League of American Engineers 2022

LAE2022-Volume 1-R3

Paper GW001-001

A MECHANICAL ENGINEERING PERSEPCTIVE ON GLOBAL WARMING

Stephen J. Schoonmaker, Memb. ASME
Principal Engineer, Grove US, LLC
Shady Grove, PA, USA

ABSTRACT

This paper analyzes publicly available temperature data from NOAA in order to attempt to quantify the extent of global warming. Four sites are chosen essentially at random across the continental United States. These sites have uninterrupted data from the 1950's to the 2010's; this is the widest available time span seen by the author for the 4 sites. This sample is elementary, but since the US Government has commenced the dismantling of the current energy infrastructure, it must be assumed that even an elementary sample must now show convincing evidence of the warming.

This analysis is essential since the author's business is closely tied to the current energy sector, and it appears that the so-called Infrastructure Bill (Public Law 117-58-NOV. 15, 2021) is only nominally related to actual construction that would enhance American construction equipment manufacturing (most of the bill's funding is directed to other purposes). Furthermore, the author's construction equipment for the energy sector has the highest profit margins, so losing this sector will have an amplified effect on the economic sustainability of the business. Only fossil fuel development requires this type of equipment used in unpopulated areas with rough terrain conditions[1]. One does not have to mine or drill for solar power. If the planet is endangered, then clearly the author would have to give up this business, BUT ONLY if global warming is evident with a high probability - that is, a clear and present danger. This paper finds that danger is possibly there, but it is not indisputably a clear and present danger.

The analysis shows that if the temperature data is interpreted as part of a long-term cycle, then a warming trend of 0.3 deg F / decade would be predicted. This does not appear to be alarming, and the cycle could continue toward further cooling. Some sites clearly showed that temperatures were warmer than average in the 1950's, and then cooling for a few decades, and now recent warming.

If, however, the most recent trends are considered unusual, and not part of a cycle, then applying the most recent trend to the most recent temperature data would predict a 5 deg F / decade warming trend. This would seem alarming. But, there is no method apparent for knowing whether the pattern is cyclical or not.

In terms of rapid variability of temperature, both during the same day and from one day to the next, the trend is clearly toward less variation. The overall trend for less variation within a day is -0.15 deg F / decade, and the overall trend for variation from day to day is -0.04 deg F / decade. If such variation is considered an indication of weather getting more severe (and the author has observed people stating this), then the data actually indicates weather is getting less severe.

Assuming the global warming trend is not cyclical, and there is an urgent need to reduce CO_2 emissions, calculations in this paper show that even if all automobiles in the US were electric vehicles (EV's), with electric power generation without new emissions, the reduction of emissions would be entirely negated by Communist China's current construction of 300 GW of new coal-fired power plants.

Assuming 10% of the US vehicle fleet (automobiles and commercial vehicles) were EV's, calculations in this paper show that 65,000 windmills will need to be deployed at a cost of 260 Billion dollars. But this would not have an appreciable impact on emissions. If 50% of the fleet was EV's, 325,000 windmills would be needed at a cost of 1.3 Trillion dollars. Combined-cycle natural gas turbines are also cost estimated, but they would contribute to emissions. Nuclear power plants are also cost estimated, but nuclear power remains uneconomical and unacceptable to the US population. Particularly since the US Government has capitulated with

[1] https://www.manitowoc.com/grove/rough-terrain-cranes/rt9130e-2

respect to the development of spent fuel rod repositories, nuclear power plants should no longer be built.

INTRODUCTION

Over the last 5 years or so, the author has witnessed people lamenting that the weather is getting hotter and more severe. This seemed strange to the author since the people saying this were not actually old enough to make a valid personal comparison across decades of time. Presumably the global warming narrative from the infotainment complex[2] has made this a fact in their minds, and thus the statements would seem valid to them.

Therefore, the author determined to perform his own analysis of temperature data. Since the author had family members near Seattle, Denver, Detroit, and Philadelphia, it seemed appropriate to select these 4 locations for analysis. These sites were actually well distributed across the North American continent. Although this would not be exhaustive analysis, if global warming was a clear and present danger, any such sample MUST be sufficient to show a conclusive warming trend. Academic and government sources of information are considered biased since universities and government bureaucracies have a conflict of interest; they get funding for research if, and only if, the global warming trend is confirmed.

BACKGROUND

The author is familiar with the term Greenhouse Effect starting from the 1970's. At that time, the author was very interested in space exploration; it was found then that the planet Venus was exceedingly hot (such as 900 deg F). Scientists stated that this was caused by CO_2 in the atmosphere which allowed solar radiation to reach the planet surface, but not allow energy to leave the planet. Subsequently, it was decried as an issue for planet Earth since Brazil was destroying its rain forest, and greater amounts of combustion exhaust gases were being emitted from developing countries, particularly by Communist China. The author's home state of Pennsylvania had many steel mills and large factories in the 1970's. Now they are almost entirely gone, and presumably the massive emissions from them have simply moved to places like Communist China. This paper assumes that the dismantling of our current energy infrastructure is based on the scientific fact that there is global warming, and that the CO_2 level in the atmosphere is the cause of global warming. This has certainly been the message from the infotainment complex for at least 30 years.

This paper utilizes historic temperature data from NOAA. This was found at the following URL:

https://www.ncdc.noaa.gov/cdo-web/search

Appendix A shows the steps that were followed to obtain the data sets. Appendix B shows a sample of the data as would be seen in Excel®. The data sets are provided in a CSV file that included the following which was utilized in the analysis:

1. Date of the observation.
2. TMAX - maximum temperature for the day.
3. TMIN - minimum temperature for the day.

The following criteria were applied for selecting data sets:

1. A weather observation site near the 4 selected cities.
2. Uninterrupted data from 1 Jan 1950 to 31 Dec 2019 (this was seen to be the widest available time span).

These criteria would allow customized software to analyze the temperature data without manually altering the data sets. Searching the NOAA data, there were very few locations with observations older than 1950 and yet continuing to the present. But, the 1950's should predate the Brazilian destruction of the rain forest, and it is assumed that uninterrupted Third World combustion emissions have increased since the 1950's (probably rising most notably with the rule of Deng Xiaoping in Communist China assisted by the globalists in the United States during the Clinton administration). Note that the 2020's are not always included in order to allow simple analysis by convenient decades (1950's through 2010's). The analysis is based on broad trends across a span of 70 years; if the threat is as real as has been portrayed, then the recent few years would not alter statistical conclusions.

Figure 1 shows the distribution of the 4 cities. Essentially they were randomly selected from 4 regions of the United States - East Coast, Mid West, West, and Pacific Coast (based on the author's family members).

Figure 1

When searching the NOAA system for data sets, there would be a number of weather observation sites near the chosen cities. But most of the sites did not have complete data for the required span of decades. The following were eventually found to meet the acceptance criteria:

[2] The infotainment complex can be seen as a mass media system that would stretch from Kevin Costner's 1995 Waterworld to current social media outlets likely considering this paper as disinformation.

1. Philadelphia - Philadelphia International Airport (PHL).
2. Detroit - Indianapolis International Airport (IND). Detroit was the most difficult to attempt to find a complete data set, and eventually it was necessary to use a nearby state. The author evaluated Detroit Metro Airport, Detroit City Airport, Ann Arbor, and Lansing. The NOAA website lists dozens of sites near cities along with the date range. These Detroit area sites showed data back to the 1940's, but when analyzed in the customized software, "holes" (days without observations) were found.
3. Denver - Colorado Springs Municipal Airport (COS). Note that Denver International Airport was built much later than the 1940's.
4. Seattle - Seattle Tacoma Airport (SEA).

WEATHER ANALYSIS

The analysis of the temperature data was performed in stages by customized software. The following stages were completed:

1. Least squares curve fit applied to entire data set (for TMAX and TMIN) to find the slope of the increase in temperature. This involved the least squares method applied to about 26000 data points. This provided the most broad view of the trend of the data, and it did include the years in the 2020's decade.
2. Segregation of the data into 7 sets of data for 7 decades (1950's to 2010's). Then found the average TMAX and TMIN for the decades, as well as the slope of the curve for each of the 7 decades. This provided a broad view of decades (but cold months and hot months were combined).
3. Determination of the monthly average of TMAX and TMIN for all years in the 7 decades (70 values for each month). These 70 averages for a month were then averaged to determine the overall coldest and hottest months of the years. Then for the hottest and coldest months, a set of data was created for TMAX across the 70 years by decade (now cold time of year and hot time of year are not combined). In similar manner, a set of data was created for TMIN across the 70 years by decade.
4. Scanning of the entire data set by day to find all the record high temperatures. Then the year of the record temperature was used to determine which decades had higher numbers of records set.
5. Least squares curve fit applied to the entire data set for the difference between TMAX and TMIN (called TDIFF). This is the daily temperature change. This was expected to indicate any trends for weather becoming more rapidly variable and thus more severe.
6. Least squares curve fit applied to the entire data set for the difference between TMAX from one day to the next day, and the same for TMIN (results called TMAXD2D and TMIND2D). This was also expected to indicate any trends for weather becoming more rapidly variable and thus more severe.
7. Segregation of the TDIFF, TMAXD2D, and TMIND2D data into 7 sets of data for 7 decades (1950's to 2010's). Then found the average of these 3 values for the decades, as well as the slope of the curve for each of the 7 decades. This provided a broad view of decades and any broad trend across the decades for temperature rapid variability.

Analysis 1

Analysis 1 used the entire data set. The least squares curve fit method was applied. Note that all analyses were performed by a custom C# program that read the NOAA CSV file, preformed analysis, and then wrote an output file as a CSV file.

Figure 1-1 shows the raw data for TMAX at PHL, and Figure 1-2 shows it for TMIN. As one might expect there is little to be seen by this view of the data.

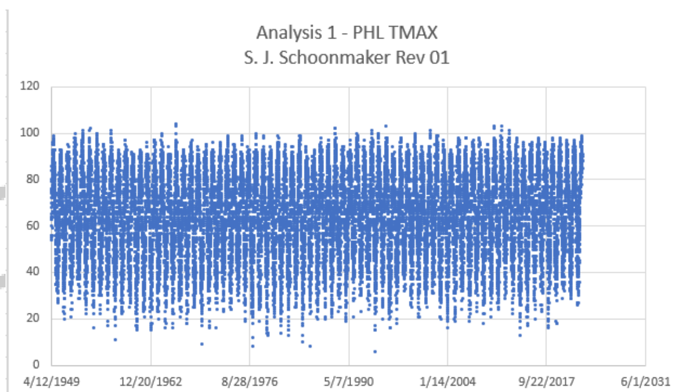

Figure 1- 1

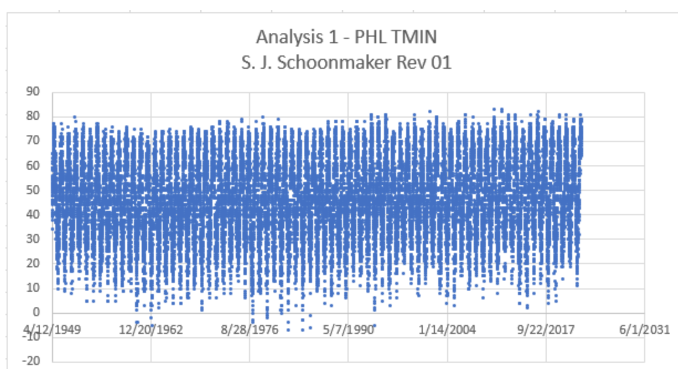

Figure 1- 2

It would be possible to show the linear curve fit to the data in the figures, but it would only appear as a horizontal line (the slope is too small to be observed). Table 1-1 shows the results of the slope for the linear curve fit. The slope of the linear curve fit is taken as the trend of the temperature change in deg F / decade.

Table 1-1

PHL A1. TMAX: Slope of linear curve (deg/10y):	0.41
PHL A1. TMIN: Slope of linear curve (deg/10y):	0.66
IND A1. TMAX: Slope of linear curve (deg/10y):	0.26
IND A1. TMIN: Slope of linear curve (deg/10y):	0.54
COS A1. TMAX: Slope of linear curve (deg/10y):	0.34
COS A1. TMIN: Slope of linear curve (deg/10y):	0.28
SEA A1. TMAX: Slope of linear curve (deg/10y):	0.4
SEA A1. TMIN: Slope of linear curve (deg/10y):	0.53

It is seen that both TMAX and TMIN show an increasing trend for all 4 sites. The increase is between 0.26 and 0.66 deg F per decade. It would seem unlikely that an individual would actually be able to notice a 0.5 deg F change across that time span.

This data can confirm the warming trend. But it would also be possible that the data set is not spanning enough time to see that a recent apparent overall rise in temperature is part of a larger cycle, with a time span of a century or more for example. This could make recent temperature changes less of a concern.

Analysis 2

Analysis 2 segregates the data set into groups of data by decade. A graph of this raw data for a decade would look similar to Figure 1 (i.e. not very instructive). Table 2-1 and Figure 2-1 show the decade averages and trends from the 7 sets of data for TMAX at PHL.

