Data Visualization to Communicate Our Climate

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1. Introduction

Climate change is a difficult situation that we all face. Communicating our situation has also been difficult. As a data scientist I find that the best way to communicate difficult situations is through data. In this paper we will use data visualization to get a better understanding of our climate situation.

We will be using data from the dslabs library in R. If you have not had a chance to explore the data sets from dslabs I recommend them, it is a fun and easy way to explore small data sets. The data we will be using is the following:

historic_co2

Concentration of carbon dioxide in ppm by volume from direct measurements at Mauna Loa (1959-2018 CE) and indirect measurements from a series of Antarctic ice cores (approx.-800,000-2001 CE).

Source: Mauna Loa data from NOAA. Ice core data from Bereiter et al. 2015 via NOAA.

temp_carbon

Annual mean global temperature anomaly on land, sea and combined, 1880-2018. Annual global carbon emissions, 1751-2014.

Source: NOAA and Boden, T.A., G. Marland, and R.J. Andres (2017) via CDIAC

greenhouse_gases

Concentrations of the three main greenhouse gases carbon dioxide, methane and nitrous oxide. Measurements are from the Law Dome Ice Core in Antarctica. Selected measurements are providedevery 20 years from 1-2000 CE.

Source: MacFarling Meure et al. 2006 via NOAA.

More on the dslabs data sets can me found here

And more on NOAA, which stands for National Oceanic and Atmospheric Administration, where this data is from can be found here

2. Downloading the data

```
# downloading libraries
library(tidyverse)
```

```
## -- Attaching packages --------------------------------------- tidyverse 1.3.1 --

## v ggplot2 3.3.5     v purrr   0.3.4
## v tibble  3.1.1     v dplyr   1.0.5
## v tidyr   1.1.3     v stringr 1.4.0
## v readr   1.4.0     v forcats 0.5.1

## -- Conflicts ------------------------------------------ tidyverse_conflicts() --
## x dplyr::filter() masks stats::filter()
## x dplyr::lag()    masks stats::lag()
```

```
library(dslabs)
library(ggplot2)
library(ggthemes)
library(scales)
```

```
##
## Attaching package: 'scales'

## The following object is masked from 'package:purrr':
##
##     discard

## The following object is masked from 'package:readr':
##
##     col_factor
```

```
#downloading the data
data("historic_co2")
data("temp_carbon")
data("greenhouse_gases")
```

3. Temperatures

Before we dive into the data visualizations let us take a quick look at the data we are working with for temperatures

```
#looking at the data
dim(temp_carbon)
```

```
## [1] 268   5
```

```
head(temp_carbon)
```

```
##   year temp_anomaly land_anomaly ocean_anomaly carbon_emissions
## 1 1880        -0.11        -0.48         -0.01              236
## 2 1881        -0.08        -0.40          0.01              243
## 3 1882        -0.10        -0.48          0.00              256
## 4 1883        -0.18        -0.66         -0.04              272
## 5 1884        -0.26        -0.69         -0.14              275
## 6 1885        -0.25        -0.56         -0.17              277
```

```
tail(temp_carbon)
```

```
##     year temp_anomaly land_anomaly ocean_anomaly carbon_emissions
## 263 1874           NA           NA            NA              174
## 264 1875           NA           NA            NA              188
## 265 1876           NA           NA            NA              191
## 266 1877           NA           NA            NA              194
## 267 1878           NA           NA            NA              196
## 268 1879           NA           NA            NA              210
```

```
summary(temp_carbon)
```

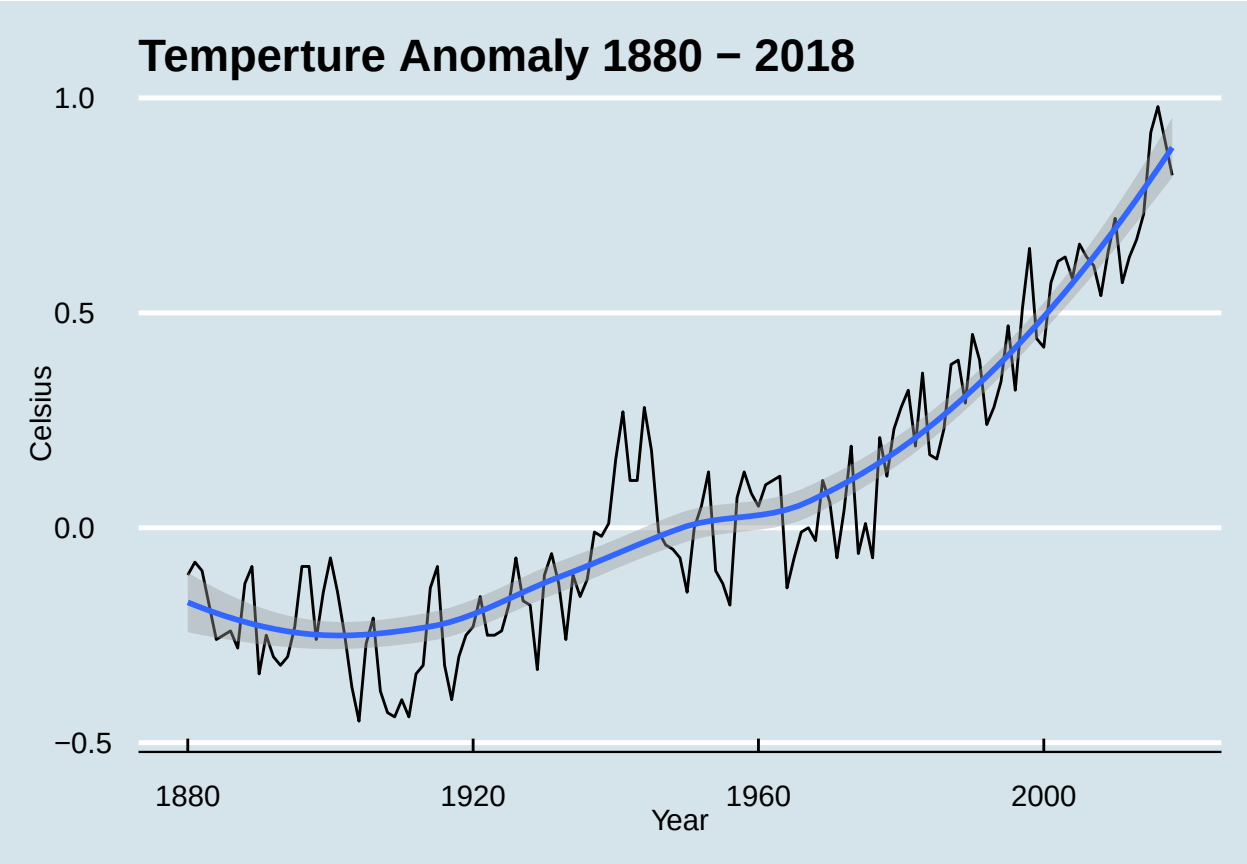
```
##       year       temp_anomaly     land_anomaly      ocean_anomaly
##  Min.   :1751   Min.   :-0.450   Min.   :-0.69000   Min.   :-0.46000
##  1st Qu.:1818   1st Qu.:-0.180   1st Qu.:-0.31500   1st Qu.:-0.17000
##  Median :1884   Median :-0.030   Median :-0.05000   Median :-0.01000
##  Mean   :1884   Mean   : 0.060   Mean   : 0.07086   Mean   : 0.05273
##  3rd Qu.:1951   3rd Qu.: 0.275   3rd Qu.: 0.30500   3rd Qu.: 0.25500
##  Max.   :2018   Max.   : 0.980   Max.   : 1.50000   Max.   : 0.79000
##                 NA's   :129      NA's   :129        NA's   :129
##  carbon_emissions
##  Min.   :   3.00
##  1st Qu.:  13.75
##  Median : 264.00
##  Mean   :1522.98
##  3rd Qu.:1431.50
##  Max.   :9855.00
##  NA's   :4
```

```
str(temp_carbon)
```

```
## 'data.frame':    268 obs. of  5 variables:
##  $ year            : num  1880 1881 1882 1883 1884 ...
##  $ temp_anomaly    : num  -0.11 -0.08 -0.1 -0.18 -0.26 -0.25 -0.24 -0.28 -0.13 -0.09 ...
##  $ land_anomaly    : num  -0.48 -0.4 -0.48 -0.66 -0.69 -0.56 -0.51 -0.47 -0.41 -0.31 ...
##  $ ocean_anomaly   : num  -0.01 0.01 0 -0.04 -0.14 -0.17 -0.17 -0.23 -0.05 -0.02 ...
##  $ carbon_emissions: num  236 243 256 272 275 277 281 295 327 327 ...
```

plot of temperatures anomaly 1880-2018

```
temp_carbon %>% filter(year >= 1880) %>%
  ggplot(aes(year,temp_anomaly)) +
  geom_line() +
  geom_smooth() +
  xlab("Year") +
  ylab("Celsius") +
  ggtitle("Temperture Anomaly 1880 - 2018") +
  theme_economist()
```



Above we can see that annual mean temperatures have been rising over the last century. The following is a quote from NASA explaining why that matters:

So, the Earth's average temperature has increased about 2 degrees Fahrenheit during the 20th century. What's the big deal?

