Climate Change ~ its possible cause and effect ~

INFO290 Final Project
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Introduction

Global warming affects many policy areas. One of the examples is the water disaster mitigation policy. When the strength and frequency of the tropical cyclone increase, the expected tidal height by storm surge disaster also increase. Actually, there were many damages by tropical cyclone all around the world in 2018 summer. For example, the economic loss by Hurricane Florence was 17 ~ 22 billion dollars and the second largest international airport in Japan was sank under the water by the storm surge. In order to protect the hinterland of dikes, policymakers need to design coastal infrastructure appropriately adopting up-to-date or predicted environmental changes.

However, there is a controversial discussion if the strength and frequency of tropical cyclone are increasing, or not. Even whether the atmosphere is warming or not is a burning question. Therefore, the influence of global warming should be evaluated quantitatively. Also, we wish to review and visualize the statistics/data of carbon emission by the electric generation sector in the USA, check its correlation with US's GDP to investigate the sources of energy driving US's growth.

Research Questions

We answered the following research question in our project.

1. Phenomenon -Climate Change-
    a. How is the average temperature shifting in the past 200 years?
    b. How does the average temperature in the U.S. distribute over every 50 years? Does it different each other?
2. Possible Cause
    a. What is the correlation between the annual average temperature in the U.S. and the number of hurricanes or the max window's strength of hurricanes in the year?
3. Possible Effect
    a. What are the trends of carbon emission from electricity generation due to different fuels?
    b. How that correlates with USA's GDP? Is it getting more or less carbon efficient?

Datasets

The revised Atlantic Hurricane database by Chris Landsea, James Franklin, and Jack Beven
Earth Surface Temperature Data since 1750 by Berkeley Earth
https://www.kaggle.com/berkeleyearth/climate-change-earth-surface-temperature-data

CO2 emissions by coal electric generation
https://www.kaggle.com/berhag/co2emissions

Global GDP dataset
https://data.worldbank.org/indicator/ny.gdp.mktp.cd

Hurricanes and Typhoons, 1851-2014 ~Location, wind, and pressure of tropical cyclones in Atlantic and Pacific Oceans~ by NOAA (National Oceanic and Atmospheric Administration)
https://www.kaggle.com/noaa/hurricane-database

Analysis Result

1-a: How is the average temperature shifting in the past 200 years?

Figure1 is the average temperature in the U.S. from 1768 to 2013, which is based on the earth surface temperature data by Berkeley Earth. At the beginning of the period, the variance of the average temperature is larger than in recent years. The scattered distribution is estimated to be caused by the inaccurate thermometer and an inconsistent number of observatories. However, after about 1850, the observed average temperature looks more reliable because the variance of the average temperature becomes smaller. In the later analysis, we will use the data only after 1850 considering the reliability of measured temperature.

As for the shift of the average temperature, there is an increasing trend after 1850. The average temperature in 1850 and 2013 was 8.248 and 11.297-celsius degree, respectively. The increase between the two years is about 3.0 degree.

However, this is just an intuitive description of the increasing trend. In the next section, the increasing trend will be analyzed statistically.

Table1: Average temperature in the U.S. in periodic years

year	1850	1900	1950	2000	2013
Average temperature in the U.S.[°C]	8.248	9.022	8.656	9.65	11.297

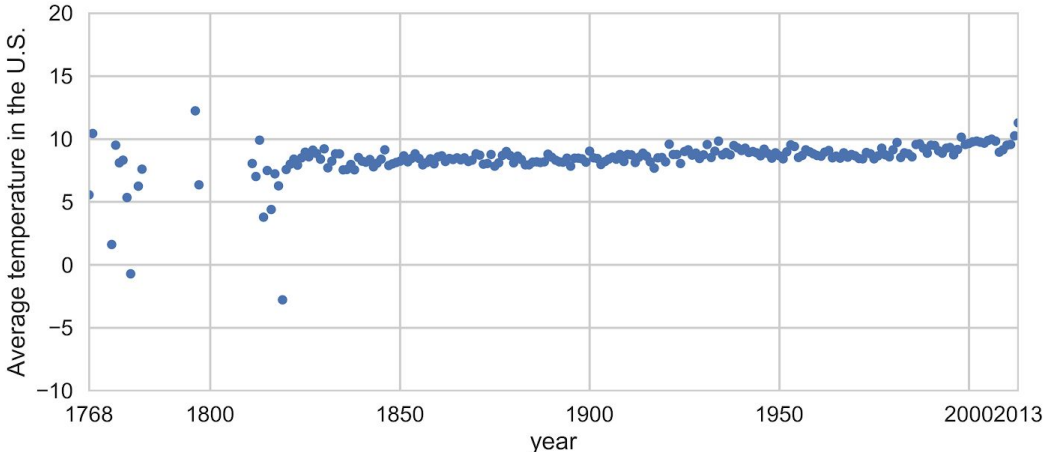

Figure1: Average Temperature in the U.S. by year

1-b: How does the average temperature in the U.S. distribute over every 50 years? Does it different each other?

