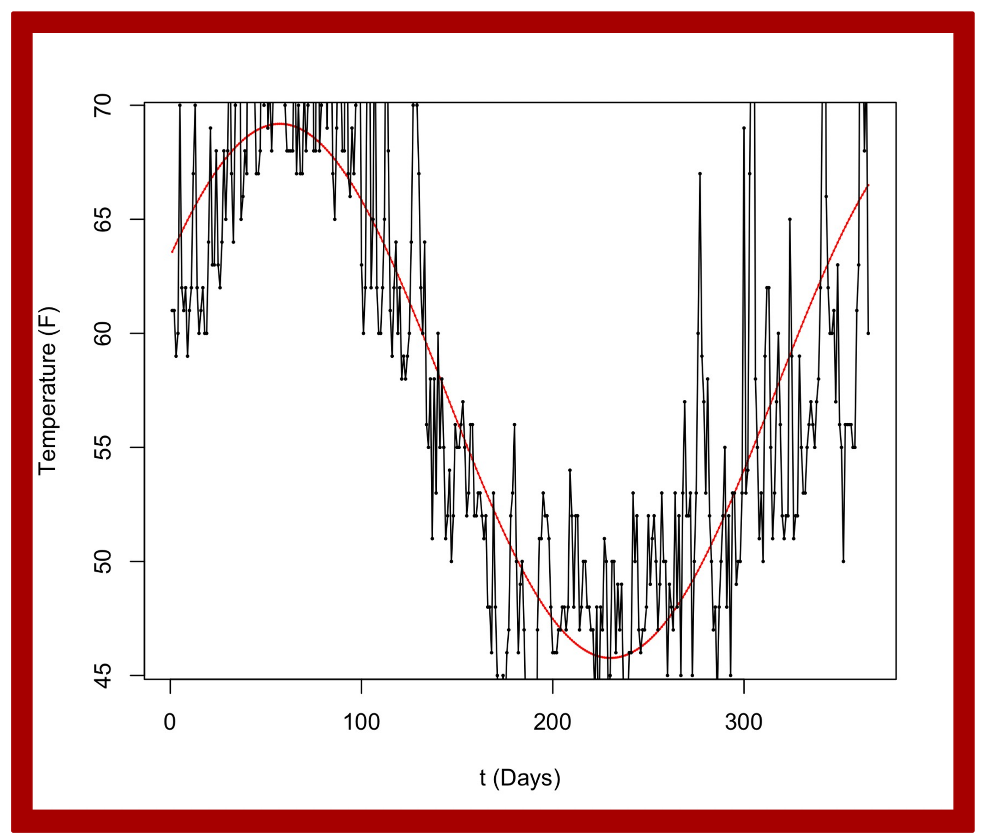


Fig 3. *Aberdeen, Washington Fitting (i = 1)*
The figure above compares the temperature data (in black) to the periodic fit of the data given by the function (in red) for the first year of the Aberdeen, Washington data set. As can be seen, the periodic fit provides a relatively good fit for the temperature data.

- **Amplitude:** The amplitude for a given year is the highest temperature of the year minus the lowest. It shows the range of temperatures over that year.
- **Period:** The period for a given year is $2\pi/\omega_i$. The period helps us observe the seasonality of our data (how seasonal patterns fluctuate over time).
- **Phase:** The phase for a given year tells us when in the year temperatures are at a maximum or minimum. An increase in the phase means the peaks and troughs of the temperature data occur *later* in the year, and vice versa.
- **Vertical Shift:** The vertical shift (C_i) represents a change in the overall average temperature throughout the year. For example, a positive vertical shift implies an increase in temperature for most months, and so on.