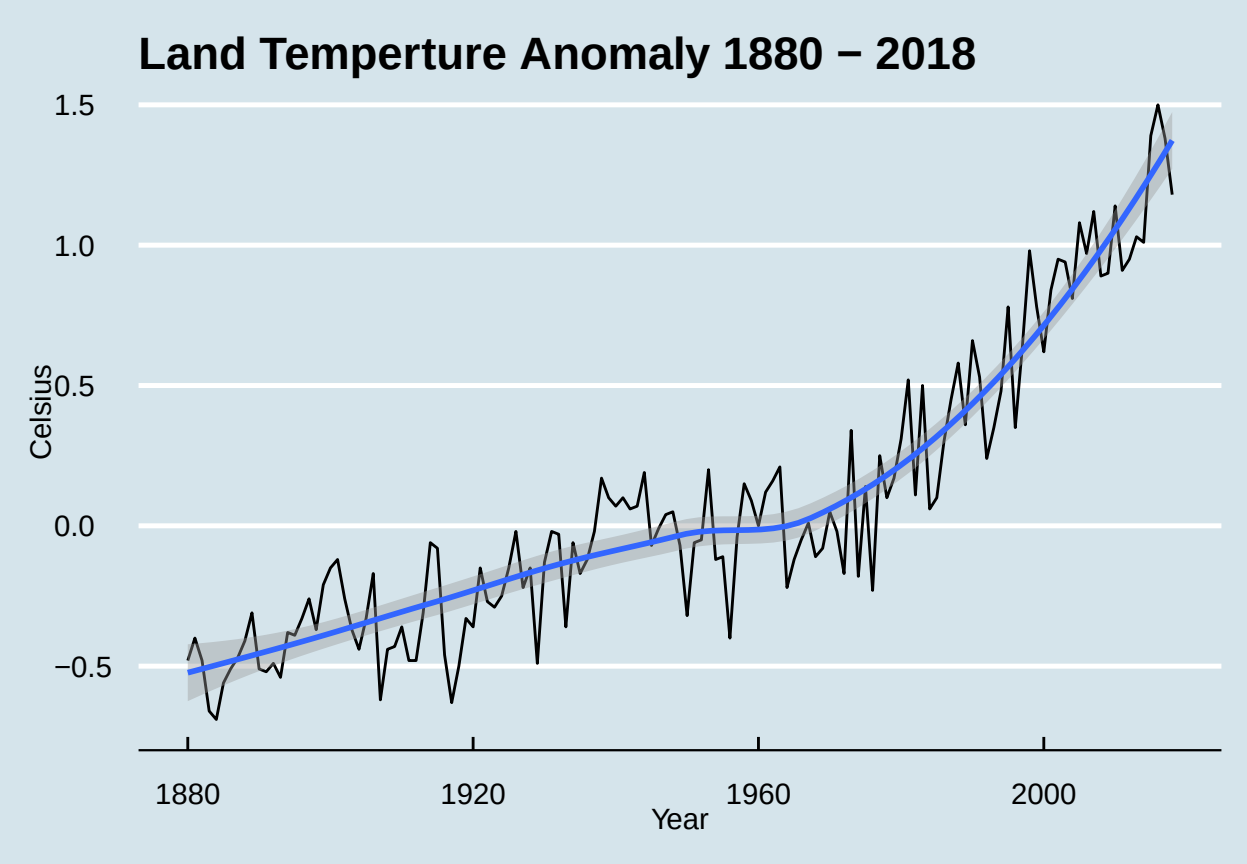
Two degrees may sound like a small amount, but it's an unusual event in our planet's recent history. Earth's climate record, preserved in tree rings, ice cores, and coral reefs, shows that the global average temperature is stable over long periods of time. Furthermore, small changes in temperature correspond to enormous changes in the environment.

For example, at the end of the last ice age, when the Northeast United States was covered by more than 3,000 feet of ice, average temperatures were only 5 to 9 degrees cooler than today.

https://climate.nasa.gov/effects/

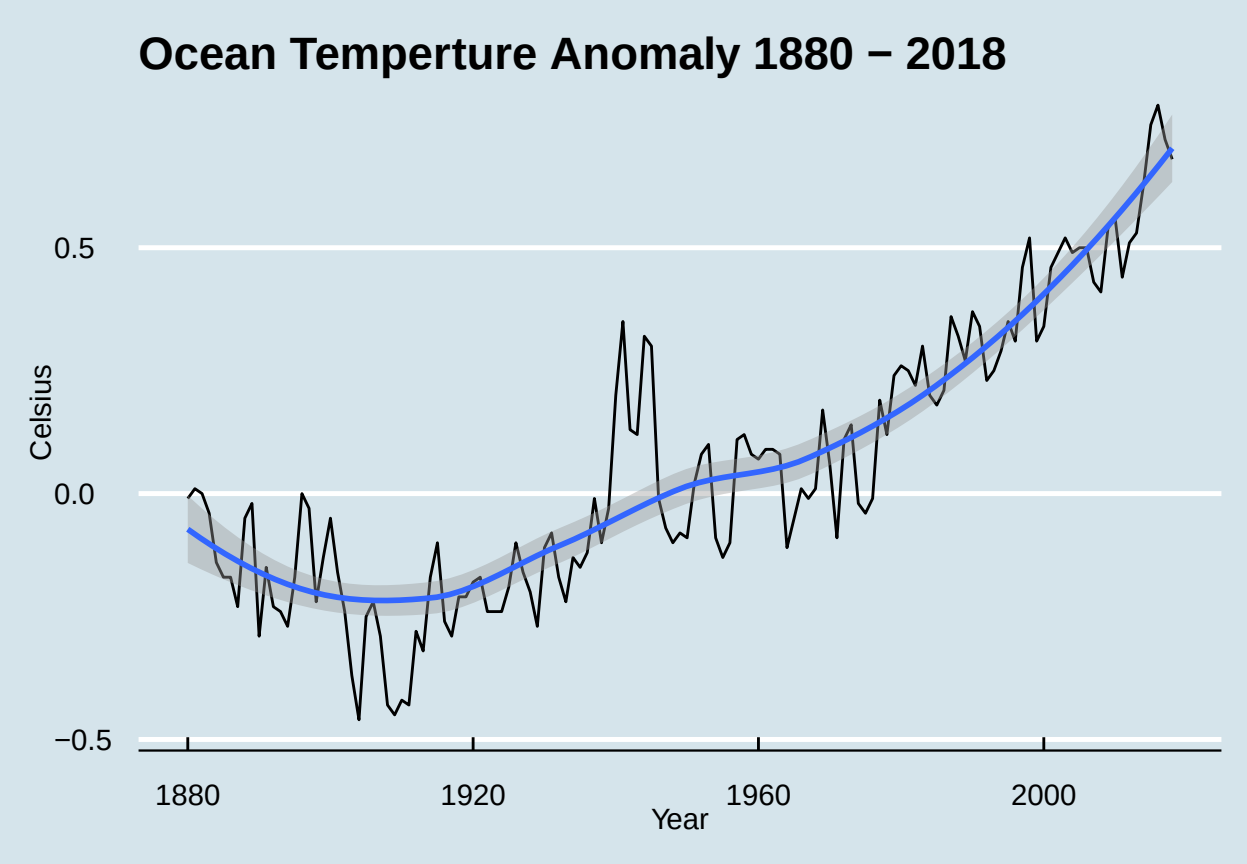
plot of land temperatures from 1880-2018

```
temp_carbon %>% filter(year >= 1880) %>%
  ggplot(aes(year,land_anomaly)) +
  geom_line() +
  geom_smooth() +
  xlab("Year") +
  ylab("Celsius") +
  ggtitle("Land Temperture Anomaly 1880 - 2018") +
  theme_economist()
```



plot of ocean temperatures from 1880-2018

```
temp_carbon %>% filter(year >= 1880) %>%
  ggplot(aes(year,ocean_anomaly)) +
  geom_line() +
  geom_smooth() +
  xlab("Year") +
  ylab("Celsius") +
  ggtitle("Ocean Temperture Anomaly 1880 - 2018") +
  theme_economist()
```



All three graphs show that our climate has had rising temperatures over the past century.

4. Observed Carbon

Now let us take a look at the data we will use for observed carbon.

```
#looking at the data
dim(historic_co2)
```

```
## [1] 694   3
```

```
head(historic_co2)
```

```
## # A tibble: 6 x 3
##    year   co2 source
##   <dbl> <dbl> <chr>
## 1  1959  316. Mauna Loa
## 2  1960  317. Mauna Loa
## 3  1961  318. Mauna Loa
## 4  1962  318. Mauna Loa
## 5  1963  319. Mauna Loa
## 6  1964  320. Mauna Loa
```

```
tail(historic_co2)
```

```
## # A tibble: 6 x 3
##      year   co2 source
##     <dbl> <dbl> <chr>
## 1 -790081  225. Ice Cores
## 2 -791903  218. Ice Cores
## 3 -794903  199. Ice Cores
## 4 -799286  199. Ice Cores
## 5 -801975  203. Ice Cores
## 6 -803182  202. Ice Cores
```

```
summary(historic_co2)
```