Table 2-1 PHL TMAX data by decades

Decade	TMAX slope (deg/10yr)	TMAX avg.
1950s	-1.18	64.3
1960s	3.06	62.66
1970s	0.97	63.83
1980s	4.03	63.82
1990s	0.79	65.07
2000s	0.92	64.84
2010s	1.36	65.81

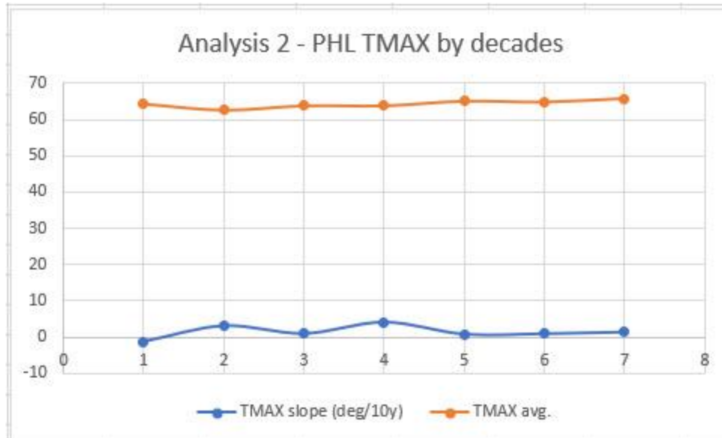

Figure 2- 1

It is seen that the TMAX average temperature (which is averaging cold and hot times of year) shows an increasing trend, but the 1950's started somewhat warm compared to the following decades. It is seen that the slope of the curves starts negative (the cooling trend after the 1950's), and that an apparent higher rate of warming than today occurs in the 1960's and 1980's.

Table 2-2 and Figure 2-2 show the same data for TMIN. It seems similar. There is an initial cooling trend, then warming, with the most recent decade with the highest average.

Table 2-2 PHL TMIN data by decades

Decade	TMIN slope (deg/10yr)	TMIN avg.
1950s	-0.15	46.28
1960s	4.72	43.73
1970s	-0.57	46.11
1980s	2.24	45.41
1990s	1.6	47.63
2000s	1.51	47.91
2010s	2.04	49

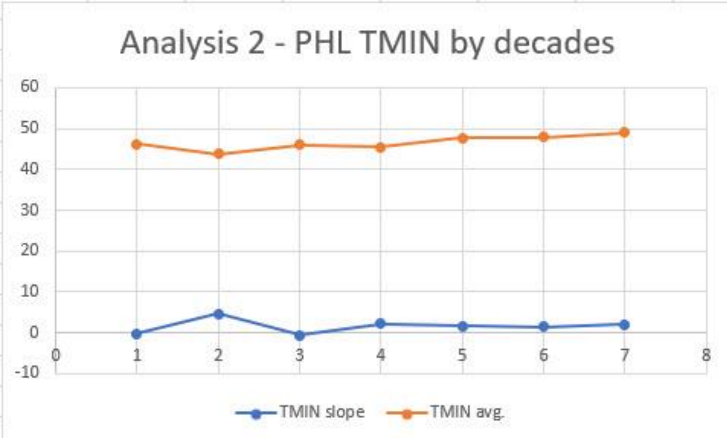

Figure 2- 2

Table 2-3 and Figure 2-3 show the TMAX data by decades for IND. It is somewhat similar to PHL, but the most recent decade TMAX average is only 0.7 deg higher than the first decade. For PHL, this was 1.5.

Table 2-3 IND TMAX data by decades

Decade	TMAX slope (deg/10yr)	TMAX avg.
1950s	-0.7	62.7
1960s	2.38	61.83
1970s	-0.27	62.06
1980s	2.62	62.41
1990s	2.67	62.67
2000s	1.01	62.91
2010s	1.44	63.42

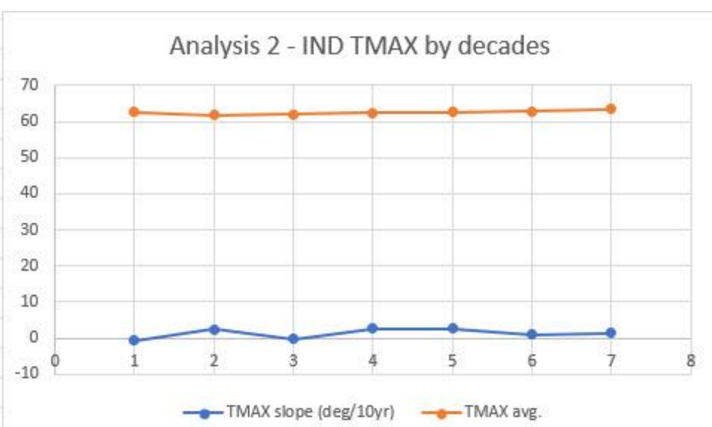

Figure 2- 3

Table 2-4 and Figure 2-4 show the TMIN data by decades for IND. It is again similar to PHL, and the most recent decade TMAX average is 2.4 deg higher than the first decade. For PHL, this was 2.8.

Table 2-4 IND TMIN data by decades

Decade	TMIN slope (deg/10yr)	TMIN avg.
1950s	1.39	42.74
1960s	2.8	41.93
1970s	-0.39	42.51
1980s	1.13	42.89
1990s	2.63	43.89
2000s	1.82	44.7
2010s	2.06	45.11

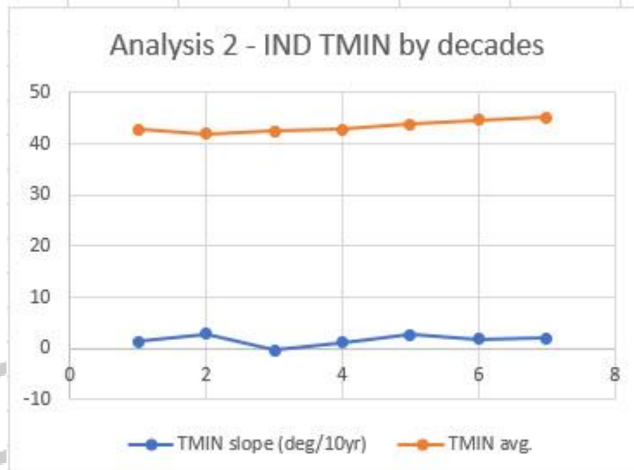

Figure 2- 4

Table 2-5 and Figure 2-5 show the TMAX data by decades for COS. It is again somewhat similar to PHL, but the most recent decade TMAX average is 1.7 deg higher than the first decade.

Table 2-5 COS TMAX data by decades

Decade	TMAX slope (deg/10yr)	TMAX avg.
1950s	3.68	63.13
1960s	-0.53	61.98
1970s	1.64	61.52
1980s	2.18	61.72
1990s	1.59	62.02
2000s	0.21	63.15
2010s	1.13	64.86

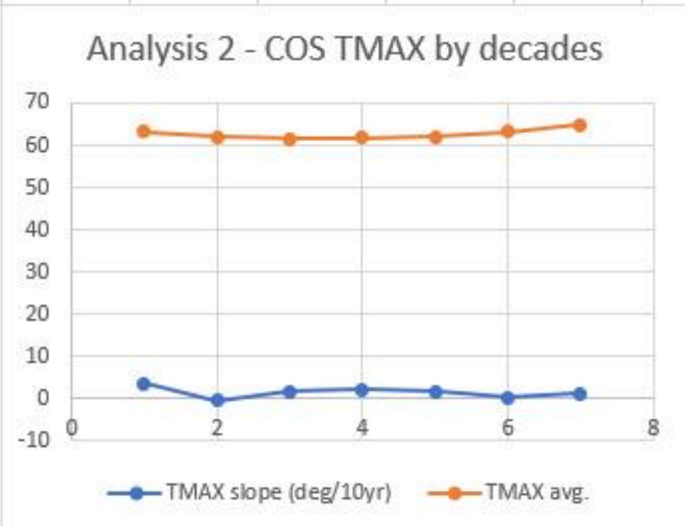

Figure 2- 5

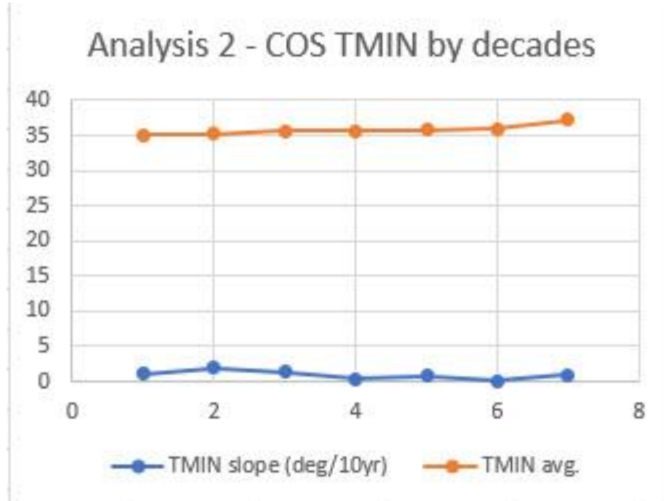

Figure 2- 6

Table 2-6 and Figure 2-6 show the TMIN data by decades for COS. It is again similar to PHL, and the most recent decade TMAX average is 2.1 deg higher than the first decade. For PHL, this was 2.8. Also, this is the first instance of no initial cooling trend. Each decade the average temperature is essentially the same or increasing.

Table 2-6 COS TMIN data by decades

Decade	TMIN slope (deg/10yr)	TMIN avg.
1950s	1.02	35.13
1960s	1.97	35.22
1970s	1.33	35.66
1980s	0.36	35.6
1990s	0.78	35.75
2000s	0.05	35.93
2010s	0.96	37.23

Table 2-7 and Figure 2-7 show the TMAX data by decades for SEA. It is not similar to PHL, and the most recent decade TMAX average is 3 deg higher than the first decade (the highest difference seen for TMAX).

Table 2-7 SEA TMAX data by decades

Decade	TMAX slope (deg/10yr)	TMAX avg.
1950s	2.46	58.09
1960s	2.16	59.29
1970s	3.56	59.35
1980s	2.84	59.61
1990s	-1.34	60.43
2000s	1.45	59.59
2010s	4.11	61.14

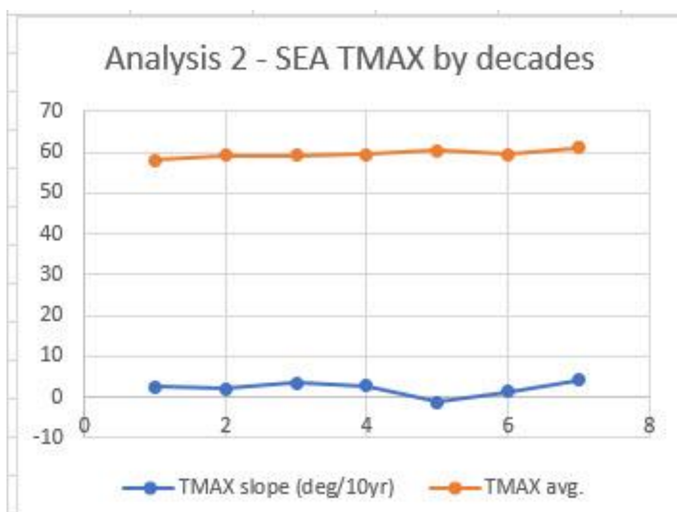

Figure 2- 7

Table 2-8 and Figure 2-8 show the TMIN data by decades for SEA. It is again not really similar to PHL, and the most recent decade TMIN average is 4 deg higher than the first decade. This is the highest difference seen for TMIN. But, there is a nearly 2 deg increase from the 1950's to 1960's, and for the other sites this temperature in that time span decreased.

Table 2-8 SEA TMIN data by decades

Decade	TMIN slope (deg/10yr)	TMIN avg.
1950s	4.66	42.43
1960s	3.04	44.31
1970s	1.97	44.68
1980s	0.63	44.58
1990s	0.55	45.3
2000s	0.88	44.96
2010s	2.89	46.43

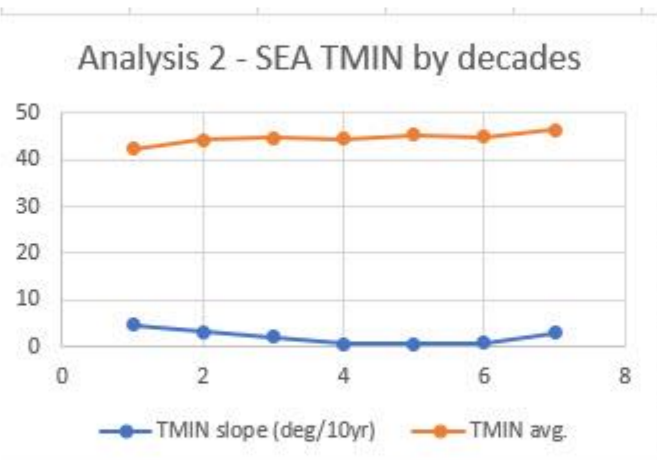

Figure 2- 8

Analysis 3

Analysis 3 does not average temperatures from cold and warm times of the year. In this case, the temperature of individual months were analyzed. For each decade, there are 10 occurrences of each month. The TMAX and TMIN temperatures were averaged for each month for each decade. This produced 70 average temperatures grouped into the 7 decades.

Furthermore, the 70 average temperatures for a month could then be averaged to determine the coldest and hottest months of the year for the particular site. Then for these 2 months, the trends for the monthly averages were analyzed. First, all the TMAX data is presented, then the TMIN data is presented later.

Table 3-1 shows the monthly average TMAX for PHL for January. The average for all the values in the table is 40.06. This was the coldest such average for the 12 months, so it is taken as the coldest month of the year. Data from the other 3 sites also indicated January as the coldest month. The overall average for IND for January was 35.48. The overall average for COS was 43.11. The overall average for SEA was 45.39.

Table 3-2 shows the monthly average TMAX for PHL for July. The average for all these values is 87.01. This was the highest such average for the 12 months, so it is taken as the hottest month of the year. Data from the other 3 sites also indicated July as the hottest month. The overall average for IND for July was 85.4. The overall average for COS was 85.19. The overall average for SEA was 75.68.

