# Mauna Loa Vignette

## Data Import and Packages

Packages

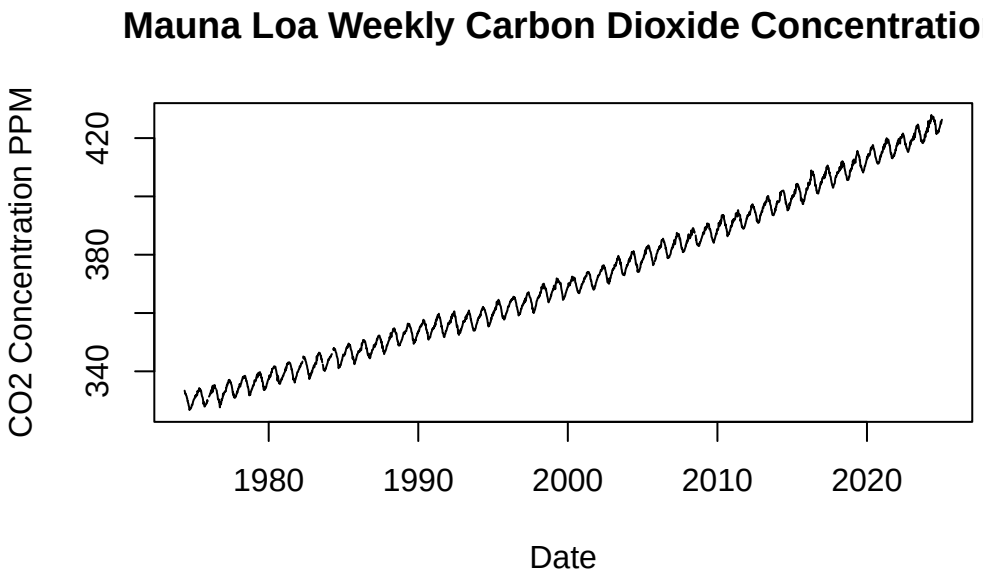
```
library(tidyverse)
```

```
-- Attaching core tidyverse packages ------------------------ tidyverse 2.0.0 --
v dplyr     1.1.4     v readr     2.1.5
v forcats   1.0.0     v stringr   1.5.1
v ggplot2   3.5.1     v tibble    3.2.1
v lubridate 1.9.3     v tidyr     1.3.1
v purrr     1.0.2
-- Conflicts ------------------------------------------ tidyverse_conflicts() --
x dplyr::filter() masks stats::filter()
x dplyr::lag()    masks stats::lag()
i Use the conflicted package (<http://conflicted.r-lib.org/>) to force all conflicts to becor
```

Data import

```
mauna_loa_weekly <-
  read.table('ftp://aftp.cmdl.noaa.gov/products/trends/co2/co2_weekly_mlo.txt')

mauna_loa_weekly <- mauna_loa_weekly[, c(1, 2, 3, 5)]

names(mauna_loa_weekly) <- c('year', 'month', 'day', 'co2ppm')

mauna_loa_weekly$date <- as.Date(paste(mauna_loa_weekly$year, mauna_loa_weekly$month, mauna_l

mauna_loa_weekly <- mauna_loa_weekly[, c('date', 'co2ppm')]

mauna_loa_weekly[mauna_loa_weekly$co2ppm == -999.99, ]$co2ppm = NA
```

```r
plot(
  mauna_loa_weekly$date,
  mauna_loa_weekly$co2ppm,
  type = 'l',
  xlab = 'Date',
  ylab = 'CO2 Concentration PPM',
  main = 'Mauna Loa Weekly Carbon Dioxide Concentration'
)
```

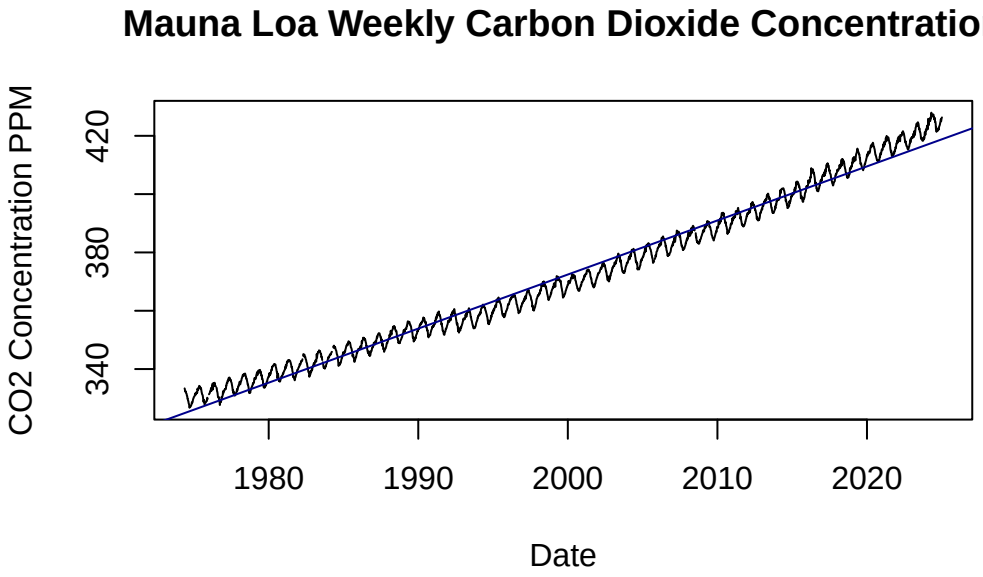



```r
trend <- lm(mauna_loa_weekly$co2ppm ~ mauna_loa_weekly$date)
summary(trend)
```

```
Call:
lm(formula = mauna_loa_weekly$co2ppm ~ mauna_loa_weekly$date)

Residuals:
    Min      1Q  Median      3Q     Max
-8.1674 -2.5142 -0.1861  2.5542 10.4471

Coefficients:
                        Estimate Std. Error t value Pr(>|t|)
(Intercept)           3.168e+02  1.583e-01  2001.0   <2e-16 ***
mauna_loa_weekly$date 5.077e-03  1.307e-05   388.5   <2e-16 ***
---
```

```
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 3.57 on 2623 degrees of freedom
  (18 observations deleted due to missingness)
Multiple R-squared:  0.9829,    Adjusted R-squared:  0.9829
F-statistic: 1.51e+05 on 1 and 2623 DF,  p-value: < 2.2e-16
```