Although the previous analysis in 1-a shows an increasing trend of average temperature intuitively, the evidence is not enough to determine the increase in temperature. For example, the temperature in 1950 was 8.656-celsius degree, which is lower than the average temperature in 1900 (9.022 ℃). This decrease in the temperature is a contradiction of our assumption. Thus, we should focus on rather groups of periodic data than point data in order to analyze the phenomenon more quantitatively.

Figure 2 and 3 shows the distribution of the average temperature in the U.S. dividing the data into every 50 years. Assuming that each period shows normal distribution, one-way ANOVA and Tukey-Kramer method can be applied.

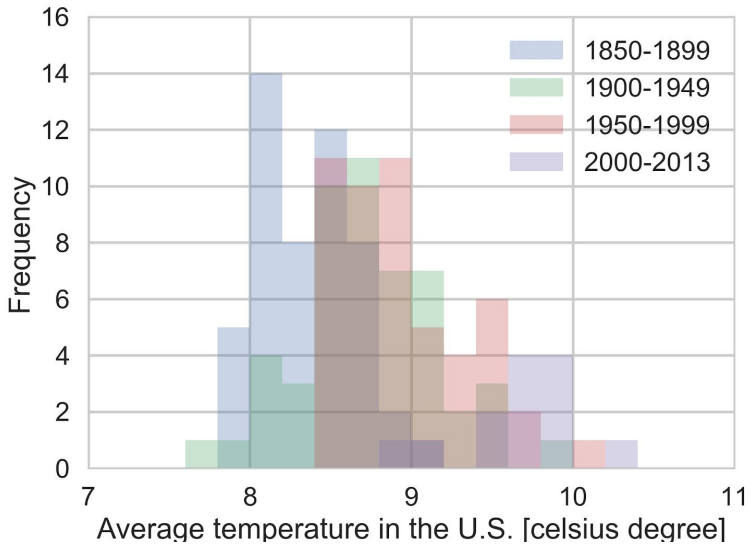

Figure2: Distribution of the average temperature in the U.S. by every 50 years

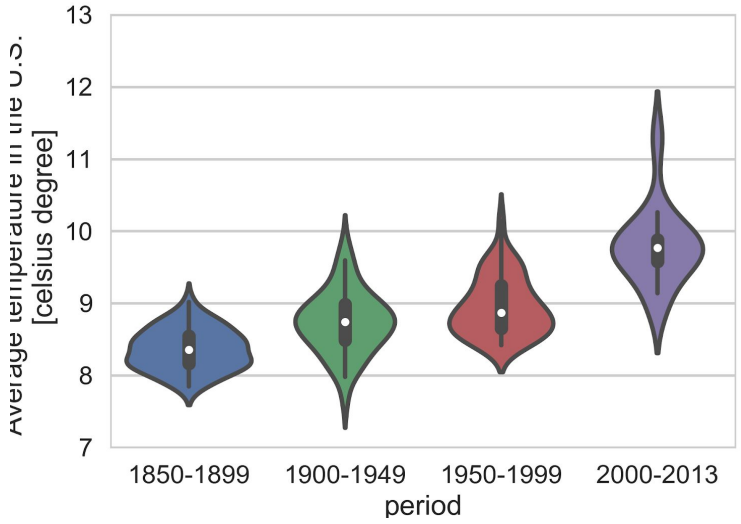

Figure3: Violin plot of the average temperature in the U.S. by every 50 years

According to the one-way ANOVA analysis, the F-value is 53.19 (p-value = 6.62×10^{-24}). Therefore, at least one of the samples among the four-period samples shows a statistically significant difference. In addition, table 2 shows the result of the Tukey-Kramer method. All null hypothesis is rejected, which mean all of the difference of the four-period samples combination is statistically significant. Thus, the average temperature of every 50 years is likely to be increasing.

As the Figure1 shows the increasing trend of average temperature intuitively, the increasing trend is also demonstrated statistically. In the next section, we will estimate the effect of this increasing temperature from the point of tropical cyclones.