Table 3-1 – January Monthly Average TMAX (deg F) for 10 yrs

1950s	1960s	1970s	1980s	1990s	2000s	2010s
52.26	40.97	31.26	37.68	49	39.61	40.1
44.13	32.87	34.55	33.13	43.16	39.29	35.42
44.65	38.29	42.48	32.45	43.77	46.71	45.94
44.71	35.48	42.58	41.26	45.16	34.35	43.48
39.94	42.35	42.87	33.68	34.55	32.26	37.13
38.97	36.13	44.71	34.77	44.94	38.55	37.81
38.29	36.1	36.03	41.65	37.32	49.13	42.26
36.42	43.81	27.68	38.42	39.84	45.65	44.32
38.39	36.19	35.13	35.74	47.97	43.06	41.39
40.23	36.32	39.9	44.68	43.13	35.48	40.52

Table 3-2 – July Monthly Average TMAX (deg F) for 10 yrs

1950s	1960s	1970s	1980s	1990s	2000s	2010s
84.81	83.45	85.32	88.23	86.81	81.68	90.87
86.35	84.97	86.71	85.68	87.32	84.26	91.9
90.48	82.32	85.52	86.06	85.16	88.84	90.81
88.45	87.61	86.77	88.77	90.52	87.39	88.03
89.06	85.94	86.84	82.29	90.84	84.19	86.74
91.06	83.71	85.77	85.32	90.45	87.55	87.16
81.68	90.06	84.16	87.97	82.16	88.35	89.87
87.9	85.58	87.87	89.19	87.13	85.9	87.39
85.84	86.39	84.26	91.65	86.29	88.13	87.87
84.29	82.74	84.77	84.97	91.06	85	89.87

Table 3-3 shows the average January TMAX temperature for PHL and the slope of the linear curve fit for the values within the decade. This data is also shown in Figure 3-1.

Table 3-3 – PHL Jan. TMAX average and trend

Decade	TMAX slope (deg/10yr)	TMAX avg.
1950s	-12.72	41.8
1960s	0.28	37.85
1970s	-0.6	37.72
1980s	6.87	37.35
1990s	-3.15	42.88
2000s	2.09	40.41
2010s	2.09	40.84

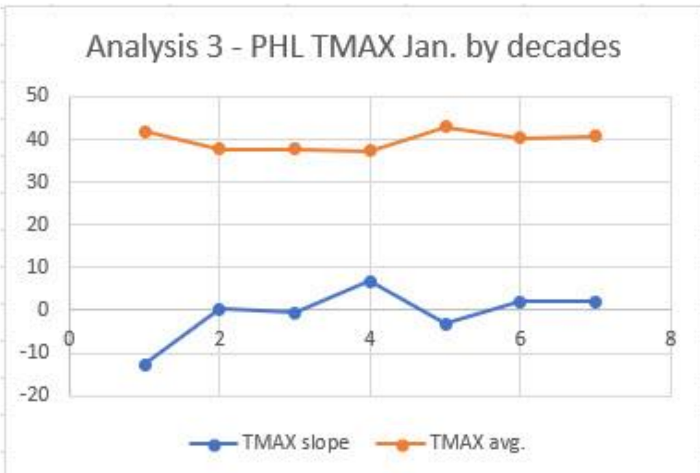

Figure 3- 1

Table 3-3 shows a -12.7 deg/10yr trend for the 1950's. This seemed unusually large. The 10 values for the 1950's were used in Excel® and then the LINEST() function used. Figure 3-2 shows the 10 values with the LINEST points. It is reasonable; LINEST indicated the slope as -1.27 deg/yr.

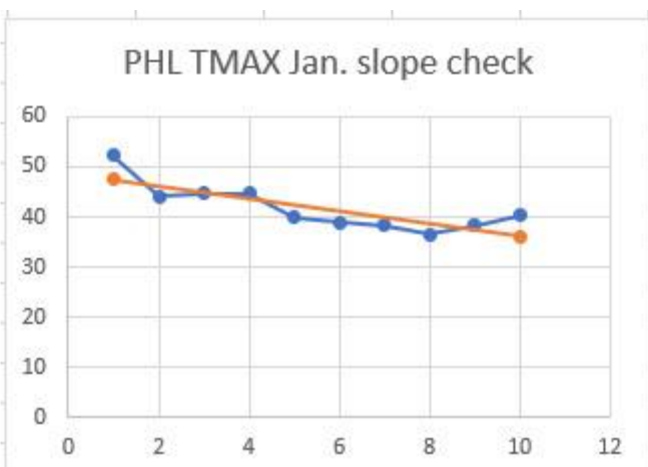

Figure 3- 2

Although Analysis 2 showed an overall warming trend, Table 3-3 shows that the warmest decade for January for PHL was 1990's, and the 1950's and 1990's exceeded the value for the most recent decade. In terms of a warming trend, the highest slope of the linear curve fit was the 1980's, but that seems to be due to how cold the decade was (it has the lowest average temperature).

Table 3-4 shows the average July TMAX temperature for PHL and the slope of the linear curve fit for the values within the decade. This data is also shown in Figure 3-3.

Table 3-4 – PHL July TMAX average and trend

Decade	TMAX slope (deg/10yr)	TMAX avg.
1950s	-2.39	86.99
1960s	1.51	85.28
1970s	-1.17	85.8
1980s	1.74	87.01
1990s	0.94	87.77
2000s	2.94	86.13
2010s	-2.93	89.05

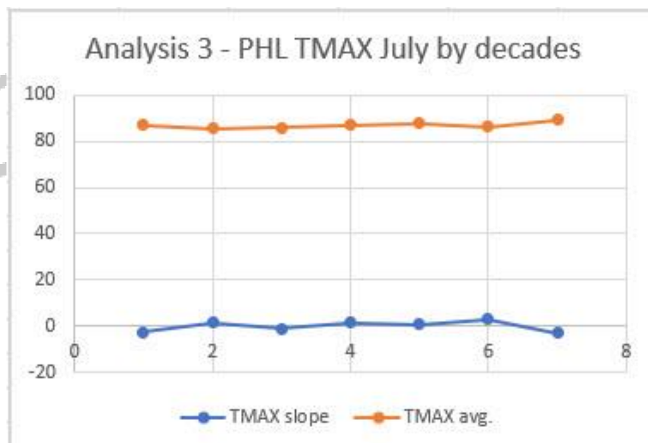

Figure 3- 3

As seen in Table 3-4, the most recent decade (2010's) has a clearly higher July average TMAX. But the trend is actually a cooling one (-2.93 deg/10yr). Figure 3-4 shows the values for 2010's and how the slope of the linear curve fit is negative. Of course, it must be realized that analyzing based on decades is essentially arbitrary. There may be cycles of increasing/decreasing temperatures across larger spans of time than decades. In fact, the author believes that in the 1970's there were scientists considering the 11-year sun spot cycle as related to weather patterns; the author has not investigated if this is still considered a valid investigation. Regardless of such cycles, if a recent global warming trend was certain and unique in history, then the trend would appear whether the data was segregated by 5, 10, or 15 years.

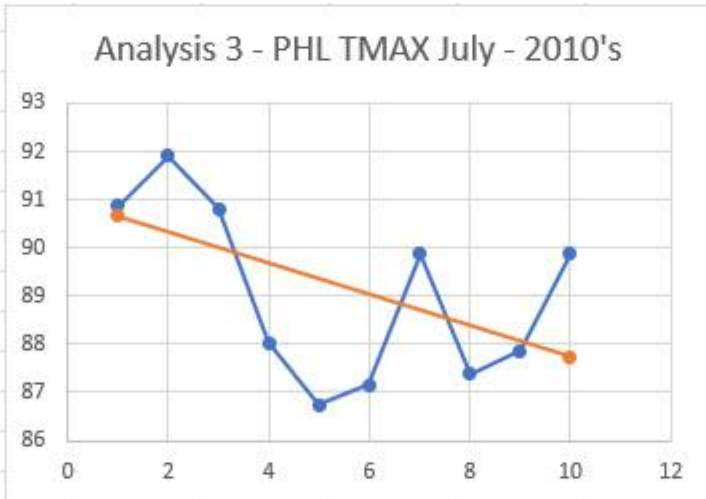

Figure 3- 4

Table 3-5 shows the average January TMAX temperature for IND and the slope of the linear curve fit for the values within the decade. This data is also shown in Figure 3-5. This actually shows the most recent decade as cooling, but still somewhat high temperatures in the 1950's, then cooling, then some recent somewhat higher temperatures.

Table 3-5 – IND January TMAX average and trend

Decade	TMAX slope (deg/10yr)	TMAX avg.
1950s	-11.64	37.48
1960s	0.45	34.63
1970s	-9.99	31.63
1980s	6.81	34.35
1990s	-3.61	36.6
2000s	0.53	37.11
2010s	3.5	35.33

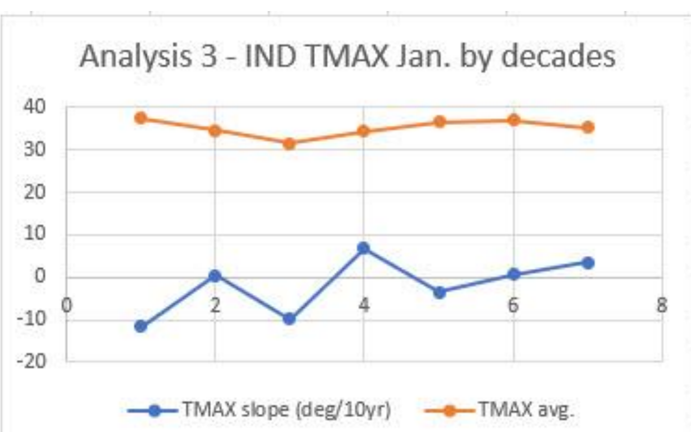

Figure 3- 5

Table 3-6 shows the average July TMAX temperature for IND and the slope of the linear curve fit for the values within the decade. This data is also shown in Figure 3-6. This is again similar to PHL - cooling, then warming, but most recent decade with a cooling trend.

Table 3-6 – IND July TMAX average and trend

Decade	TMAX slope (deg/10yr)	TMAX avg.
1950s	-1.46	85.63
1960s	3.98	84.49
1970s	1.25	84.99
1980s	-0.35	86.51
1990s	1.97	85.48
2000s	-2.31	83.83
2010s	-4.6	86.44

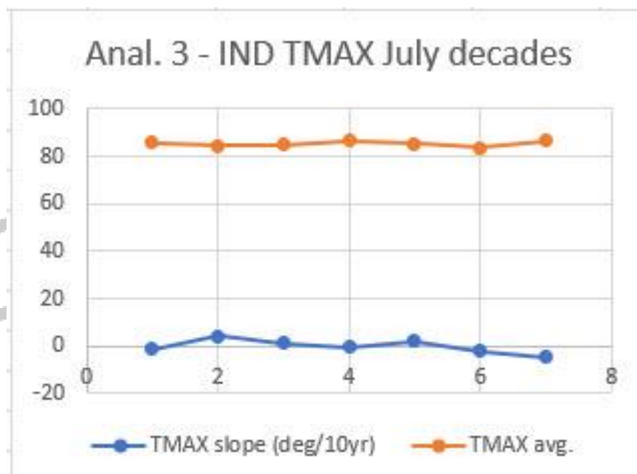

Figure 3- 6

Table 3-7 shows the average January TMAX temperature for COS and the slope of the linear curve fit for the values within the decade. This data is also shown in Figure 3-7. The same overall trend seems apparent. Warmer temperatures in the 1950's, cooling, then recent warming (but not with cooling trend for 2010's).

Table 3-7 – COS January TMAX average and trend

Decade	TMAX slope (deg/10yr)	TMAX avg.
1950s	-1.29	45.06
1960s	5.3	42.49
1970s	-9.02	38.95
1980s	0.37	42.28
1990s	1.56	43.35
2000s	-0.24	43.77
2010s	2.29	45.85

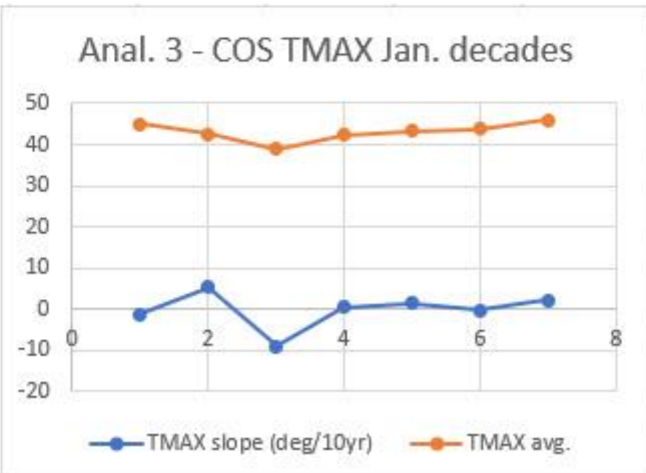

Figure 3- 7

Table 3-8 shows the average July TMAX temperature for COS and the slope of the linear curve fit for the values within the decade. This data is also shown in Figure 3-8. This is somewhat different. The 1950's are not obviously higher temperatures. But the value does drop for the 1990's, and then the most recent 2 decades are nearly identical, and higher than most of the previous decades. And, the most recent decade has a slight cooling trend.

