The Algebra of Earth Science

Introduction

Many of the measured parameters in Earth science are changing with time. Are these changes linear or not? If they are linear (with a good correlation), then we can predict future changes with some confidence.

Increasing Carbon Dioxide

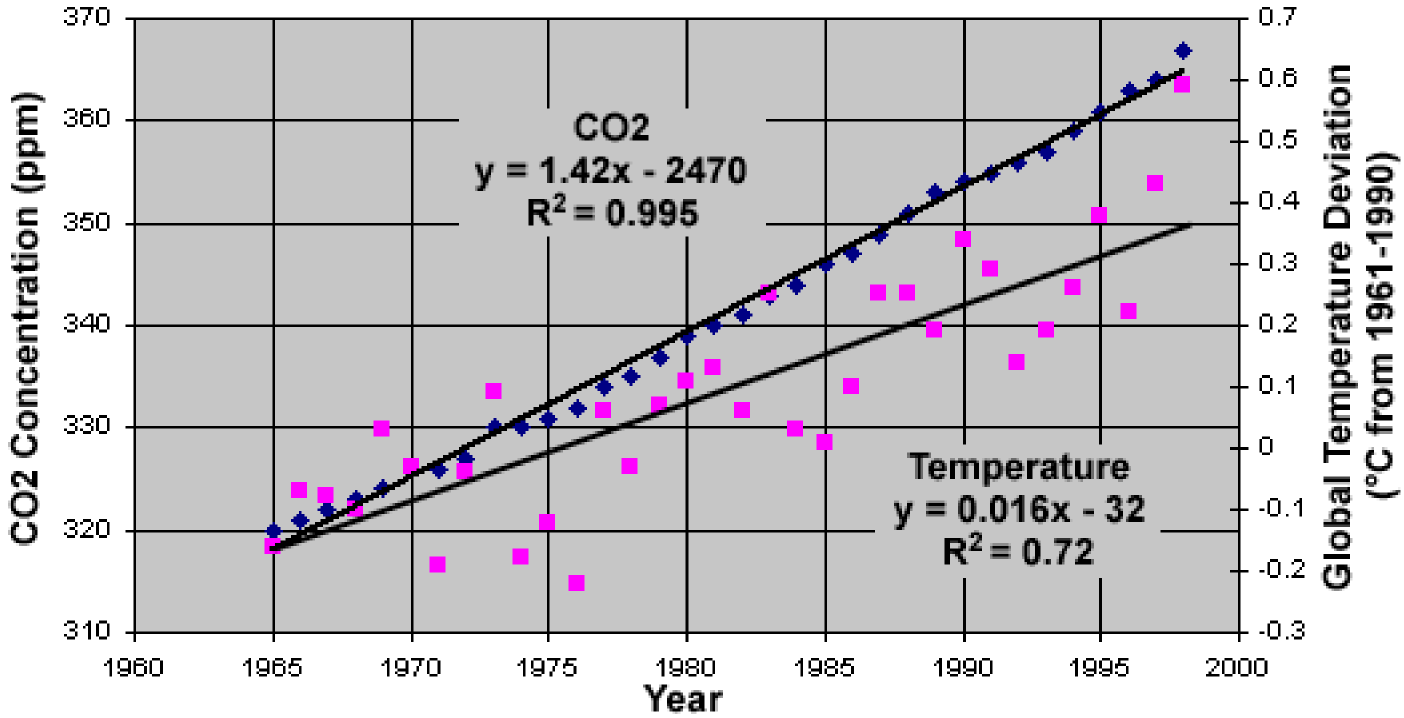
The Carbon Dioxide (CO_2) in the atmosphere is relatively small (less than 1 part in a 1000), but it is an important "greenhouse gas" that traps infrared light from the Earth, making the Earth warm up. Is the amount increasing linearly (each year adds the same amount)?

Take the data of CO_2 versus time and plot it on normal x-y graph paper (or use a graphing calculator). Does the resulting plot look linear? If so, draw a line through the data (you can use a stick of spaghetti to find the best line that covers the most data points). Since the line is a very good fit, you can estimate what it will do at a later time by extending the line. What year should the amount of CO_2 exceed 370 parts per million?

Now look at the third column. This data represents the global average temperature measurement, as a difference from the average of the years 1961-1990, measured in degrees Celsius. Plot this data as a function of time, on x-y graph paper or a graphing calculator (shown here as squares). Is this trend linear? Is the fit a good fit (are all the points very close to a line, or is there more scatter? (Can you use a spaghetti noodle to cover all the points, or do you need a fettuccini noodle?)