Table2: Result of the Tukey-Kramer method to
the average temperature in every 50 years

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Multiple Comparison of Means - Tukey HSD,FWER=0.05
=================================================
  group1    group2  meandiff lower  upper  reject
-------------------------------------------------
1850-1899 1900-1949  0.3798  0.1747 0.585   True
1850-1899 1950-1999  0.5957  0.3905 0.8008  True
1850-1899 2000-2013  1.4364  1.1262 1.7465  True
1900-1949 1950-1999  0.2158  0.0107 0.421   True
1900-1949 2000-2013  1.0565  0.7464 1.3667  True
1950-1999 2000-2013  0.8407  0.5306 1.1509  True
-------------------------------------------------
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2-b: What is the correlation between the annual average temperature in the U.S. and the number of hurricanes or the max window's strength of hurricanes in the year?

Figure 4 shows the relationship between the average temperature and the number of the hurricane and maximum hurricane wind in each year.

Firstly, the number of hurricanes is intermediately correlated with the average temperature with the low p-value. This is not a evidence of causation but there is certain possibility that high temperature cause more hurricanes. When the temperature of the sea surface increase, updraft air current become stronger. Then, the more hurricane may be produced.

Secondly, the strength of the hurricane window shows a weaker correlation with the average temperature with the low p-value. However, there is still a possibility that rising temperature make the hurricanes stronger because stronger updraft air current also causes the larger hurricanes. We tried to use the lowest air pressure as an indicator of the strength of a hurricane too, but the only recent data was available about the air pressure.

By the way, the distribution of the average temperature and the distribution of the maximum hurricane window look normally distributed. On the other hand, the number of hurricanes shows rather Poisson distribution than a normal distribution. The reason is estimated that hurricane is a rare event and not happen frequently. Such are phenomenon often follows a Poisson distribution.

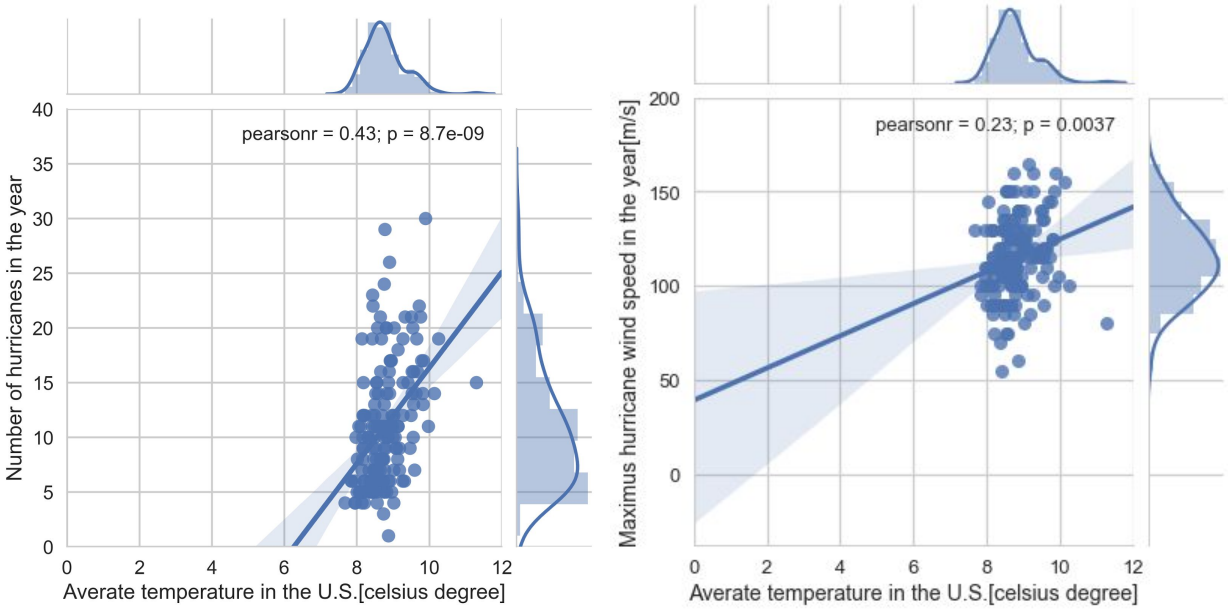

Figure4: Number of hurricanes(left) and maximum hurricane wind (right) according to the average temperature in each year

3-a: What are the trends of carbon emission from electricity generation due to different fuels?

