# Statistics 120
# Time Series Applications

One of the Observatories on Mauna Loa



## 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.
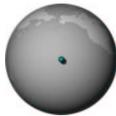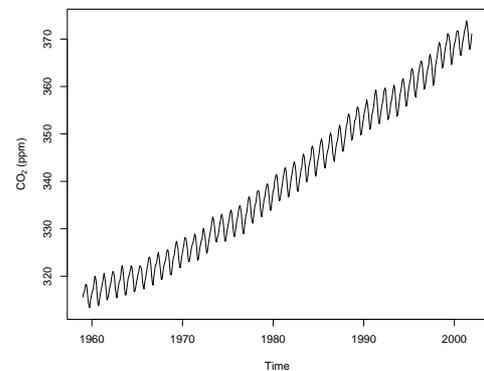


## The Carbon Dioxide Series

- 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 $CO_2$ 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The observations were considered so significant they they were initially classified as "Top Secret" so that they could not be published.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 from Hilo Bay





Hawaii from Space



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

## Interpretation

- $CO_2$ 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

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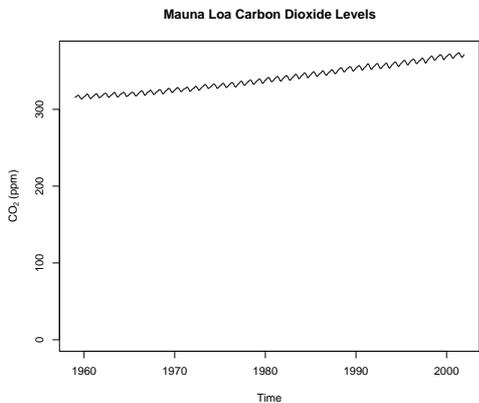
## Investigating the Trend

- 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")
```

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## Estimating the Percentage Increase

- We can compute the percentage increase in the $CO_2$ 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 $CO_2$ since 1959.

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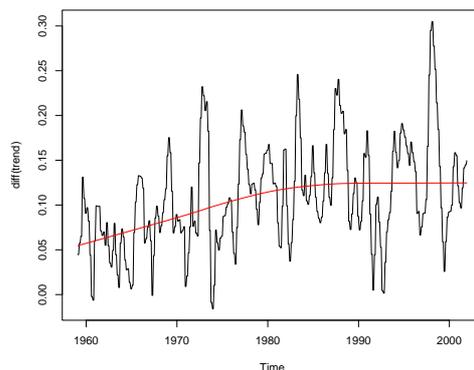
## Seasonal Decomposition

- 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)
```

---
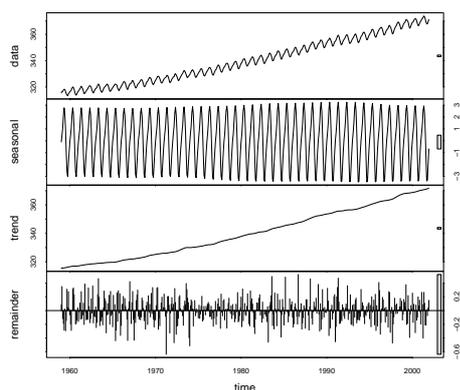
## Conclusion

- Up until 1980 the level of $CO_2$ 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 CO2.

- An additional data is available from bubbles of air trapped in antartic ice.

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Atmospheric $CO_2$ concentration.
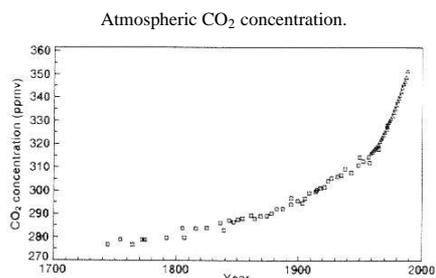
The squares are measurements from antarctic ice cores and the triangles are the Mauna Loa measurements.

## Investigating the Seasonal Effects

- One possible explanation for the seasonal variation in $CO_2$ level is the seasonal pattern of photosynthesis in plants.

- Most of the earths plants are in the Northern Hemisphere, and since plants are most active during the summer we might expect that the $CO_2$ levels are at their lowest during the Northen summer.

- We can check this by producing a plot of the seasonal subseries.

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

---
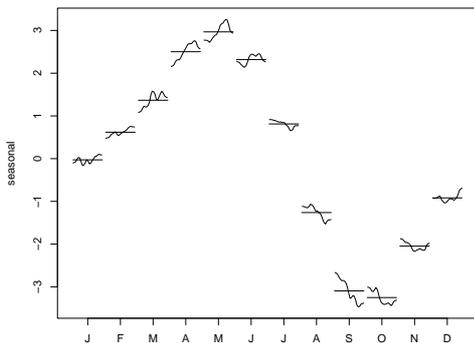
## The Effects of $CO_2$ Increase

- It is clear that $CO_2$ 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 $CO_2$ levels is very suggestive.