The periodic fitting allows us to see how the amplitude, period, phase, and average of the data (in this case the **TMAX** variable, maximum temperature) change over the roughly 20 years timespan of the data. By analyzing these aspects of **TMAX**, it can be determined how temperatures are changing over time for each of the cities.

$$y_1(t) = 11.7sin(0.018t + 0.530) + 57.5$$

Fig 4. *Periodic function for Aberdeen, Washington i=1*

Fig 5[3]

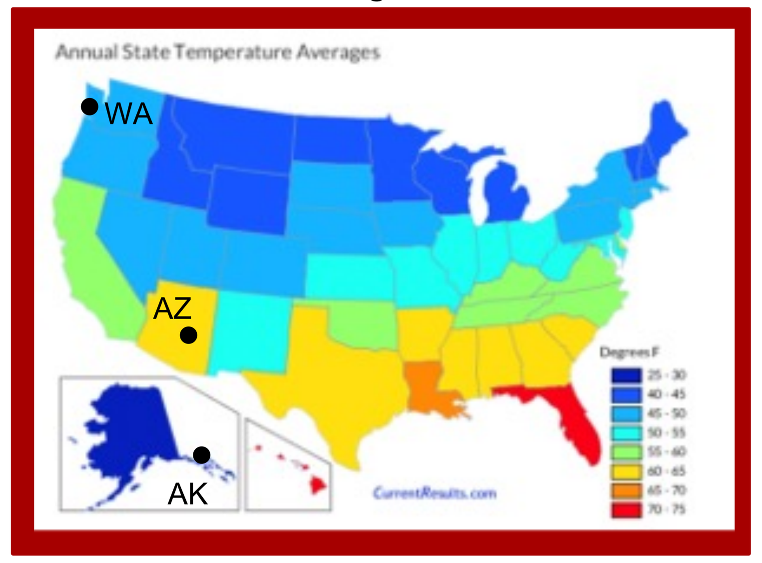


Fig 5. show the average annual temperatures for each US state, based on yearly data from 1971-200 collected from the NOAA (Current Results).

Selected Cities:
1. Aberdeen, Washington (WA)
2. Juneau, Alaska (AK)
3. Apache Junction, Arizona (AZ)

These cities were selected because of the variety of their range in temperatures. The state of Washington has a relatively temperate climate with a wide range of temperatures (it experiences four seasons). Alaska, on the other hand, has disproportionately cold weather. Contrastingly, Arizona has relatively warm weather (extremely hot summers and mild winters).

Results on Temperate Climate

Aberdeen, Washington:

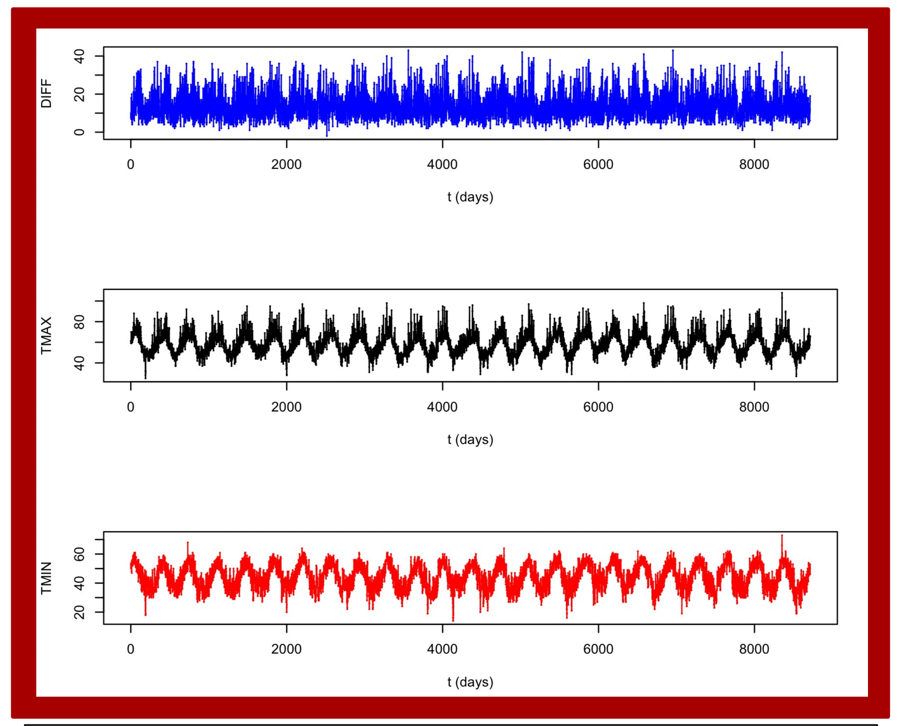


Fig 6. *Dynamics of TMIN (min. temp.), TMAX (max. temp.), and DIFF (TMAX - TMIN) over time*