Table 3-8 – COS July TMAX average and trend

Decade	TMAX slope (deg/10yr)	TMAX avg.
1950s	3.4	84.88
1960s	-0.83	84.7
1970s	4.33	84.2
1980s	-1.94	85.73
1990s	3.27	83.18
2000s	-2.62	86.66
2010s	-0.26	86.67

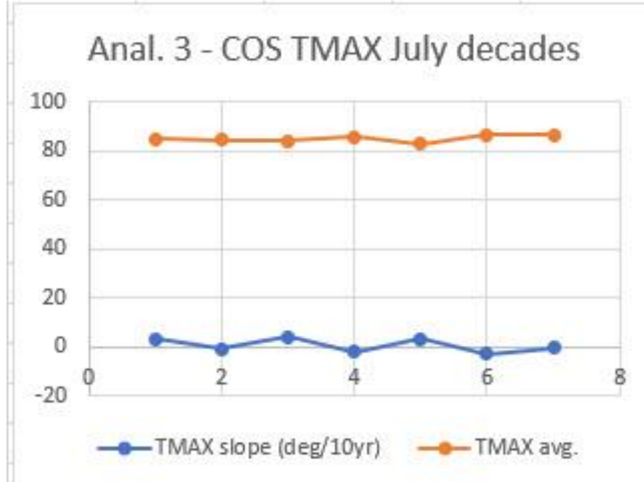

Figure 3- 8

Table 3-9 shows the average January TMAX temperature for SEA and the slope of the linear curve fit for the values within the decade. This data is also shown in Figure 3-9. This is the first set of data in this analysis that one would expect for a clear warming trend. The first decade is not warmer that most, as in the previous sites. Furthermore, the final decade shows a slope for further increases.

Table 3-9 – COS January TMAX average and trend

Decade	TMAX slope (deg/10yr)	TMAX avg.
1950s	8.88	42.37
1960s	-3.01	43.94
1970s	2.42	44.4
1980s	1.39	46.15
1990s	-0.71	46.95
2000s	-2.78	46.26
2010s	2.14	47.85

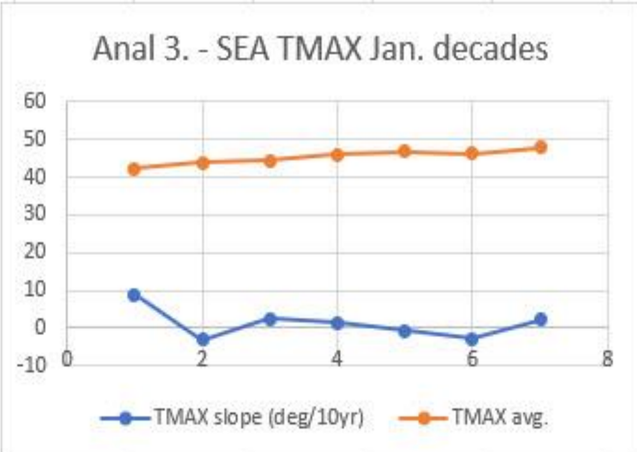

Figure 3- 9

Table 3-10 shows the average July TMAX temperature for SEA and the slope of the linear curve fit for the values within the decade. This data is also shown in Figure 3-10. This is similar to the January data for trends for SEA. Although in the 1980's there is a drop in the average temperature that might be similar to the cooling trend seen in the previous sites.

Table 3-10 – SEA July TMAX average and trend

Decade	TMAX slope (deg/10yr)	TMAX avg.
1950s	2.33	74.21
1960s	-1.42	75.6
1970s	2.37	75.97
1980s	3.16	73.99
1990s	-3.36	75.89
2000s	6	76.32
2010s	5.92	77.72

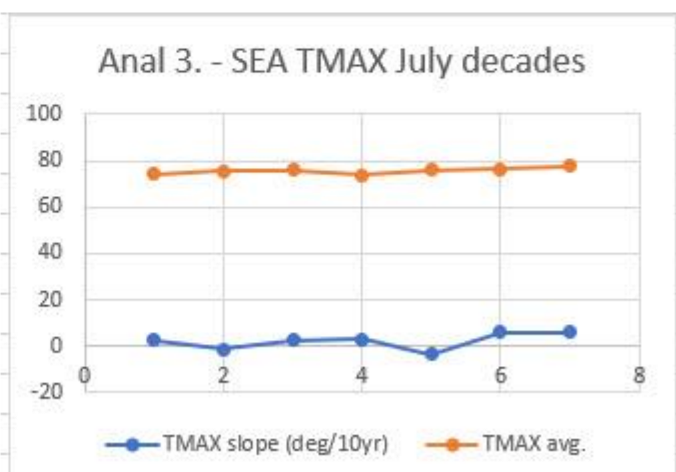

Figure 3- 10

It seems apparent that some score calculation is needed to capture the overall sites and their results for this analysis. Unfortunately there would seem to be different scoring calculations that would be appropriate depending on whether the data had an underlying cycle or not. Thus, two different scores are developed; one for each possible interpretation.

The first scoring method assumes there is no underlying cycle. In this case, the most recent data is considered unique and expected to continue. The most recent slope value is assumed to predict the temperature change for the future decade. For example, for SEA TMAX for July, the final slope value from Table 3-10 was 5.92 deg F. The final average temperature was 77.72 deg F. Adding the slope value to the average value would give a prediction for the entire 2020's. In this case, 83.64 deg F. The average temperature for all decades is 75.67 deg F (which was used earlier to determine that July was the hottest month in the year). The difference between the predicted value and the average is 7.97 deg F. This is taken as the warming score for SEA for TMAX for the hottest month.

This approach can be described with formula. Equation 1 is the calculation for the predicted temperature for the hottest month for TMAX using the final decade (the f subscript). Note that *m* is the slope and it is in deg F/decade. So the predicted temperature for the 2020's just adds this value (formulae not showing the slope in deg/decade times the 10 years). Equation 2 is the score which is the difference between the predicted temperature and the overall average for the hottest month for TMAX. For the example previously explained, the result from Equation 1 was 83.64. The result from Equation 2 is 7.97. Equations 3 and 4 are the same but for the coldest month.

$$T'_{TMAX,h} = T_{f,h} + m_{f,h} \qquad \text{Eq. 1}$$
$$S_{TMAX,h} = T'_{TMAX,h} - T_{avg,h} \qquad \text{Eq. 2}$$

$$T'_{TMAX,c} = T_{f,c} + m_{f,c} \qquad \text{Eq. 3}$$
$$S_{TMAX,c} = T'_{TMAX,c} - T_{avg,c} \qquad \text{Eq. 4}$$

The total score, S, for the site for TMAX is Equation 5. It is just the sum of the coldest and the hottest month scores. The higher this value, the greater the predicted warming.

$$S_{TMAX} = S_{TMAX,c} + S_{TMAX,h} \qquad \text{Eq. 5}$$

The second scoring method averages the slopes for the decades. If there is a cycle to the warming and cooling trends, then one would expect the increasing and decreasing trends to "cancel out" to some degree. For the SEA TMAX information shown in Table 3-10, the average slope is 2.14 deg F/decade. The previous scoring method was based on the predicted temperature at the end of the 2020's with respect to the average. For this second scoring method, the equivalent is this average slope since it is the predicted change in temperature at the end of the 2020's. This is reflected in Equation 6 for the hottest month and Equation 7 for the coldest month (again not showing multiplying the slope / decade times the 10 years; scoring is normalized to a 10 year prediction).

$$C_{TMAX,h} = m_{avg,h} \qquad \text{Eq. 6}$$

$$C_{TMAX,c} = m_{avg,c} \qquad \text{Eq. 7}$$

As before, the total score, C, for the site for TMAX is Equation 8. It is just the sum of the coldest and hottest month scores. The higher this value, the greater the predicted warming.

$$C_{TMAX} = C_{TMAX,c} + C_{TMAX,h} \qquad \text{Eq. 8}$$

Table 3-11 shows the results for the 4 sites for the S score for January, the coldest month. Table 3-12 shows the results for July, the hottest month. Table 3-13 shows the overall score for the 4 sites for the first scoring method.

Table 3-11 – $S_{TMAX,c}$ for 4 sites

	$T_{f,c}$	$m_{f,c}$	$T_{avg,c}$	$T'_{TMAX,c}$	$S_{TMAX,c}$
PHL	40.81	2.09	39.83	42.9	3.07
IND	35.33	3.5	35.3	38.83	3.53
COS	45.85	2.29	43.11	48.14	5.03
SEA	47.85	2.14	45.42	49.99	4.57

Table 3-12 – $S_{TMAX,h}$ for 4 sites

	$T_{f,h}$	$m_{f,h}$	$T_{avg,h}$	$T'_{TMAX,h}$	$S_{TMAX,h}$
PHL	89.05	-2.93	86.86	86.12	-0.74
IND	86.44	-4.6	85.34	81.84	-3.5
COS	86.67	-0.26	85.15	86.41	1.26
SEA	77.72	5.92	75.67	83.64	7.97

Table 3-13 – S_{TMAX} for 4 sites

	S_{TMAX}
PHL	2.33
IND	0.03
COS	6.29
SEA	12.54
Average	5.2975

The results in Table 3-13 could be considered a worst-case prediction. The most recent temperature is used with the most recent slope with lesser accounting for any previous trends (although it does compare the latest prediction with the overall average, and the overall average is based on all 7 decades). The results show warming is quite different at the different sites, with IND showing nothing. But, this scoring method strongly indicates that on average for the United States, there should about a 5 deg F increase in temperature by the end of the 2020's, and this would be expected to be an issue of concern.

Table 3-14 shows the results for the 4 sites for the C scoring method. This is a rather different result. It shows that the IND site is generally cooling for the 7 decades, and would be predicted to continue to do so. PHL would also be cooling, but to a lesser extent. COS and SEA show warming, and SEA showing significant warming. This scoring is not a strong indication of warming across the United States (perhaps concluding a 0.3 deg F/decade warming). This prediction would be expected to warrant much less concern. However, there appears to be no way to definitively determine to what extend the variation is cyclical.

Table 3-14 – C_{TMAX}

	$C_{TMAX,c}$	$C_{TMAX,h}$	C_{TMAX}
PHL	-0.73	0.09	-0.64
IND	-1.99	-0.22	-2.21
COS	-0.15	0.76	0.61
SEA	1.19	2.14	3.33
Average			0.2725

To this point, Analysis 3 has only worked with TMAX for the coldest and hottest months. All the same data can be analyzed for TMIN. Tables 3-15 and 3-16 show the slope and average temperature for TMIN for PHL.

Table 3-15 – PHL January TMIN average and trend

Decade	TMIN slope (deg/10yr)	TMIN avg.
1950s	-10.62	26.88
1960s	1.99	22.62
1970s	-1.58	23.08
1980s	3.98	22.19
1990s	-1.19	27.8
2000s	1.92	26.4
2010s	0.86	26.09

Table 3-16 – PHL July TMIN average and trend

Decade	TMIN slope (deg/10yr)	TMIN avg.
1950s	0.03	67.58
1960s	4.97	65.56
1970s	-1.8	67.68
1980s	0.9	67.75
1990s	-1.21	70.15
2000s	1.56	68.83
2010s	-2.04	71.74

Tables 3-17 and 3-18 show the slope and average temperature for TMIN for IND.

Table 3-17 – IND January TMIN average and trend

Decade	TMIN slope (deg/10yr)	TMIN avg.
1950s	-11.17	21.36
1960s	0.15	17.88
1970s	-6.7	14.82
1980s	7.32	18.43
1990s	-3.65	21.81
2000s	0.38	21.35
2010s	1.57	19.42

Table 3-18 – IND July TMIN average and trend

Decade	TMIN slope (deg/10yr)	TMIN avg.
1950s	2.52	64.96
1960s	4.42	64.15
1970s	1.44	64.87
1980s	-1.11	66.22
1990s	2.07	65.69
2000s	-0.52	65.37
2010s	-3.38	67.81

Tables 3-19 and 3-20 show the slope and average temperature for TMIN for COS.

Table 3-19 – COS January TMIN average and trend

Decade	TMIN slope (deg/10yr)	TMIN avg.
1950s	-3.09	16.98
1960s	9.57	15.49
1970s	-7.25	14.68
1980s	-0.8	17.54
1990s	-1.01	17.39
2000s	-1.48	18.04
2010s	2.91	18.37

Table 3-20 – COS July TMIN average and trend

Decade	TMIN slope (deg/10yr)	TMIN avg.
1950s	-1.31	56.28
1960s	2.9	57.19
1970s	1.08	57.3
1980s	-3.56	57.24
1990s	2.22	55.99
2000s	-2.19	57.78
2010s	-1.6	59.01

Tables 3-21 and 3-22 show the slope and average temperature for TMIN for SEA.

Table 3-21 – SEA January TMIN average and trend

Decade	TMIN slope (deg/10yr)	TMIN avg.
1950s	10.27	32.35
1960s	-0.53	34.53
1970s	0.47	35.05
1980s	1.11	35.75
1990s	1.1	37.11
2000s	-2.47	36.41
2010s	-0.62	37.68

Table 3-22 – SEA July TMIN average and trend

Decade	TMIN slope (deg/10yr)	TMIN avg.
1950s	2.29	52.21
1960s	1.89	55.11
1970s	0.8	55.55
1980s	-0.09	55.38
1990s	0.1	56.16
2000s	2.11	55.95
2010s	3.67	58.1

Table 3-23 shows the results for the 4 sites for the S score for TMIN for January, the coldest month. Table 3-24 shows the results for July, the hottest month. Table 3-25 shows the overall score for the 4 sites for the first scoring method. The results are similar to TMAX (Table 3-13), but the score is not as high (4 deg F vs. 5.3 deg F).

