"Analyzing Global Surface Temperatures Since 1750"

Purpose for Research

The inspiration for analyzing global temperature data stems from the "hot-button" nature of the associated issues of global warming and global climate change. Through various studies, of which we chose the "Third National Climate Assessment Report", published in 2014, there are predicted impacts that stem from a warming Earth such as changing regional precipitation trends, an increase in heavy downpour frequency, rising sea-level, and more intense hurricane seasons in the North Atlantic Basin, just to name a few. We want to find out for ourselves if these predictions are predicated on a sound assumption that the Earth is exhibiting a clearly defined warming trend in the near-term.

Another purpose for researching this topic comes from the public confusion that is created, in part, by cable news networks who have viewership numbers in the millions every work week. The three main news networks differ sharply on how climate change is presented with a recent study showing nearly 60% of shows on FOX News having a dismissive tone towards the topic while CNN and MSNBC both had accepting tones over 70% of the time. There was even a subset of shows that offered differing opinions on the topic, only fueling more public confusion on the matter. We wanted to bring clarity to the idea of whether the Earth's surface layer was exhibiting warming to at least address part of the confusion on climate change.

Out last purpose for the research was to look at the feasibility of the Paris Agreement, which is a multi-national pact among 174 nations, whose primary objective is to limit global warming in this century to less than 2 degrees Celsius since pre-industrial (assumed to mean "since the last Industrial Revolution) levels.

Goal

The chief goal of our research is two-fold. First, we want to determine if the Earth has been warming since the onset of the Second Industrial Revolution, which we estimate to be between 1870 and 1914 using a research article published on this topic. Further, if the warming is occurring, what is the rate of heating, and what are some patterns we can observe?

Data Sources

Our primary source for data came from a data set on Kaggle.com entitled, “Climate Change: Earth Surface Temperature Data, Exploring Global Temperatures Since 1750”. One of the key limitations to our analysis was the lack of variables included in the data set which only included dates, average monthly temperature data, temperature uncertainty expressed as the 95% confidence interval about the monthly mean, a various geographical information depending on the data set used. Some included cities as well as latitude and longitude coordinates. Others, included countries. Additional data sources include data from the U.S. Energy Information Administration, the Organisation for Economic Co-operation and Development, and NASA.

Analysis

We start with the local scope, focusing on Lubbock. The first slide on this analysis (slide 7), plots the temperature uncertainty averaged over a year against each year for which we had data. There’s a clear trend of declining uncertainty from roughly 1820 to 1925. This means the data that is most-desirable to work with is generally that from the last century.

There were three different approaches to finding the rate of temperature change in Lubbock (slide 8). In the initial step of the analysis, we took the temperature data for Lubbock and filtered out data since before 1900. This was done for two reasons. First, we wanted to work with data that had relatively minimized uncertainty given the data set. Second, we’re interested in analyzing temperature change trends after the cited Industrial Revolution, so 1900 is a reasonable year to begin with. The next step was inspired by trying to find the maximized and minimized slope of the linear regression line using theoretical temperatures calculated using both the average temperature of each month and its associated average temperature uncertainty. The reasoning for this was to look at the largest and smallest possible rate of heating in Lubbock within the 95% confidence interval to provide an alarmist and skeptic point of view that is still reasonable. The mathematics for calculating the theoretical monthly temperatures for each of these analyses is included on slide 9. These theoretical temperatures were then averaged over a year and then those theoretical average yearly temperatures were plotted against the year.

All three temperature analyses performed on Lubbock produced increasing rates of temperature change. The plots for the analyses were produced using R and are included in slides 10, 11, and 12. The first temperature analysis for Lubbock only considered average temperatures for each month and discarded any consideration of the temperature uncertainty. The slope of the associated linear regression line had a slope equivalent to 0.73 degrees Celsius of heating per 100 years. The second analysis showed that, given theoretical temperatures meant to minimize the rate of warming while still adhering to the 95% confidence interval for each month of data, the rate of warming was still positive at 0.42 degrees Celsius per 100 years. The last analysis, which sought to maximize the rate of heating, reflected a rate of heating of 1.07 degrees Celsius per 100 years.