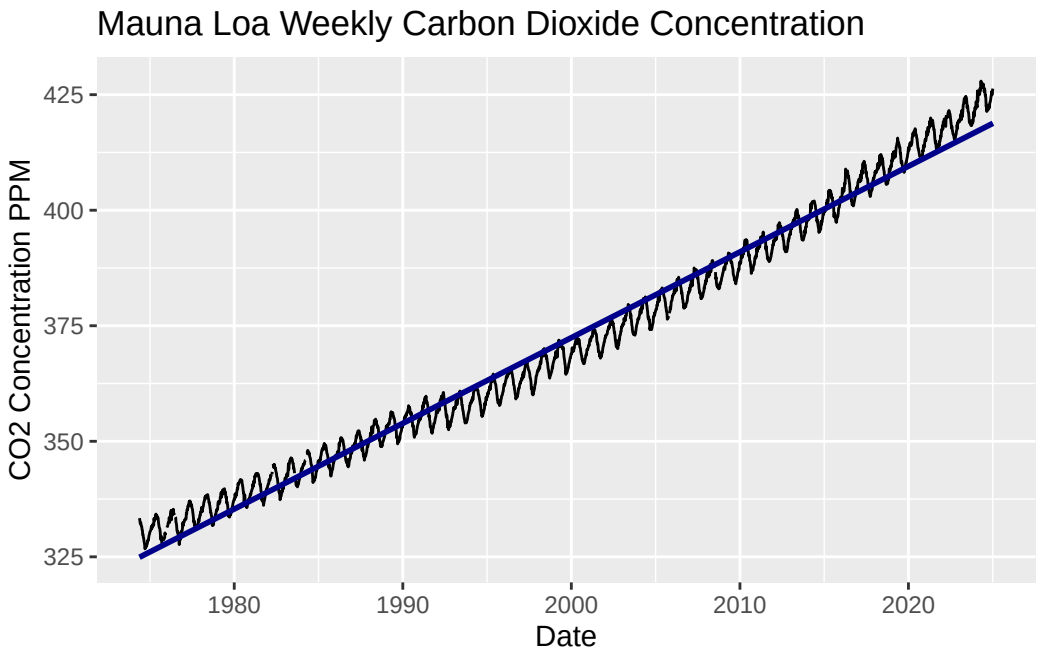
```r
plot(
  mauna_loa_weekly$date,
  mauna_loa_weekly$co2ppm,
  type = 'l',
  xlab = 'Date',
  ylab = 'CO2 Concentration PPM',
  main = 'Mauna Loa Weekly Carbon Dioxide Concentration'
)

abline(trend, col = "darkblue")
```




```r
ggplot(data = mauna_loa_weekly, aes(date, co2ppm)) +
  geom_line() +
  xlab('Date') +
  ylab('CO2 Concentration PPM') +
  ggtitle('Mauna Loa Weekly Carbon Dioxide Concentration') +
  stat_smooth(method = lm, color = 'dark blue')
```

```
`geom_smooth()` using formula = 'y ~ x'
```

