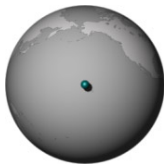


# **Statistics 120**

## **Time Series Applications**

## Atmospheric Carbon Dioxide Levels

- The island of Hawaii is a volcanic cone which rises roughly 17km from the ocean floor to the top of its tallest peak.
- The two tallest peaks, *Mauna Loa* and *Mauna Kea*, are ideal places for astronomical observatories.
- This is because the peaks are high and comparatively isolated meaning that the air is very clear and there is very little light pollution.



## Mauna Loa from Hilo Bay



## Hawaii from Space



The picture shows the peaks of Mauna Loa and Mauna Kea.  
The Kilauea volcano is marked in red.

## One of the Observatories on Mauna Loa

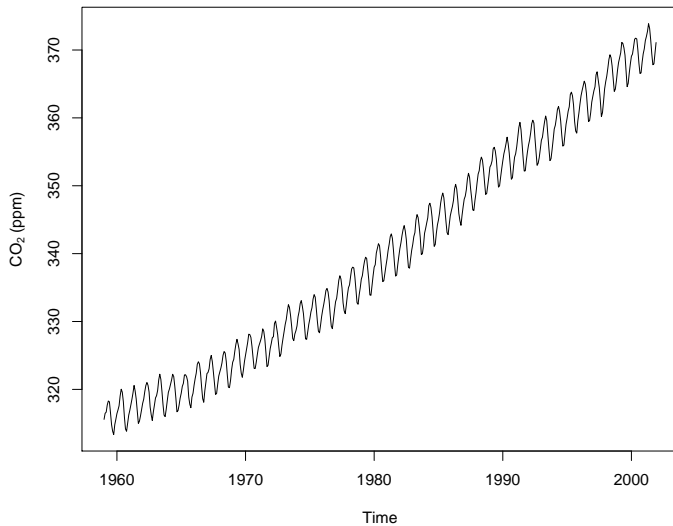


## The Carbon Dioxide Series

- Because of its isolation, Mauna Loa provides an ideal location to sample the gases present in the earth's atmosphere.
- A record of the concentration of atmospheric CO<sub>2</sub> has been made there since the 1950s.
- The observations were considered so significant they they were initially classified as “Top Secret” so that they could not be published.

```
> plot(co2,  
      main="Mauna Loa CO2 Levels",  
      ylab="CO2 (ppm) ")
```

## Mauna Loa Carbon Dioxide Levels



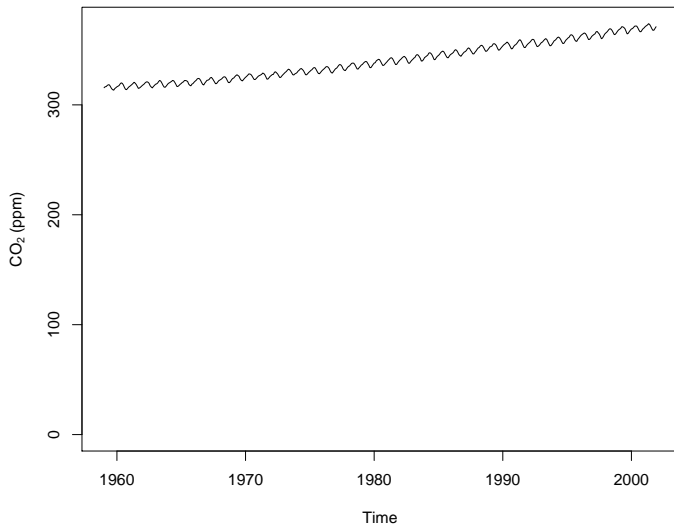
## Interpretation

- CO<sub>2</sub> levels are clearly increasing with time.
- In addition to the trend upwards, there is a clear seasonal component.
- We need to be careful increasing the level of increase because zero is not shown on the y axis.

```
> plot(co2, ylim = range(0, co2),  
       main="Mauna Loa CO2 Levels",  
       ylab="CO2 (ppm) ")
```