Finally, we performed a seasonal analysis on Lubbock's data using R to clean and manipulate the data, and then we used Python to create the plot. Each season in Lubbock shows a warming trend over time with the greatest heating taking place during the spring and summer seasons. This is significant as Lubbock's primary severe weather season is between roughly May 1st and June 15th. A warmer surface layer in the atmosphere, all other things being equal, will produce a stronger updraft for a thunderstorm, which increases the size of hail, the intensity of rainfall, and the risk for downburst wind-events.

On the global scale we were curious to learn what the rates of change would be by country using data from 1900 through 2013 (slide 26). One interesting observation was the relative heating present near Kazakhstan and Mongolia. Furthermore, the northern hemisphere appears to be warming faster than the southern hemisphere. The rates of warming for the period specified ranged from +0.66 to +1.74 degrees Celsius per 100 years.

Turning our attention back to the Paris agreement, we were curious to see what year 2 degrees of warming would be achieved assuming a linear rate of warming defined by the slope of the linear regression line for each country's average temperature per year vs. year plot (slide 27). The resulting year was the determined by rounding up to the nearest integer the result of the following formula.

$$1900 + \frac{200}{[rate\ of\ warming\ per\ 100\ years]}$$

We ultimately found that the mean year the 2-degree threshold would be breached among the world's countries is 2104, making the Paris Agreement main objective tenable assuming the linear rate of heating is a viable way of projecting future warming. Without doing further research on the matter given the time-limiting constraint of the project, we hypothesize such an assumption is not reasonable, especially given the faster warming that has been observed in the last 30 years versus the warming realized between 1900 and 1975.

Conclusion

Following our analysis, we can make the following conclusions regarding the trend in Earth's surface temperature and supplementary data that touched on carbon dioxide, a primary greenhouse gas cited for inducing some non-negligible proportion of the warming realized in the last century (slide 42). First, the data analyzed at varying scales, whether it be local, national, or global, all showed a definitive warming since 1900. Second, there is a strong verified correlation between the increase in global surface temperatures and the increases in sea level, global conventional energy production, crude oil production, and global CO_2 emissions. Third, the average year the current nations of Earth will achieve 2 degrees of warming (in Celsius) is 2104; however, this is based on a likely-faulty assumption that the rate of heating will be linear using the data since 1900. Given that our plots showed a more-accelerated rate of heating after roughly 1975, it's reasonable to predict the average year Earth's countries will record 2 degrees of warming since 1900 is sooner than 2104. Finally, given the recent disproportionate increase in CO_2 emissions in the Asia & Oceania region of the world, if we are to curb the rate at which CO_2 is emitted into our atmosphere, the nation's in the Asia & Oceania will need to take the lead.

Prescriptive Measures

Prescriptive measures are difficult to articulate without a firmer ability to project temperature change through the rest of the 21st century. As a result, we suggest (slide 43) advocacy for research initiatives that aim to determine the extent of warming in the coming century, or later, so efficient, actionable policy can be enacted without meaningful contrarian repute. Second, we also advocate for research initiatives that seek to find a cost-competitive, carbon-neutral alternative to conventional, carbon-based fuels (that isn't nuclear). Finally, simply recommend, akin to a public service announcement, that members of our audience, and ourselves included, aim to live a life with activities that ultimately reduce our carbon footprint.

Further Research

Subsequent research (slide 44) to this analysis could include investigating projections for various scientifically-lined sources of global temperature change such that a non-linear model could be derived that more accurately extrapolates surface temperature change. With this research we could say, more definitively, if the 2 degrees Celsius increase threshold set forth in the Paris Agreement is possible, and if it isn't possible, what is a reasonable limit to set for ourselves. Second, additional research could be done into the necessary rate of change in CO_2 emissions in Asia/Oceania within the next 25, 50, and 100 years to prevent the cited 2-degree warming threshold. A similar analysis could be applied on the global scope as well.