The top plot of figure 1 shows the breakdown of various sources of carbon in the USA for the year 2016. It shows that transportation and electricity generation activities are tied first for the largest contribution to carbon emissions in the USA, each at 28% of the total emission.

Since electricity production is the largest contributor, we use its carbon emission data that is provided by the environmental protection agency to analyse the trends in carbon emission in this context. Given its large contribution, we expect it to be a good proxy to giving good insights into the trends of carbon emission of the USA as a whole. Moreover, the trend of increasing adoption of electric transportation vehicles will only mean that this slice will have increasing weightage in the overall emission data.

The bottom plot of figure 5 shows the breakdown carbon emissions from various fuels for electricity production in the US. The overall emission trend is constant for the period from 1989 to 2016, with a slight decrease after 2009. This could be due to the decreased economic activity after the 2008-2008 financial crisis. There is a marked decrease in electricity production using petroleum while there is a marked increase in that using natural gas. The increase in the use of natural gas could be due to fracking in the US.

The y-axis is on a logarithmic scale. Therefore, the higher an area is on the y-axis, the disportionately larger its contribution to the overall emission is. The largest contributor is the

coal electric power sector. The enormity of this sector explains why the topic of American “clean coal” industry was a big topic in the 2016 Presidential election. More precisely, coal takes up nearly 50% of electricity production in the US.