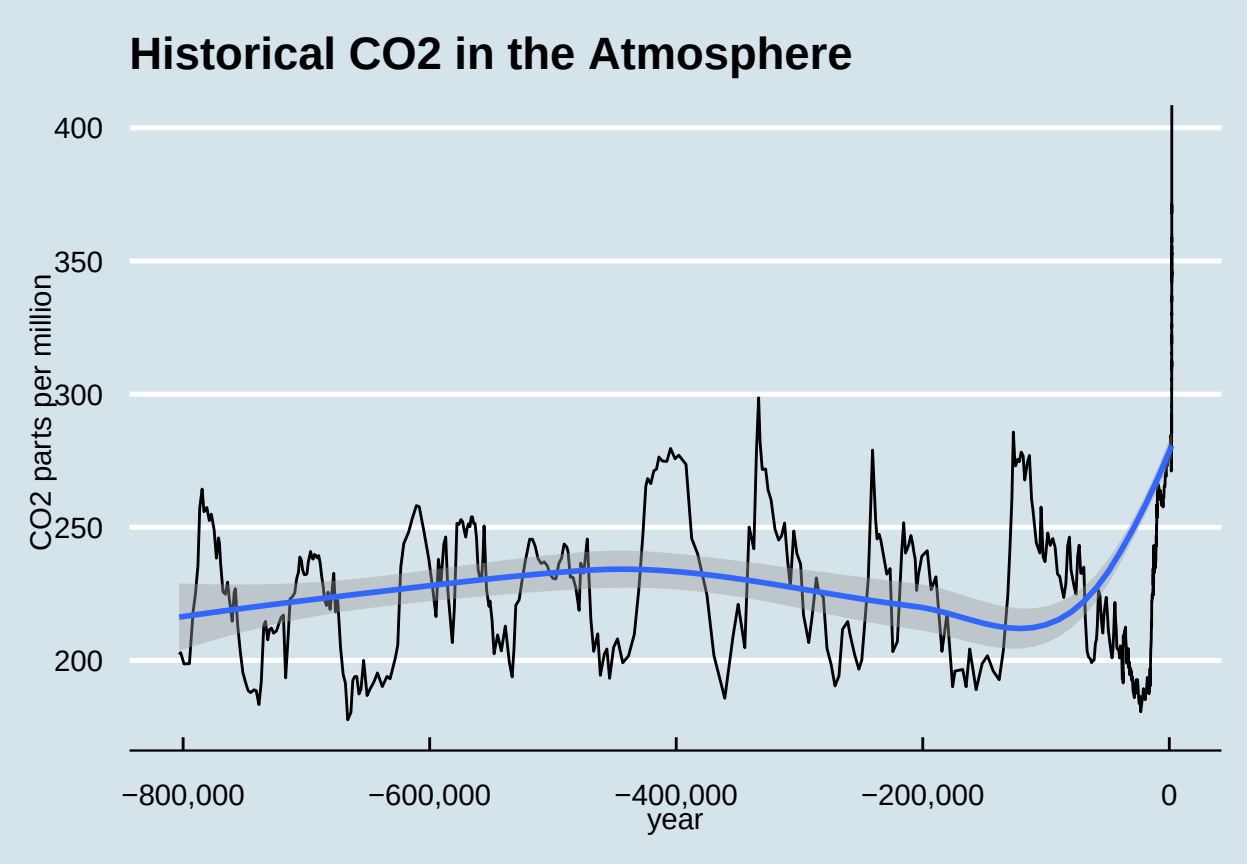
```
##       year              co2           source
##  Min.   :-803182   Min.   :177.7   Length:694
##  1st Qu.:-470498   1st Qu.:206.7   Class :character
##  Median : -43278   Median :236.9   Mode  :character
##  Mean   :-219753   Mean   :245.9
##  3rd Qu.:  -8924   3rd Qu.:271.8
##  Max.   :   2018   Max.   :408.5
```

```
str(historic_co2)
```

```
## spec_tbl_df[,3] [694 x 3] (S3: spec_tbl_df/tbl_df/tbl/data.frame)
##  $ year  : num [1:694] 1959 1960 1961 1962 1963 ...
##  $ co2   : num [1:694] 316 317 318 318 319 ...
##  $ source: chr [1:694] "Mauna Loa" "Mauna Loa" "Mauna Loa" "Mauna Loa" ...
```

plot of historical CO2 in the atmosphere

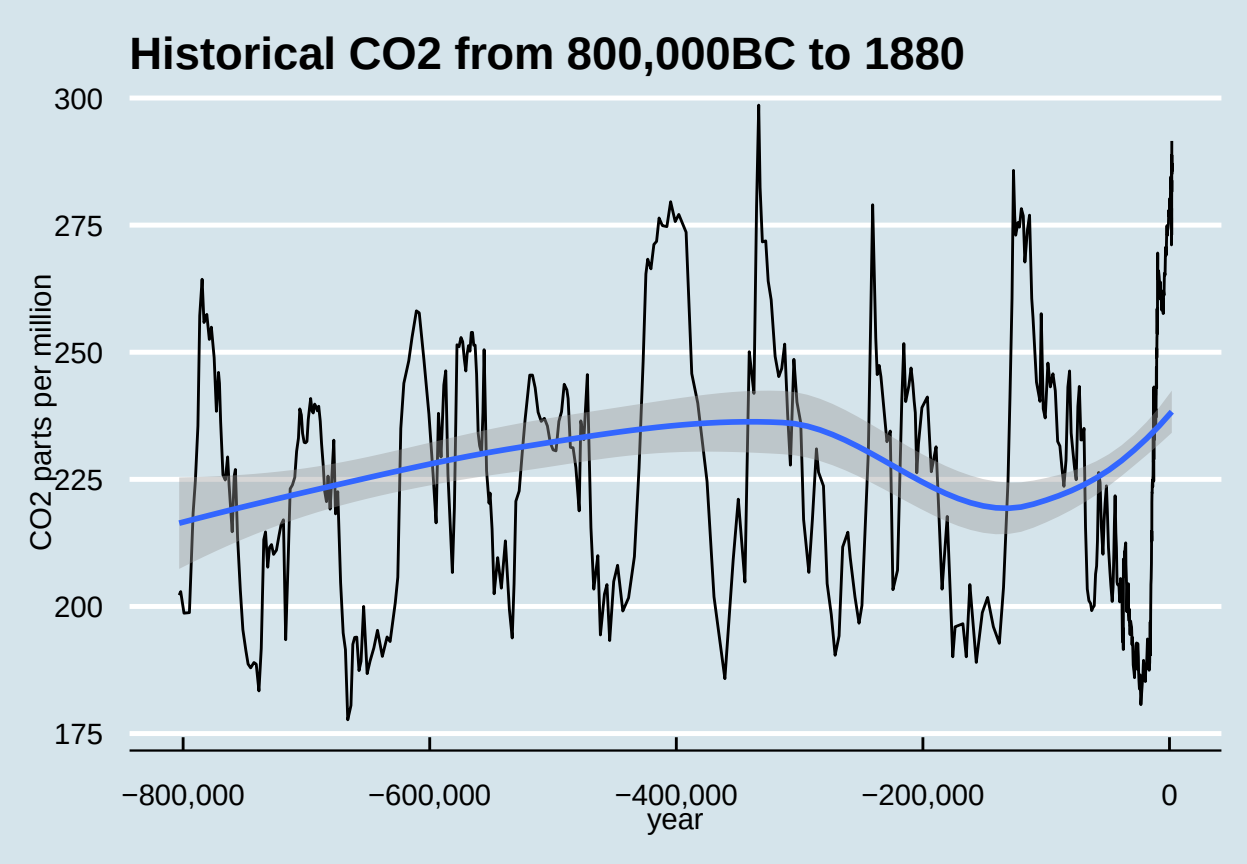
```
historic_co2 %>% ggplot(aes(year,co2)) +
  geom_line() +
  geom_smooth() +
  scale_x_continuous(labels = label_comma()) +
  ylab("CO2 parts per million") +
  ggtitle("Historical CO2 in the Atmosphere") +
  theme_economist()
```



As you can see the carbon in our atmosphere has a cyclical pattern that fluctuates over 100,000 year time frames. The recent results are completely out of the norm of the past 800,000 years.

plot of historical CO2 up to 1880

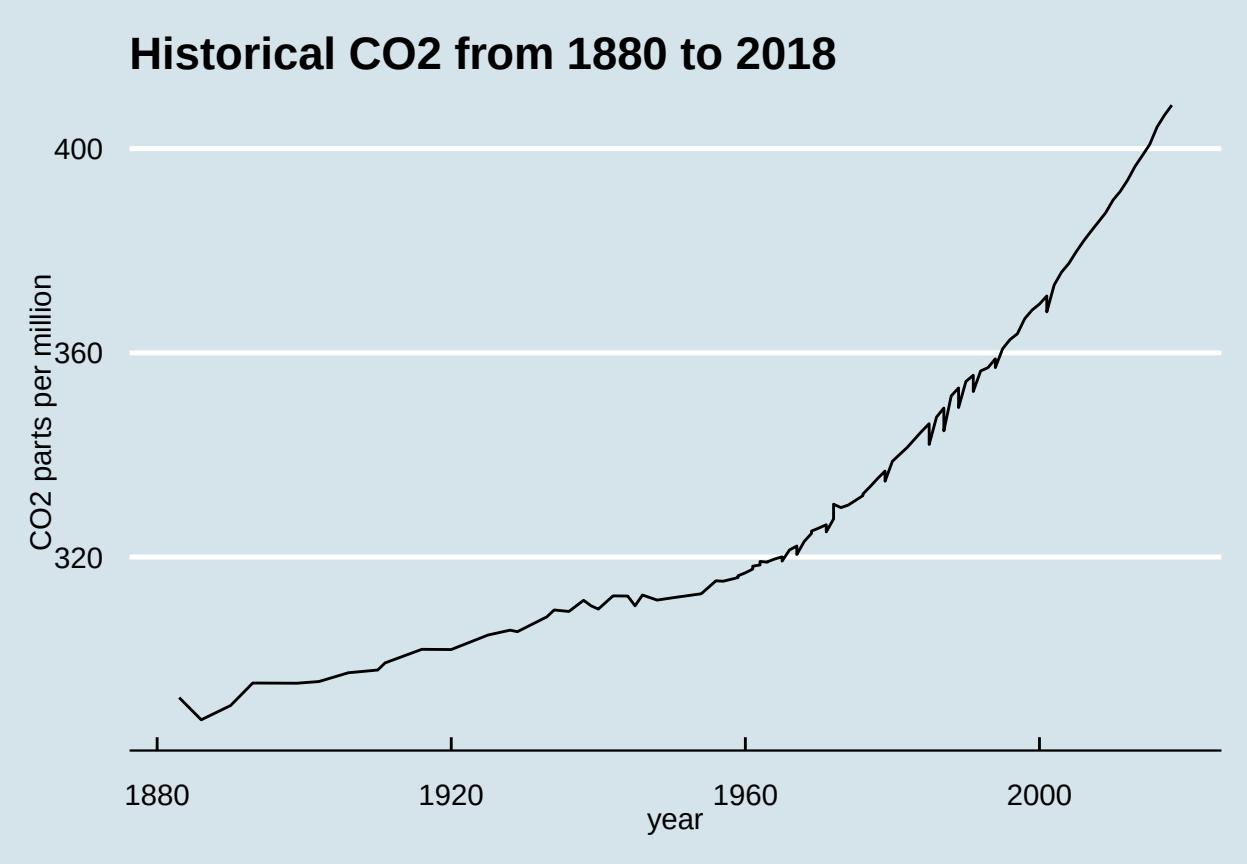
```
historic_co2 %>% filter(year <= 1880) %>%
  ggplot(aes(year,co2)) +
  geom_line() +
  geom_smooth() +
  scale_x_continuous(labels = label_comma()) +
  ylab("CO2 parts per million") +
  ggtitle("Historical CO2 from 800,000BC to 1880") +
  theme_economist()
```