Relevant Source Code

For Lubbock Analysis (in R):

```
#import data from the dataset and assign it to a variable called 'cityData'
cityData <- read.csv("GlobalLandTemperaturesByCity.csv")

#investigate the data set to take inventory of its characteristics including
#variable names
str(cityData)
head(cityData)

#bring the dplyr package into the project
library(dplyr)

#filter out data for the city of Lubbock and assign it to 'LubbockData'
LubbockData <- filter(cityData, City == "Lubbock")

#create a plot that shows increasing certainty over time for the
#Lubbock data set

#to limit the number of data points in the proposed plot, we'll average
#values of a year and plot that while omitting years containing missing data
LBBuncertaintyByYear <- na.omit(group_by((LubbockData %>% mutate(year =
  as.numeric(format(as.POSIXct(dt), format = "%Y")))),
  year) %>% summarize(avUncertainty=mean(AverageTemperatureUncertainty)))

#look at the first 15 rows of LBBuncertaintyByYear to make sure the
#data looks good and reasonable
head(LBBuncertaintyByYear, 15)
```

```
#----------------LUBBOCK TEMPERATURE UNCERTAINTY PLOT------------------------#

library(ggplot2)

#make the plot

uncertaintyPlot <- ggplot(LBBuncertaintyByYear, aes(x=year, y=avUncertainty,
  color=avUncertainty)) + geom_point() + scale_color_gradient(low="dark green",
  high="red") + ggtitle("Yearly Temperature Uncertainty in Lubbock") +
  ylab("Temperature Uncertainty in °C") +
  xlab("Year") + theme(plot.title = element_text(hjust=0.5)); uncertaintyPlot



#create 2 new variables (columns) that represent the upper and lower bound
#temperature values for the 95% confidence interval for a particular time period
#and store this new data set in LBB
LBB <- mutate(LubbockData, MaxTemp = AverageTemperature +
(AverageTemperatureUncertainty/2),
              MinTemp = AverageTemperature - (AverageTemperatureUncertainty / 2))

#add a column for only year to the LBB data set for the sake of performing a
#group_by operation later
LBB <- mutate(LBB, year = as.numeric(format(as.POSIXct(dt), format = "%Y")))

#create 3 plots of temperature vs. year in Lubbock

#The first plot will be the most straight-forward plot, taking
#the average temperature for each year and plotting it against that year

#The second plot seeks to maximize warming over time within the 95% confidence
#interval by assuming a temperature at the lower bound for the first year in the
#data series and increasing the location of the theoretical temperature of each
#year linerally over the time frame of the data set such that the theoretical
#temperature taken for the last year is at the upper bound of the 95%
#confidence interval for that year.
```

```
#The third plot seeks to minimize the warming (maximize the cooling if there is
#cooling) over time by taking the process employed for plot 2, but taking the
#reverse of it such that we start at the upper bound of the 95% confidence
#interval for the first year and end up at the lower bound of the 95% confidence
#interval for the last year

#add two columns to the LBB data set that will be used for the second and
#third plots as described above

#the following is added ensure row_number works as intended for subsequent functions
detach("package:ggplot2", unload="TRUE")
detach("package:plyr", unload="TRUE")
LBB <- filter(LBB, year >= 1900 & year <= 2012)
LBB <- mutate(LBB, fastWarmT = MinTemp + AverageTemperatureUncertainty *
                (row_number() - 1)/(nrow(LBB) - 1), slowWarmT = MaxTemp -
                (AverageTemperatureUncertainty * (row_number() - 1)/(nrow(LBB) - 1)))

#check the data set for reasonableness
head(LBB); tail(LBB)

#group the LBB data set by year and produce three different data sets
# 1. mean average temperature by year
# 2. mean fastWarmT by year
# 3. mean slowWarmT by year

meanWarm <- na.omit(group_by(LBB, year) %>% summarize(avTemp =
  mean(AverageTemperature)))
fastWarm <- na.omit(group_by(LBB, year) %>% summarize(avTemp = mean(fastWarmT)))
slowWarm <- na.omit(group_by(LBB, year) %>% summarize(avTemp = mean(slowWarmT)))