- The greenhouse gases act as a blanket arount the earth and it has been suggested that the result of this will be an increase in global temperatures.

- Is there evidence of this?

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## 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()
```

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## 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 lattitudes 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.
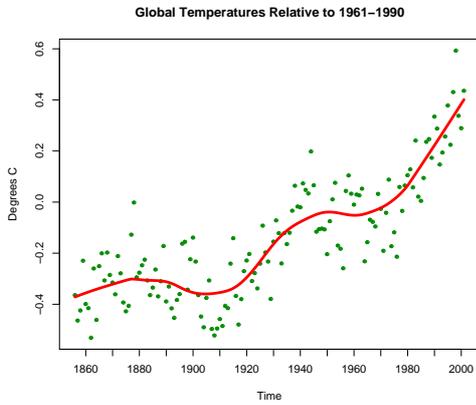
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Global Temperatures Relative to 1961–1990

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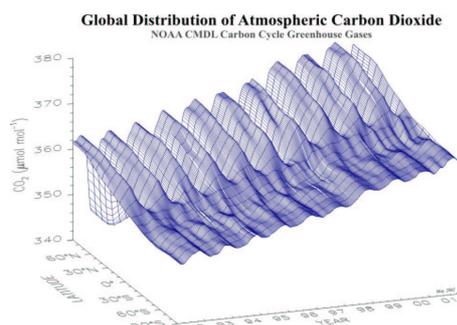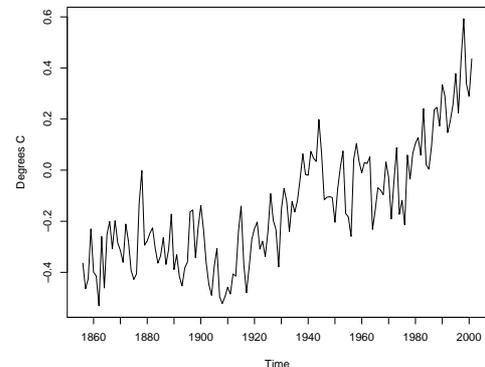


### Global Distribution of Atmospheric Carbon Dioxide
NOAA CMDL Carbon Cycle Greenhouse Gases

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## Emphasising the Trend

- The trend in the previous plot is clear, but we can 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**



*(Scatter plot of global temperatures in Degrees C vs Time (1860–2000) with a red lowess smoothing curve.)*

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## 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.
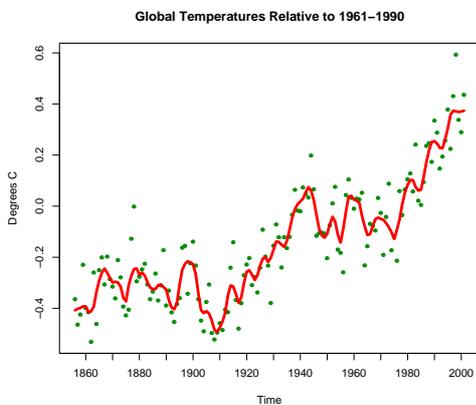  - Sea level rises.
  - Extreme weather conditions.

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## Finer Detail

- There is a hint of hidden structure in this series.
- Using less smoothing may uncover something.
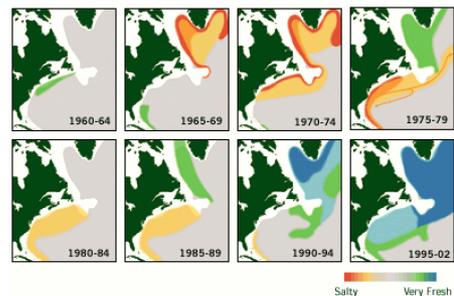
```
> plot(gtemp,
       type = "p", pch=20, col = "green4",
       main = "Global Temperatures . . .",
       ylab = "Degrees C",
       axes = FALSE)
> lines(lowess(gtemp, f = .05),
       col = "red", lwd = 4)
> axis(1, at = seq(1850, 2000, by = 10))
> axis(2)
> box()
```

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## 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.

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**Global Temperatures Relative to 1961–1990**



*(Scatter plot of global temperatures in Degrees C vs Time (1860–2000) with a red lowess smoothing curve using less smoothing.)*

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Fresh Water in the North Atlantic



*(Eight maps of the North Atlantic showing salinity from 1960-64 to 1995-02, with a color scale from Salty to Very Fresh.)*

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## 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.

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## 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 interfers 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/.