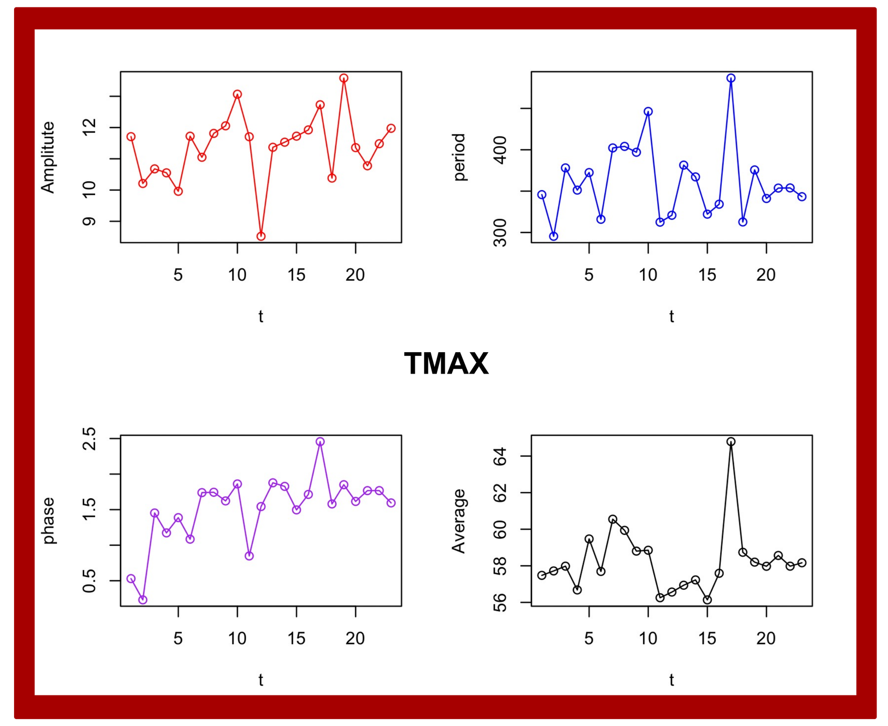


Fig 7. *Dynamics of Amplitude, Period, Phase, and Average over time t (years)*

It can be seen in Fig. 6 how the three variables TMIN, TMAX, and DIFF oscillate over time (~23 years, over 8,000 days). TMIN represents the minimum temperature on a given day (t), TMAX the maximum temperature, and DIFF the difference between the two (TMAX – TMIN). As can be seen, the variables are relatively periodic, speaking to the accuracy of the fitting. Fig. 7 shows an almost negligible increase in the amplitude for the TMAX of this data set over time. The period oscillates but roughly stays the same. The phase increases from about 0.5 to 1.5 over the roughly 23 year gap. The average shows an increase of about 0.5-1 degree F.

Results on Cold Climate

Juneau, Alaska:

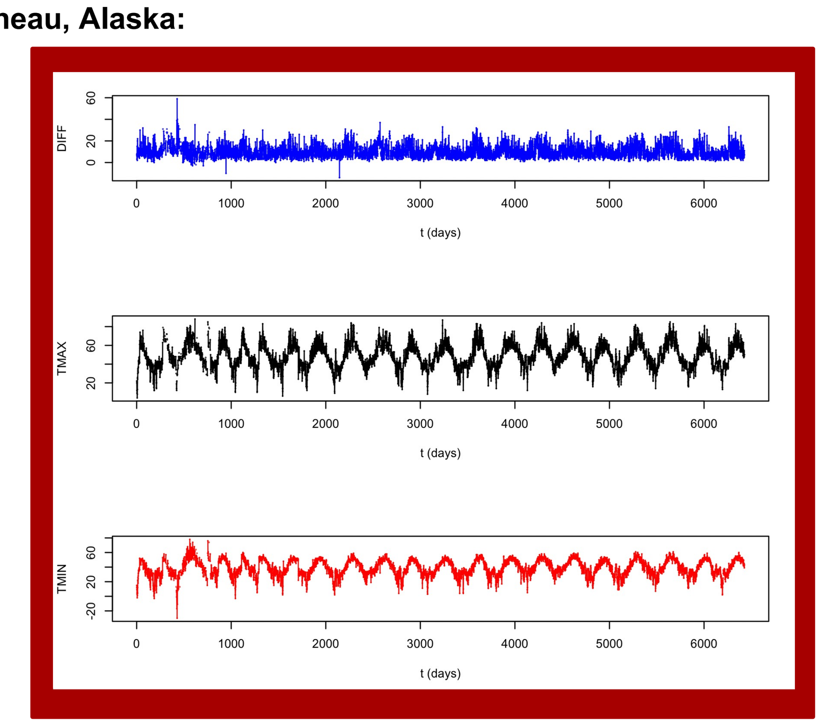


Fig 8. *Dynamics of TMIN, TMAX, and DIFF over time*

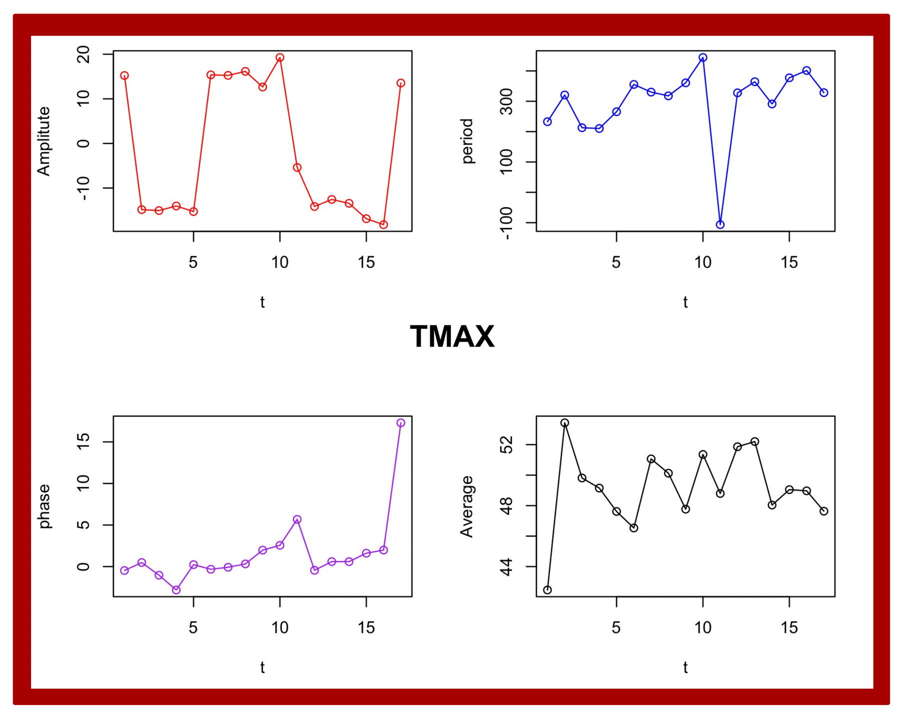


Fig 9. *Dynamics of Amplitude, Period, Phase, and Average over time t (years)*

Fig. 8 shows how TMIN, TMAX, and DIFF oscillate over time in the Juneau, Alaska dataset (~17 years, over 6,000 days). It can be seen from this figure that the fit is not as accurate as the previous data set (this is also reflected in Fig. 9). Sharp drops and jumps are seen in the Amplitude and phase graphs in Fig. 9, and there is also a sharp dip in the Period at around t=11 (year 11). These are areas where the periodic fit is less accurate. This makes it more difficult to determine trends in temperature for this area over time. Excluding the discontinuities in the amplitude, it seems to remain constant in the 17 year time period. There is a slight increase in both the phase and period. The average appears to decrease by about 2 degrees.