#check to see if the data looks good/reasonable
head(meanWarm); tail(meanWarm)
head(fastWarm); tail(fastWarm)
```

```
head(slowWarm); tail(slowWarm)


#------------------------LUBBOCK AVERAGE TEMP PLOTS----------------------#

#source code for completing the first plot

library(ggplot2)

#plot with linear regression line

meanWarmingPlot1 <- ggplot(meanWarm, aes(x=year, y=avTemp, color = avTemp)) +

  geom_point() + scale_color_gradient(low="blue", high="red") +

  ggtitle("Yearly Average Temperatures In Lubbock") + ylab("Average Temperature in
°C") +

  xlab("Year") + theme(plot.title = element_text(hjust=0.5)) + geom_smooth(method=lm)

#draw the plot

meanWarmingPlot1


#plot with loess smoothed fit line

meanWarmingPlot2 <- ggplot(meanWarm, aes(x=year, y=avTemp, color = avTemp)) +

  geom_point() + scale_color_gradient(low="blue", high="red") +

  ggtitle("Yearly Average Temperatures In Lubbock") + ylab("Average Temperature in
°C") +

  xlab("Year") + theme(plot.title = element_text(hjust=0.5)) +
geom_smooth(color="yellow")

#draw the plot

meanWarmingPlot2


#print the slope of maxWarming (deg C delta/year)

coef(lm(meanWarm$avTemp ~ meanWarm$year))[2]

#Value: +0.729 degC/100 years


#-----------------------LUBBOCK MAXIMIZED WARMING RATE PLOTS------------------------#

#source code for completing the first plot

library(ggplot2)

#plot with linear regression line

fastWarmingPlot1 <- ggplot(fastWarm, aes(x=year, y=avTemp, color = avTemp)) +

  geom_point() + scale_color_gradient(low="blue", high="red") +
```

```
  ggtitle("Yearly Average Temperatures In Lubbock with Maximized Warming") +
  ylab("Average Theotetical Temperature in °C") +
  xlab("Year") + theme(plot.title = element_text(hjust=0.5)) + geom_smooth(method=lm)
#draw the plot
fastWarmingPlot1

#plot with loess smoothed fit line
fastWarmingPlot2 <- ggplot(fastWarm, aes(x=year, y=avTemp, color = avTemp)) +
  geom_point() + scale_color_gradient(low="blue", high="red") +
  ggtitle("Yearly Average Temperatures In Lubbock with Maximized Warming") +
  ylab("Average Theotetical Temperature in °C") +
  xlab("Year") + theme(plot.title = element_text(hjust=0.5)) +
geom_smooth(color="yellow")
#draw the plot
fastWarmingPlot2

#print the slope of maxWarming (deg C delta/year)
coef(lm(fastWarm$avTemp ~ fastWarm$year))[2]
#Value: +1.039 degC/100 years

#------------------LUBBOCK MINIMIZED WARMING RATE PLOTS------------------#
#source code for completing the second plot
#plot with linear regression line
slowWarmingPlot1 <- ggplot(slowWarm, aes(x=year, y=avTemp, color = avTemp)) +
  geom_point() + scale_color_gradient(low="blue", high="red") +
  ggtitle("Yearly Average Temperatures In Lubbock with Minimized Warming") +
  ylab("Average Theotetical Temperature in °C") +
  xlab("Year") + theme(plot.title = element_text(hjust=0.5)) + geom_smooth(method=lm)
#draw the plot
slowWarmingPlot1

#plot with loess smoothed fit line
slowWarmingPlot2 <- ggplot(slowWarm, aes(x=year, y=avTemp, color = avTemp)) +
```

```
  geom_point() + scale_color_gradient(low="blue", high="red") +
  ggtitle("Yearly Average Temperatures In Lubbock with Minimized Warming") +
  ylab("Average Theotetical Temperature in °C") +
  xlab("Year") + theme(plot.title = element_text(hjust=0.5)) +
geom_smooth(color="yellow")
#draw the plot
slowWarmingPlot2

#print the slope of maxWarming (deg C delta/year)
coef(lm(slowWarm$avTemp ~ slowWarm$year))[2]
#value: +0.420 degC/100 years

library(dplyr)



#-------------WARMING BY COUNTRY WORLD MAP PLOT----------------#
#Working on plotting temperature change rates and the year we'll eclipse 2 degrees of
warming
#in Celsius using googleVis package and graphics

#import country data
countryData <- read.csv("GlobalLandTemperaturesByCountry.csv")

#add a year variable to the data
countryData <- mutate(countryData, year=as.numeric(format(as.POSIXct(dt), format =
"%Y")))

#group the data by country and year, find the average temperature per year, and omit
yearly data
#that contain missing information