Before 1880, the CO2 ppm would peak around 300 and drop down to below 200.

plot of historical Co2 from 1880-2018

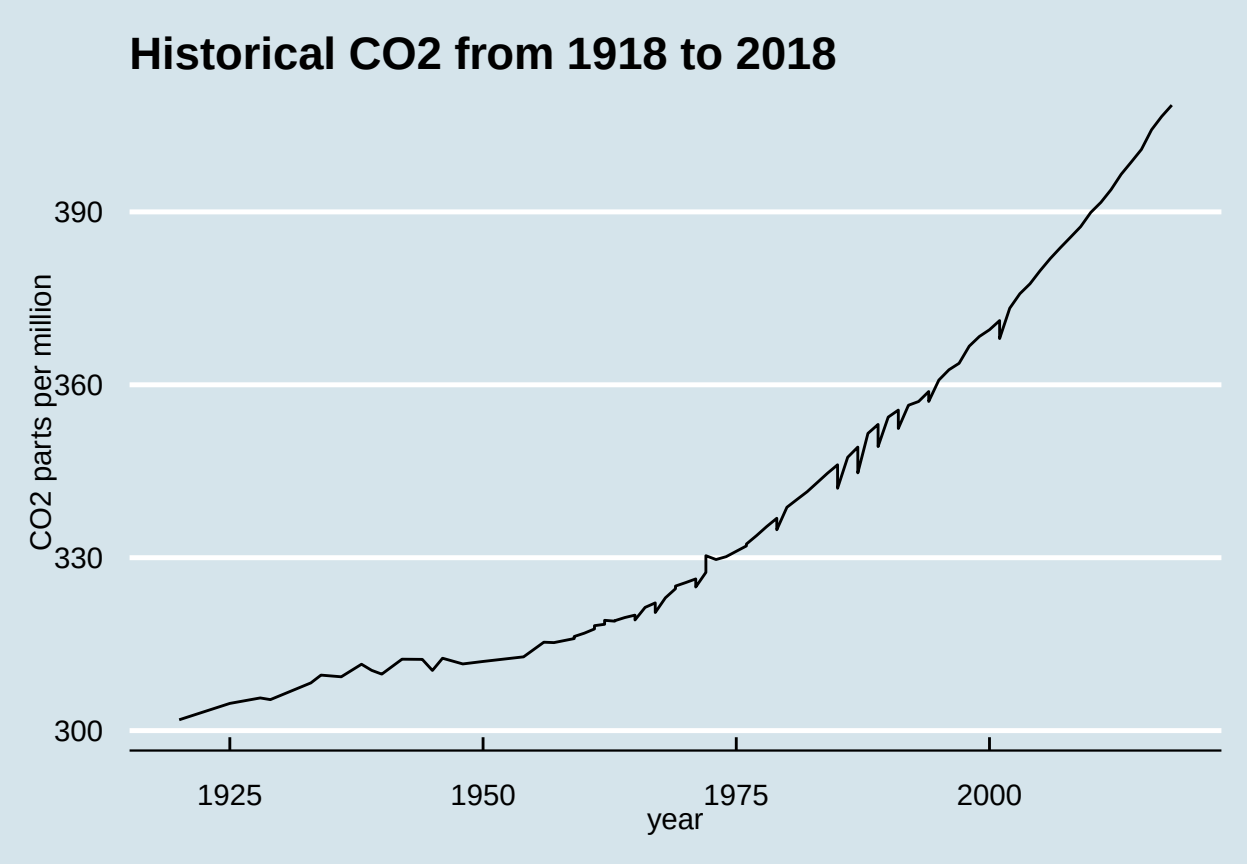
```
historic_co2 %>% filter(year >= 1880) %>%
  ggplot(aes(year,co2)) +
  geom_line() +
  ylab("CO2 parts per million") +
  ggtitle("Historical CO2 from 1880 to 2018") +
  theme_economist()
```



Since 1880 the observed carbon in the atmosphere has greatly deviated from the previous pattern. Blowing past the previous peak level of 300 and even going above 400.

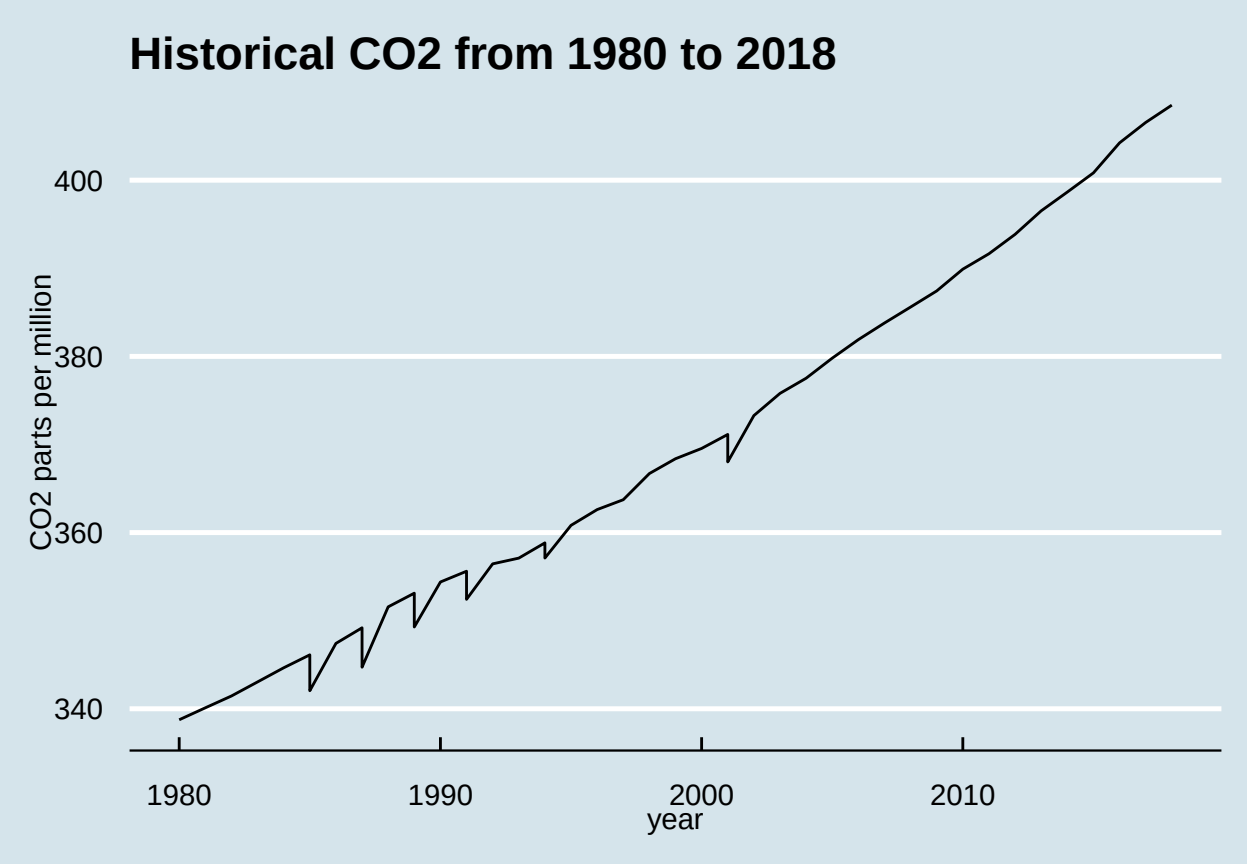
plot of historical Co2 from 1918-2018

```
historic_co2 %>% filter(year >= 1918) %>%
  ggplot(aes(year,co2)) +
  geom_line() +
  ylab("CO2 parts per million") +
  ggtitle("Historical CO2 from 1918 to 2018") +
  theme_economist()
```