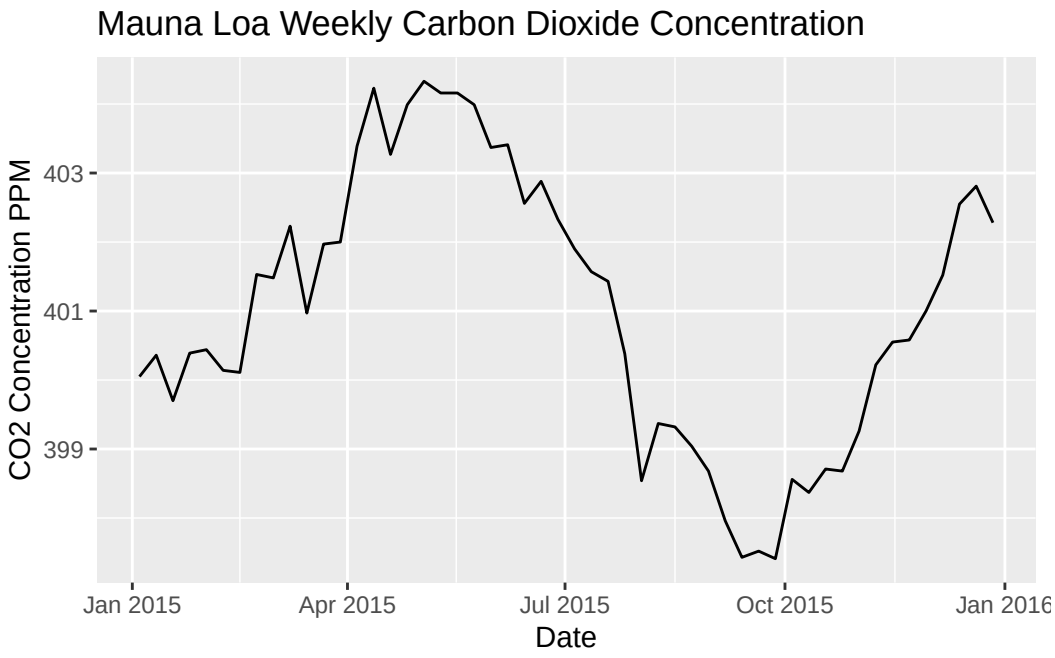
```
Warning: Removed 18 rows containing non-finite outside the scale range
(`stat_smooth()`).
```




```
mauna_loa_weekly |>
  subset(year(date) == 2015) |>
  summary()
```

```
      date                co2ppm
 Min.   :2015-01-04   Min.   :397.4
 1st Qu.:2015-04-03   1st Qu.:399.4
 Median :2015-07-01   Median :401.0
 Mean   :2015-07-01   Mean   :401.0
 3rd Qu.:2015-09-28   3rd Qu.:402.6
 Max.   :2015-12-27   Max.   :404.3
```

```
ggplot(data = mauna_loa_weekly %>% subset(year(date) == 2015), aes(date, co2ppm)) +
  geom_line() +
  xlab('Date') +
  ylab('CO2 Concentration PPM') +
  ggtitle('Mauna Loa Weekly Carbon Dioxide Concentration')
```



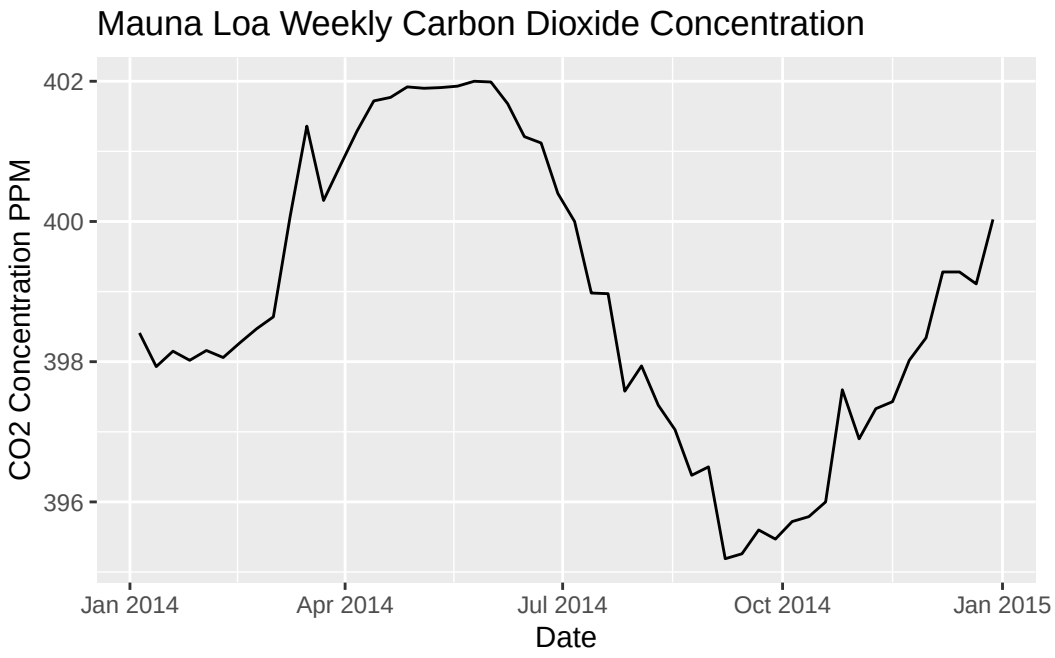

```
mauna_loa_weekly |>
  subset(year(date) == 2015) |>
  subset(co2ppm == max(co2ppm))
```

```
           date co2ppm
2138 2015-05-03 404.33
```

```
mauna_loa_weekly |>
  subset(year(date) == 2015) |>
  subset(co2ppm == min(co2ppm))
```

```
           date co2ppm
2159 2015-09-27 397.41
```

```
ggplot(data = mauna_loa_weekly %>% subset(year(date) == 2014), aes(date, co2ppm)) +
  geom_line() +
  xlab('Date') +
  ylab('CO2 Concentration PPM') +
  ggtitle('Mauna Loa Weekly Carbon Dioxide Concentration')
```



