**INVESTIGATING EVIDENCE FOR CLIMATE CHANGE**

Modified from O’Reilly, C.M., D.C. Richardson, and R.D. Gougis. 15 March 2017. Project EDDIE: Climate Change. Project EDDIE Module 8, Version 1.

Learning objectives:

* To analyze global temperature data to see if Earth’s average global temperatures are really increasing
* To analyze CO2 data to see if atmospheric levels are really increasing
* To correlate CO2 data with global temperature to see if there is a relationship
* To compare current trends with rates of change during pre-historic periods using ice core data
* To interpret what these results mean for understanding current climate change
* To learn basic shortcuts and graphing in Excel

Why this matters: Current climate change is affecting many aspects of the environment, with socio-economic consequences. For example, a warmer climate can allow new diseases to be introduced and persist (e.g. West Nile became established in the United States after an unusually warm winter allowed the mosquitos that carry the virus to survive and spread). We are concerned not only with the actual temperature, but also with the rate that the temperature changes. Very rapid changes make it more likely that species (maybe even including humans!) cannot adapt and will go extinct.

Outline:

1. Activity A: Determine current rates of air temperature and CO2 change from modern datasets.
2. Activity B: Explore whether temperature and CO2 concentrations are related.
3. Activity C: Compare current rates to pre-historical rates of change using data from an ice core to investigate how climate has changed in the past.

**Activity A:** How much are temperature and atmospheric CO2 changing?

**Changes in air temperature -** Scientists from the Goddard Institute for Space Studies, NASA, compiled temperature datasets from weather stations all over the world to create the dataset you are going to be working with today to answer the question: Is earth “warming”? The data you will use are from years 1880-2013.

1. Before you conduct your analysis, you should first make your predictions. What slope would indicate a warming Earth? What slope would indicate Earth’s average global temperature was not changing? What slope would indicate a cooling Earth? Sketch lines in the axes below to show what the expected slopes would be in these different scenarios.

oC

oC

oC

time

time

time

 cooling warming no change

1. Getting the air temperature data: These data are compiled by the Goddard Institute for Space Studies, NASA, and are made available via the Earth Policy Institute. <http://www.earth-policy.org/data_center/> Select Climate, Energy and Transportation. The dataset you are looking for is called something similar to “Average Global Temperature, 1880-2014 (Celsius)”, about 15 rows down. This dataset has been downloaded for you and can be found on Canvas.
2. Open up the dataset. Make a scatter plot of temperature change over time.
3. Now, determine the rate of change. Determining rates of change graphically is straightforward. The average rate of change is just the change in temperature divided by the change in time, or change in y divided by the change in x, or the slope of a line that fits through the data. These are all the same thing. Luckily, Excel can calculate the slope of a line very easily. So, to determine the rate of change (slope) add a trend line. When you do this, make sure to select the options to show the equation of the line and the R2 value. The equation is written in the form *y = mx + b*, where *m* is the slope and *b* is the intercept. The value for *m* is the rate of change.

The R-squared (R2) is a statistic resulting from a linear regression analysis, which is the statistical name for what you just did by adding a trend line. It describes the proportion of variation in the dependent variable explained by the independent variable. When R2 ~1, the data form a perfectly straight line. As the data become more scattered from the line, R2 decreases toward 0. Higher R-squared values indicate a stronger relationship between the two variables. Record your R2 value down with your slope.

* 1. Equation for the line:
	2. R2 =
	3. Rate of air temperature change (include units):
	4. Given your analysis, is Earth warming? How do you know?
1. Many scientists claim that drastic changes in global temperature began in the mid-1900s when fossil-fuel-powered transportation became a mainstay for most families. Test this hypothesis by adjusting your trendline so that it only looks at the most recent decades, after personal transportation became common. You can do this by:
	* Decide on the year in the mid-1900s that you want to begin the trendline. Scroll to that year and select the data (year and temperature) from that year all the way to the most recent year.
	* Create a Scatter plot just as you did before, and add a trendline with the R2.
	1. Equation for the line:
	2. R2 =
	3. Rate of air temperature change (include units):
	4. Compare the slopes of these two lines (1880 through mid-1990s versus mid-1990s through 2013). Does your analyses support the hypothesis that the rate of global average temperature is greater since the 1950s?
	5. Write your answer on the board to compare with others

**Changes in atmospheric CO2 -** In 1958, Dr. Charles David Keeling (1928-2005), who was a scientist at Scripps Institute of Oceanography, began collecting data on atmospheric CO2 concentration at the Mauna Loa Observatory located in Hawaii. This dataset is what allowed us to understand the degree to which climate change is human-caused through our burning of fossil fuels and release of CO2 into the atmosphere. Due to his scientific achievements, Dr. Keeling was awarded the National Medal of Science by President George W. Bush in 2002. This is the highest award for lifetime scientific achievement that can be granted in the U.S. Today, you get to analyze this same dataset, except that you have more data that was available to Dr. Keeling and his colleagues, because your dataset extends up to current time.

1. Getting the atmospheric CO2 data: The longest measurements of atmospheric CO2 concentrations have been done in Mauna Loa, Hawaii. The simplest way to access the data is directly from the Mauna Loa page. <http://www.esrl.noaa.gov/gmd/ccgg/trends/>. This data can be found under the Mauna Loa tab on the Excel spreadsheet you previously downloaded from Canvas.
2. As you did for air temperature, plot a graph of CO2 vs time.
3. Determine the current rate of change for atmospheric CO2 data by fitting a trend line, as you did for air temperatures.
	1. Equation for the line:
	2. R2 =
	3. Rate of air CO2 change (include units):
	4. Based on your analysis, has atmospheric CO2 concentration increased? How confident are you in these results? What phenomenon explains the matching patterns of average global temperature and atmospheric CO2?