countryTemps <- na.omit(countryData %>% group_by(Country, year) %>%
  summarize(avT = mean(AverageTemperature)))

#filter out years later than 1900
```

```
countryTemps <- filter(countryTemps, year > 1899)

#get a data frame with average 100 year temperature changes by country
country100yrTdeltaRate <- group_by(countryTemps, Country) %>%
  summarize(Warming_Rate_Per_100_Years_By_degC =
  round(100 *coef(lm(avT ~ year))[2], digits = 2))

#bring in the googleVis package
library(googleVis)

#plot the map
Global100MeanTchange <- gvisGeoMap(country100yrTdeltaRate,
      locationvar = "Country",
      numvar= "Warming_Rate_Per_100_Years_By_degC",
      options = list(colors='[0xF9FF33, 0xFF3333, 0xB22828]'))
plot(Global100MeanTchange)

#-----YEAR TO REACH 2 DEGREE THRESHOLD WORLD MAP PLOT--------#

#determine year when country's average yearly temp will exceed 2 degrees
#above pre-industrialized levels (or avereage yearly temp will be about
#2 deg C higher than average yearly temp around 1900)

twoDegreeEclipseYear <- mutate(country100yrTdeltaRate,
  Year_to_Eclipse_2_Degree_Warming = ceiling(1900 + 200/
  Warming_Rate_Per_100_Years_By_degC))
#mean value of the Year_to_Eclipse_2_Degree_Warming variable, rounded up
ceiling(mean(twoDegreeEclipseYear$Year_to_Eclipse_2_Degree_Warming))
#Average Year to 2 deg threshold: 2104

#plot the map
Global2DegEclipse <- gvisGeoMap(twoDegreeEclipseYear,
  locationvar = "Country",
```

```
  numvar= "Year_to_Eclipse_2_Degree_Warming",
  options = list(colors='[0xB22828, 0xFF3333, 0xF9FF33]'))
plot(Global2DegEclipse)



#----CLEANING & EXPORTING DATA FOR SEASONAL LUBBOCK PLOT IN PYTHON----#
#filter out seasonal data for lubbock and group into 1820-1900, 1900-1940, 1940-1980,
1980-2013 clusters
#temperatures will then be averaged within the seasonal, periodic clusters

#bring the stringi package in to manipulate the string in the dt variable of the LBB
data set
library(stingi)

#create a new column of data for the month in LBB and name this data set LBBmonth
LBBmonths <- mutate(LBB, month = as.numeric(substr(dt, 6, 7)))

#get the pre-1901 winter data
LBB_DJF1900 <- na.omit(LBBmonths %>% filter((month == 12 | month == 1 | month == 2) &
year <= 1900) %>%
  group_by(dt) %>% summarize(avT = AverageTemperature))
LBB_DJF_1900_T <- mean(LBB_DJF1900$avT)
#get the 1900-1940 winter data
LBB_DJF1940 <- na.omit(LBBmonths %>% filter((month == 12 | month == 1 | month == 2) &
year >= 1900 &
  year <= 1940) %>% group_by(dt) %>% summarize(avT = AverageTemperature))
LBB_DJF_1940_T <- mean(LBB_DJF1940$avT)
#get the 1940-1980 winter data
LBB_DJF1980 <- na.omit(LBBmonths %>% filter((month == 12 | month == 1 | month == 2) &
year >= 1940 &
  year <= 1980) %>% group_by(dt) %>% summarize(avT = AverageTemperature))
LBB_DJF_1980_T <- mean(LBB_DJF1980$avT)
#get the 1980-2013 winter data
LBB_DJF2013 <- na.omit(LBBmonths %>% filter((month == 12 | month == 1 | month == 2) &
year >= 1980) %>%
```

```
  group_by(dt) %>% summarize(avT = AverageTemperature))

LBB_DJF_2013_T <- mean(LBB_DJF2013$avT)

#construct winter T vector

winterTs <- c(LBB_DJF_1900_T, LBB_DJF_1940_T, LBB_DJF_1980_T, LBB_DJF_2013_T)


#get the pre-1901 spring data

LBB_MAM1900 <- na.omit(LBBmonths %>% filter((month == 3 | month == 4 | month == 5) &
year <= 1900) %>%

  group_by(dt) %>% summarize(avT = AverageTemperature))

LBB_MAM_1900_T <- mean(LBB_MAM1900$avT)

#get the 1900-1940 spring data

LBB_MAM1940 <- na.omit(LBBmonths %>% filter((month == 3 | month == 4 | month == 5) &
year >= 1900 &

  year <= 1940) %>% group_by(dt) %>% summarize(avT = AverageTemperature))

LBB_MAM_1940_T <- mean(LBB_MAM1940$avT)

#get the 1940-1980 spring data

LBB_MAM1980 <- na.omit(LBBmonths %>% filter((month == 3 | month == 4 | month == 5) &
year >= 1940 &

  year <= 1980) %>% group_by(dt) %>% summarize(avT = AverageTemperature))

LBB_MAM_1980_T <- mean(LBB_MAM1980$avT)

#get the 1980-2013 spring data

LBB_MAM2013 <- na.omit(LBBmonths %>% filter((month == 3 | month == 4 | month == 5) &
year >= 1980) %>%

