**TRACKING CLIMATE CHANGE**

Learning objectives:

Students will be able to:

* Accessing publically available online data sources
* Graph and visualize real-world data in Excel (GoogleSheets)
* Use global temperature data to test whether Earth’s average global temperatures are increasing
* Analyze CO2 data to see if atmospheric levels are really increasing
* Correlate CO2 data with global temperature to demonstrate the relationship
* Compare current trends with rates of change during pre-historic periods using ice core data
* Interpret what these results mean for understanding anthropogenic climate change

Why this matters: As we have seen throughout this course, anthropogenic climate change is affecting many aspects of the environment, and carries socio-economic consequences. For example, a warmer climate can allow new diseases to be introduced and persist (ex. West Nile became established in the United States after an unusually warm winter allowed the mosquitos that carry the virus to survive and spread). While temperature change itself is challenging to ecosystems, the rapidity of the rate of change is potentially cataphoric. Very rapid changes make it more likely that species (including humans!) cannot adapt and will go extinct.

Outline:

**Activity A:** Determine current rates of air temperature and CO2 change from modern datasets.

**Activity B:** Explore whether temperature and CO2 concentrations are related.

**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.

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**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. As a warm up (pun fully intended), **fill in the graphs below with the linear trends you would expect from the following**: a) slope indicating a warming Earth, b) slope indicating a Earth’s average global temperature was unchanging, and c) slope indicating a cooling Earth? These fundamental graphs underpin the work you will be doing with actual data in the steps that follow.

oC

oC

oC

time

time

time

a) cooling c) no change c) warming

1. Downloading 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 for this exercise is “Average Global Temperature, 1880-2014 (Celsius)”, about 15 rows down. Download this excel file and save on your computer in a location where you can find it again.
2. Open up the dataset in Excel (preferred) or GoogleSheets. Make a scatter plot of temperature vs. time. Include all graphs in your submission from here on out!!!
3. Now, determine the rate of change and add these to the white board. 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 trendline. 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.
   * Write your answer for c. on the board to compare with the class.
   1. Equation for the line:
   2. R2 =
   3. Rate of air temperature change (include units)- write on board:
   4. Compare the slopes of these two lines (1880 through mid-1900s versus mid-1900s through 2013). Does your analyses support the hypothesis that the rate of global average temperature is greater since the 1950s?

**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 has become so significant that Dr. Keeling was awarded the National Medal of Science by President George W. Bush in 2002, the highest award for lifetime scientific achievement in the U.S. **These data have become widely known as the Keeling curve**. The measurements are 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. You will 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/> (You can already see some graphs plotted on this page, but since you want to analyze these data yourself to determine a rate of change, you need to download them). Select the ‘Data’ tab and select “Mauna Loa CO2 annual mean data” from the options to initial the download.

Open the corresponding .txt file. This is a common format for datasets that are relatively small and easily downloadable. There is a lot of text at the top that describes the dataset. There are three columns of data a) years, b) mean CO2 as ppm (parts per mil, or micromoles per mol of air), and c) estimated uncertainty in the annual mean also called the standard deviation.

Since you only need the data, the easiest way to do this is to highlight the data section of the web page, including the headings (year, mean, unc). Copy then paste into Excel, on a new worksheet in the same file that has the global temperature data. You need to play around with the formatting of these data to insure that each column of data from the .txt file is in its own column in Excel. Depending on your version of Excel, the best way to do this might be slightly different so you will have to play around with this. The data are space delineated so set to that option to be able to see the data in columns (with GoogleSheets, use the “split data into columns” feature after you paste).

1. As you did for air temperature, plot a graph of CO2 vs time. You may need to rescale your y-axis to really emphasize the range of values for this variable.
2. 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)- write on board:
   4. Based on your analysis, has atmospheric CO2 concentration increased? How confident are you in these results?

**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, are these variables (atmospheric CO2 concentration and average global temperature) correlated? Is this relationship what you expected? Explain….

#### STOP HERE BEFORE YOU GO ON AND CHECK IN WITH PROF BECK!

We will watch the following as a group-<https://www.youtube.com/watch?v=JS2PhRd_5NA>

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

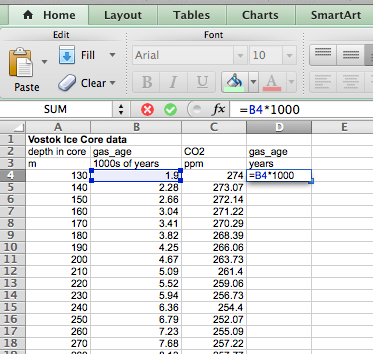
**An exploration of the Vostok Ice Core –** Our analyses so far have only looked at recent history. How can we compare the recent data to pre-historic time where we do not have instrument records? How do current rates of change compared to those experienced on Earth in the past? To explore this, we can 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. From the Law of Superposition, you know that deep ice is older than shallower ice. There are two proxy records that you will analyze from the ice cores. The first is temperature, which is derived from δD isotopic ratios (labeled delta D in the dataset) in the ice of the core. The second proxy is CO2 concentration, which has been measured directly from air bubbles trapped in the ice. We will use these data to see what rates of change were like during pre-industral times when anthropogenic activity was relatively minimal.

1. The Vostok ice core data is available through the Carbon Dioxide Information Analysis Center (CDIAC) <http://cdiac.esd.ornl.gov/>. Under the Data dropdown menu, select Climate. Then select Temperature. At the bottom of that page there is a dataset called “Historic isotopic temperature record from the Vostok Ice core, Antarctica”. Select this link, which provide information about the core location, and then select ‘Digital Data’ on the top of the page. Similar to the CO2 data, you need to highlight the column headings and then down all the rows, excluding all the text in the starred box. This will take a while…. I am having you do this because this is exactly what you would have to go through if you wanted to say use these data as part of a research project! Download the Vostok ice core data to Excel and save it as a new tab in your file.
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. Remember, δD represents the proportion of two types of hydrogen (2H and 1H) relative to some standard. 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. Create a new column in your spreadsheet. Using the empirical relationship between temperature and deuterium concentration given by the formula below, calculate the paleo-temperature at Vostok:

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

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. The diagram below give an example (the formula in the example is not correct). Once you have your formula, you can then copy and paste that cell down, or use other shortcuts. Make sure to provide a column heading.



1. Begin with the temperature data, and graph it using ice age as the independent variable. 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 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?
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. Write your answer for on the board to compare with the class.

1. Rate of pre-historic temperature change (with units)- put this on the board!
2. To download the Vostok ice core CO2 data, under the CDIAC website <http://cdiac.esd.ornl.gov/> select ‘Atmospheric Trace Gases & Aerosols’. Then select ‘Carbon Dioxide (CO2)’. On the next page there is a link to ‘Vostok, Antarctica (Baronla et al.).’ You can then download the data and convert it into Excel columns in the same way you did previously. Prepare a plot of CO2 concentration as a function of (gas) age. Plot (gas) age on the x axis and CO2 on the y 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. Quantify how 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?
3. 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)
4. 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? How could you use these data and observations to counter an anthropogenic climate change denial argument?