Year	CO2 (ppm) (Parts per million)	Global Temperature Anomaly (¡C from 1961-1990)
1965	320	-0.16
1966	321	-0.07
1967	322	-0.08
1968	323	-0.1
1969	324	0.03
1970	326	-0.03
1971	326	-0.19
1972	327	-0.04
1973	330	0.09
1974	330	-0.18
1975	331	-0.12
1976	332	-0.22
1977	334	0.06
1978	335	-0.03
1979	337	0.07
1980	339	0.11
1981	340	0.13
1982	341	0.06
1983	343	0.25
1984	344	0.03
1985	346	0.01
1986	347	0.1
1987	349	0.25
1988	351	0.25
1989	353	0.19
1990	354	0.34
1991	355	0.29
1992	356	0.14
1993	357	0.19
1994	359	0.26
1995	361	0.38
1996	363	0.22
1997	364	0.43
1998	367	0.59
1999	369	0.33

Data sources:
CO_2 : (from WRI)
Data from Siple station and Law Dome ice cores, CDIAC
Temperature: (from GCMD)
Jones, P.D., D.E. Parker, T.J. Osborn, and K.R. Briffa. 2000. Global and hemispheric temperature anomalies land and marine instrumental records. In Trends: A Compendium of Data on Global Change. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, U.S. Department of Energy, Oak Ridge, Tenn., U.S.A.

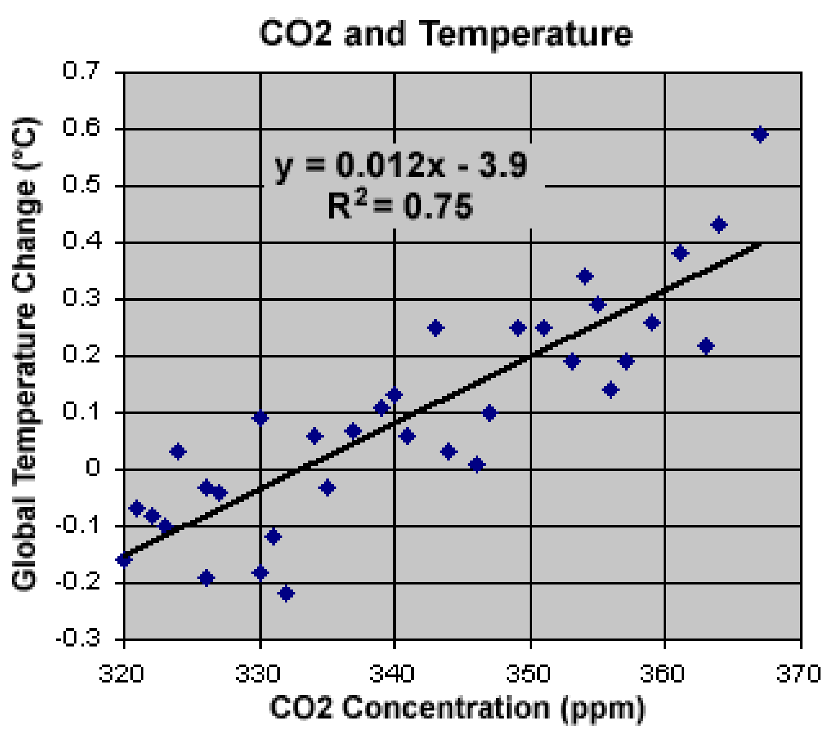


(teachers — blank out the solution plots before handing this out to students)

If you plot both the second column and the third column data on a single plot, the data from the third column will all be very low on the graph. In cases like this, we often use a different y-axis scale for one set of data than the other (shown above).

Are the effects correlated?

Two effects are **correlated** if changes in one are proportional to changes in the other. We explore correlations by plotting one variable versus the other one, rather than each one versus time. Note that there is more scatter on this plot than in the CO_2 versus time plot. The correlation coefficient, r, is 0.75 which is good but not as good as .99 (the CO_2 versus time plot). A value of 1 is a perfect correlation and allows accurate predictions. Lower correlations show trends but cannot be used to make good predictions.



Other data which are related to global warming may not be measured over as long a time history, but still are useful to examine for trends. One is the retreat of glaciers (measured in meters from a time in the past, in this case 1985).

Take these two data sets and plot them versus the year of measurement individually, as in the first plot of the last page.

Which data set has a better linear fit versus time?

Why do you suppose that is true?

Year	Nose Position of Rainbow Glacier (relative to 1985)	Annual Galveston Average Sea Level
1985	0	1521
1986	-11	1535
1987	-22	1497
1988	-33	1483
1989	-44	1519
1990	-55	1581
1991	-60	1611
1992	-75	1578
1993	-96	1564
1994	-116	1575
1995	-137	1599
1996	-161	1530
1997	-181	1577
1998	-201	1620
1999	-241	1589
2000	-246	1556

Now plot the second column data against the third column data, much as in the lower plot of the previous page. Are the two data correlated?

Now, be careful - just because two data sets are correlated does not mean that one causes the other - they could both be caused by a third effect. In this case global warming makes the glacier retreat. The melting glaciers do cause the sea level to rise, but also the sea level rises because the water is warming up and expanding.

