

Lab 3: Exploring temperature and carbon dioxide relationships

Introduction

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.

In Part A, you will use modern datasets to determine current rates of air temperature and CO₂ change. In Part B, you'll explore whether temperature and CO₂ concentrations are related. And in Part C, you'll compare current rates to pre-historical rates of change using data from an ice core to investigate how climate has changed in the past.

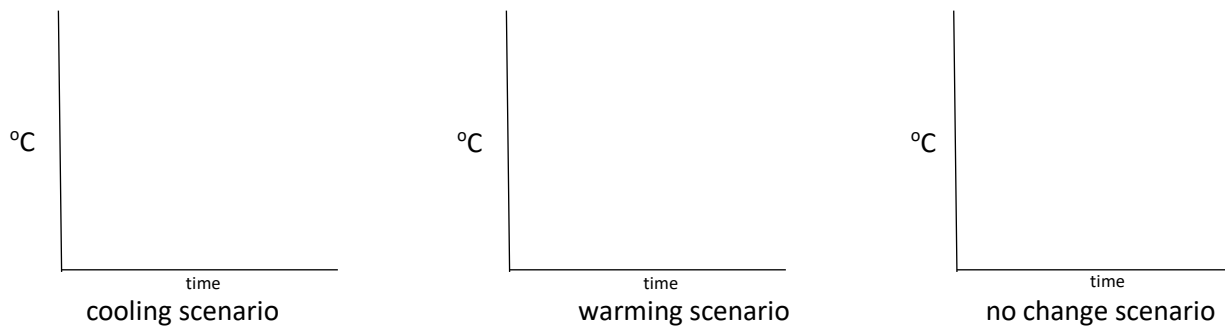
After completing this Lab, you should be able to:

- Analyze global temperature data and determine if Earth's average global temperatures are changing
- Analyze CO₂ data to determine if atmospheric levels are changing
- Correlate CO₂ data with global temperature to see if there is a relationship
- Compare current trends with rates of change during pre-historic periods using ice core data
- Interpret your results in the context of current climate change impacts
- Practice using shortcuts and graphing in Excel

Part 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 1880-2019.

1. Before you conduct your analysis, you should first make your predictions.
 - a. What slope would indicate a warming Earth (positive, negative, or flat)?
 - b. What slope would indicate Earth's average global temperature was not changing?
 - c. What slope would indicate a cooling Earth?
 - d. On a separate piece of paper, sketch graphs to represent what the expected slopes would be in these different scenarios. Below are template axes to use for your graphs. You can submit the photo of the graphs separately, or copy/paste them into the document you will submit.



WHERE DO THE DATA COME FROM?

You don't need to do this, as I've already downloaded the data you need for this section; however, the data are publicly available and you can explore further, if you choose. These data are compiled by the Goddard Institute for Space Studies, NASA https://data.giss.nasa.gov/gistemp/tabledata_v4/GLB.Ts+dSST.txt. You can also download the data as an Excel file (<https://data.giss.nasa.gov/gistemp/>).

GLOBAL TEMPERATURE DATA 1880-2019

- A. If you have not already done so, download/save the Lab3Data file somewhere on your computer that you can find again. Open the file. You'll notice at the bottom of the spreadsheet are multiple tabs for the different data sets we'll be using. Make sure that you're in the **Global Temperature** tab.
- B. Create a scatterplot and 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 , which happens to be the slope of a line that fits through the data. Luckily, Excel can calculate the slope of a line very easily. 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 R^2 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.
2. Copy/paste the scatterplot, with the regression line and R^2 value into the document you will submit.
3. The R-squared (R^2) 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 $R^2 \sim 1$, the data form a perfectly straight line. As the data become more scattered from the line, R^2 decreases toward 0. Higher R-squared values indicate a stronger relationship between the two variables. Record the following information.
 - a. Equation for the line:
 - b. $R^2 =$
 - c. Rate of air temperature change (include units):
 - d. Given your analysis, is Earth warming? How do you know?

- C. 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 scatterplot just as you did before and add a trendline with the R^2 .
4. Copy/paste your graph into the document you are submitting.
5. Record the following information from step C.
- a. Years of analysis:
 - b. Equation for the line:
 - c. $R^2 =$
 - d. Rate of air temperature change (include units):
 - e. Compare the slopes of these two lines (1880 through 2019 versus mid-1900s through 2019). Do 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 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. We're going to take another look at Dr. Keeling's data and the more recent data collected at the Moana Loa site.

WHERE DO THE DATA COME FROM?

If you'd like to download your own data, you can do so from the Mauna Loa page

<http://www.esrl.noaa.gov/gmd/ccgg/trends/>. If you visit the Moana Loa website, you'll see some familiar graphs, such as the one in *Field Notes from a Catastrophe* and from Lab 1. Since we want to analyze these data yourself to determine a rate of change, the graphs don't do us much good. Select the 'Data' tab. Scroll down to the bottom of the page to 'Data'. Select "Mauna Loa CO₂ annual mean data." These data are in a .csv format, which will probably open in Notepad (Windows) or a similar text viewer on other operating systems. Excel can technically open these types of files, too, if you import the data. There is a lot of text at the top that describes the dataset. The data are presented as a column of years, the mean CO₂ as ppm (parts per mil, or micromoles per mol of air), and the last column is the estimated uncertainty in the annual mean is the standard deviation.

