Name:______________________________

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# 8 Paleoclimate: Earth's climate and orbital variations

## 8.1 Introduction

While the gravitational force on the Earth is dominated by the force of gravity between the Earth and the Sun, other bodies in the Solar System affect the orbit of the earth in small ways, leading to some variations in orbital parameters over time. Given that the orbital parameters of planets can have an effect on climate, changes in the orbital parameters can lead to climate changes over long periods of time.

In this lab, we will investigate several effects on the Earth's orbital parameters over time, and see how, together, they are expected to lead to variations in Earth's climate.

We will also learn about how scientists can measure the past climate of the Earth uses samples of ice that have accumulated over hundreds of thousands of years. We will see whether the predictions of climate change from the changes in orbital parameters are matched by the climate record.

Finally, we will consider recent changes in climate and compare them to historical changes.

Before we begin, let's review the timeline of the Earth's history, which is shown graphically in Figure 8.1 The Earth was formed, along with the Sun, about 4.5 *billion* years ago. The simplest forms of life arose about 2-4 billion years ago. Abundant life on Earth started about 0.5 billion years ago (500 million years). Dinosaurs disappeared about 65 million years ago. The first homo sapiens appeared about 200 thousand years ago (=0.2 million years = 0.0002 billion years!).

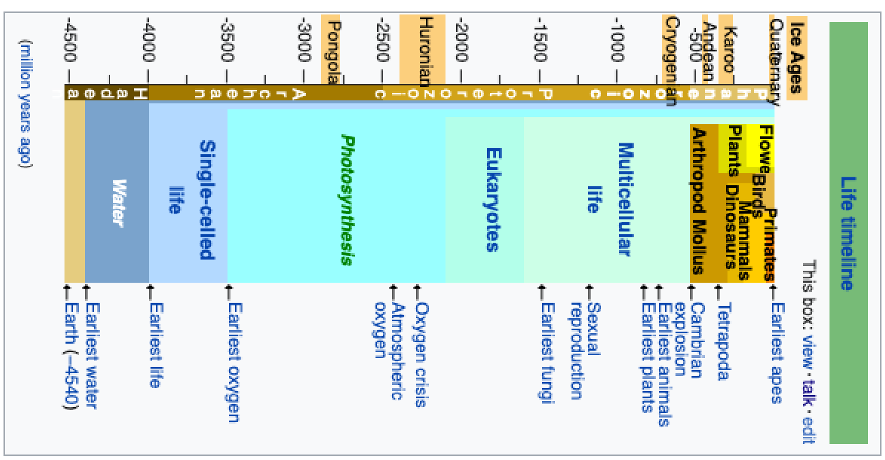



Figure 8.1:

## 8.2 Milankovich Cycles

Changes in the orbital parameters of Earth are often known as *Milankovich cycles*. Read about these at the following two sites:

- https://earthobservatory.nasa.gov/features/Milankovitch and find out who Milutin Milankovitch was.
- https://climate.nasa.gov/news/2948/milankovitch-orbital-cycles-and-their-role-in-earths-climate

1. Define the following terms in your own words:
   (a) eccentricity **(1 point)**
   (b) obliquity (or tilt) **(1 point)**
   (c) precession **(1 point)**

Let's investigate how variations in these parameters are expected to lead to climate changes on Earth.

Go to http://cimss.ssec.wisc.edu/wxfest/Milankovitch/earthorbit.html

Notes on using this simulator:

- The red and gray buttons at the bottom can be turned on and off. Red is on; gray is off. In some cases, multiple buttons can be selected at the same time, such as tilt, precession and eccentricity.
- The yellow triangle on the graph on the side can be adjusted to move around in time.

Click on "Orbit" and "Faster Orbit," as well as "Top View" and "Oblique View" to see how the system works. Also drag the yellow arrow on the chart up and down.

Click on the button "Top View". You should now be able to view the orbit of the earth from above. Note where in the orbit the Earth is closest to the Sun (perihelion) and where it is farthest (aphelion),

2. At what time of the year is the Earth the farthest from the Sun? What season is that in the northern hemisphere? What can you infer about the importance of distance from the Sun on climate at the current time? **(3 points)**

Click on the button "Oblique View". You should now be able to view the tilt of the earth on its axis as it rotates around the sun.

3. Describe the direction of the tilt of the N pole of the Earth's rotation axis at aphelion. (*Hint: Using the 'Season Lock' button may be useful.) **(1 point)**

4. Describe the direction of the tilt at perihelion. **(1 point)**

Select the “Eccentricity” button and go to “Top View.” Drag the yellow arrow up and down and make note of any changes you see.

