## 7.9 PROJECTS

### Project 7.1 Climate change

The causes and consequences of global warming are of intense interest. The consensus of the global scientific community is that the primary cause of global warming is an increased concentration of "greenhouse gasses," primarily carbon dioxide ($CO_2$) in the atmosphere. In addition, it is widely believed that human activity is the cause of this increase, and that it will continue into the future if we do not limit what we emit into the atmosphere.

To understand the causes of global warming, and to determine whether the increase in $CO_2$ is natural or human-induced, scientists have reconstructed ancient climate patterns by analyzing the composition of deep ocean sediment core samples. In a core sample, the older sediment is lower and the younger sediment is higher. These core samples contain the remains of ancient bottom-dwelling organisms called *foraminifera* that grew shells made of calcium carbonate ($CaCO_3$).

Virtually all of the oxygen in these calcium carbonate shells exists as one of two stable isotopes: oxygen-16 ($^{16}O$) and oxygen-18 ($^{18}O$). Oxygen-16 is, by far, the most common oxygen isotope in our atmosphere and seawater at about 99.76% and oxygen-18 is the second most common at about 0.2%. The fraction of oxygen-18 incorporated into the calcium carbonate shells of marine animals depends upon the temperature of the seawater. Given the same seawater composition, colder temperatures will result in a higher concentration of oxygen-18 being incorporated into the shells. Therefore, by analyzing the ratio of oxygen-18 to oxygen-16 in an ancient shell, scientists can deduce the temperature of the water at the time the shell formed. This ratio is denoted $\delta^{18}O$; higher values of $\delta^{18}O$ represent lower temperatures.

Similarly, it is possible to measure the relative amounts of carbon isotopes in calcium carbonate. Carbon can exist as one of two stable isotopes: carbon-12 ($^{12}C$) and carbon-13 ($^{13}C$). (Recall from Section 4.4 that carbon-14 ($^{14}C$) is radioactive and used for radiocarbon dating.) $\delta^{13}C$ is a measure of the ratio of carbon-13 to carbon-12. The value of $\delta^{13}C$ can decrease, for example, if there were a sudden injection of $^{12}C$-rich (i.e., $^{13}C$-depleted) carbon. Such an event would likely cause an increase in warming due to the increase in greenhouse gasses.

In this project, we will examine a large data set [68] containing over 17,000 $\delta^{18}O$ and $\delta^{13}C$ measurements from deep ocean sediment core samples, representing conditions over a period of about 65 million years. From this data, we will be able to visualize deep-sea temperature patterns over time (based on the $\delta^{18}O$ measurements) and the accompanying values of $\delta^{13}C$. We can try to answer two questions with this data. First, is there a correspondence between changes in carbon output and changes in temperature? Second, are recent levels of carbon in the atmosphere and ocean "natural," based on what has happened in the past?

*Part 1: Read and plot the data*

First, download the file named `2008CompilationData.csv` from the book website.[1] Examine the file and write a function that creates four parallel lists containing information about $\delta^{18}$O and $\delta^{13}$C readings: one list containing the $\delta^{18}$O measurements, one list containing the $\delta^{13}$C measurements, one list containing the sites of the measurements, and a fourth list containing the ages of the measurements. (Note that the `Age (ma)` column represents the ages of the samples in millions of years.) If a row is missing either the $\delta^{18}$O value or the $\delta^{13}$C value, do not include that row in your lists.

Using `matplotlib`, create scatter plots of the $\delta^{18}$O and $\delta^{13}$C measurements separately with respect to time (we will use the list of sites later). Be sure to appropriately label your axes. Because there is a lot of data here, your plots will be clearer if you make the dots small by passing `s = 1` into the `scatter` function. To create two plots in separate windows, precede the first plot with `pyplot.figure(1)` and precede the second plot with `pyplot.figure(2)`:

```
pyplot.figure(1)

# plot d18O data here

pyplot.figure(2)

# plot d13C data here

pyplot.show()  # after all the figures
```

*Part 2: Smooth and plot the data*

Inconsistencies in sampling, and local environmental variation, result in relatively noisy plots, but this can be fixed with a smoothing function that computes means in a window moving over the data. This is precisely the algorithm we developed in Section 7.2. Write a function that implements this smoothing algorithm, and use it to create three new lists — for $\delta^{18}$O, $\delta^{13}$C, and the ages — that are smoothed over a window of length 5.