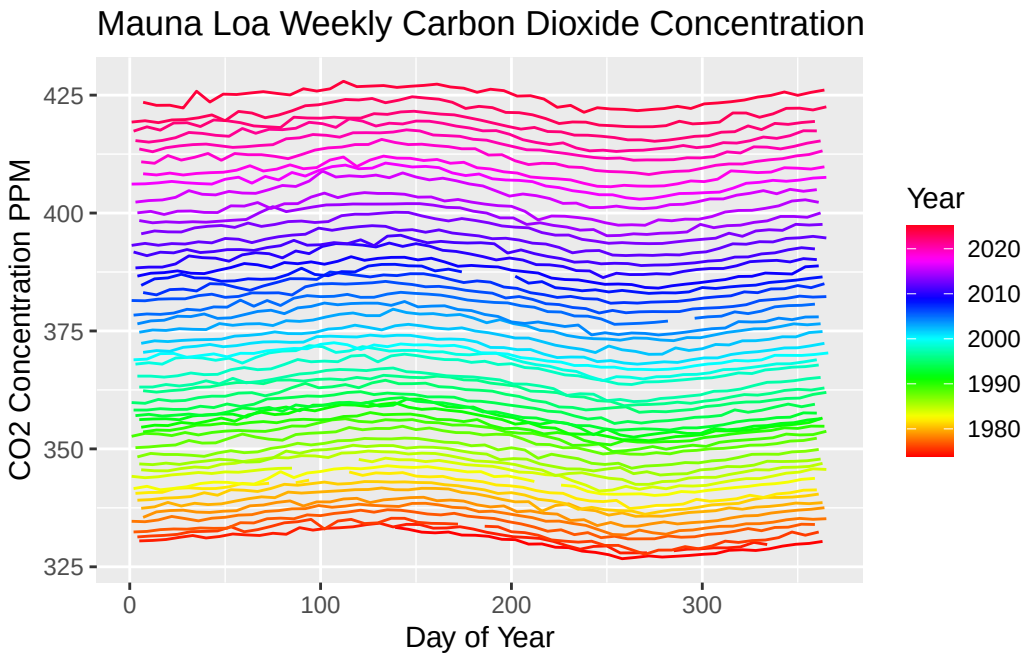

```
mauna_loa_weekly |> subset(year(date) == 2014) |>
  subset(co2ppm %in% c(min(co2ppm), max(co2ppm)))
```

```
           date co2ppm
2089 2014-05-25 402.00
2104 2014-09-07 395.19
```

```
mauna_loa_weekly$year <- year(mauna_loa_weekly$date)
mauna_loa_weekly$yday <- yday(mauna_loa_weekly$date)
```

```
ggplot(data = mauna_loa_weekly, aes(yday, co2ppm, colour = year, group = year)) +
  geom_line() +
  xlab('Day of Year') +
  ylab('CO2 Concentration PPM') +
  ggtitle('Mauna Loa Weekly Carbon Dioxide Concentration') +
  scale_color_gradientn('Year', colors = rainbow(length(unique(mauna_loa_weekly$year))))
```

```
Warning: Removed 4 rows containing missing values or values outside the scale range
(`geom_line()`).
```