5. How do you think eccentricity could impact climate? **(3 points)**

6. The predicted effects on temperature show a regular spacing in time. What is the approximate amount of time for each cycle (the time between successive peaks in the purple line)? **(2 points)**

Unselect the “Eccentricity” button and click on “Precession.” Drag the yellow arrow up and down while you are in the ”Top View.” Do the same for ”Oblique View.” Make a note of any changes you see while moving the yellow arrow while in ”Oblique View” and ”Top View.” (Note, you might want to start off moving the yellow arrow slowly, paying attention to the Earth).

7. From this investigation, describe what you think Precession means. How do you think precession could impact climate? **(3 points)**

8. The predicted effects on temperature show a regular spacing in time. What is the approximate amount of time for each cycle (the time between successive peaks in the purple line)? **(2 points)**

Unselect the “Precession” button and click on “Tilt.” Drag the yellow arrow up and down while in Top view and Oblique View, make note of any changes you see.

9. What is the approximate amount of time for each tilt cycle (the time between successive peaks in the purple line)? **(2 points)**

Collectively, the natural variations in these three parameters are called the Milankovitch Cycles. To see the combined effect of all three cycles, click on Eccentricity, Precession and Tilt at the same time. Note the “Cycle” indicated by the purple line that you see in the right-hand graph. It is a combination of all three effects, and predicts the change in temperature coming from the combined effect of the different orbital parameter variations.

10. In your own words, explain how the tilt of the earth and its orbit determine the amount of solar radiation we receive. **(3 points)**

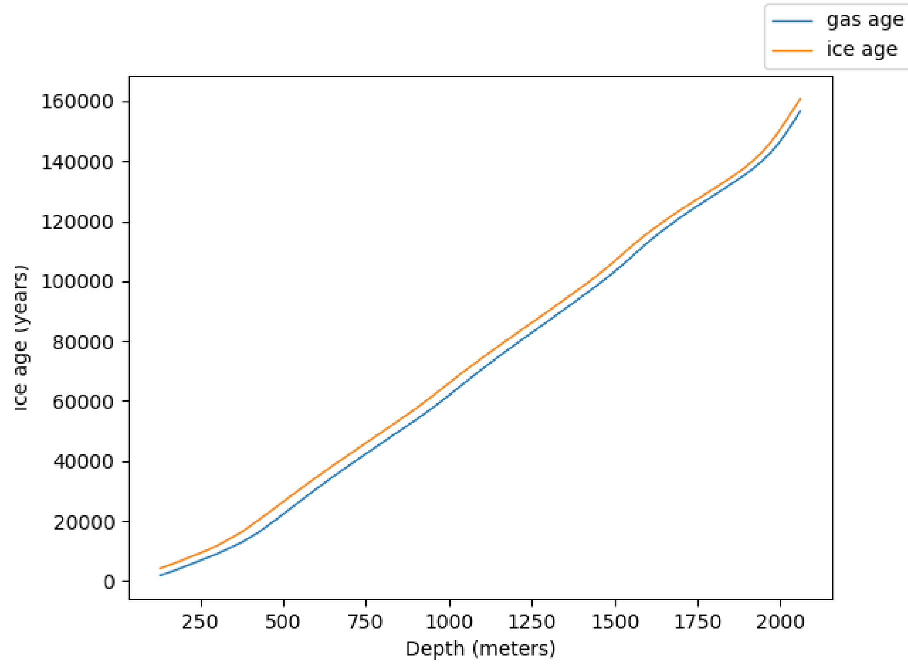
## 8.3 Ice cores and past climate record

The Vostok ice core was the result of a collaborative ice-drilling project between Russia and the U.S. in 1998. The core was drilled at the Russian station named Vostok in East Antarctica and produced the deepest ice core ever recovered. It reached a depth of 3,623 meters and the trapped air in the ice reveals changes in atmospheric composition of trace gases, which can be used to study temperatures in the past as well as the amount of certain gases in the Earth's atmosphere in the past. The deeper the ice core goes, the further back in time we are able to examine. In total, there was about 420,000 years worth of data that was able to be provided from the Vostok ice cores.

To learn more about ice cores, watch the video at:
https://d32ogoqmya1dw8.cloudfront.net/files/eslabs/cryosphere/ice_core_video.v2.mp4

11. What does each layer of an ice core represent? (Select one of the following.) **(2 points)**
    (a) a different atmospheric gas
    (b) a different year of weather and snow
    (c) a different glacier

Age is calculated in two different ways within an ice core. The ice age is calculated from an analysis of annual layers in the top part of the core, and using an ice flow model for the bottom part (the details of which are beyond the scope of this unit). The gas age data accounts for the fact that gas is only trapped in the ice at a depth well below the surface where the pores close up. The following is a plot of both types of ages as a function of depth below the surface.