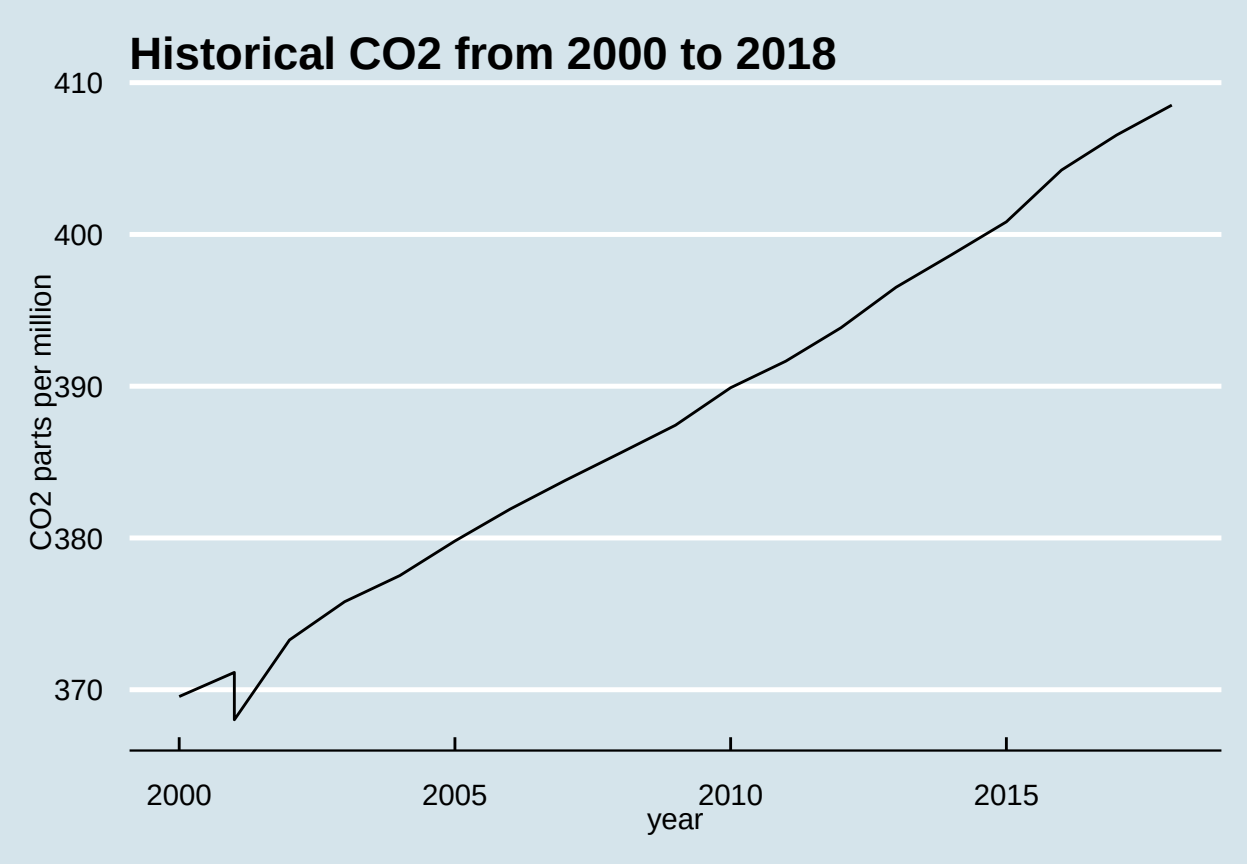
plot of historical Co2 from 1980-2018

```
historic_co2 %>% filter(year >= 1980) %>%
  ggplot(aes(year,co2)) +
  geom_line() +
  ylab("CO2 parts per million") +
  ggtitle("Historical CO2 from 1980 to 2018") +
  theme_economist()
```



plot of historical Co2 from 2000-2018

```
historic_co2 %>% filter(year >= 2000) %>%
  ggplot(aes(year,co2)) +
  geom_line() +
  ylab("CO2 parts per million") +
  ggtitle("Historical CO2 from 2000 to 2018") +
  theme_economist()
```

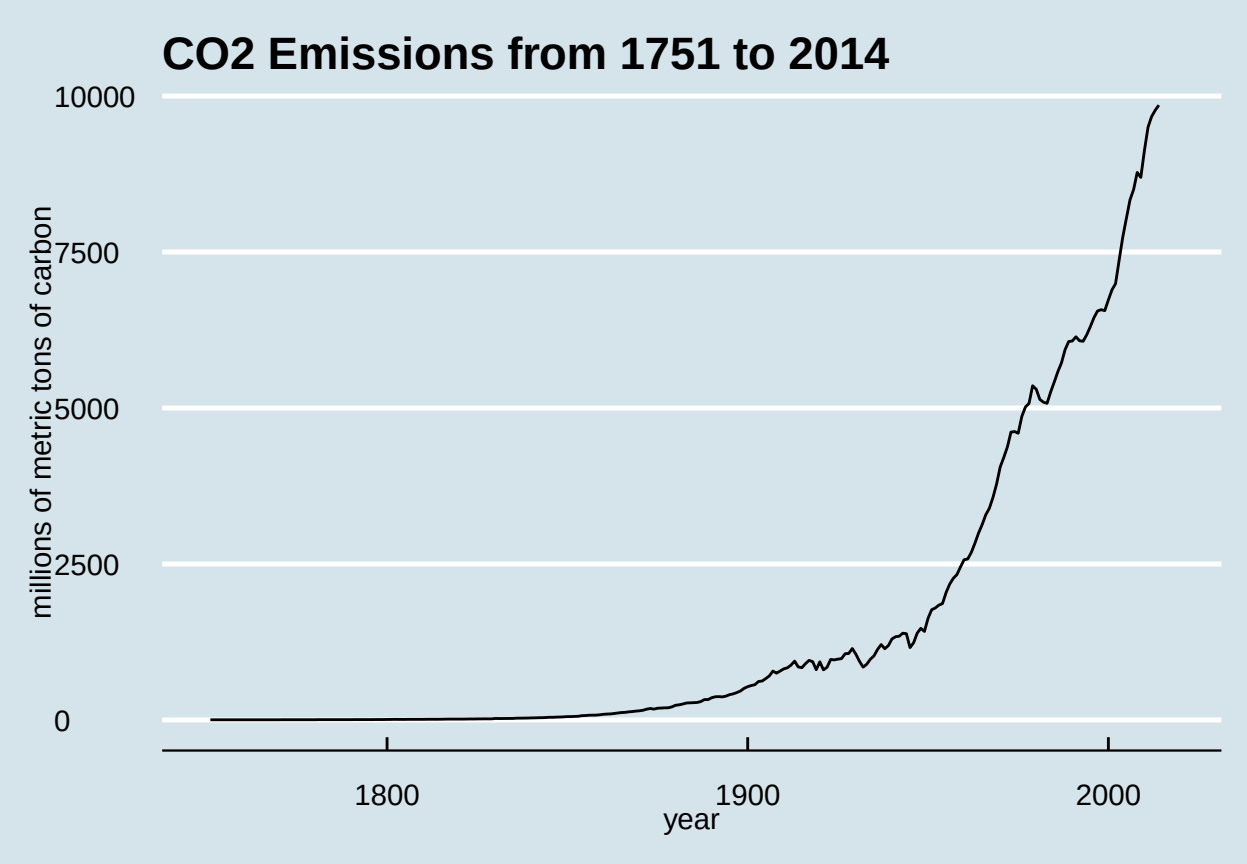


The last three graphs show that the co2 in the atmosphere is continuing to rise to record levels.

5. Carbon Admissions

plot of carbon emissions from 1751 to 2014

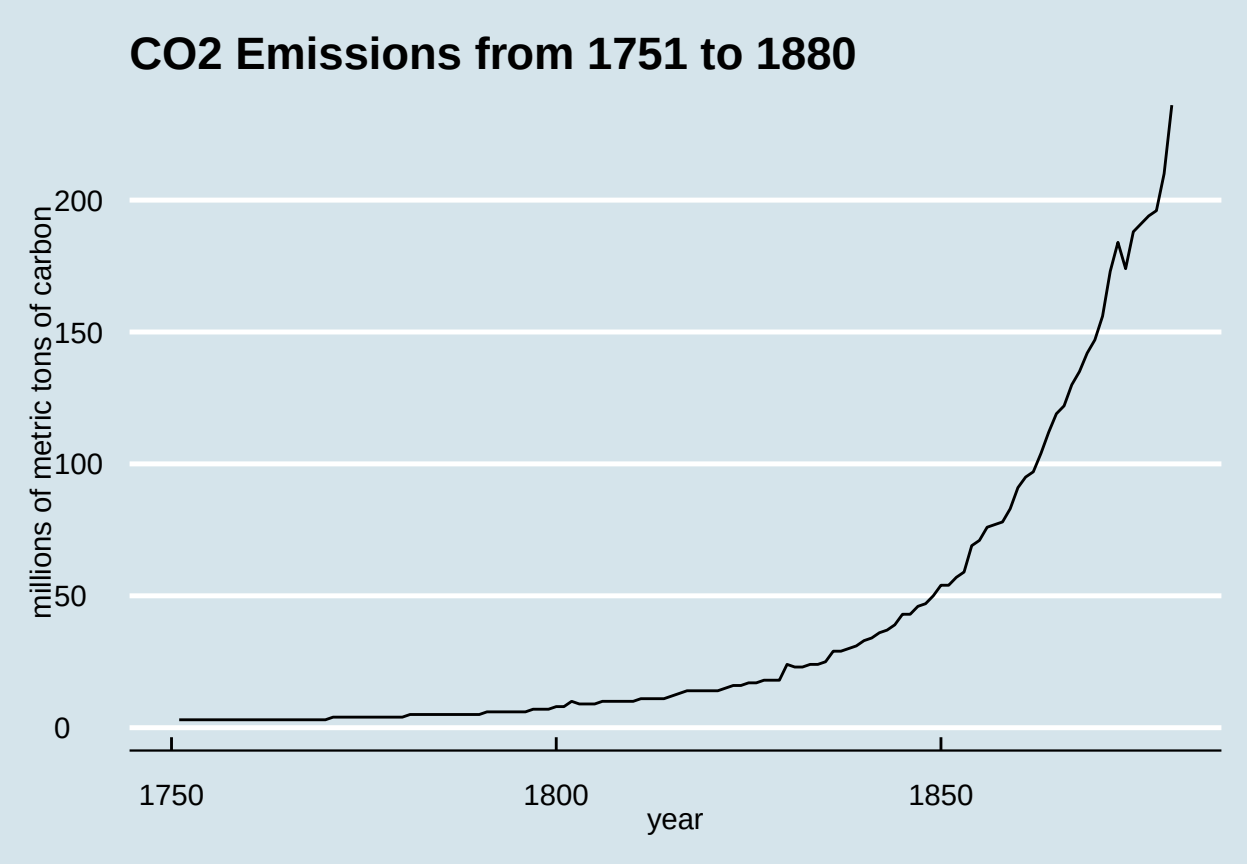
```
temp_carbon %>% ggplot(aes(year,carbon_emissions)) +
  geom_line() +
  ylab("millions of metric tons of carbon") +
  ggtitle("CO2 Emissions from 1751 to 2014") +
  theme_economist()
```



The CO2 emissions have gone way up as well. That may answer the question of why the observed CO2 has deviated so much from the previous pattern.