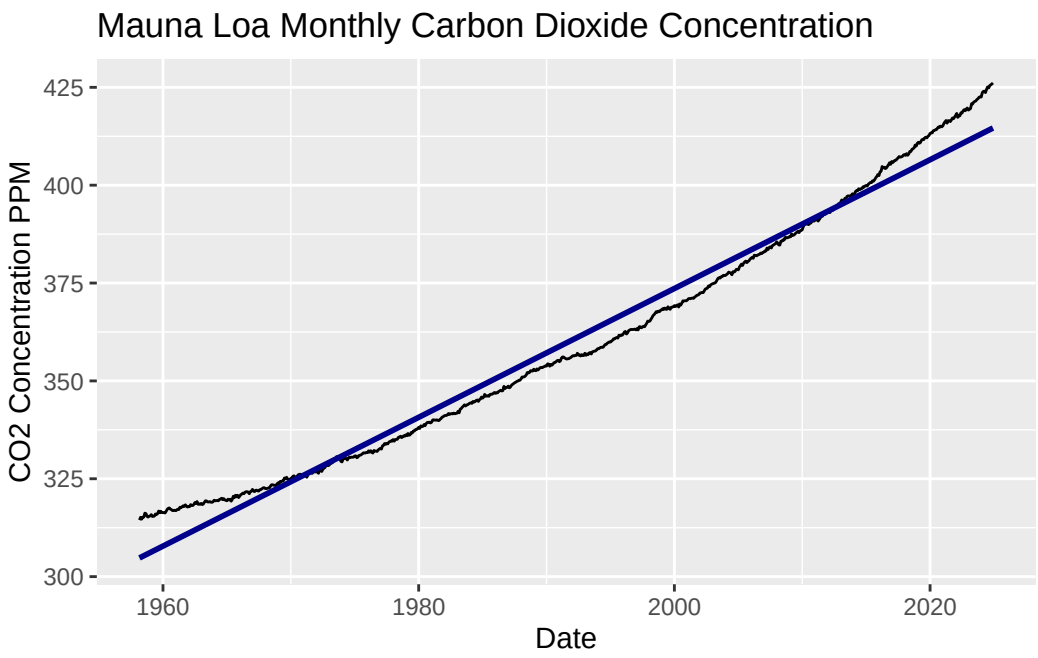

```
mauna_loa_monthly <- read.table('ftp://aftp.cmdl.noaa.gov/products/trends/co2/co2_mm_mlo.txt

mauna_loa_monthly <- mauna_loa_monthly[, c(1, 2, 5)]

names(mauna_loa_monthly) = c('year', 'month', 'co2ppm')

mauna_loa_monthly$date <- as.Date(paste(mauna_loa_monthly$year, mauna_loa_monthly$month, '01

summary(mauna_loa_monthly)
```

```
      year          month            co2ppm          date
 Min.   :1958   Min.   : 1.000   Min.   :314.4   Min.   :1958-03-01
 1st Qu.:1974   1st Qu.: 4.000   1st Qu.:330.5   1st Qu.:1974-11-08
 Median :1991   Median : 7.000   Median :355.8   Median :1991-07-16
 Mean   :1991   Mean   : 6.512   Mean   :359.7   Mean   :1991-07-17
 3rd Qu.:2008   3rd Qu.: 9.750   3rd Qu.:385.5   3rd Qu.:2008-03-24
 Max.   :2024   Max.   :12.000   Max.   :426.1   Max.   :2024-12-01
```

```
ggplot(data = mauna_loa_monthly, aes(date, co2ppm)) +
  geom_line() +
  xlab('Date') +
  ylab('CO2 Concentration PPM') +
```

```
  ggtitle('Mauna Loa Monthly Carbon Dioxide Concentration') +
  stat_smooth(method = lm, color = 'dark blue')
```

```
`geom_smooth()` using formula = 'y ~ x'
```

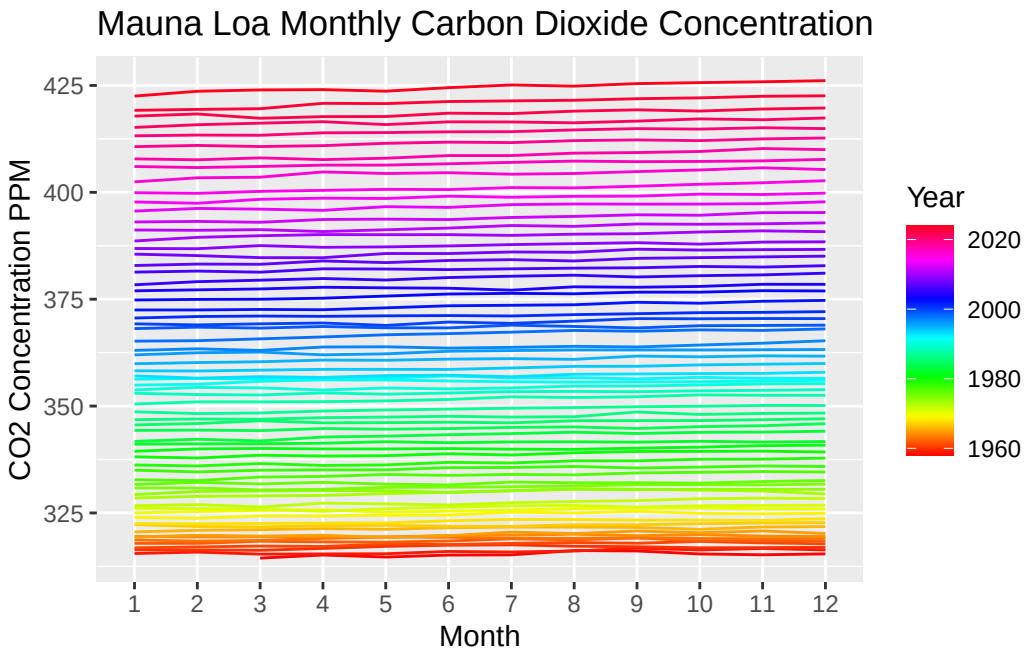



```
monthly_linear_trend <- lm(co2ppm ~ date, data = mauna_loa_monthly)
summary(monthly_linear_trend)
```

```
Call:
lm(formula = co2ppm ~ date, data = mauna_loa_monthly)

Residuals:
   Min     1Q Median     3Q    Max
-6.038 -3.352 -1.681  3.141 11.519

Coefficients:
             Estimate Std. Error t value Pr(>|t|)
(Intercept) 3.243e+02  2.386e-01  1359.2   <2e-16 ***
date        4.504e-03  2.259e-05   199.4   <2e-16 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
Residual standard error: 4.508 on 800 degrees of freedom
Multiple R-squared:  0.9803,    Adjusted R-squared:  0.9803
F-statistic: 3.977e+04 on 1 and 800 DF,  p-value: < 2.2e-16
```