To compare the oxygen and carbon isotope readings, it will be convenient to create two plots, one over the other, in the same window. We can do this with the `matplotlib` `subplot` function:

```
pyplot.figure(3)
pyplot.subplot(2, 1, 1) # arguments are (rows, columns, subplot #)

# plot d18O here

pyplot.subplot(2, 1, 2)

# plot d13C here
```

[1]This is a slightly "cleaned" version of the original data file from `http://www.es.ucsc.edu/~jzachos/Data/2008CompilationData.xls`

*Part 3: The PETM*

Looking at your smoothed data, you should now clearly see a spike in temperature (i.e., rapid decrease in $\delta^{18}$O) around 55 ma. This event is known as the Palaeocene-Eocene Thermal Maximum (PETM), during which deep-sea temperatures rose 5° to 6° Celsius in fewer than 10,000 years!

To investigate further what might have happened during this time, let's "zoom in" on this period using data from only a few sites. Create three new lists, one of ages and the other two of measurements, that contain data only for ages between 53 and 57 ma and only for sites 527, 690, and 865. Sites 527 and 690 are in the South Atlantic Ocean, and site 865 is in the Western Pacific Ocean. (Try using list comprehensions to create the three lists.)

Plot this data in the same format as above, using two subplots.

**Question 7.1.1** *What do you notice? What do your plots imply about the relationship between carbon and temperature?*

*Part 4: Recent history*

To gain insight into what "natural" $CO_2$ levels have looked like in our more recent history, we can consult another data set, this time measuring the $CO_2$ concentrations in air bubbles trapped inside ancient Antarctic ice [48]. Download this tab-separated data file from the book website, and write code to extract the data into two parallel lists — a list of ages and a list of corresponding $CO_2$ concentrations. The $CO_2$ concentrations are measured in parts per million by volume (ppmv) and the ages are in years.

Next, plot your data. You should notice four distinct, stable cycles, each representing a glacial period followed by an interglacial period. To view the temperature patterns during the same period, we can plot the most recent 420,000 years of our $\delta^{18}$O readings. To do so, create two new parallel lists — one containing the $\delta^{18}$O readings from sites 607, 659, and 849 for the last 420,000 years, and the other containing the corresponding ages. Arrange a plot of this data and your plot of $CO_2$ concentrations in two subplots, as before.

**Question 7.1.2** *What do you notice? What is the maximum* $CO_2$ *concentration during this period?*

*Part 5: Very recent history*

In 1958, geochemist Charles David Keeling began measuring atmospheric $CO_2$ concentrations at the Mauna Loa Observatory (MLO) on the big island of Hawaii. These measurements have continued for the past 50 years, and are now known as the *Keeling curve*. Available on the book website (and at `https://scrippsco2.ucsd.edu/assets/data/atmospheric/stations/in_situ_co2/weekly/weekly_in_situ_co2_mlo.csv`) is a CSV data file containing weekly $CO_2$ concentration readings (in ppmv) since 1958. Read this data into two parallel lists, one containing the $CO_2$ concentration readings and the other containing the dates of the readings. Notice that the file contains a long header in which each line starts with a quotation mark. To read past this header, you can use the following `while` loop:

```
line = inputFile.readline()  # inputFile is your file object name
while line[0] == '"':
    line = inputFile.readline()
```

Each of the dates in the file is a string in `YYYY-MM-DD` format. To convert each of these date strings to a fractional year (e.g., `2013-07-01` would be `2013.5`), we can use the following formula:

```
year = float(date[:4]) + (float(date[5:7]) + float(date[8:10])/31) / 12
```

Next, plot the data.

**Question 7.1.3** *How do these levels compare with the maximum level from the previous 420,000 years? Is your plot consistent with the pattern of "natural"* $CO_2$ *concentrations from the previous 420,000 years? Based on these results, what conclusions can we draw about the human impact on atmospheric* $CO_2$ *concentrations?*