Plot of CO2 Emissions from 1751 to 1880

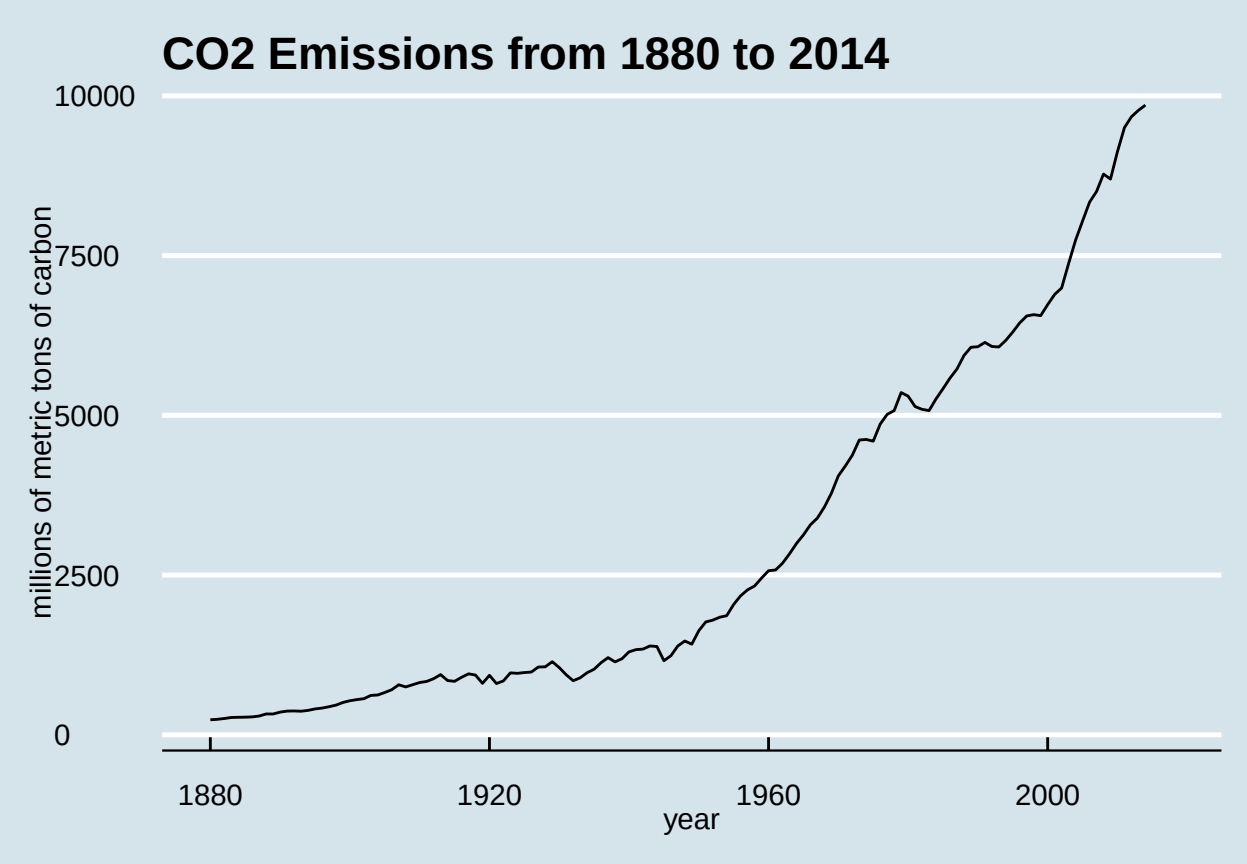
```
temp_carbon %>% filter(year <= 1880) %>%
  ggplot(aes(year,carbon_emissions)) +
  geom_line() +
  ylab("millions of metric tons of carbon") +
  ggtitle("CO2 Emissions from 1751 to 1880") +
  theme_economist()
```



In 1751 there was emissions of 3 millions metric tons of carbon. By 1880 it had risen to 236 million

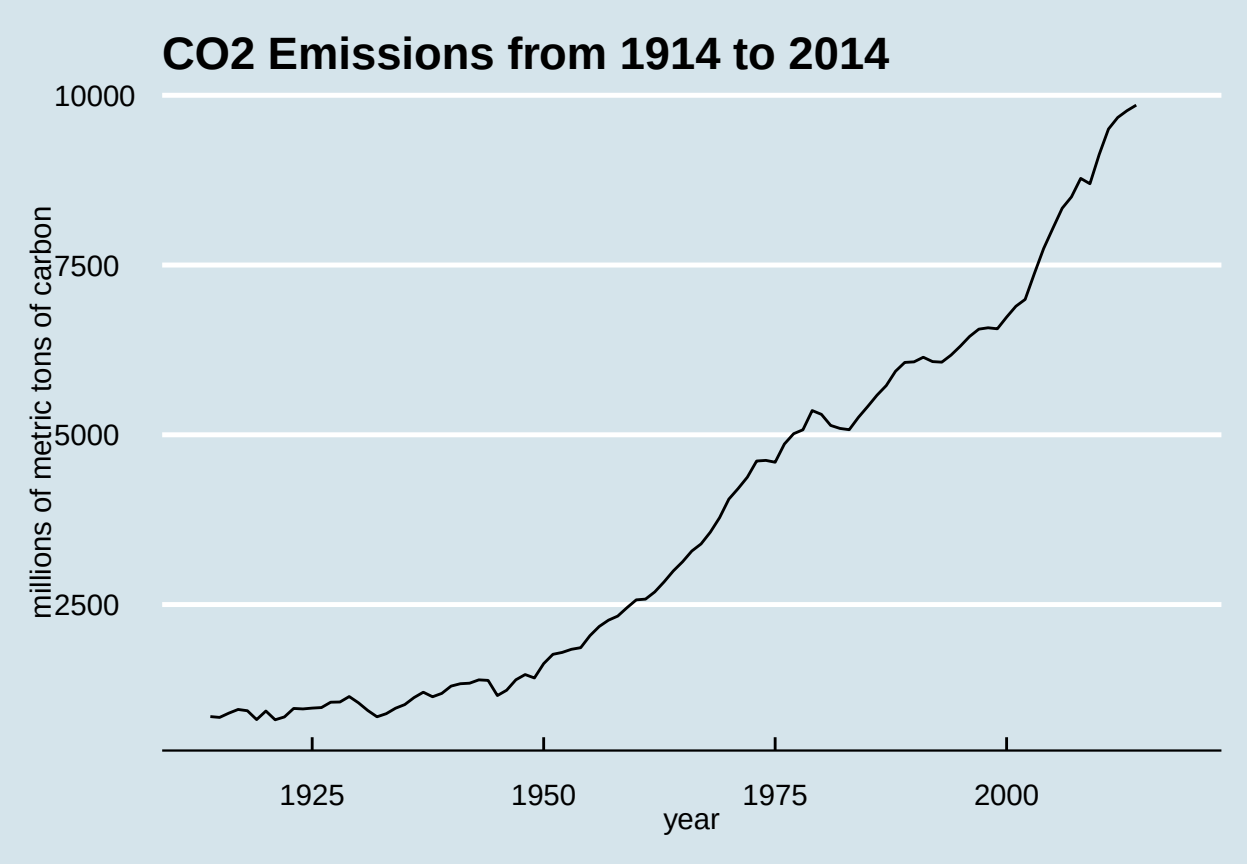
Plot of CO2 Emissions from 1880 to 2014

```
temp_carbon %>% filter(year >= 1880) %>%
  ggplot(aes(year,carbon_emissions)) +
  geom_line() +
  ylab("millions of metric tons of carbon") +
  ggtitle("CO2 Emissions from 1880 to 2014") +
  theme_economist()
```