Results on Warm Climate

Apache Junction, Arizona:

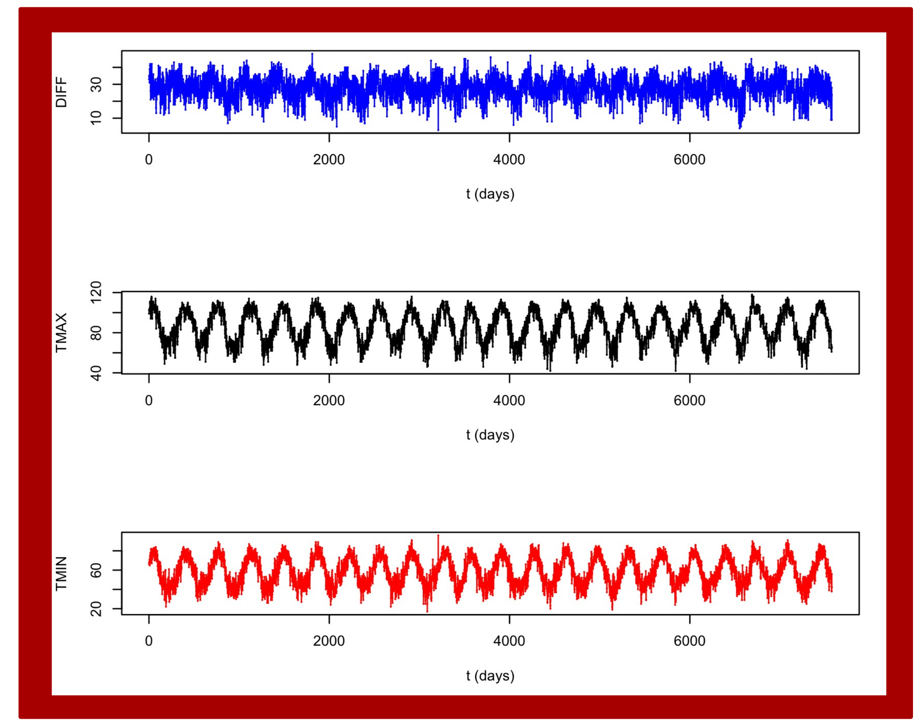


Fig 10. *Changing of TMIN, TMAX, and DIFF over time*

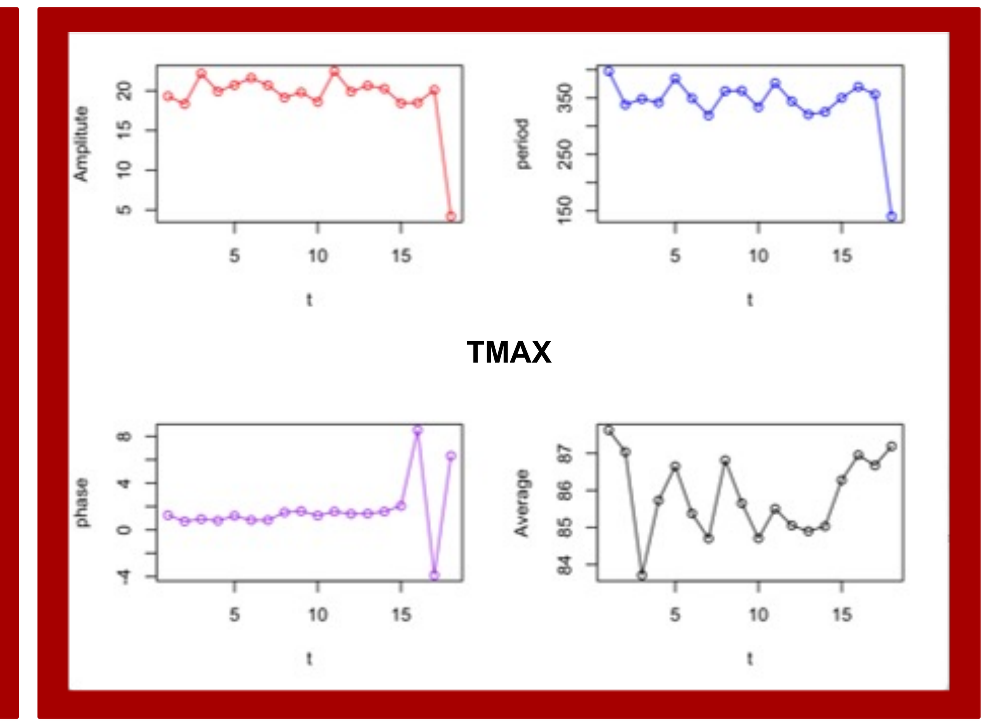


Fig 11. *Dynamics of Amplitude, Period, Phase, and Average over time t (years)*

Fig. 10 shows how TMIN, TMAX, and DIFF oscillate over time in the Apache Junction, Arizona dataset (~20 years, over 7,000 days). It can be seen from this figure and also Fig. 11 that the fit for this dataset is also not as accurate as the fit for the Aberdeen, Washington dataset, however, it is more accurate than the fit for the Juneau, Alaska dataset. The periodic behavior in Fig. 10 is less erratic, and there less spontaneous drops and jumps in the graphs of TMAX pictured in Fig. 11. It seems that the fit for the data is relatively accurate up until year 15 (t=15 in Fig. 11). Based off of this, it appears as if there is a slight increase in amplitude over time, while the period and average decrease ever so slightly. The phase remains about constant.

Conclusions

- Analysis on temperate climate (Aberdeen, Washington) revealed that there may have been a slight increase in maximum temperature over the last roughly 23 years. However, any increase in maximum temperature would be very small. The amplitude and average of the maximum temperature both increased by about 0.5 degree F, suggesting there has been an increase in maximum temperature, but this increase is quite small. The increase in phase also implies that perhaps maximum temperatures are occurring *later* in the year as time has progressed.
- Analysis on cold climate (Juneau, Alaska) revealed that the periodic fitting was not very accurate for the Juneau, Alaska dataset (it had the worst fit and most irregularities out of the 3 datasets). This is likely due to holes in the data set that made it more difficult to obtain a periodic fit. Many days across the 17 year dataset were not recorded, so the missing data for days likely disturbed the periodic fitting. Excluding the abnormalities in the data and analytical results, the evidence suggests there was likely little change in maximum temperature across time (however, there may have been a small decrease in temperature as large as 2 degrees F).