MOANA LOA CO₂ DATA 1959-2019

- D. Switch over to the Moana Loa CO₂ tab in the spreadsheet. As you did for air temperature, create a scatterplot graph of CO₂ vs time.

- E. Determine the current rate of change for atmospheric CO₂ data by fitting a trend line, as you did for air temperatures.
6. Copy/paste a copy of your graph into the document you are submitting. Include the following information for your graph:
 - a. Equation for the line:
 - b. $R^2 =$
 - c. Rate of air CO₂ change (include units):
 - d. 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?

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

7. To determine whether a change in Moana Loa CO₂ corresponds well with a change in air temperature, you can plot temperature against CO₂. To do this, highlight the Moana Loa CO₂ data from 1959 to present, copy them, and then paste them next to the temperature data from the same years (you won't have any data for 1880-1958 for Moana Loa CO₂). Then make a graph with CO₂ on the x axis and temperature on the y axis.
 - a. Copy/paste the graph you created into the document you're submitting
 - b. Equation for the line:
 - c. $R^2 =$
 - d. Based on your analysis, could atmospheric CO₂ concentration explain the increase in average global temperature?

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

REVISITING 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. Recall from Lab 1 that 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, which 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.

Refresh your memory by viewing the links below:

- [Antarctic Ice Core Research at USGS National Ice Core Lab](#)
- [Ice Core Secrets Could Reveal Answers to Global Warming](#) and other videos at [The National Ice Core Laboratory](#)

WHERE DO THE DATA COME FROM?

If you wanted to download the data, The Vostok ice core data is available through the Carbon Dioxide Information Analysis Center (CDIAC) <https://cdiac.ess-dive.lbl.gov/>. Under the Data dropdown menu, select Climate. Then select Temperature. Then down at the bottom of that page there is a link 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. You can right click anywhere on the page. In the pop-up menu, select Save As, and use the new window to navigate to the location where you want the file to save to. Like the Moana Loa data, the data will open in Notepad (Windows) or can be imported into Excel.

- F. 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. I’ve already calculated the paleo-temperature at Vostok based on the formula describing the empirical relationship between temperature and deuterium concentration:

$$\text{Temperature (in degrees C)} = -55.5 + (\text{delta D} + 440) / 6$$

If you want to reproduce this calculation, 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 gives 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.

	A	B	C	D	E
1	Vostok Ice Core data				
2	depth in core	gas_age	CO2	gas_age	
3	m	1000s of years	ppm	years	
4	130	1.9	274	=B4*1000	
5	140	2.28	273.07		
6	150	2.66	272.14		
7	160	3.04	271.22		
8	170	3.41	270.29		
9	180	3.82	268.39		
10	190	4.25	266.06		
11	200	4.67	263.73		
12	210	5.09	261.4		
13	220	5.52	259.06		
14	230	5.94	256.73		
15	240	6.36	254.4		
16	250	6.79	252.07		
17	260	7.23	255.09		
18	270	7.68	257.22		

VOSTOCK ICE CORE TEMPERATURES

- G. Switch over to the Vostok Temp tab in the spreadsheet. Graph the Temperature C data on the y-axis (dependent variable), and the ice_age year BP on the x-axis (independent variable). This time, you'll create a scatter plot with straight lines, which connects all of the points you're graphing. 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 your previous analyses (0 = 0 year Before Present (BP), which is now). This is the custom for research that investigates patterns over long time periods. Adjusting the y axis so that the range along the axis is smaller will make the data be more prominent on the graph.
8. Copy/paste the graph you created into the document you are submitting and answer the following questions.
- Do you think these data are a good representation of pre-historic rates of change?
 - Are we currently in a glacial or interglacial period?
 - How long does a glacial and interglacial period last?
- Glacial:
- Interglacial:
9. Add a trend line and the R^2 value to the ice core temperature data. Copy/paste the graph into the document you are submitting. Do you think this line is a good representation of long-term rates of temperature change? Why or why not?
10. 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 specific data point, it will tell you the data values for that point. List the values of the of the data points at the beginning and end of the time period segment that you think has the steepest slope. Include the years BP in your response (e.g., end point: 55.17C, 0 years BP; start point 55.17C, 17 years BP):
11. 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. Copy/paste the graph into the document you are submitting.
- Record the of pre-historic temperature change (with units).

WHERE DO THE DATA COME FROM?

If you want to download the Vostok ice core CO₂ data, under the CDIAC website <https://cdiac.ess-dive.lbl.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.

VOSTOCK CARBON DIOXIDE

12. Switch to the Vostock CO₂ tab. Create a scatterplot with lines of CO₂ concentration as a function of (gas) age. Plot (gas) age on the x axis and CO₂ on the y axis. Copy/paste your graph into the document you are submitting and answer the following questions.

- a. 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?
 - b. 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?
- 13. Create 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.
 - a. Copy/paste your graph into the document you're submitting.
 - b. Rate of pre-historic atmospheric CO₂ change (with units):
- 14. Compare the fastest natural rate of change with the modern rate of change. (Remember to check your units are equivalent).
 - a. 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? Explain using complete sentences.
 - b. 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? Explain using complete sentences.