Table 3-23 – $S_{TMIN,c}$ for 4 sites

	$T_{f,c}$	$m_{f,c}$	$T_{avg,c}$	$T'_{TMIN,c}$	$S_{TMIN,c}$
PHL	26.09	0.86	25	26.95	1.94
IND	19.42	1.57	19.3	20.99	1.69
COS	18.37	2.91	16.93	21.28	4.35
SEA	37.68	-0.62	35.56	37.06	1.5

Table 3-24 – $S_{TMIN,h}$ for 4 sites

	$T_{f,h}$	$m_{f,h}$	$T_{avg,h}$	$T'_{TMIN,h}$	$S_{TMIN,h}$
PHL	71.74	-2.04	68.47	69.7	1.23
IND	67.81	-3.38	65.58	64.43	-1.15
COS	59.01	-1.6	57.26	57.41	0.15
SEA	58.1	3.67	55.49	61.77	6.28

Table 3-25 – S_{TMIN} for 4 sites

	S_{TMIN}
PHL	3.17
IND	0.54
COS	4.5
SEA	7.78
Avg	3.9975

Table 3-26 shows the results for the 4 sites for the C score for TMIN for the 4 sites. The final score is similar to TMAX (0.27 vs. 0.28); if there is cyclical variation, the warming effect prediction is again much lower.

Table 3-26 – C_{TMIN} for 4 sites

$C_{TMIN,c}$	$C_{TMIN,h}$	C_{TMIN}	$C_{TMIN,c}$
PHL	-0.66	0.34	-0.32
IND	-1.72	0.78	-0.94
COS	-0.16	-0.35	-0.51
SEA	1.33	1.54	2.87
Average			0.275

Analysis 4

Analysis 4 is a different approach to the detection of a trend for warming. In this case, TMAX for each particular day of the year is analyzed across the 70 years (except for leap years where the day in February would be fewer than 70). The year with the highest value becomes the "record high" for the day. These record highs were within a particular decade, of course. If there is a warming trend, then more record highs should occur in later decades.

Figures 4-1 through 4-4 show the results for the 4 sites. The results seem similar to previous analysis. PHL, IND, and COS show a high number of record highs in the 1950's, then fewer records, then a high number for the 1990's, and then the 2010's again with a high number. PHL for the 2010's does not exceed the 1950's or 1990's level, but IND and COS do have the 2010's as the most record highs. SEA is different in that the 1950's had few records, and then 1960's had more, but then the 1990's has more, and finally the 2010's have the most again. And, as before, it would seem important to know whether the variation is part of a longer time scale cycle or not. No numerical score was developed for this analysis. It was used as a check on the previous analysis, and the analyses do appear sufficiently similar to be considered valid.

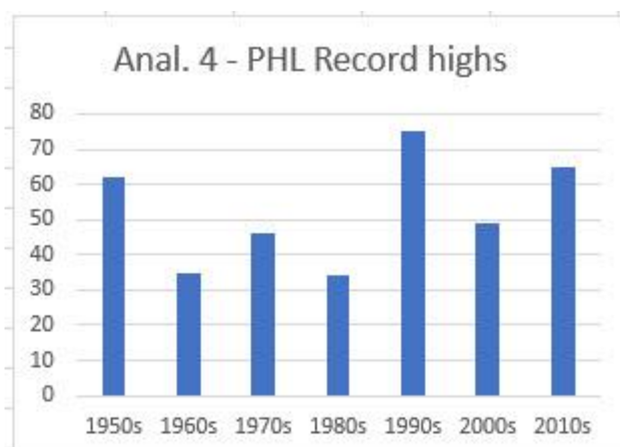

Figure 4- 1

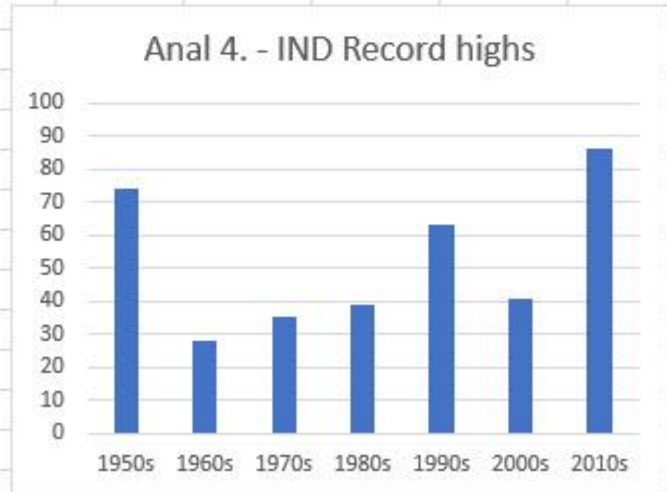

Figure 4- 2

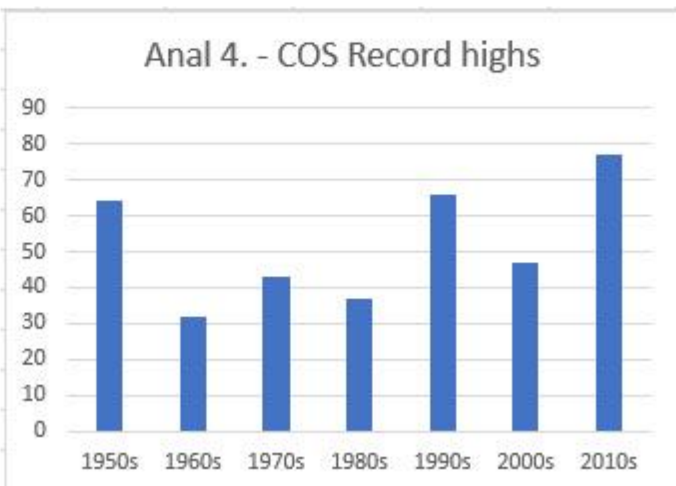

Figure 4- 3

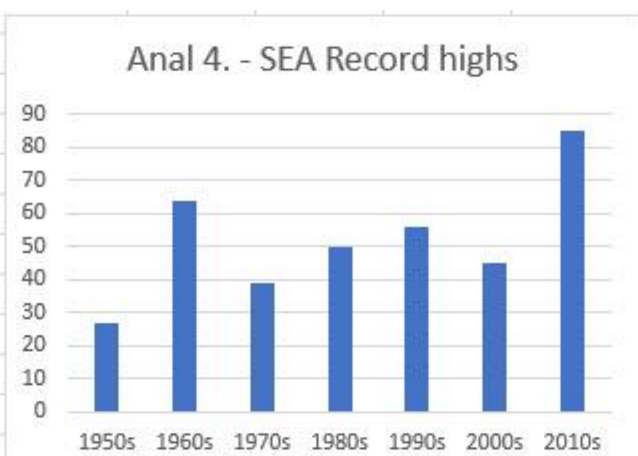

Figure 4- 4

Analysis 5

Analysis 5 is the first analysis to investigate trends in the variability of temperature with respect to time. This is expected to indicate whether weather is become more severe than in the past. Weather fronts passing the sites should be producing temperature changes. Large temperature drops in a period of time is often portrayed as a significant indicator of the severity of a thunderstorm.

Analysis 5 uses the difference between TMAX and TMIN for all 70 years of data in a single curve (similar to Analysis 1). Note that taking the absolute value of the difference is not necessary since TMAX is known to be greater than TMIN.

Figure 5-1 shows the raw data for PHL. As with Analysis 1, it is not particularly instructive; although, it is interesting that a few times there have been differences of nearly 50 deg F.

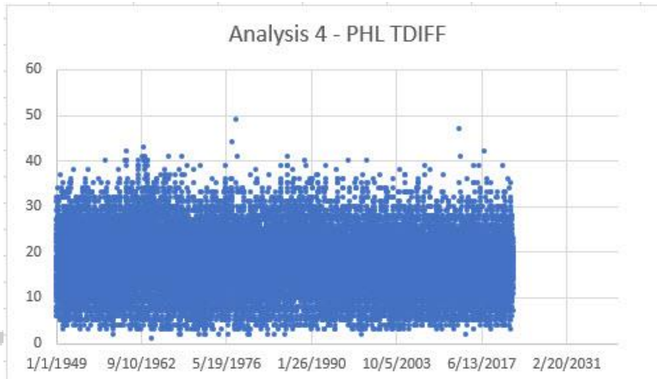

Figure 5- 1

As before, least squares curve fit is used to evaluate the slope of this curve. If the difference was trending to more rapid variation, then the slope would be positive. Table 5-1 shows the results for the 4 sites. It is seen that trend is mostly negative. Although the slope for COS is essentially zero, PHL, IND, and SEA all show that change in temperature (temperature drop for a constant time period of 1 day) is decreasing across the entire time of the raw data (this analysis includes the years of the 2020's).

Table 5-1 – TDIFF trend for 4 sites (deg F/10yr)

PHL TDIFF: Slope of linear curve	-0.25
IND TDIFF: Slope of linear curve	-0.29
COS TDIFF: Slope of linear curve	0.05
SEA TDIFF: Slope of linear curve	-0.14

Analysis 6

Analysis 6 uses the difference between TMAX and TMIN from one day to the next day. TMAXD2D is the difference for TMAX from day to day. TMIND2D is the difference for TMIN from day to day. In this case, the absolute value is applied to the difference since the next day may have a higher or lower temperature. Again, this is used as a single curve across the entire time of the raw data.

Table 6-1 shows the results for the 4 sites. It is a similar result to Analysis 5. Again, 3 of the 4 sites shows a trend toward decreasing day-to-day temperature variation, and the 4th site shows only a very slight increasing trend. The average reduction in the day-to-day temperature variation can be taken as -0.04 deg F/decade.

Table 6-1 – day-to-day trend for 4 sites (deg F/10yr)

PHL TMAXD2D: Slope of linear curve	-0.03
PHL TMIND2D: Slope of linear curve	-0.09
IND TMAXD2D: Slope of linear curve	-0.08
IND TMIND2D: Slope of linear curve	-0.05
COS TMAXD2D: Slope of linear curve	0.04
COS TMIND2D: Slope of linear curve	0.01
SEA TMAXD2D: Slope of linear curve	-0.04
SEA TMIND2D: Slope of linear curve	-0.06
Average	-0.0375

Analysis 7

Analysis 7 analyzes TDIFF, TMAXD2D, and TMIND2D by decades (similar to Analysis 3). Tables 7-1 through 7-3 and Figures 7-1 through 7-3 shows the results for PHL. Table 7-1 shows that the average change in daily TMAX starts at 18.02 deg F for the 1950's and essentially steadily decreases (as seen in Figure 7-1) to 16.8 deg F for the 2010's. Average slope for all the decades is -0.21, and that is similar to the Analysis 5 result of -0.25. Table 7-2 and Figure 7-2 show similar results for the change in TMAX from one day to the next.

Table 7-3 and Figure 7-3 show a less clear trend for TMIN from one day to the next; the overall average slope for all the decades is only -0.06 deg F/decade. Although the most recent decade has a slope of 0.45, the 1950's positive slope was almost twice as large. This data seems to clearly indicate that weather is not becoming more severe based on this statistic.

Table 7-1 – PHL TDIFF average and trend

Decade	TDIFF slope (deg/10yr)	TDIFF avg.
1950s	-1.03	18.02
1960s	-1.66	18.92
1970s	1.53	17.72
1980s	1.79	18.4
1990s	-0.81	17.44
2000s	-0.59	16.94
2010s	-0.68	16.8
Average	-0.21	17.75

Table 7-2 – PHL TMAXD2D average and trend

Decade	TMAXD2D slope (deg/10yr)	TMAXD2D avg.
1950s	-0.05	6.08
1960s	-0.51	5.71
1970s	-0.58	5.99
1980s	0.29	5.81
1990s	-0.84	5.68
2000s	0.24	5.72
2010s	0.2	5.89
Average	-0.18	5.84

Table 7-3 – PHL TMIND2D average and trend

Decade	TMIND2D slope (deg/10yr)	TMIND2D avg.
1950s	0.83	4.46
1960s	-0.84	5.01
1970s	-0.13	4.49
1980s	-0.01	4.59
1990s	-0.6	4.31
2000s	-0.11	4.12
2010s	0.45	4.34
Average	-0.06	4.47

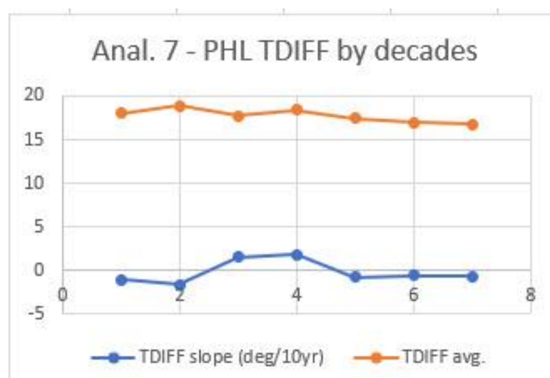

Figure 7- 1

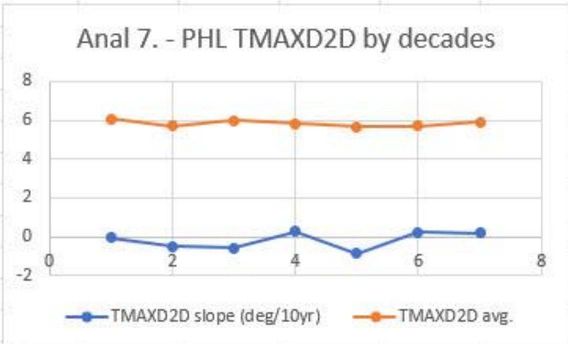

Figure 7- 2

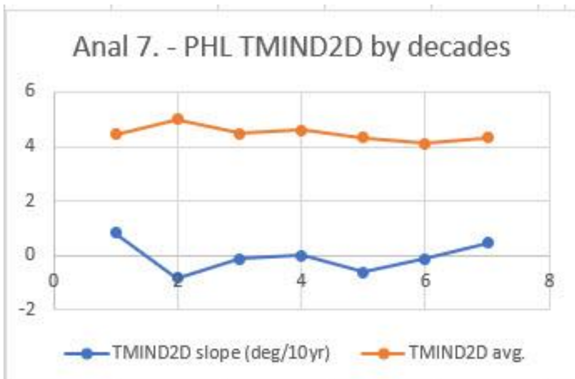

Figure 7- 3

Tables 7-4 through 7-6, and Figures 7-4 through 7-6 show the results for IND. Table 7-4 shows that the daily temperature change at 19.96 deg F for the 1950's and drops to 18.31 deg F for the 2010's. TMAX day-to-day (Table 7-5) drops from 6.52 to 5.99 deg F. TMIN day-to-day (Table 7-6), as with PHL, shows little change over the 70 years; it did increase for a few decades, and the decreased in recent decades.