- Analysis on hot climate (Apache Junction, Arizona) revealed that the periodic fitting was also not entirely accurate for the Apache Junction, Arizona (however, the fit was more accurate than for the Juneau, Alaska dataset). This inaccuracy is also likely due to holes in the data set. There were also many days across the 20 year dataset that were not recorded, so the missing data for days likely disturbed the periodic fitting. Excluding the abnormalities in the data and analytical results (not looking past year 15), the evidence suggests there was also likely little change in maximum temperature across this dataset as well; the amplitude, phase, and period of the maximum temperature remain relatively constant. It appears as if the average maximum temperature decreased by about one degree.
- Overall, there was no evidence of large increases or decreases in temperature across the three cities in the past roughly twenty years. Analysis concludes that there may have been a small increase in average maximum temperature in Aberdeen, Washington by about 0.5-1 degree F, and small increases in average maximum temperature in Juneau, Alaska (2 degrees F) and Apache Junction, Arizona (1 degree F). However, the accuracy of the periodic fit of the model is called into question due to gaps in the datasets. Further analysis would be needed to completely determine the behavior of maximum temperature over time in each of these regions, however, the analysis provide likely approximations/possibilities of the trends of temperature in these areas over this time period.

Literature Cited & Acknowledgements

1. Dahlman, Rebecca Lindsey and Luann Dahlman. "Climate Change: Global Temperature." *Climate.Gov*, NOAA, 18 Jan. 2023, www.climate.gov/news-features/understanding-climate/climate-change-global-temperature.
2. NOAA Climate.gov (data retrieved)
3. "Average Annual Temperature for Each US State." *Average Annual Temperatures by USA State - Current Results*, Current Results, 2023, www.currentresults.com/Weather/US/average-annual-state-temperatures.php.

- Thank you so much Dr. Yun Kang for your guidance!