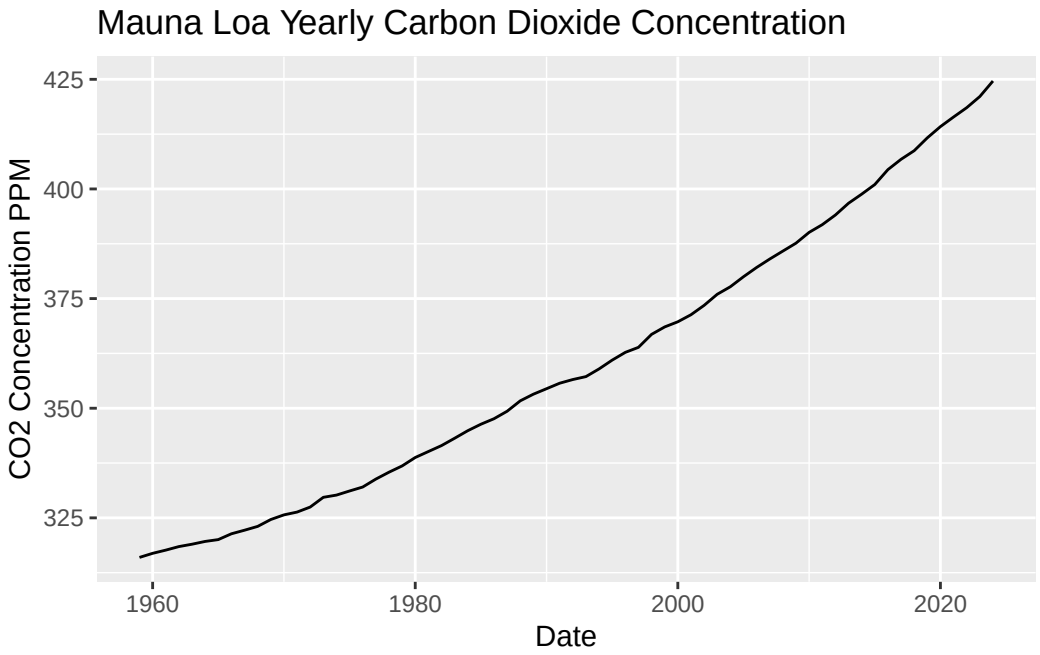
```
ggplot(data = mauna_loa_monthly, aes(factor(month), co2ppm, colour = year, group = year)) +
  geom_line() +
  xlab('Month') +
  ylab('CO2 Concentration PPM') +
  ggtitle('Mauna Loa Monthly Carbon Dioxide Concentration') +
  scale_color_gradientn('Year', colors = rainbow(length(unique(mauna_loa_weekly$year))))
```




```
mauna_loa_yearly <-
  read.table('ftp://aftp.cmdl.noaa.gov/products/trends/co2/co2_annmean_mlo.txt')
names(mauna_loa_yearly) <- c('year', 'co2ppm', 'uncertainty')
head(mauna_loa_yearly)
```

```
  year co2ppm uncertainty
1 1959 315.98        0.12
2 1960 316.91        0.12
3 1961 317.64        0.12
4 1962 318.45        0.12
5 1963 318.99        0.12
6 1964 319.62        0.12
```

```
ggplot(data = mauna_loa_yearly, aes(year, co2ppm)) +
    geom_ribbon(data = mauna_loa_yearly, aes(ymin = co2ppm - uncertainty, ymax = co2ppm + unc
  geom_line() +
  xlab('Date') +
  ylab('CO2 Concentration PPM') +
  ggtitle('Mauna Loa Yearly Carbon Dioxide Concentration')
```




```
mauna_loa_yearly$co2ppm.inc <- c(NA, diff(mauna_loa_yearly$co2ppm))
summary(mauna_loa_yearly)
```

```
      year          co2ppm       uncertainty     co2ppm.inc
 Min.   :1959   Min.   :316.0   Min.   :0.12   Min.   :0.420
 1st Qu.:1975   1st Qu.:331.4   1st Qu.:0.12   1st Qu.:1.140
 Median :1992   Median :356.1   Median :0.12   Median :1.700
 Mean   :1992   Mean   :360.2   Mean   :0.12   Mean   :1.671
 3rd Qu.:2008   3rd Qu.:385.4   3rd Qu.:0.12   3rd Qu.:2.130
 Max.   :2024   Max.   :424.6   Max.   :0.12   Max.   :3.530
                                               NA's   :1
```

```
mauna_loa_yearly %>% na.omit() %>% subset(co2ppm.inc %in% c(min(co2ppm.inc), max(co2ppm.inc)))
```

```
   year co2ppm uncertainty co2ppm.inc
```