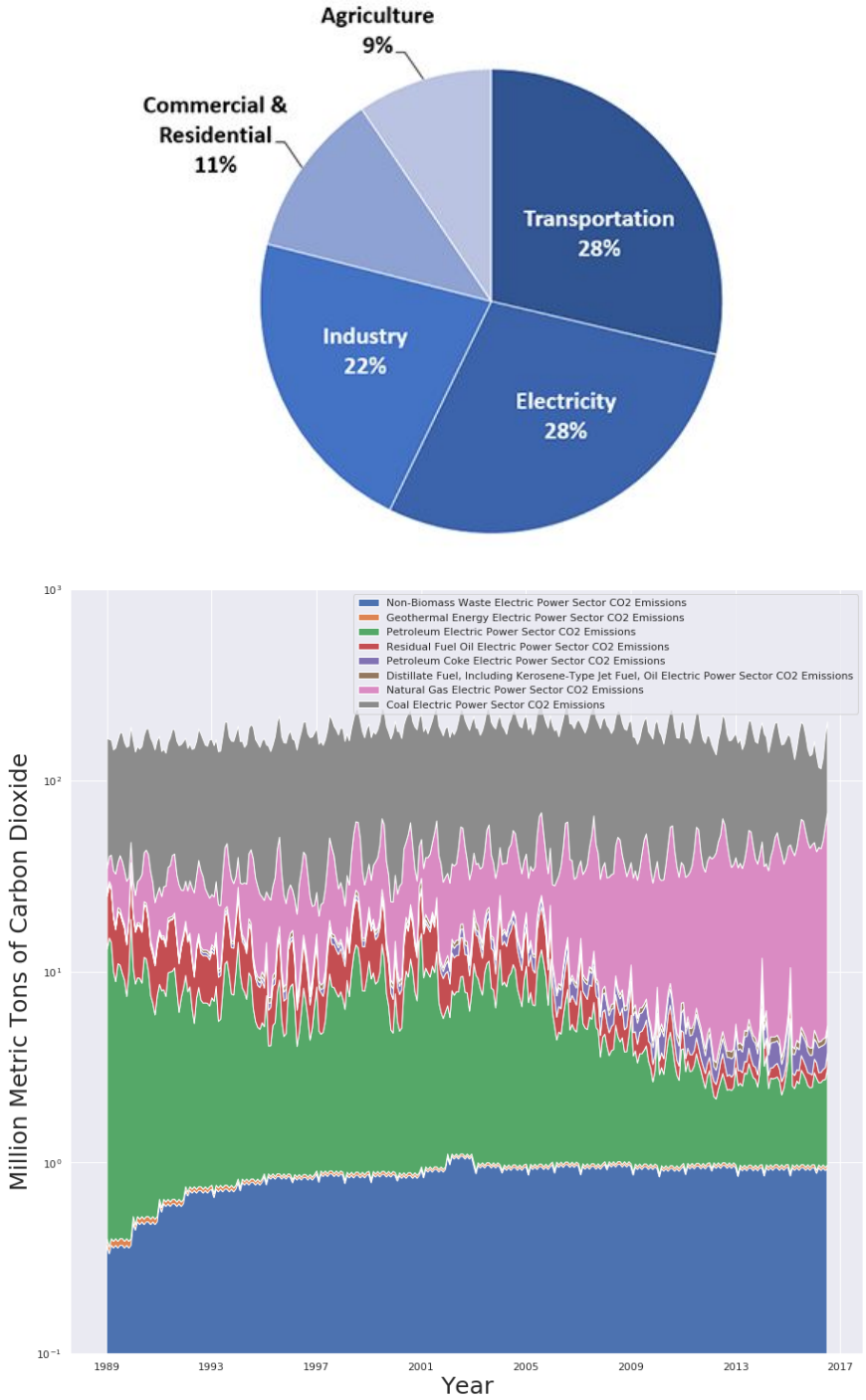

Figure 5: Sources of carbon emission of the USA in 2016 (top) and breakdown of carbon emission by various fuels in electricity production (bottom)

3-b: How that correlates with USA's GDP? Is it getting more or less carbon efficient?

We are interested in the overall carbon efficient of the American economy. As explained before, we have chosen to use the carbon emission figures from electricity production as a proxy for the trends for the whole economy. We believe this to be a good proxy for now and better one going into the future.

The right y-axis of figure 6 shows that for the period 1990 to 2016, there is an overall improvement of US's GDP at PPP (a measure of standard of living). There is a marked dip in the period post the 2008-2009 financial crisis possibly due to a drop in economic activity and increase in unemployment.

The left y-axis shows that, for the same period, the ratio of carbon emitted in energy production to GDP PPP has dropped by about half. This implies that the overall economy is getting more carbon efficient. Also, there seems to be an increasing trend of decrement after 2005. These are good news for climate change. However, we note that the overall carbon emitted for the period as shown in figure 5 is approximately constant. Therefore, there is a need to further increase carbon efficiency, even more rapidly, to bring about a significant change in carbon emission to slow down climate change.

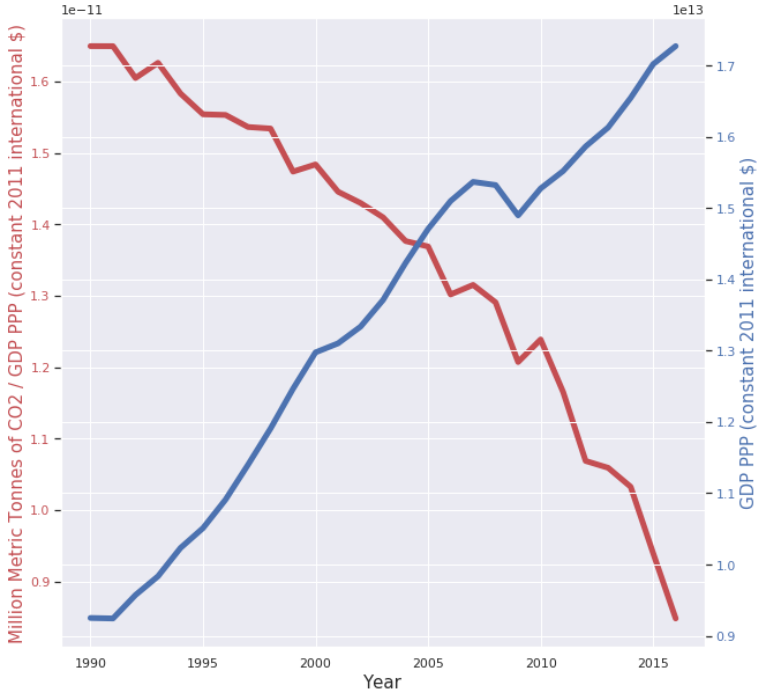

Figure 6: Ratio of total carbon emission from electricity generation to USA's GDP at Purchasing Power Parity and GDP PPP, both plotted against time

Conclusion

Increasing trend of the average temperature in the U.S. is demonstrated intuitively and statistically. In addition, The increasing temperature is correlated with the number of hurricanes and the strongest wind speed of hurricanes. The correlation cannot determine the causation, but there is certain possibility that climate change is making the hurricane more frequent and stronger. Thus, the government should take the recent and predicted change of hurricanes into consideration when they decide the height and robustness of water dikes.

The USA is producing as much carbon dioxide from electricity generation now as 20 years back. The dominant source of carbon is coal.

It is becoming more carbon efficient when measured by the ratio of carbon emission from electricity generation to GDP PPP. In fact, it is about twice as efficient in 2016 as 1990. There seems to be an increasing rate of improvement. This is an encouraging trend in our fight against climate change but clearly more needs to be done to actually reverse the emission figure, which has stayed fairly constant for the whole period.