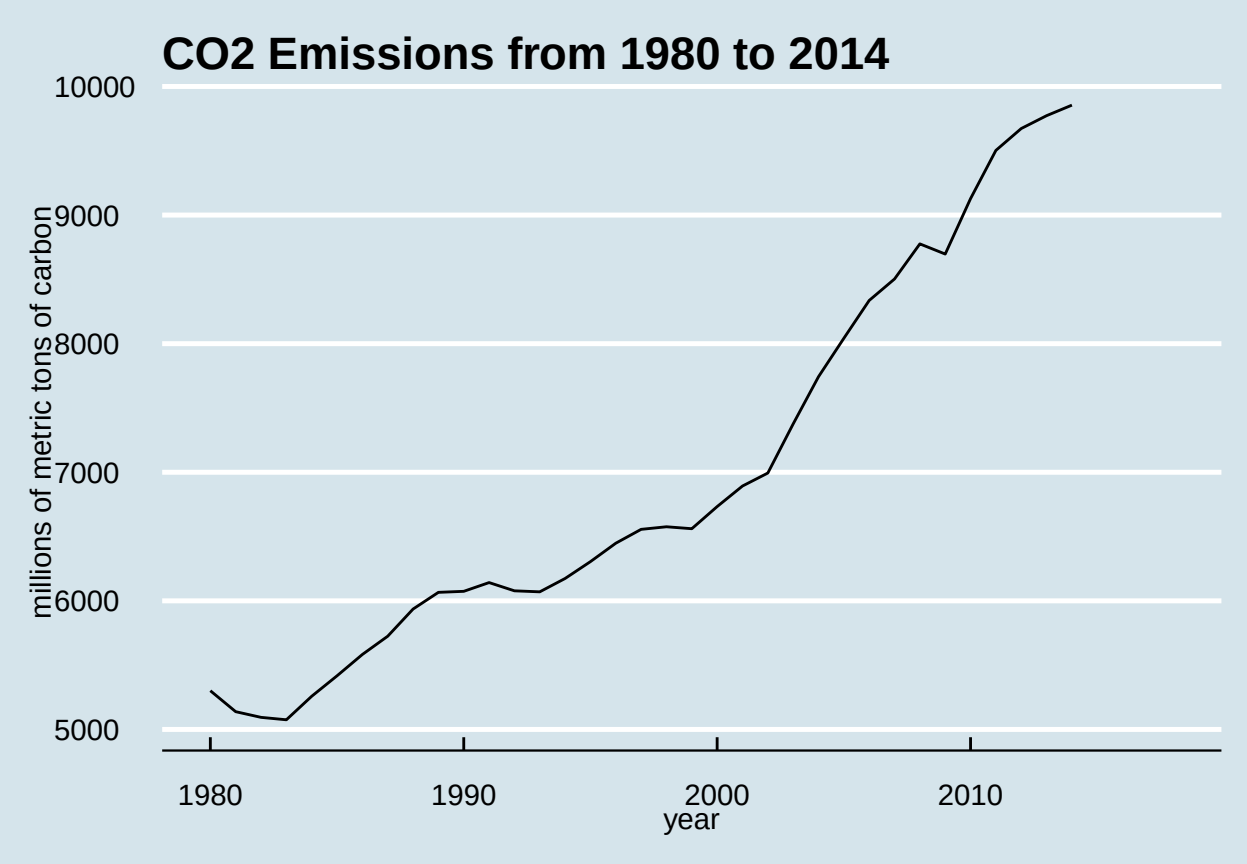
From 1880 to 2014 the CO2 emissions continued to rise.

```
temp_carbon %>% filter(year >= 1914) %>%
  ggplot(aes(year,carbon_emissions)) +
  geom_line() +
  ylab("millions of metric tons of carbon") +
  ggtitle("CO2 Emissions from 1914 to 2014") +
  theme_economist()
```



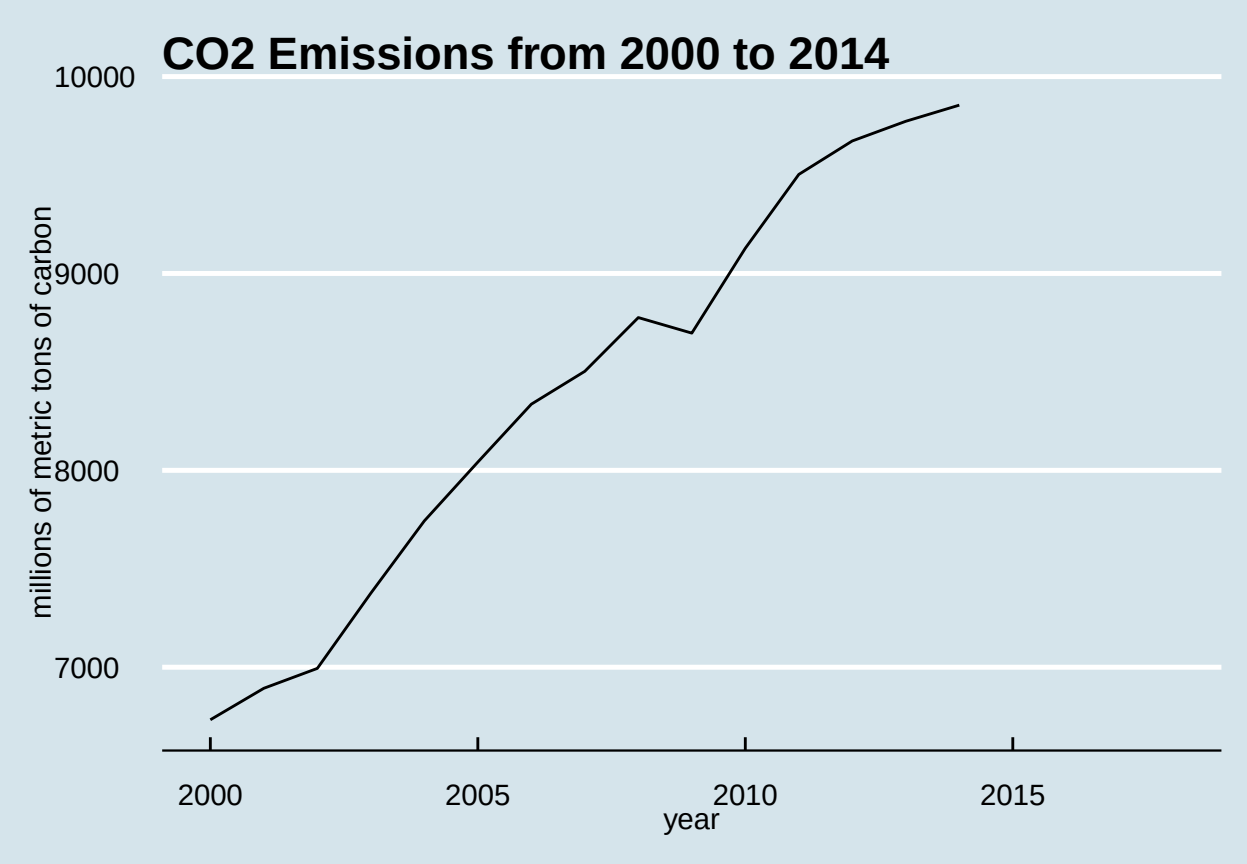
Plot of CO2 Emissions from 1980 to 2014

```
temp_carbon %>% filter(year >= 1980) %>%
  ggplot(aes(year,carbon_emissions)) +
  geom_line() +
  ylab("millions of metric tons of carbon") +
  ggtitle("CO2 Emissions from 1980 to 2014") +
  theme_economist()
```



Plot of CO2 Emissions so far this century

```
temp_carbon %>% filter(year >= 2000) %>%
  ggplot(aes(year,carbon_emissions)) +
  geom_line() +
  ylab("millions of metric tons of carbon") +
  ggtitle("CO2 Emissions from 2000 to 2014") +
  theme_economist()
```



In these last three plots we can see the continued rise of CO2 emissions.

6. Greenhouse Gases

looking at the data

```
dim(greenhouse_gases)
```

```
## [1] 300   3
```

```
head(greenhouse_gases)
```

```
##   year gas concentration
## 1   20 CO2         277.7
## 2   40 CO2         277.8
## 3   60 CO2         277.3
## 4   80 CO2         277.3
## 5  100 CO2         277.5
## 6  120 CO2         277.6
```

```
tail(greenhouse_gases)
```

```
##     year gas concentration
```

```
## 295 1900 N2O         277.2
## 296 1920 N2O         285.2
## 297 1940 N2O         287.7
## 298 1960 N2O         292.3
## 299 1980 N2O         302.6
## 300 2000 N2O         315.4
```

```
summary(greenhouse_gases)
```

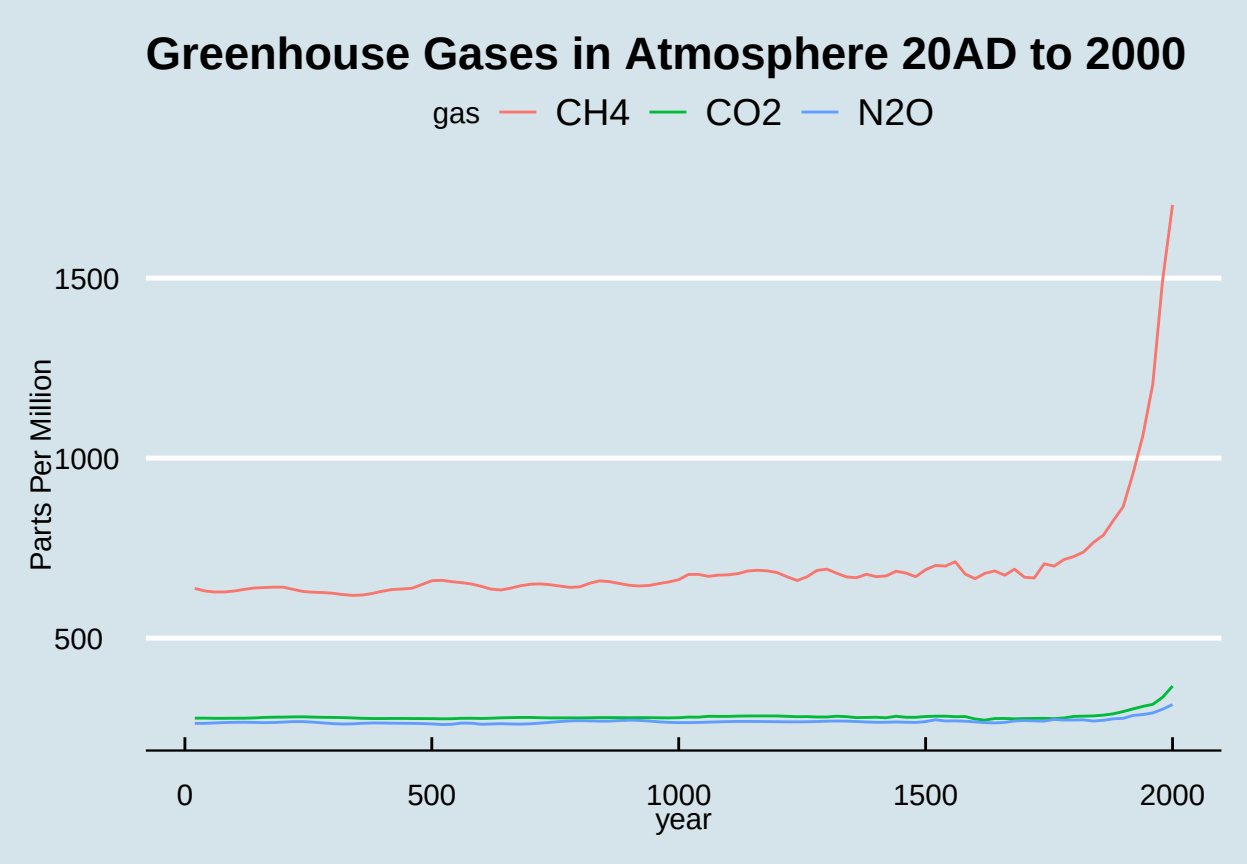
```
##       year          gas            concentration
##  Min.   :  20   Length:300         Min.   : 260.0
##  1st Qu.: 515   Class :character   1st Qu.: 269.7
##  Median :1010   Mode  :character   Median : 279.7
##  Mean   :1010                      Mean   : 416.2
##  3rd Qu.:1505                      3rd Qu.: 641.0
##  Max.   :2000                      Max.   :1703.4
```

```
str(greenhouse_gases)
```

```
## 'data.frame':    300 obs. of  3 variables:
##  $ year         : num  20 40 60 80 100 120 140 160 180 200 ...
##  $ gas          : chr  "CO2" "CO2" "CO2" "CO2" ...
##  $ concentration: num  278 278 277 277 278 ...
```