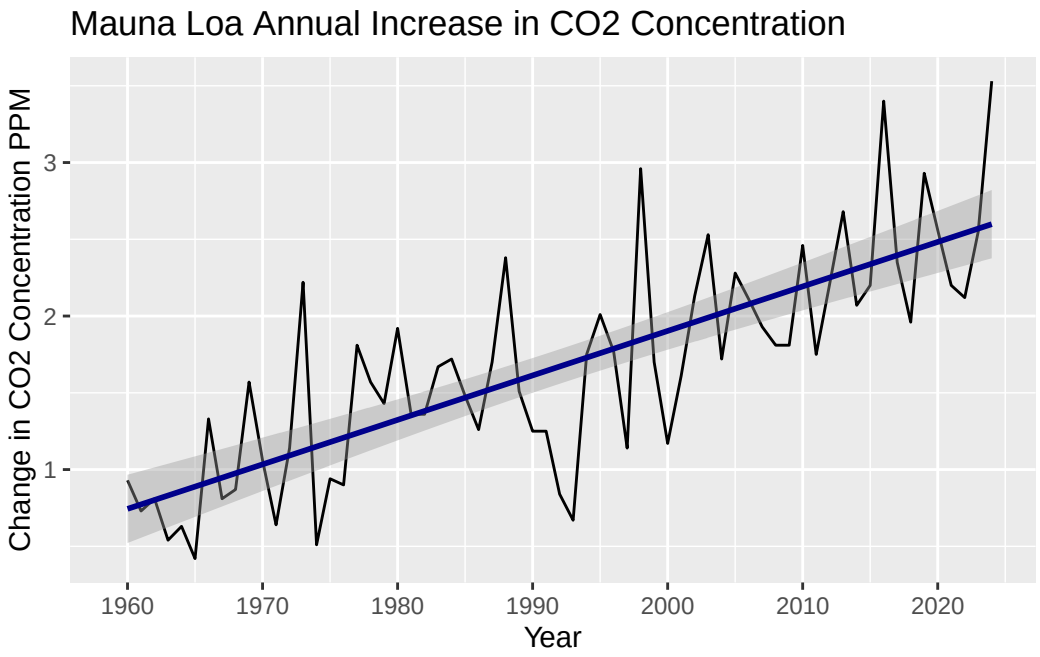
```
7   1965 320.04        0.12       0.42
66  2024 424.61        0.12       3.53
```

```
ggplot(data = mauna_loa_yearly, aes(year, co2ppm.inc)) +
  geom_line() +
  xlab('Year') +
  ylab('Change in CO2 Concentration PPM') +
  ggtitle('Mauna Loa Annual Increase in CO2 Concentration') +
  stat_smooth(method = lm, color = 'dark blue') +
  scale_x_continuous(breaks = seq(1960, 2020, 10)) +
  theme(axis.text.x = element_text(angle = 0, vjust = 0.7))
```

```
`geom_smooth()` using formula = 'y ~ x'
```

```
Warning: Removed 1 row containing non-finite outside the scale range
(`stat_smooth()`).
```

```
Warning: Removed 1 row containing missing values or values outside the scale range
(`geom_line()`).
```



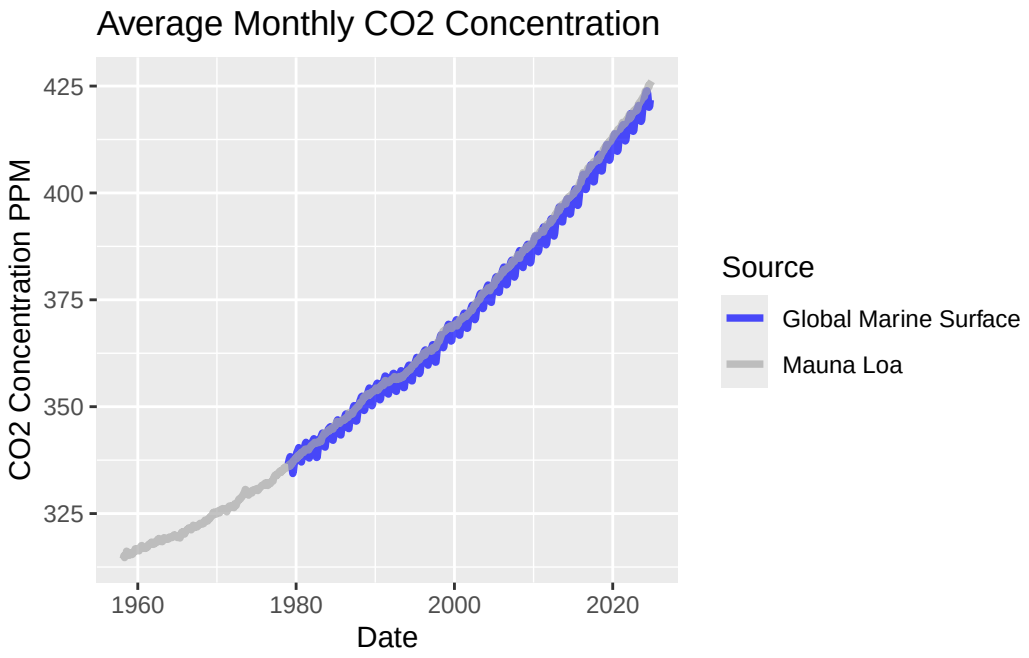
### Global Marine Surface Data

```
global_monthly <- read.table('ftp://aftp.cmdl.noaa.gov/products/trends/co2/co2_mm_gl.txt')
global_monthly <- global_monthly[, c(1, 2, 4)]
names(global_monthly) <- c('year', 'month', 'co2ppm')
global_monthly$date <-
  as.Date(paste(global_monthly$year, global_monthly$month, '01', sep = '-'),
          format = '%Y-%m-%d')

global_annual <- read.table('ftp://aftp.cmdl.noaa.gov/products/trends/co2/co2_annmean_gl.txt
names(global_annual) <- c('year', 'co2ppm', 'uncertainty')
global_annual$co2ppm.inc <- c(NA, diff(global_annual$co2ppm))
head(global_annual)
```

