**Rubric – Ice Cores (18 pts total)**

**Written responses**

We suggest having students write these in a lab notebook which is then turned in and graded. Alternatively, the instructor may choose to spot-grade in class, or to grade turned-in Jupyter Notebooks. While we provide the answer and points for every question, the instructor may elect to grade only a few questions, focusing on learning objectives central to the course.

Answers are given in green below.

Pause for Analysis: Examining the data

1. Scroll down past the abstract to where columns of data for analysis by the University of Bern. What are the first three columns of the data? (1 pt)  
   The first three columns of data are:  
   Column 1: Depth (m)   
   Column 2: Age (EDC3\_gas\_a) years BP   
   Column 3: CO2 (ppmv) measured at University of Bern

(For reference, the other columns are as follows☺

Column 4: CO2 sigma error (ppmv) measured at University of Bern   
Column 5: Depth (m)   
Column 6: Age (EDC3\_gas\_a) years BP   
Column 7: CO2 (ppmv) measured at LGGE in Grenoble

1. What are the units of depth? m (1 pt)
2. What are the units of "age?" years before present, or BP (1 pt)
3. What are the units of CO2? (ppmv). Parts per million by volume means the number of CO2 molecules per million other molecules in the air. (1 pt)
4. Look at the first row of the data: this represents the top of the ice core, which would have been closest to the surface. Thus it is the "youngest" part of the ice core. How many years before present is this measurement for? At what depth was it measured? What was the CO2 amount? (257.8 ppmv). (1 pt)
5. How does this compare to the preindustrial value of 280 ppmv and the present value of 411 ppmv? (A lot higher today!) (1 pt)

Pause for analysis: Years before present

* The present would be off the plot to the right - 10,000 years to the right, or about ¼ of the x-axis length. (1 pt)

Pause for Analysis: Time series of temperature

1. What is the range of temperatures recorded for this period?   
   -46 to -30 C, or -50.8 to -22 F. (1 pt)  
     
   Does this seem like a reasonable range - keep in mind that the core is from Greenland. Look up the monthly temperature at Summit, Greenland here: http://www.summitcamp.org/status/weather/index?period=1month. (To put these temperatures into perspective, at 7 am this morning it was about -3 deg C here in Tacoma.)  
   The monthly temperature may be something like -60 to -40 C in February, or -30 to 2 C in July. So this range is reasonable but a little cooler. (1 pt)
2. Recall that in a Dansgaard Oeschger (DO) event, the Arctic temperature first increases rapidly and then cools slowly. Find what you think could be a DO event in the plot and zoom in around it. (0 pt)
3. By how much did it warm? How long did it take?  
   Answers will vary. For example, 300 years to warm ~7C, or 105 years to warm 6 C. (1 pt)
4. Do you think this rate of warming was fast? What consequences do you think this plants, animals, and humans?  
   Answers will vary. 6 C in 100 years seems very fast, and this would have major effects on plants, animals, and humans. (1 pt)
5. How long did it take to cool back down again?  
   Answers will vary. It took ~2000 years. (1 pt)

Pause for Analysis: Milankovitch event

1. (eccentricity = 100,000 years, axial tilt = 41,000 years, and wobble = 26,000 years). The most obvious climate oscillation pattern of Milankovitch evident here is: Eccentricity, because we see large spikes at, e.g. ~240,000 and ~340,000. (1 pt)
2. Sketch this figure onto a separate sheet of paper and label the peaks corresponding to the climate oscillation pattern you identified above. The figure should resemble the plot in the key. (1 pt)

Pause for Analysis: CO2 and temperature

1. Do you see a correlation between CO2 and temperature? Yes. (0 pt)
2. Which changes first, temperature or CO2? Temperature changes before CO2 (1 pt)
3. Does this make sense? Give your reasoning why or why not and then read the following argument and rebuttal. Accept any reasonable answer. Students may respond “no,” because CO2 causes a rise in temperature, so CO2 should increase first. Or they may respond “yes,” or “partly,” because the ocean circulation changes and orbital fluctuations cause the rise in temperature. They may speculate that this somehow causes the rise in CO2, which the further increases temperature (1 pt).

Discussion prompts

2. Look up the CO2 concentration in modern times (see https://www.esrl.noaa.gov/gmd/ccgg/trends/) and add the most current value to your printout of the plot above. As of Feb 2020, the CO2 amount is ~412 ppm. This will put the new point almost twice as high as on the current plot. (1 pt)

3. As a class, we'll discuss how climate change in modern times differs from (and is similar to) the changes evident in that figure. Notes for the discussion: climate change in modern times is different because it is driven by fossil fuel emissions, rather than orbital or oceanic circulation changes. In fact, we are due for a cooling now (although “now” means on timescales of hundreds of years), rather than more warming. The warming atmosphere is warming the ocean, as in the past, but oceans are currently absorbing CO2, rather than emitting it due to the warmer ocean temperatures, as in the past, because the atmospheric CO2 concentration is higher than that in the ocean. The oceans will slow down the uptake of CO2 with time, removing that sink and causing atmospheric CO2 and thus temperature to rise more quickly. We do not currently see CO2 lagging temperature, but rather tracking it very well, at first, and then exceeding it, as shown to the far right of the plot. The fact that CO2 is rising faster than temperature indicates that it will take time for temperature to catch up, meaning there is a lot more warming to come. Students may note that looking at the close correlation between CO2 and temperature over the record, and considering that CO2 is now above 400 ppm, it seems that temperatures will become a lot higher than they have been for the last 425,000 years. We are basically running a big experiment. Climate scientists are trying to predict the outcome, but there are a lot of uncertainties. It is evident from there work, however, that there will be serious negative consequences. (0 pt)

**Figures**

**To be graded in class or by reviewing turned-in Jupyter Notebooks. Grading of figures after class is considered optional.**

* Part 2: Develop your plotting skill – compare figure in student Jupyter Notebook to that in key. (1 pt)