## Mauna Loa Carbon Dioxide Levels



## Estimating the Percentage Increase

- We can compute the percentage increase in the CO<sub>2</sub> level as follows.

```
> m59 = mean(window(co2, start = c(1959, 1),  
                    end = c(1959, 12)))
```

```
> m01 = mean(window(co2, start = c(2001, 1),  
                    end = c(2001, 12)))
```

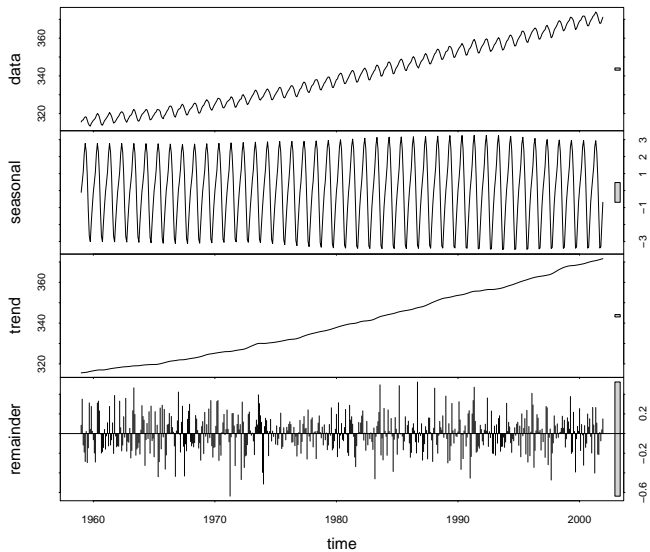
```
> 100 * (m01 - m59) / m59  
[1] 17.37728
```

- There has been a more than 17% increase in the level of atmospheric CO<sub>2</sub> since 1959.

## Seasonal Decomposition

- The presence of a seasonal component makes it hard to see the pattern present in the series.
- To see the trend without the superimposed seasonal effect we can carry out a seasonal decomposition.

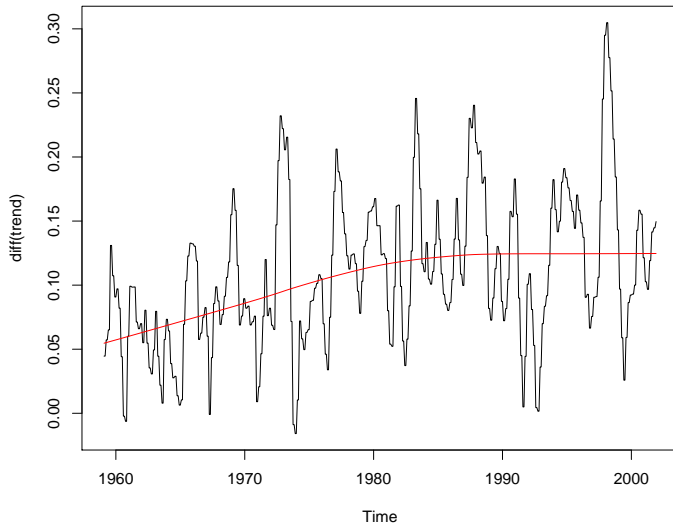
```
> sd = stl(co2, s.win=12, t.win=12)  
> plot(sd)
```



## Investigating the Trend

- The long-term trend is not just a straight line, but appears to be curving upwards.
- One way to check this is to examine the month-to-month differences in the series (this is like differentiating a smooth function).
- If the month-to-month differences are increasing then the trend will be becoming steeper.