Table 7-4 – IND TDIFF average and trend

Decade	TDIFF slope (deg/10yr)	TDIFF avg.
1950s	-2.09	19.96
1960s	-0.41	19.9
1970s	0.12	19.56
1980s	1.48	19.51
1990s	0.04	18.78
2000s	-0.82	18.21
2010s	-0.62	18.31

Table 7-5 – IND TMAXD2D average and trend

Decade	TMAXD2D slope (deg/10yr)	TMAXD2D avg.
1950s	-0.73	6.42
1960s	-0.48	6.07
1970s	-0.13	6.1
1980s	0.43	5.89
1990s	-0.64	5.95
2000s	0.23	5.69
2010s	-0.19	5.99

Table 7-6 – IND TMIND2D average and trend

Decade	TMIND2D slope (deg/10yr)	TMIND2D avg.
1950s	-0.34	5.09
1960s	0.1	5.54
1970s	0.39	5.63
1980s	-0.74	5.43
1990s	-0.39	5.27
2000s	-0.46	5.09
2010s	0.06	5.16

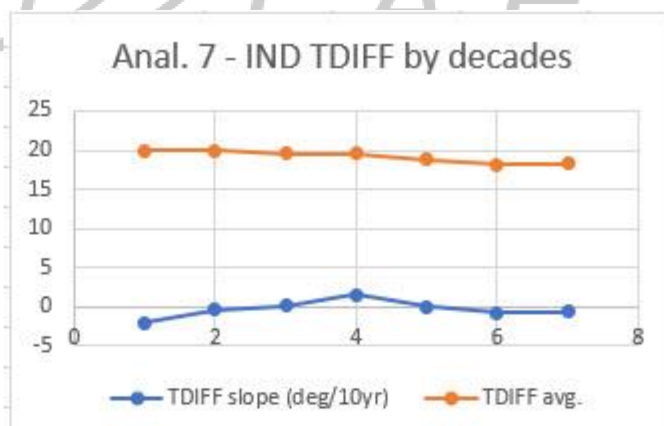

Figure 7- 4

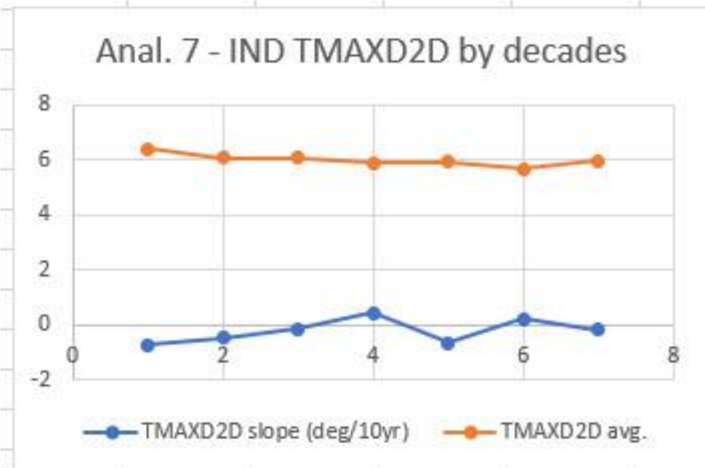

Figure 7- 5

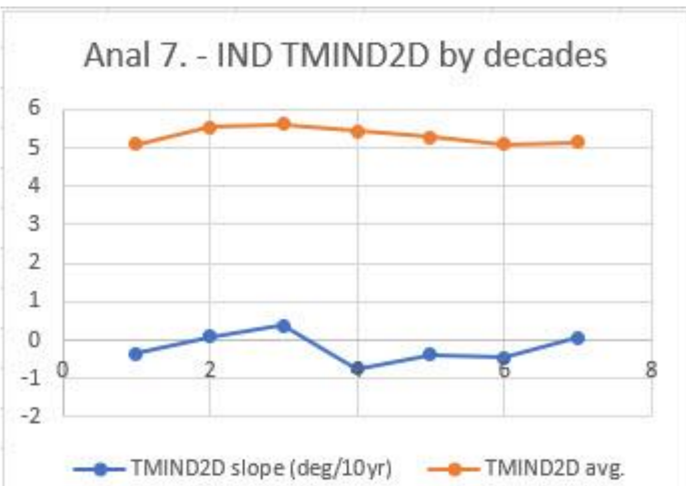

Figure 7- 6

Tables 7-7 through 7-9, and Figures 7-7 through 7-9 show the results for COS. This site is not clearly similar to PHL and IND. Table 7-7 and Figure 7-7 show that the daily temperature change decreases for a few decades and the increases, and then ends slightly lower that the first decade. TMAX day-to-day (Table 7-8 and Figure 7-8) shows little change or trend. TMIN day-to-day (Table 7-9 and Figure 7-9) is similar to TDIFF; it decreases, then increases, and ends slightly lower than the first decade.

Table 7-7 – COS TDIFF average and trend

Decade	TDIFF slope (deg/10yr)	TDIFF avg.
1950s	2.66	27.99
1960s	-2.5	26.77
1970s	0.31	25.85
1980s	1.82	26.12
1990s	0.82	26.27
2000s	0.16	27.22
2010s	0.17	27.63

Table 7-8 – COS TMAXD2D average and trend

Decade	TMAXD2D slope (deg/10yr)	TMAXD2D avg.
1950s	-0.88	7.83
1960s	0.41	7.73
1970s	0.16	7.84
1980s	0.35	7.7
1990s	-0.33	7.77
2000s	0.71	7.98
2010s	0.16	7.91

Table 7-9 – COS TMIND2D average and trend

Decade	TMIND2D slope (deg/10yr)	TMIND2D avg.
1950s	-0.69	4.79
1960s	-0.04	4.46
1970s	-0.07	4.51
1980s	0.33	4.33
1990s	0.54	4.36
2000s	0.8	4.65
2010s	-0.65	4.69

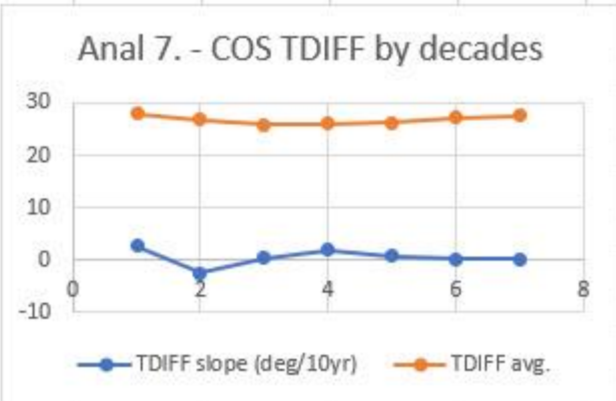

Figure 7- 7

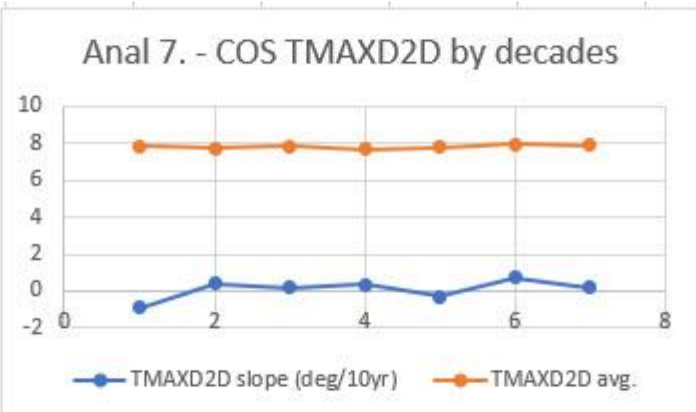

Figure 7- 8

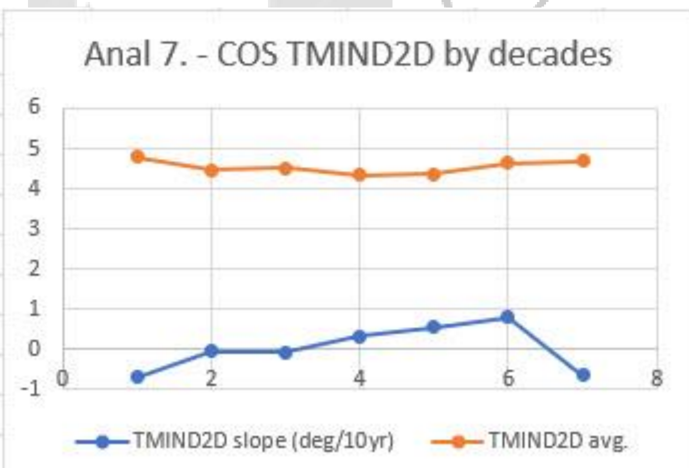

Figure 7- 9

Tables 7-10 through 7-12, and Figures 7-10 through 7-12, show the results for SEA. This site is again similar to PHL and IND. Table 7-10 and Figure 7-10 show that the daily temperature change decreases steadily from 15.66 deg F to 14.7 deg F. TMAX day-to-day (Table 7-11 and Figure 7-11) decreases from 4.29 deg F to 4.05 deg F. TMIN day-to-day (Table 7-12 and Figure 7-12) decreases from 3.17 deg F to 2.7 deg F.

Clearly there is no evidence of greater variation of temperature in weather patterns as a indication of more severe weather conditions. In fact, the opposite is clearly indicated.

Table 7-10 – SEA TDIFF average and trend

Decade	TDIFF slope (deg/10yr)	TDIFF avg.
1950s	-2.2	15.66
1960s	-0.88	14.97
1970s	1.59	14.67
1980s	2.21	15.03
1990s	-1.89	15.13
2000s	0.57	14.63
2010s	1.21	14.7

Table 7-11 – SEA TMAXD2D average and trend

Decade	TMAXD2D slope (deg/10yr)	TMAXD2D avg.
1950s	-0.37	4.29
1960s	-0.23	4.18
1970s	-0.14	4.25
1980s	0.24	4.1
1990s	-0.47	4.08
2000s	0.34	4.1
2010s	0.08	4.05

Table 7-12 – SEA TMIND2D average and trend

Decade	TMIND2D slope (deg/10yr)	TMIND2D avg.
1950s	-0.56	3.17
1960s	-0.26	2.84
1970s	-0.22	2.94
1980s	0.27	2.81
1990s	-0.34	2.8
2000s	0.18	2.74
2010s	-0.27	2.7

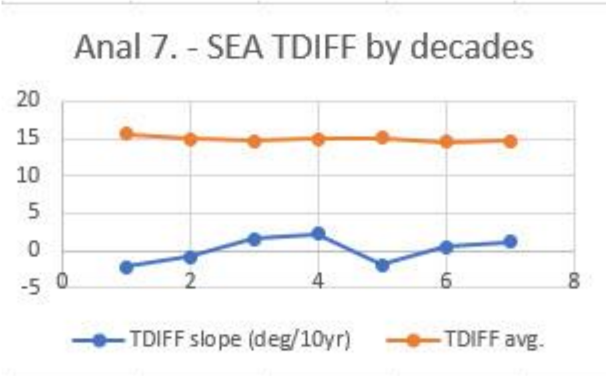

Figure 7- 10

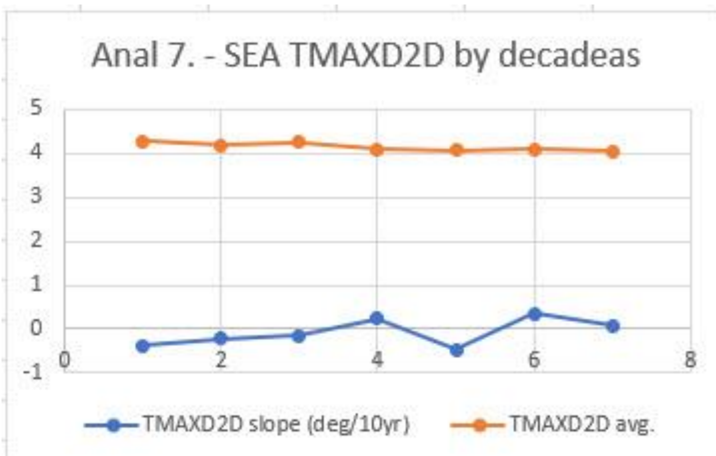

Figure 7- 11

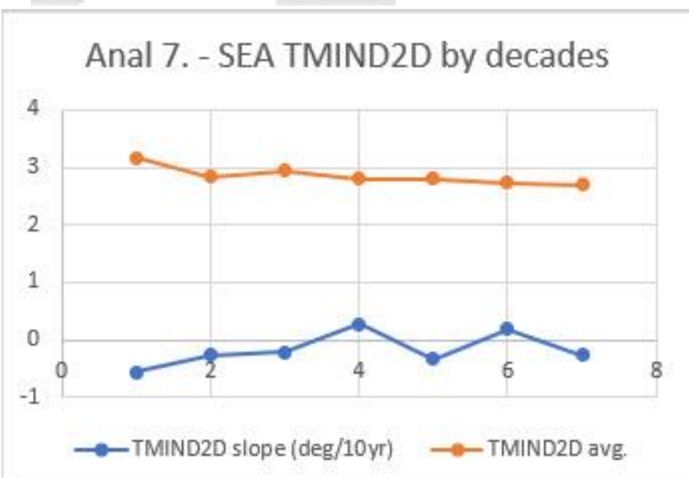

Figure 7- 12

WEATHER ANALYSIS CONCLUSIONS

The analysis of temperature data in this paper could be indicating a unique warming trend for the planet. If, however, there is a cycle to the temperature changes over a time-frame longer than 70 years, then there may not be anything unique or alarming occurring. The analysis of temperature changes experienced daily indicates no trend toward more severe weather conditions. The opposite is indicated; these variations are becoming less severe.