  group_by(dt) %>% summarize(avT = AverageTemperature))

LBB_MAM_2013_T <- mean(LBB_MAM2013$avT)

#construct spring T vector

springTs <- c(LBB_MAM_1900_T, LBB_MAM_1940_T, LBB_MAM_1980_T, LBB_MAM_2013_T)


#get the pre-1901 summer data

LBB_JJA1900 <- na.omit(LBBmonths %>% filter((month == 6 | month == 7 | month == 8) &
year <= 1900) %>%

  group_by(dt) %>% summarize(avT = AverageTemperature))

LBB_JJA_1900_T <- mean(LBB_JJA1900$avT)

#get the 1900-1940 summer data
```

```
LBB_JJA1940 <- na.omit(LBBmonths %>% filter((month == 6 | month == 7 | month == 8) &
year >= 1900 &

  year <= 1940) %>% group_by(dt) %>% summarize(avT = AverageTemperature))

LBB_JJA_1940_T <- mean(LBB_JJA1940$avT)

#get the 1940-1980 summer data

LBB_JJA1980 <- na.omit(LBBmonths %>% filter((month == 6 | month == 7 | month == 8) &
year >= 1940 &

  year <= 1980) %>% group_by(dt) %>% summarize(avT = AverageTemperature))

LBB_JJA_1980_T <- mean(LBB_JJA1980$avT)

#get the 1980-2013 summer data

LBB_JJA2013 <- na.omit(LBBmonths %>% filter((month == 6 | month == 7 | month == 8) &
year >= 1980) %>%

  group_by(dt) %>% summarize(avT = AverageTemperature))

LBB_JJA_2013_T <- mean(LBB_JJA2013$avT)

#construct summer T vector

summerTs <- c(LBB_JJA_1900_T, LBB_JJA_1940_T, LBB_JJA_1980_T, LBB_JJA_2013_T)


#get the pre-1901 autumn data

LBB_SON1900 <- na.omit(LBBmonths %>% filter((month == 9 | month == 10 | month == 11)
& year <= 1900) %>%

  group_by(dt) %>% summarize(avT = AverageTemperature))

LBB_SON_1900_T <- mean(LBB_SON1900$avT)

#get the 1900-1940 autumn data

LBB_SON1940 <- na.omit(LBBmonths %>% filter((month == 9 | month == 10 | month == 11)
& year >= 1900 &

  year <= 1940) %>% group_by(dt) %>% summarize(avT = AverageTemperature))

LBB_SON_1940_T <- mean(LBB_SON1940$avT)

#get the 1940-1980 autumn data

LBB_SON1980 <- na.omit(LBBmonths %>% filter((month == 9 | month == 10 | month == 11)
& year >= 1940 &

  year <= 1980) %>% group_by(dt) %>% summarize(avT = AverageTemperature))

LBB_SON_1980_T <- mean(LBB_SON1980$avT)

#get the 1980-2013 autumn data

LBB_SON2013 <- na.omit(LBBmonths %>% filter((month == 9 | month == 10 | month == 11)
& year >= 1980) %>%

  group_by(dt) %>% summarize(avT = AverageTemperature))
```

```
LBB_SON_2013_T <- mean(LBB_SON2013$avT)

#construct autumn T vector

autumnTs <- c(LBB_SON_1900_T, LBB_SON_1940_T, LBB_SON_1980_T, LBB_SON_2013_T)


#column combine the periodic seasonal temperatures

LBBseasonalTs <- cbind(winterTs, springTs, summerTs, autumnTs)


#move the Lubbock seasonal temperatures to the parent folder as a csv file

#named "LBBseasonalTemps.csv"

write.csv(LBBseasonalTs, "LBBseasonalTemps.csv")


#calculate the rate of warming for each season since 1900


#winter analysis

season <- na.omit(LBBmonths %>% filter((month == 12 | month == 1 | month == 2) & year
>= 1900))

season <- group_by(season, year) %>% summarize(avT = mean(AverageTemperature))

seasonRate <- 100 * coef(lm(season$avT ~ season$year))[2]

seasonRate

#warming rate per 100 years during the winter since 1900: 0.41 deg C


#spring analysis

season <- na.omit(LBBmonths %>% filter((month == 3 | month == 4 | month == 5) & year
>= 1900))

season <- group_by(season, year) %>% summarize(avT = mean(AverageTemperature))

seasonRate <- 100 * coef(lm(season$avT ~ season$year))[2]

seasonRate

#warming rate per 100 years during the spring since 1900: 1.07 deg C


#summer analysis

season <- na.omit(LBBmonths %>% filter((month == 6 | month == 7 | month == 8) & year
>= 1900))

season <- group_by(season, year) %>% summarize(avT = mean(AverageTemperature))

seasonRate <- 100 * coef(lm(season$avT ~ season$year))[2]
```

```
seasonRate
#warming rate per 100 years during the summer since 1900: 0.98 deg C


#autumn analysis
season <- na.omit(LBBmonths %>% filter((month == 9 | month == 10 | month == 11) &
year >= 1900))
season <- group_by(season, year) %>% summarize(avT = mean(AverageTemperature))
seasonRate <- 100 * coef(lm(season$avT ~ season$year))[2]
seasonRate
#warming rate per 100 years during the autumn since 1900: 0.79 deg C
```