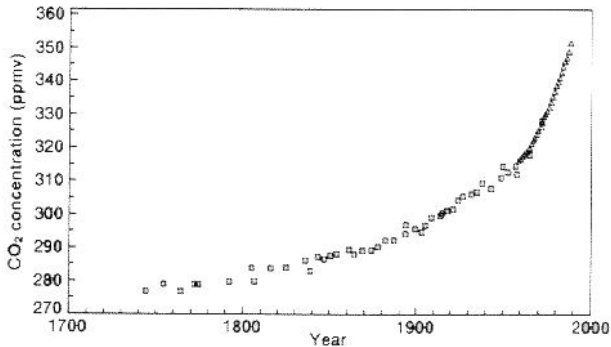
```
> trend = sd$time.series[,2]
> plot(diff(trend))
> lines(lowess(diff(trend)), col="red")
```



## Conclusion

- Up until 1980 the level of CO<sub>2</sub> in the atmosphere was increasing at a faster and faster rate.
- This now appears to scaled back to a constant rate of increase.
- It is worth trying to put the values into context by comparing them with other sources of information on atmospheric CO<sub>2</sub>.
- An additional data is available from bubbles of air trapped in antartic ice.

## Atmospheric CO<sub>2</sub> concentration.



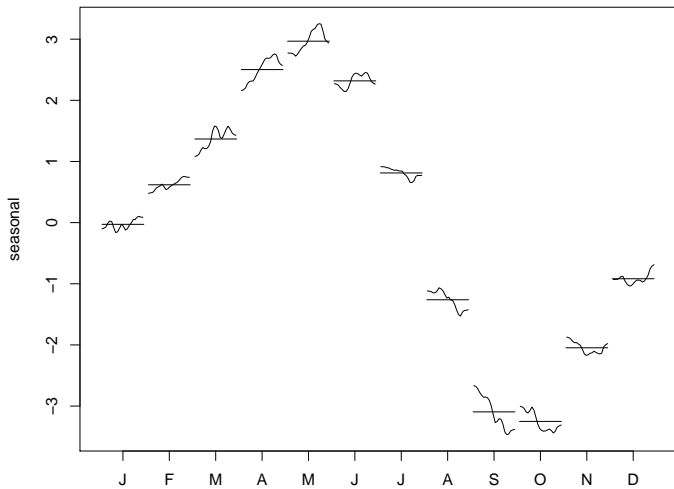
The squares are measurements from antarctic ice cores and the triangles are the Mauna Loa measurements.



## Investigating the Seasonal Effects

- One possible explanation for the seasonal variation in CO<sub>2</sub> level is the seasonal pattern of photosynthesis in plants.
- Most of the earth's plants are in the Northern Hemisphere, and since plants are most active during the summer we might expect that the CO<sub>2</sub> levels are at their lowest during the Northern summer.
- We can check this by producing a plot of the seasonal subseries.

```
> seasonal = sd$time.series[,1]  
> monthplot(seasonal)
```

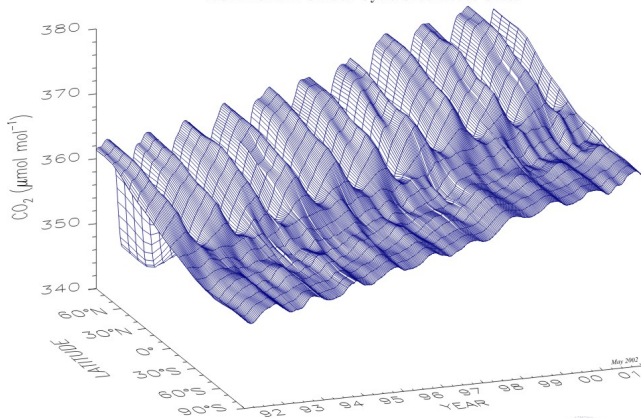


## Seasonal Effects

- Contrary to expectation, the highest  $CO_2$  levels are in late spring and the lowest levels are in late fall.
- $CO_2$  levels at higher latitudes to show the kinds of seasonal variation which we have hypothesized.
- $CO_2$  variation closer to the equator seems to be out of phase with this.

## Global Distribution of Atmospheric Carbon Dioxide

NOAA CMDL Carbon Cycle Greenhouse Gases



Three dimensional representation of the latitudinal distribution of atmospheric carbon dioxide in the marine boundary layer. Data from the NOAA CMDL cooperative air sampling network were used. The surface represents data smoothed in time and latitude. Principal investigators: Pieter Tans and Thomas Conway, NOAA CMDL Carbon Cycle Greenhouse Gases, Boulder, Colorado, (303) 497-6678 (ptans@cmdl.noaa.gov, <http://www.cmdl.noaa.gov/ccgg>).