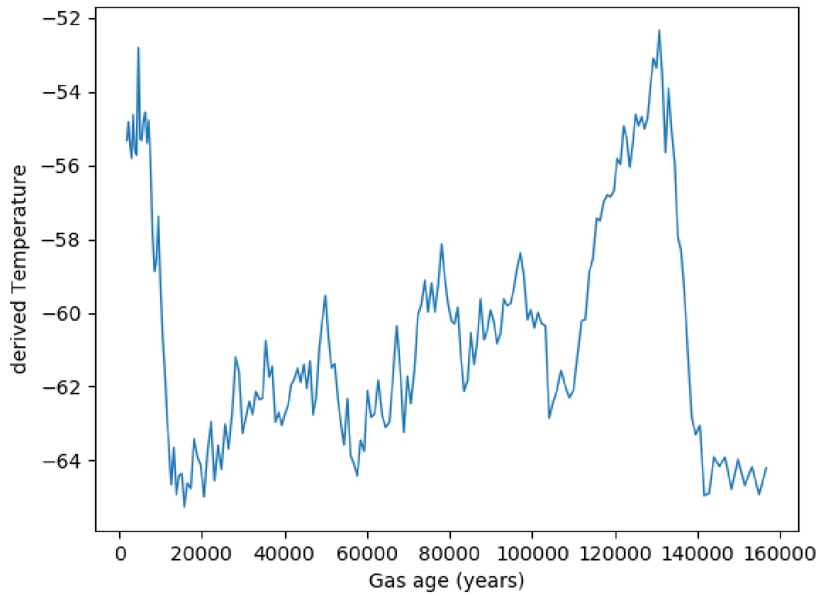

12. What is the gas age at a depth of 500 meters? **(2 points)**

13. At what depth in the ice core is the ice age closest to 100,000 years? **(2 points)**

14. Based on what you read, why is there is difference between the gas age and the ice age? **(2 points)**

The maximum amount of moisture that air can hold drops with decreasing temperatures. When humid air cools, the water molecules will condensate to form precipitation. Heavier isotopes (atoms with an extra neutron) have a slightly higher tendency to condensate, so humid air gradually loses relatively more and more of the heavier water molecules. Every time precipitation forms, the air mass becomes more depleted in heavy isotopes. During cold conditions (e.g., during winter or in a cold climatic period), the air masses arriving in over ice sheets have cooled more and have formed more precipitation, which means that the remaining vapor is more depleted in heavy isotopes. Measuring the abundance of different isotopes can be used as a proxy for temperature.

The following is a plot of the derived temperature vs age:




15. Approximately how long ago did the maximum temperature occur? **(2 points)**

16. Approximately how long ago did the minimum temperature occur? **(2 points)**

## 8.4 Relation of paleoclimate to orbital parameter variations

Milankovitch found that there are seasonal and latitudinal variations in the amount of solar radiation the earth receives. We have seen that it is possible to measure the past climate of the Earth over the past several hundred thousand years. Let's see whether the observed climate changes match up with the predicted ones from orbital parameter variations.

Go back to http://cimss.ssec.wisc.edu/wxfest/Milankovitch/earthorbit.html

Turn off (grey) all of the orbital parameters (eccentricity, tilt, precession). Turn on (red) the "Vostok Ice Core" button to plot a green line that represents Earth's recent temperature fluctuations. Note that the data here go back about 400,000 years, while the data we used in the last section only go back about 160,000 years. Can you match up the last graph with the data shown by the green line?

17. Are present day temperatures the warmest we have ever experienced in the last 400,000 years? **(2 points)**

Click on the 'Eccentricity' box on the bottom of the screen. This will produce a purple line on the Vostok ice core graph.

18. Does the shape of the Earth's orbit by itself correlate well with the observed temperature record? **(2 points)**

Unclick the 'Eccentricity' box on the bottom of the screen. Click on the 'Precession' box on the bottom of the screen to produce another purple line on the Vostok ice core graph.

19. Does the precession of the Earth's rotation axis by itself correlate well with the observed temperature record? **(2 points)**

Unclick the 'Precession' box on the bottom of the screen. Click on the 'Tilt' box on the bottom of the screen. This will produce a purple line on the Vostok ice core graph.

20. Does the tilt of the Earth's rotation axis by itself correlate well with the observed temperature record? **(2 points)**

Experiment with combining multiple effects of tilt, eccentricity, and precession.