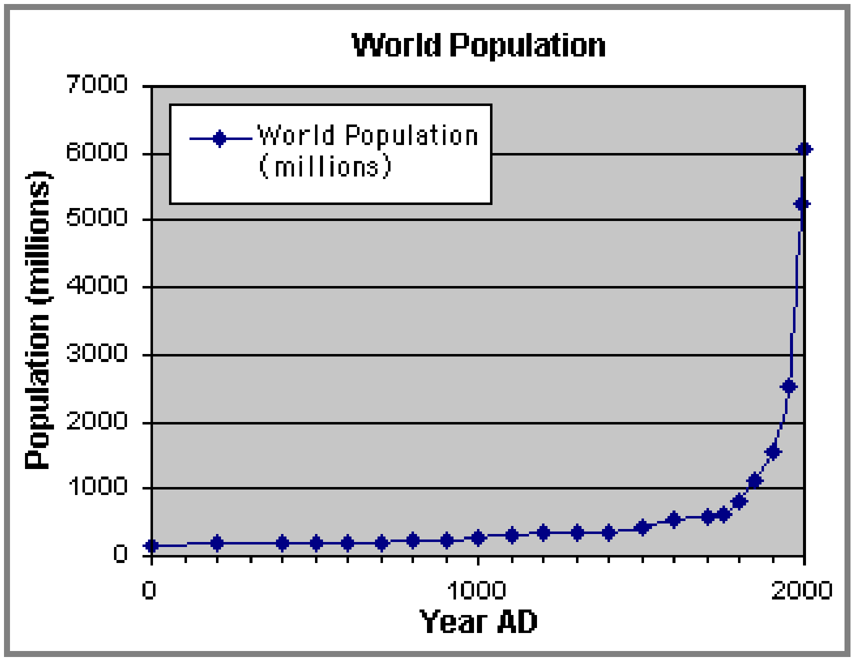
Non-linear Trends

Not all trends in Earth science are linear trends. Some trends are quadratic, or even exponential (the rate of increase is increasing with time). The World's population growth is a non-linear data set. Let's look at the data (from the U.S. census and the World Resources International web sites) (next page).

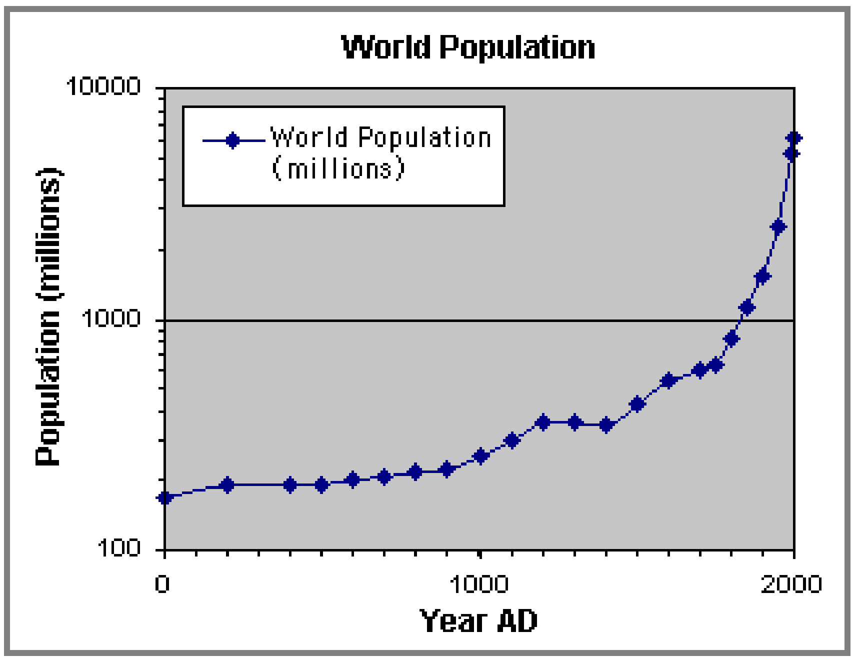
Plot this data versus time.

Year	World Population (millions)
0	170
200	190
400	190
500	190
600	200
700	207
800	220
900	226
1000	254
1100	301
1200	360
1300	360
1400	350
1500	425
1600	545
1700	600
1750	629
1800	813
1850	1128
1900	1550
1950	2521
1990	5266
2000	6055

If you only look at the first thousand years, the trend in population is very nearly linear. Disease, famines and plagues caused decreases in the total world population - for example the Bubonic plague of the 1200's. However, if you continue the plot past 1500, it is clear that the population is growing much faster than the linear trend of the first century.



Plotting the y-axis on a logarithmic scale helps make the plot a little more linear. A **logarithmic** axis has each step being a factor of ten in value, not a simple addition. Trends which are linear when plotted using a logarithmic axis, are called **exponentials**. An exponential has each year being a constant multiple of the previous year.



The world's population is rising even faster than an exponential - the slope of the curve on the logarithmic plot near 2000 is much larger than the slopes prior to that. This is because the birth rate alone causes an exponential growth. In addition, advance in medicine, immunization and nutrition helps people to live longer than before, adding to the numbers of humans - thus the term "population explosion". It is not surprising that overpopulation is the root cause of many, if not most, of Earth's environmental problems. A sustainable world is one in which the numbers of people are in balance with the world's resources to supply them.

For the best sources of numeric Earth data:

World Resources Institute:	**http://earthtrends.wri.org/index.cfm**
NASA Global Change Master Directory.	**http://gcmd.nasa.gov/md/index.html**
ESIP Federation Home Page	**http://www.esipfed.org**