## The Effects of CO<sub>2</sub> Increase

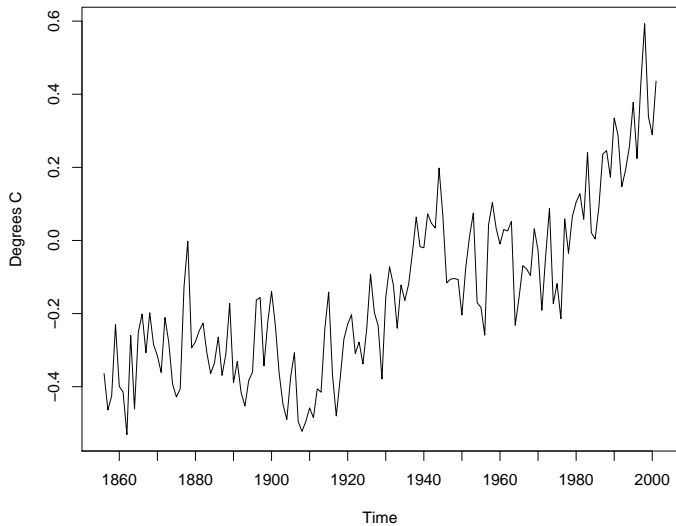
- It is clear that CO<sub>2</sub> and other so-called greenhouse gasses are increasing.
- It is likely that it is human activity which is responsible – the correlation of burning of huge amount of fossil fuel with an increase in CO<sub>2</sub> levels is very suggestive.
- The greenhouse gases act as a blanket around the earth and it has been suggested that the result of this will be an increase in global temperatures.
- Is there evidence of this?

## Global Temperature Change

- The monthly global temperature series is available from the University of East Anglia Climate Research Unit.
- The series currently extends from January 1856 up to July 2002.
- You can find the latest yearly series is available in the class data area.

```
> plot(gtemp,  
      main = "Global Temperatures . . .",  
      ylab = "Degrees C",  
      axes = FALSE)  
> axis(1, at = seq(1850, 2000, by = 10))  
> axis(2)  
> box()
```

### Global Temperatures Relative to 1961–1990



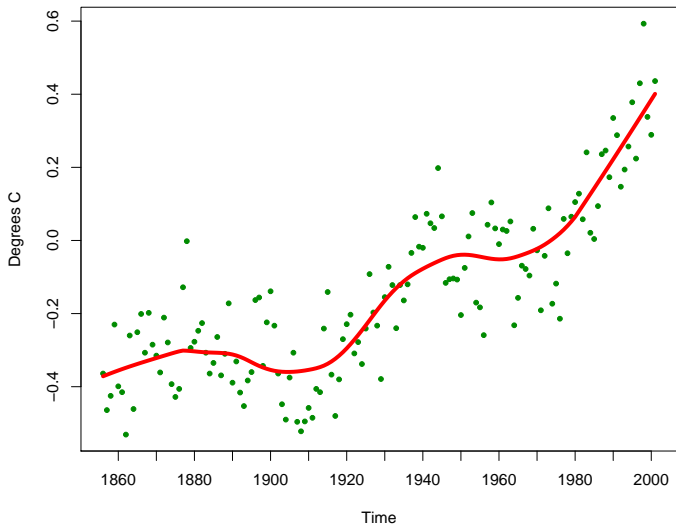
## Emphasising the Trend

- The trend in the previous plot is clear, but we can create an alternative plot which emphasises the effect.

```
> plot(gtemp,  
      type = "p", pch=20, col = "green4",  
      main = "Global Temperatures . . .",  
      ylab = "Degrees C",  
      axes = FALSE)  
> lines(lowess(gtemp, f = .3),  
      col = "red", lwd = 4)  
> axis(1, at = seq(1850, 2000, by = 10))  
> axis(2)  
> box()
```