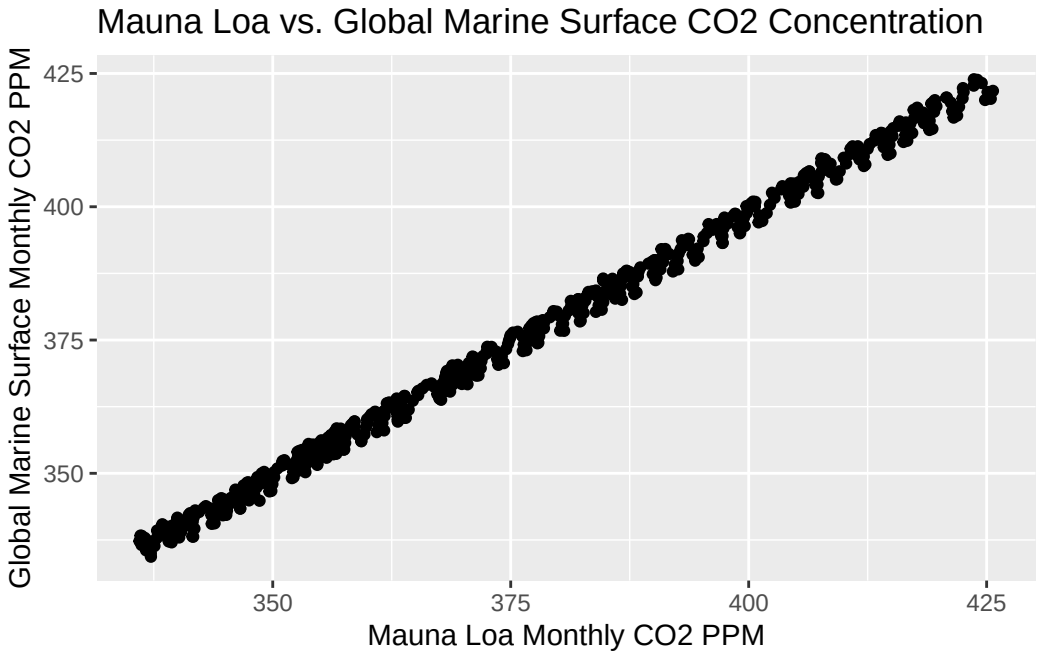
```
  year co2ppm uncertainty co2ppm.inc
1 1979 336.85        0.11         NA
2 1980 338.91        0.07       2.06
3 1981 340.11        0.09       1.20
4 1982 340.85        0.03       0.74
5 1983 342.53        0.05       1.68
6 1984 344.07        0.07       1.54
```

```
combined_monthly <- rbind.data.frame(
  mauna_loa_monthly %>% mutate(Source = 'Mauna Loa'),
  global_monthly %>% mutate(Source = 'Global Marine Surface')
)

ggplot(data = combined_monthly, aes(date, co2ppm, color = Source, group = Source)) +
  geom_line(size = 1.3, alpha = 0.7) +
  xlab('Date') +
  ylab('CO2 Concentration PPM') +
  ggtitle('Average Monthly CO2 Concentration') +
  scale_color_manual(values = c('blue', 'dark grey'))
```

```
Warning: Using `size` aesthetic for lines was deprecated in ggplot2 3.4.0.
i Please use `linewidth` instead.
```




```
combined_monthly <- inner_join(
  global_monthly %>% select(date, co2ppm) %>% rename(co2ppm.gl = co2ppm),
  mauna_loa_monthly %>% select(date, co2ppm) %>% rename(co2ppm.ml = co2ppm),
  by = 'date'
)

ggplot(data = combined_monthly, aes(co2ppm.ml, co2ppm.gl)) +
  geom_point() +
  xlab('Mauna Loa Monthly CO2 PPM') +
  ylab('Global Marine Surface Monthly CO2 PPM') +
  ggtitle('Mauna Loa vs. Global Marine Surface CO2 Concentration')
```


Mauna Loa vs. Global Marine Surface CO2 Concentration
Global Marine Surface Monthly CO2 PPM
425
400
375
350
350
375
400
425
Mauna Loa Monthly CO2 PPM