**Activity B:** How related are the changes in temperature and CO2?

1. To determine whether a change in CO2 corresponds well with a change in air temperature, you can plot temperature against CO2.To do this, highlight the CO2 data from 1959 onwards, copy them, and then paste them next to the temperature data from those years. Then make a graph with CO2 on the x axis and temperature on the y axis.
2. Equation for the line:
3. R2 =
4. Based on your analysis, could atmospheric CO2 concentration explain the increase in average global temperature?

**Activity C:** How do current trends compare to pre-historic rates of change?

**An exploration of the Vostok Ice Core -** When analyzing Earth’s climate, it is important to remember that Earth is 4.54 billion years old. Our analyses so far have only looked at recent history. How can we compare the recent data to pre-historic time? Are the current rates of change similar or different than those the earth has experienced in the past? To explore this, we can use data taken from ice cores that were drilled at the poles.

Hundreds of ice cores have been extracted from polar ice because they contain valuable data on atmospheric chemistry over pre-historic time. These valuable data exist in tiny air bubbles that are trapped in the ice. These air bubbles contain the same gases in the same ratios as the atmosphere at the time when the ice formed. The data you will be analyzing today are from ice cores extracted from the Vostok research station in Antarctica. As you have probably assumed, the depth of the ice core is related to how old the ice is; deep ice is older. There are two other variables that you will be analyzing from the ice cores. The first is temperature, which is reflected by isotopic ratios in the ice of the core so that these isotopic ratios can be converted into air temperatures. The second variable you will analyze is CO2 concentration, which has been measured from air bubbles trapped in the ice. We can use these data to see what rates of change were like during this pre-historic period, during which human activity has been minimal.

1. The Vostok ice core data is available through the Carbon Dioxide Information Analysis Center (CDIAC) <http://cdiac.esd.ornl.gov/>. This data is already downloaded for you and is under the Vostok temp tab on the Excel spreadsheet you have been using.
2. In these data, the temperature column is not the actual temperature, but the temperature variation or anomaly. To use actual temperatures you will have to calculate them from the ‘delta D’ content. Deuterium, or delta D, stands for the relative proportion of two types of hydrogen (2H: 1H). Changes in the proportion of these two types of hydrogen in ice-water correlate to the amount of evaporation and thus to ocean water temperature. In the next column, calculate the paleo-temperature at Vostok based on the formula describing the empirical relationship between temperature and deuterium concentration:

 Temperature (in degrees C) = -55.5 + (delta D + 440) / 6

1. You can do this easily by clicking on the new Excel cell, typing ‘=’, then typing in the formula and selecting the cell for ‘delta D’, and hitting the Enter key. Once you have your formula, you can then copy and paste that cell down, or use other shortcuts. Remember, an easy way to fill the column all the way down to the bottom is to double-click on the small green square in the bottom right corner of the highlighted part. This will tell excel to extend the equation down the entire column of data without having to drag the green corner down all the rows! Make sure to provide a column heading.
2. Begin with the new temperature data you calculated, and graph it using ice age as the independent variable (x-axis). Create a Scatter graph with straight lines between the points. Keep in mind that the x axis refers to how many thousands of years ago, so the time axis moves in the opposite direction as what you are accustomed to based on previous analyses. This is the custom for research that investigates patterns over long time periods. Adjusting the scale of the y-axis will make the data be more prominent on the graph.

To help you orient to these plots, address the following questions:

1. Do you think these data are a good representation of pre-historic rates of change?
2. Are we currently in a glacial or interglacial period?
3. How long does a glacial and interglacial period last?

Glacial:

Interglacial:

1. Add a trend line to the ice core temperature data and look at the R2 value. Do you think this line is a good representation of long-term rates of temperature change? Why or why not?
2. The next step is to calculate what the fastest rate of change might be. To do this, you want to identify a section of your data where the temperature is changing very rapidly. If you hover your mouse over a data point, it will tell you the data values for that particular point. Make note of the data point values at the beginning and end of the time period segments that you think have the steepest slopes:

Then make a new graph of only that time period, and determine the rate of change by fitting a trend line and looking at the slope.

1. Rate of pre-historic temperature change (with units):
2. Write your answer on the board to compare with others
3. Next, you are going to look at the Vostok ice core CO2 data, which can be downloaded from the CDIAC website <http://cdiac.esd.ornl.gov/> . This data is also provided in the Vostok CO2 tab on the Excel spreadsheet you have been working on. Prepare a plot of CO2 concentration (y-axis) as a function of (gas) age (x-axis).
	1. According to the CO2 data from ice cores, during which time frame(s) was there the greatest rate of change in atmospheric CO2 concentration? How does this change in atmospheric CO2 concentration correspond to what you see in the ice-core temperature record?
	2. How do CO2 concentrations recorded over time in the ice core compare to the current values for today, which you can see on the Mauna Loa web site?
4. Now make a new graph focused only on a time period of rapid change in CO2. Determine the rate of change by fitting a trend line and looking at the slope.
	1. Rate of pre-historic atmospheric CO2 change (with units):
5. Compare the fastest natural rate of change with the modern rate of change. (Remember to check your units are equivalent).

How do current (i.e., in the past ~200 years) changes in atmospheric CO2 concentration and average global temperature compare to pre-historic (i.e., in the past hundreds of thousands of years) changes in these variables? What does this suggest about whether recent changes in temperature are due to natural or anthropogenic (human) factors? It is plausible that recent increase in atmospheric carbon dioxide is a result of natural fluctuations and not human-induced?