For Lubbock Analysis (in Python):

```
#looking to import csv data that was manipulated and
#formatted in R


#the following code was used based on a tutorial on
#YouTube: https://www.youtube.com/watch?v=Tq6rCWPdXoQ


import numpy as np
import matplotlib.pyplot as plt
import csv


data = np.genfromtxt('LBBseasonalTemps.csv', delimiter=',')
to1900 = data[1, 1:5]
from1900to1940 = data[2, 1:5]
from1940to1980 = data[3, 1:5]
from1980to2013 = data[4, 1:5]


#the plotting code was based on code from the following website
#URL: https://pythonspot.com/en/matplotlib-bar-chart/


# data to plot
n_groups = 4
```

```
# create plot
fig, ax = plt.subplots()
index = np.arange(n_groups)
bar_width = 0.2
opacity = 0.8

rects1 = plt.bar(index, to1900, bar_width,
                 alpha=opacity,
                 color='y',
                 label='1820-1900')

rects2 = plt.bar(index + bar_width, from1900to1940, bar_width,
                 alpha=opacity,
                 color='orange',
                 label='1900-1940')

rects3 = plt.bar(index + 2*bar_width, from1940to1980, bar_width,
                 alpha=opacity,
                 color='r',
                 label='1940-1980')

rects4 = plt.bar(index + 3*bar_width, from1980to2013, bar_width,
                 alpha=opacity,
                 color='maroon',
                 label='1980-2013')

plt.xlabel('Season')
plt.ylabel('Temperatures in \N{DEGREE SIGN}C')
plt.title('Lubbock Temperatures by Season')
plt.xticks(index + bar_width, ('winter', 'spring', 'summer', 'autumn'))
plt.legend()
```

```
plt.tight_layout()
plt.show()
```