The following lists limitations and potential sources of inaccuracy in the analysis:

- It was difficult to find 4 sites across the continental United States that had completely consistent temperature data for the 1950’s to the present. Perhaps other sources (besides NOAA) would provide better data. Although the 4 sites were chosen at random, Detroit, in particular, did not have consistent data, and Indianapolis was used instead.
- Although cloud cover and precipitation data was seen as possible data from the NOAA data base, it seemed that this data was even more difficult to find consistent for the same site across long periods of time, but this could be investigated more thoroughly. This would also be the case for barometric pressure, and this pressure variability would probably be a better indicator for trends in weather severity.
- It may be that a trend toward higher temperature would mean more energy in the atmosphere, and that would be a factor in weather severity. This could explain the variability factors (TDIFF, TMAXD2D, TMIND2D) decreasing over time.

The following summarizes the results of the analysis:

1. The slope of the maximum daily temperature analyzed across approximately 26,000 days shows a warming trend of approximately 0.3 deg F/decade. No person would be reasonably likely to notice such an increase.
2. The slope of the minimum daily temperature analyzed across approximately 26,000 days shows a warming trend of approximately 0.5 deg F/decade. No person would be reasonably likely notice such an increase.
3. Segregating the data into 7 decades with 3,650 days in each decade and then averaging all the maximum and minimum daily temperatures (across the entire year) showed some trends for the 70 years. The following figure C-1 for Denver area shows a typical trend seen of cooling and then warming (taken from Figure 2-5):

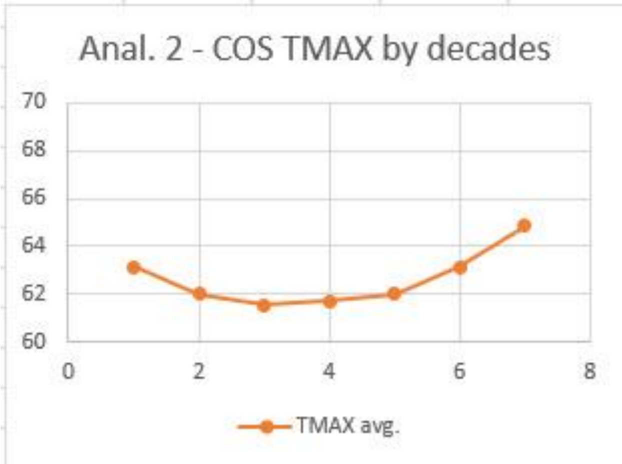

Figure C- 1

4. But the following figure C-2, for Seattle, does not show potential cyclical data (taken from Figure 2-8):

Figure C- 2

5. After determining that January is statistically the coldest month, and July the hottest month for all 4 sites, these months alone were analyzed across the decades. The trend similar to Figure C-1 was typically seen for Philadelphia, Indianapolis, and Denver; but, Seattle showed the generally increasing trend similar to Figure C-2.
6. For maximum temperature for January and July some sites showed the most recent decade (2010's) with a significant cooling trend. Philadelphia's January trend was -3 deg F/decade. Indianapolis July trend was -4.5 deg F/decade. But, Seattle's July trend was +6 deg F/decade. Assuming the most recent trend is not part of a cycle, and then applying this trend to the most recent temperature, a prediction for 10 years in the future can be computed. This can be compared to the expected average for the 70 years to get prediction of global warming. This calculation for Indianapolis was 0.03 deg/decade, i.e. no warming. But, for Seattle this was 12.54 deg F/decade. The average for this value for the 4 sites was 5 deg F/decade. This sort of increase would probably be considered alarming.
7. But if the January and July data is interpreted as cyclical, then the most recent decade (2010's) should not be used alone and projected to the future. Instead, the trend would be averaged across the 70 years to see what would be predicted considering the positive and negative trends. For Indianapolis, the average trend is -2.21 deg F/decade (i.e. cooling). For Seattle, this is +3.33 deg F/decade. Averaging the 4 sites, this calculation predicts a warming of 0.3 deg F/decade. This is a very different result.
8. Analysis of the occurrence of record high temperatures showed 3 of the 4 sites with the most recent decade having the highest number of record highs. But, some previous decades also had similarly high numbers of record highs, and also could be indicating a cycle of warm temperatures in the past with cooling and then warming, such as the following typical result (taken from Figure 4-3):

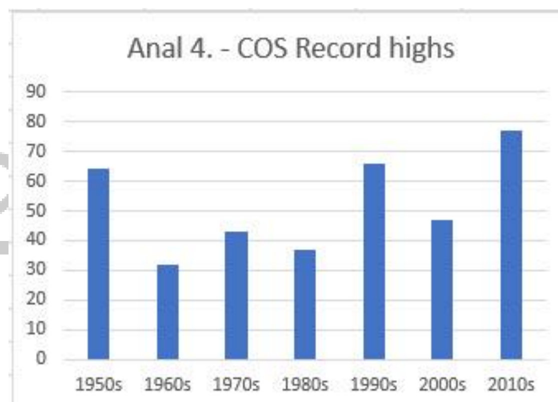

Figure C- 3

9. Change in daily temperatures (both within a single day and from one day to the next) showed a decreasing trend for virtually all the cases. Each site was analyzed in 3 ways for the trend across the 26,000 days. 9 of the 12 calculations showed the temperature variation decreasing (weather apparently becoming less severe). The other 3 calculations (for Indianapolis) was essentially no change in variation (+0.05 deg F/decade).
10. The change in daily temperature by decades also showed the decreasing trend. 7 of the 12 calculations showed the most recent decade (2010's) with a negative trend; this would predict that the variability in temperature would continue to become less severe. Of the other 5 calculations, only 1 indicated a trend of more than 0.2 deg F/decade.

CARBON EMMISSIONS ANALYSIS

Assuming that there is a unique and unprecedented trend for global warming, and this poses a threat to the United States economy, it seems reasonable to consider means to reduce CO_2 in the atmosphere. The most common solution proposed, and the one likely to impact the mechanical engineering profession in particular, is the transition to electric vehicles (to be referred to as EV's).

Although one might consider that this transition would be beneficial to the engineering profession as new technologies are developed and commercialized, it would be a disaster to the profession if it turned out that the EV's were more expensive to acquire and operate, and then the global warming threat found to be false. The immense expense for the transition would wind up wasted effort. Competitor nations which would not make the EV transition would wind up with an economic advantage. This paper attempts to quantify the impact of the EV transition by comparing it to a competitor nation's publicly stated objective of expanding the use of coal-fired electric generation plants.

On March 3, 2020, the Yahoo! Finance on-line news site included a link to an article that stated that the China Electricity Group indicated that coal-power capacity will reach 1,300 GW by 2030, up from 1,050 GW. The article stated that 300 GW of new coal-fired capacity (after accounting for retirement of older plants) is anticipated. The following is the link:

http://carbonbrief.org/analysis-will-china-build-hundreds-of-new-coal-plnats-in-the-2020s

It seems reasonable to assume that Communist China would engage in this development. Coal is expected to be the most economical power generation for China, and economic development has been the primary goal projected by the Communist Party and the People's Liberation Army for decades.

This paper attempts to evaluate the carbon emissions from these power plants with respect to automobile use in the United States. The following is taken as the number of automobiles driven each day in the United States:

$$A_{US} = 200,000,000 \qquad \text{Eq. 10}$$

The following is taken as the continuous power generated by the internal combustion engine of the typical automobile as driven (obviously at any given moment in time some are lower and some are much higher):

$$HP_{US} = 20 \text{ hp} \qquad \text{Eq. 11}$$

The following is taken as typical number of hours the typical automobile is driven during the day using that amount of power:

$$t_{US} = 1 \text{ hr} \qquad \text{Eq. 12}$$

The total energy consumed by all automobiles in a day is estimated as follows:

$$E_{US} = A_{US} \cdot HP_{US} \cdot t_{US} = 4,000,000,000 \text{ HP-hr} \qquad \text{Eq. 13}$$

This is converted as follows:

$$E_{US} = 3,000,000,000 \text{ kW-hr} \qquad \text{Eq. 14}$$

$$E_{US} = 3,000,000 \text{ MW-hr} \qquad \text{Eq. 15}$$

The following is the coal-fired power plant capacity expected to be added by China:

$$P_{CCP} = 300,000 \text{ MW} \qquad \text{Eq. 16}$$

The following is amount of time the plants are burning fuel (these power plants are for base-power and are generating constantly):

$$t_{CCP} = 24 \text{ hr} \qquad \text{Eq. 17}$$

The following becomes the energy consumed by the power plants:

$$E = P_{CCP} \cdot t_{CCP} = 7,200,000 \text{ MW-hr} \qquad \text{Eq. 18}$$

Comparing Equation 15 to Equation 18, it is seen that the power plants will consume over twice the energy of the automobiles. The ratio is the following:

$$R_E = \frac{7,200,200}{3,000,000} = 2.4 \qquad \text{Eq. 19}$$

However, they are not burning the same fuel, and they don't have the same efficiency. The CO_2 emissions from coal combustion is taken as 228 lb/MBTU. The CO_2 emissions from gasoline is taken as 158 lb/MBTU[3]. The ratio of CO_2 from coal to gasoline becomes the following:

$$R_{fuel} = \frac{228}{158} = 1.44 \qquad \text{Eq. 20}$$

With the coal combustion emitting more carbon, the ratio for Chinese power plant emissions is increased as follows:

$$R_E' = R_E \cdot R_{fuel} = (2.4) \cdot (1.44) = 3.45 \qquad \text{Eq. 21}$$

[3] https://www.americangeosciences.org/critical-issues/faq/how-much-carbon-dioxide-produced-when-different-fuels-are-burned

The efficiency of the automobile engine is taken as the following:

$$\eta_{US} = 0.18 \qquad \text{Eq. 22}$$

The efficiency of the coal-fired power plant is take as the following:

$$\eta_{CCP} = 0.5 \qquad \text{Eq. 23}$$

The ratio of efficiencies becomes the following:

$$R_{eff} = \frac{0.18}{0.5} = 0.36 \qquad \text{Eq. 24}$$

With the internal combustion engine less efficient, the ratio for Chinese power plant emissions is decreased as follows:

$$R''_E = R'_E \cdot R_{eff} = (3.45)\cdot(0.36) = 1.24 \qquad \text{Eq. 25}$$

This indicates that the increase in carbon emissions due to new Chinese coal-fired power plants is estimated to exceed all CO_2 emissions from all automobiles driven in the United States. This is the case even though there was no consideration for commercial transportation in the US (which would generally operate all day, not just 1 hour). This means that even if the transition to EV's was completed in the current decade, carbon emissions will still increase. It may be laudable to cease the US emissions, but if the current alarm about global warming already means oceans will inundate coastal areas, it would not seem to make a difference to the global economy whether ocean level rise was 1 meter or 2 meters. It is considered obvious that without the Chinese Communist Party changing course immediately, in actions and not words, it is against the economic interest of the US Government to distort market forces in order to convince consumers to purchase EV's.

ECONOMIC IMPACT ANALYSIS

Given that the number of automobiles and their energy consumption can be estimated, it is also be possible to estimate the amount of electric power generation required to support EV's. In this analysis, commercial vehicles are also considered.

The commercial vehicles on US roads is taken to be the following percentage of all vehicles:

$$N_T = 10\,\% \qquad \text{Eq. 26}$$

The number of commercial vehicles becomes the following:

$$T_{US} = \frac{N_T}{100} A_{US} = (0.1)\cdot(200{,}000{,}000) = 20{,}000{,}000 \qquad \text{Eq. 27}$$

The following is taken as typical number of hours the typical commercial vehicle is driven during the day:

$$t_T = 8\,\text{hr} \qquad \text{Eq. 28}$$

The total number of hours for commercial vehicles consuming energy per day becomes the following:

$$T_T = 8\cdot(20{,}000{,}000) = 160{,}000{,}000\,\text{hr} \qquad \text{Eq. 29}$$

This time is computed for automobiles as follows:

$$T_{US} = t_{US}\cdot A_{US} = 1\cdot(200{,}000{,}000) = 200{,}000{,}000\,\text{hr} \qquad \text{Eq. 30}$$

The automobile and commercial vehicles (T,EV subscript) would have different power requirements. The power requirements are estimated as follows (for the EV's):

$$P_{EV} = 10\,\text{kW} \qquad \text{Eq. 31}$$

$$P_{T,EV} = 40\,\text{kW} \qquad \text{Eq. 32}$$

Note that the carbon emissions analysis previously presented assumed 20 HP for US automobiles. The 10 kW for an EV would be 13 HP, so the EV is assumed to have reduced power demands (due to the improved aerodynamics typically necessary for EV's to get acceptable range and the presumed reduced friction and parasitic losses for the electric motor system). The commercial vehicle power requirement (assumed to be constant in spite of terrain, traffic conditions, etc.) is 53 HP.