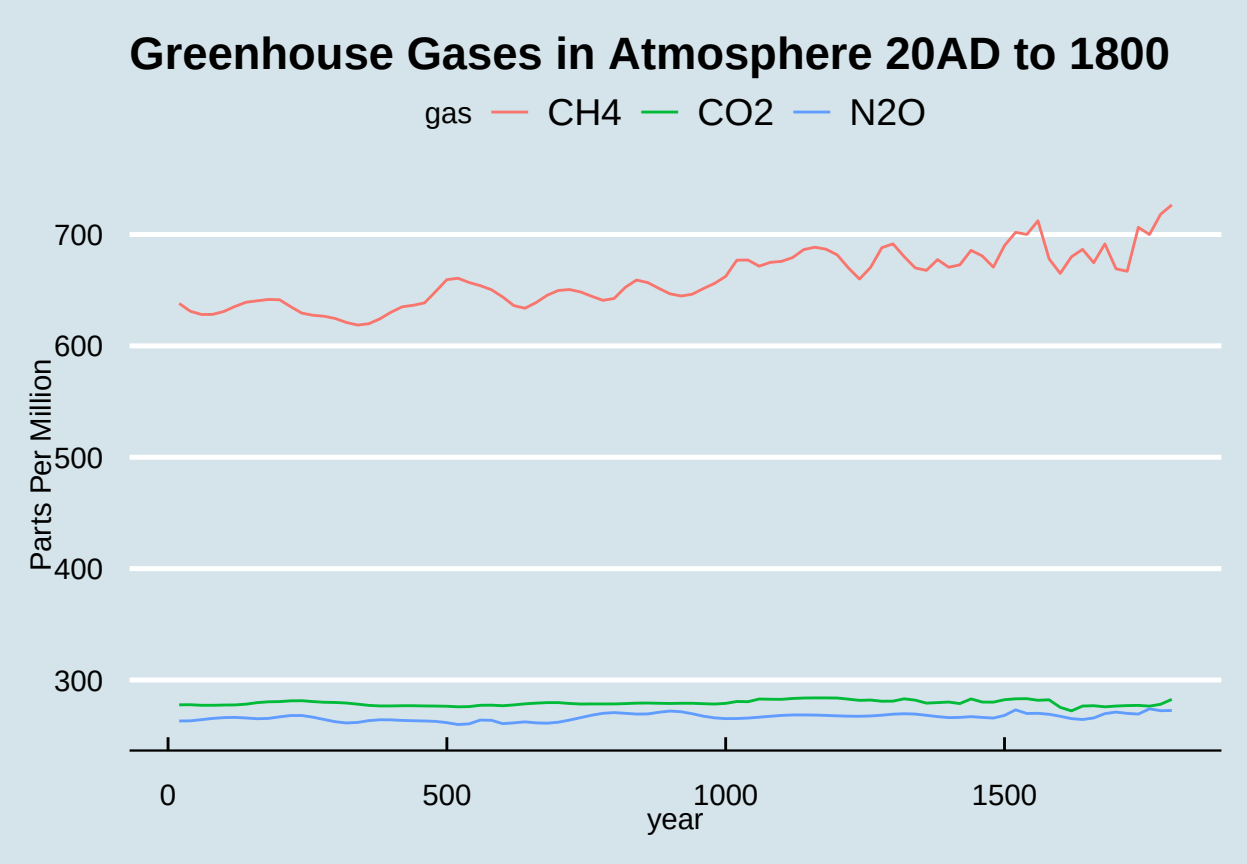
plot of greenhouse gases over the years

```
greenhouse_gases %>% ggplot(aes(year, concentration)) +
  geom_line(aes(colour = gas)) +
  ylab("Parts Per Million") +
  ggtitle("Greenhouse Gases in Atmosphere 20AD to 2000") +
  theme_economist()
```



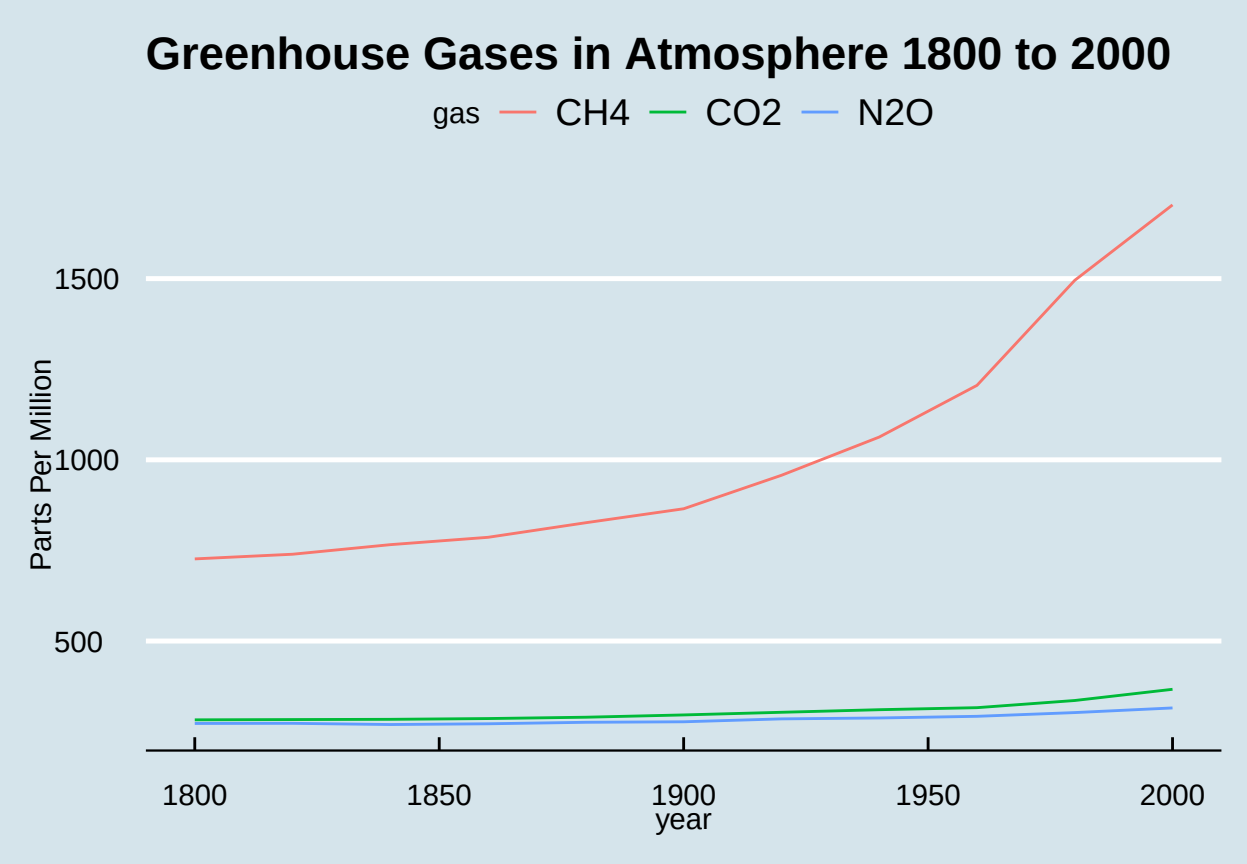
Here we can see unprecedented rise in CH4 also know as methane.

```
greenhouse_gases %>% filter(year <= 1800) %>%
  ggplot(aes(year, concentration)) +
  geom_line(aes(colour = gas)) +
  ylab("Parts Per Million") +
  ggtitle("Greenhouse Gases in Atmosphere 20AD to 1800") +
  theme_economist()
```



Up until the year 1800 the green house gases were stable.

```
greenhouse_gases %>% filter(year >= 1800) %>%
  ggplot(aes(year, concentration)) +
  geom_line(aes(colour = gas)) +
  ylab("Parts Per Million") +
  ggtitle("Greenhouse Gases in Atmosphere 1800 to 2000") +
  theme_economist()
```



But since then we have seen an unprecedented rise in greenhouse gases.

7. Summary

Climate Change is a difficult situation that we all face. We have seen through visually exploring the data that temperatures are rising, carbon concentration is rising, methane concentration is rising. The next step will be to find solutions that will allow us to level off greenhouse gases and maybe even reduce these concentrations back towards normal levels. If we don't, temperatures will continue to rise and that is an experiment I don't think we can afford to make.