### Global Temperatures Relative to 1961–1990

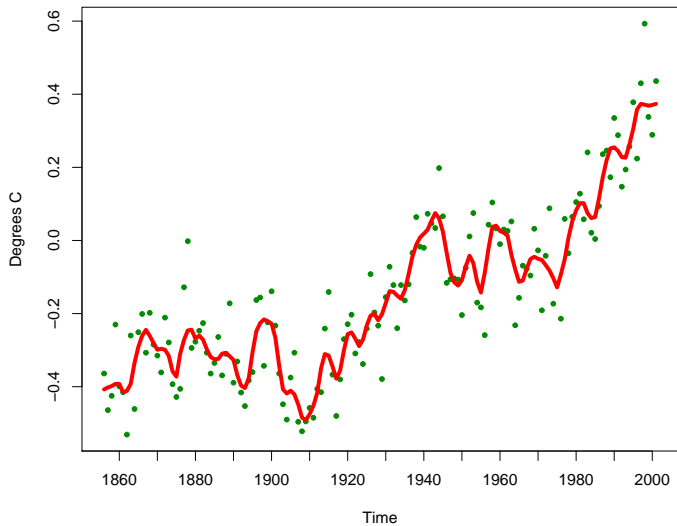


## Finer Detail

- There is a hint of hidden structure in this series.
- Using less smoothing may uncover something.

```
> plot(gtemp,  
      type = "p", pch=20, col = "green4",  
      main = "Global Temperatures . . .",  
      ylab = "Degrees C",  
      axes = FALSE)  
> lines(lowess(gtemp, f = .05),  
      col = "red", lwd = 4)  
> axis(1, at = seq(1850, 2000, by = 10))  
> axis(2)  
> box()
```

### Global Temperatures Relative to 1961–1990



## Recent Hot Years

- There is strong evidence that recent times have been hotter than years in the past.
- We can check this by sorting the years by order of temperature.

```
> rev(time(gtemp)[order(gtemp)])[1:10]
[1] 1998 2001 1997 1995 1999 1990 2000 1991
[9] 1994 1988
```

- Clearly, the world is hotter than it used to be.

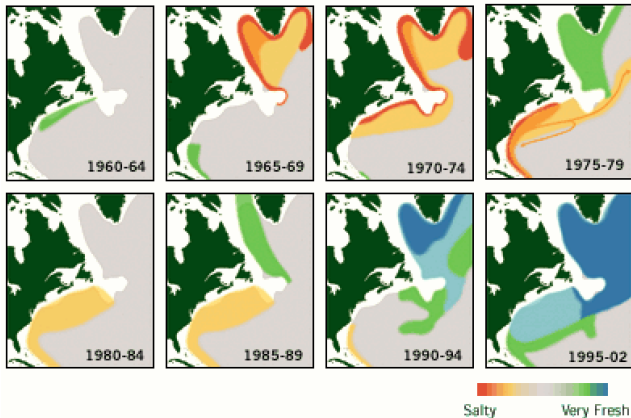
## The Side Effects of Global Warming

- Some of the effects of global warming are likely to be beneficial.
  - Less need for heating.
  - Increased agricultural yields.
- Other effects are likely to be less pleasant.
  - More need for cooling.
  - Spread of disease.
  - Sea level rises.
  - Extreme weather conditions.

## An Unexpected Effect

- One of the surprising side effects of global warming is that it is like to get much cooler in Northern Europe and North-West America.
- The reason for this is that warming is causing glacial and polar ice to melt and this is feeding a lot of fresh water into the North Atlantic.

## Fresh Water in the North Atlantic



## Fresh Water and the Gulf Stream

- The Gulf Stream is driven by cold salty water sinking in the North Atlantic, drawing warm salty water from the tropic northwards.
- The presence of fresh water in the North Atlantic interferes with this process and has the potential to stop the Gulf Stream flowing (it has done so in the past).
- Stopping the Gulf Stream could result in a 5° lowering of temperatures in much of Europe and severely affect the Northwestern USA and Canada.
- You can find out more in a feature article at the Woods Hole Oceanographic Institute.  
<http://www.whoi.edu/home/>.