The energy consumed for the classes of EV's becomes the following:

$$\begin{aligned} E_{EV} &= f_{EV}\cdot T_{US}\cdot P_{EV} \\ E_{T,EV} &= f_{T,EV}\cdot T_T\cdot P_{T,EV} \end{aligned} \qquad \text{Eq. 33}$$

where:
f_{EV} = EV fraction of US automobile fleet
$f_{T,EV}$ = EV fraction of US trucking fleet

Total energy consumed for all EV's becomes the following:

$$E = E_{EV} + E_{T,EV} \qquad \text{Eq. 34}$$

Now the daily energy consumption for all EV's can be estimated with an assumption of the fraction of the US fleet that is EV's. Assuming 10%, the following is calculated using Equations 33 and 34:

$$E_{EV} = (0.1)\cdot(200,000,000)\cdot 10$$
$$E_{T,EV} = (0.1)\cdot(160,000,000)\cdot 40$$
$$E = 200,000,000 + 640,000,000$$
$$E = 840,000,000$$

kW-hr Eq. 35

This is the amount of electrical energy that needs to be provided on a daily basis (for 10% EV). In order to determine how many power plants are needed, it is necessary to know how these vehicles are going to be recharged. This means estimating how many are recharging at the same time, and how long they will be recharging. With 200 million kW-hr's needed for automobiles, and if this energy was drawn in 1 hour, then the grid would have to handle 200 million kW or 200,000 MW of additional power. But, if only some of them are recharging at the same time, or if it took 4 times longer to charge, the power would be significantly reduced. Note, however, that the grid should not be sized based on some average demand; it should be able to handle peak conditions, such as a storm preventing recharging, and then a high percentage of the population recharges at the same time after the storm.

The following calculation can be used for the grid power requirement for EV's:

$$P_G = f_{ch}\cdot\frac{E_{EV}}{t_{ch}} + f_{T,ch}\cdot\frac{E_{T,EV}}{t_{T,ch}}$$ Eq. 36

where:

f_{ch} = Fraction of EV's charging concurrently

t_{ch} = Time for EV's to recharge

It would appear difficult to estimate these new values without actual experience (i.e. already having 10% EV's in the fleet). For the fraction of EV's concurrently charging, as mentioned earlier, the grid should be sized to handle a peak event. This value will be assumed to be 75%. It may be that some day a high percentage of workplaces will have recharging for commuters. But how would that be paid for? To have individual chargers for every vehicle in a parking lot and to measure this for individual employees and deduct from their pay would seem impractical. It is assumed they will recharge at home at night, and that 3 hour difference from 4 time zones is not enough to guarantee that East Coast cars are fully charged before West Coast starts charging. Obviously, the grid may not be nationally connected and may not be impacted exactly in this way, but the calculations are considered valid for estimating the additional power requirement on a national basis. Another factor to consider would be smart-meters that would manage the power drawn. It is assumed that recharging, at home, at night, will take 4 hours.

Commercial vehicles have a much larger energy requirement, and it would be expected that they would take longer to recharge, but trucks may also need to be "back on the road" more quickly, and commercial vehicles are likely to have more advanced recharging equipment that would take less time than automobiles (and this would have a very significant effect on the calculation). Just the same, to be conservative, the time to recharge commercial vehicles is assumed to be 8 hours (and again 75% recharging concurrently). It is interesting to note that trucking rest areas could be used for recharging when trucks are not driving, but the author has observed that an EV recharging station at a rest area on the Pennsylvania Turnpike indicated a cost of \$0.41/kW-hr. This is approximately 4 times the cost of power for a home in that part of Pennsylvania.

With these assumptions, the following can be calculated for 10% EV in the US fleet (now using MW-hr instead of kW-hr):

$$P_G = (0.75)\cdot\frac{200,000}{4} + (0.75)\frac{640,000}{8}$$
$$P_G = 37,500 + 60,000$$
$$P_G = 97,500$$

MW Eq. 37

The next issue to address is the number of power plants required to meet this new demand and an estimated cost for their construction. The following power generation options are investigated:

- Combined cycle gas turbine using natural gas.
- Windmills.
- Nuclear power plants.

Clearly the gas turbine option will have emissions that are supposed to be prevented in the first place, but this option is the most desirable economically, and if power was needed regardless of emissions, it would be the most likely solution. This then provides a perspective on the relative costs of the different options. Photovoltaics or solar concentration plants would be other options, but it does not seem that these options have been commercialized to the extent needed for such large capacity requirements.

The economic analysis for these options is quite elementary and based on simple on-line searches. But the author has the advantage of personal experience in both the energy sector (as an employee of the Ingersoll-Rand and Dresser-Rand companies) and 27 years in the construction equipment sector strongly connected to the energy sector.

Gas Turbine Option

A General Electric combined cycle power plant was determined to have a capacity of 640 MW. With 97,500 MW required (for 10% EV), there would be 150 of these plants required. According to the following article, 27,000 MW in new natural gas power generation is currently expected to come on-line for 2022 to 2025:

https://www.eia.gov/todayinenergy/detail.php?id=50436

So a modest transition to EV's would require increasing the current rate of construction of these plants by a factor of 4. The following article indicates that such power plants cost 968$/kW:

https://www.statista.com/statistics/243707/capital-costs-of-a-typical-us-combined-cycle-power-plant/

For the 650 MW plant, this becomes 630 M$. For 150 of these plants, the cost is estimated as 95 Billion dollars.

Windmill Option

Windmills currently have a typical capacity of 3 MW. However, they will not all be generating power simultaneously, and as usual, the estimate should be based on peak conditions, not average conditions. Therefore, it is assumed that wind farms at some point will only be operating at 50% capacity. This means requiring 2 times as many windmills to meet the demand. For the 97,500 MW requirement (for 10% EV), this results in the need to construct 65,000 windmills.

According to the following article, the cost is 1.3 to 2.2 M$ per MW for such a windmill:

https://www.windustry.org/how_much_do_wind_turbines_cost

Taking the lower cost estimate of 1.3 M$, the 3 MW windmill is estimated to cost 4 M$. The cost for 65,000 of then becomes 250 Billion dollars (approximately 2 times the gas turbine option). It is not known if there is available wind-capable sites for this number of windmills, or if they could be built across the US or only in certain areas (then transmission losses would need to be considered).

Nuclear Option

In general, nuclear plants of the past (such as the Limerick Generating Station in Southeastern Pennsylvania) had very large capacities, such as 2000 MW or more. However, most recent nuclear power development has been for smaller capacities using modular designs. But, almost all nuclear power projects have been cancelled. The Vogtle Units 3 and 4 appear to be the only current projects for installing nuclear power. These units are approximately 1000 MW each. The costs for these units is now estimated at 25 Billion dollars. If plants were standardized on 2000 MW, the 10% EV's would require 49 power plants. If they could be built for 10 Billion dollars (which would mean economies of scale with significant standardization by modularizing and government streamlining), then the cost would be 490 Billion dollars.

Summary

Table E-1 summarizes the 3 power generation options for 10% of the US fleet being EV's, and then Table E-2 summarizes for 50% EV's.

Table E-1 - 10% EV	Gas Turbine	Windmill	Nuclear
Number of plants	150	65,000	49
Cost per plant (M$)	630	4	10,000
Total cost (B$)	95	260	490

Table E-2 - 50% EV	Gas Turbine	Windmill	Nuclear
Number of plants	750	325000	245
Cost per plant (M$)	630	4	10000
Total cost (B$)	473	1300	2450

Note that the current power generation capacity of the US grid has been indicated as 1.1 Million MW (for 2018). The 10% EV development would mean a 9% increase. The 50% EV development would mean a 45% increase. Of course, this should mean a substantial reduction in refinery capacity, and this may also reduce emissions, since energy is needed to operate refineries.

Only the 50% EV condition would be expected to actually have an effect on the emissions issue. Gas turbines would have emissions, so it would not be a logical choice. The nuclear option appears economically impractical and politically impossible. This would indicate that only the windmill option could be viable. Therefore, 1.3 Trillion dollars is required to make an impact on emissions. This is an enormous impact, and it should not be undertaken unless global warming is more conclusive that seen in this paper. Furthermore, such reduced US emissions with 50% EV will be negated by at least a factor of 2 by China's new coal plants.

Developing capacity on the power grid is a very long and bureaucratic process. If 10% of the US fleet was actually EV in the next few years, the power would most likely not be reliably available. It would seem clear that utilities would be forced to ration power, presumably via smart-meters. Or, governments would have to enact laws to punish consumers that do not consume power as deemed necessary to sustain the grid.

It is also noted that deforestation is no longer discussed in the political discourse of the global warming issue. Brazil, in particular, should be economically sanctioned for destroying its rain forest. The solution is virtually always the need to transition from the current energy infrastructure. Considering that some parts of the US greatly benefit from the current energy infrastructure (i.e. Texas), and other parts would be expected to benefit from expanded EV manufacturing (i.e. California), it is not surprising that the current essentially Socialist US government would push so hard for the transition approach.

FUTURE WORK

There are a number of further avenues of research as follows:

1. Spend further time to search data for longer time spans beyond the 7 decades.
2. Attempt to quantify weather severity trends based on barometric pressure data.
3. Ascertain from satellite imagery whether Communist China is constructing the coal-fired plants. India has apparently also announced their construction of the largest coal-fired plant in the world.
4. The author has a copy of the "Infrastructure" Bill, but it is 1000+ pages of politician-generated information, and it is going to take a long time to quantify what actions it will actually produce.

APPENDIX A - Procedure for obtaining temperature data

https://www.ncdc.noaa.gov/cdo-web/search

Select Weather Observation Type/Dataset:
    Daily Summaries
Select Date Range:
    Start Date: 1 Jan 1949
    End Date: latest
    Apply
Search For:
    Cities
    Search Term: PHL
Search...
Philadelphia, PA US 'Add to Cart'

'Cart (Free Data) 1 item'
Select Cart Options
    Custom GHCN-Daily CSV
    Select the Date Range (repeated selection);
    Apply
    'Continue'
Custom Options: Daily Summaries
    Station Name
    Geographic Location
    Include Data Flags
    + for Air Temperature
    Select TAVG, TMAX, TMIN
    'Continue'
e-mail address and 'Remember my email address'
'Submit Order'

APPENDIX B - Sample view of temperature data

STATION	NAME	LATITUDE	LONGITUDE	ELEVATION	DATE	TAVG	TAVG ATTRIBUTES	TMAX	TMAX ATTRIBUTES	TMIN	TMIN ATTRIBUTES
USW00013739	PHILADELPHIA INTERNATIONAL AIRPORT, PA US	39.8733	-75.22681	2.1	1/1/1949			36	,,0	30	,,0
USW00013739	PHILADELPHIA INTERNATIONAL AIRPORT, PA US	39.8733	-75.22681	2.1	1/2/1949			42	,,0	30	,,0
USW00013739	PHILADELPHIA INTERNATIONAL AIRPORT, PA US	39.8733	-75.22681	2.1	1/3/1949			42	,,0	27	,,0
USW00013739	PHILADELPHIA INTERNATIONAL AIRPORT, PA US	39.8733	-75.22681	2.1	1/4/1949			41	,,0	28	,,0
USW00013739	PHILADELPHIA INTERNATIONAL AIRPORT, PA US	39.8733	-75.22681	2.1	1/5/1949			56	,,0	38	,,0
USW00013739	PHILADELPHIA INTERNATIONAL AIRPORT, PA US	39.8733	-75.22681	2.1	1/6/1949			58	,,0	37	,,0
USW00013739	PHILADELPHIA INTERNATIONAL AIRPORT, PA US	39.8733	-75.22681	2.1	1/7/1949			53	,,0	35	,,0
USW00013739	PHILADELPHIA INTERNATIONAL AIRPORT, PA US	39.8733	-75.22681	2.1	1/8/1949			60	,,0	34	,,0
USW00013739	PHILADELPHIA INTERNATIONAL AIRPORT, PA US	39.8733	-75.22681	2.1	1/9/1949			53	,,0	37	,,0
USW00013739	PHILADELPHIA INTERNATIONAL AIRPORT, PA US	39.8733	-75.22681	2.1	1/10/1949			49	,,0	42	,,0
USW00013739	PHILADELPHIA INTERNATIONAL AIRPORT, PA US	39.8733	-75.22681	2.1	1/11/1949			47	,,0	36	,,0
USW00013739	PHILADELPHIA INTERNATIONAL AIRPORT, PA US	39.8733	-75.22681	2.1	1/12/1949			38	,,0	31	,,0
USW00013739	PHILADELPHIA INTERNATIONAL AIRPORT, PA US	39.8733	-75.22681	2.1	1/13/1949			44	,,0	34	,,0

Versions:
1 - Initial revision.
2 - Added watermark.
3 - Corrected 100 GW in the Abstract to be 300 GW.
4 - Corrected typo in item 4 of the Future Research section. Improved figures wording in Weather Analysis Conclusions.