21. Which combination of eccentricity, tilt, and precession mostly closely matches the temperatures over the last 400,000 years as inferred from the ice cores? **(3 points)**

The Milankovitch Theory that cyclical variations in three elements of Earth-sun geometry combine to produce variations in the amount of solar energy that reaches Earth explains past climates. The Vostok ice core data corroborates this theory.

## 8.5 Recent climate changes

Recent studies show that the earth is warming up, for example, as demonstrated by the worldwide climates stripe shown in Figure 8.2 that we have seen before.

We will demonstrate that this warming is unlike any warming seen in the climate record.

To do this, we will use the Historic Climate Trends Learning Tool to measure the rate of current warming and compare it to the rate of past warming episodes.

After you open the tool, you should see various options at the bottom of the graph: Temperature, CO2, N2O, Methane, Trendlines, and lines. If the word / box is highlighted in blue, that means its is "turned on." If "Temperature" is not turned on already, click on "Temperature" to view past temperatures. If you don't see anything, make sure that "trendlines" and "lines" are turned on. You can "zoom" in on a region of data by clicking

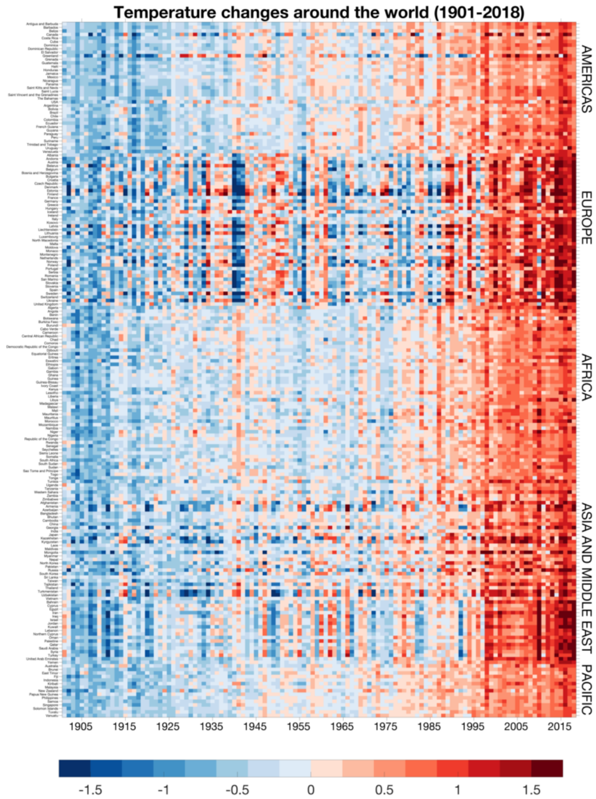



Figure 8.2: Climate stripes for all countries, showing warming around the globe over the past century.

on the graph and dragging across the range you want to see. To reset to the full time range, use the Reset item at the top.

22. Find a region where you think the temperature has risen the fastest. What range of times did you choose to measure the slope over? **(2 points)**

Zoom in on this region. To measure the rate of temperature change, we will use the "Calculate Slope" feature (at the top of the window) to calculate the average rate of change of temperature. To calculate the change in temperature across the region we are looking at, click on "Calculate Slope" and then click on "Temperature" from the drop-down menu. Once you've done this, start hovering over the graph, and you will see a dot. When you click a location on the curve, that dot will be "locked" into place. It will then ask you to select another point on the graph and calculate the slope between the two points. Do this by choosing the lowest point before a temperature rise, and then the highest point. The tool will then report the avarage rate of temperature change in degrees per year.

23. What value did you get for average rate of temperature change (which is what the slope is) during your chosen interval? **(2 points)**

Now let's measure the recent rate of temperature rise. To do so, either reset and zoom in on the far right of the plot, or use the show item at the top of the screen and select the last 5000 years. You should see a relatively constant temperature with a rise in the last 100-200 years.

Measure the rate of this temperature rise using the Calculate Slope tool as before.

24. What range of times did you choose to measure the slope over? **(2 points)**

25. What value did you get for average rate of temperature change? **(2 points)**

26. Compare the rate of temperature change in the last 100-200 years with that of the fastest rate of change in the last 800,000 years: which is bigger? **(2 points)**

27. Using the results from this section, explain how today's climate change is different from the natural episodes of climate change the Earth has experienced in the past. **(3 points)**

28. Considering the rate of change of temperature you see in the Milankovich cycle simulator, what are the connections (if any) between the Milankovitch Cycles and the current phenomenon of global warming? **(3 points)**

## 8.6 Long term climate change

Ice cores provide records of temperature over the last several hundred thousand years. This is only a tiny fraction of the Earth's history: the Earth is about 4.5 billion years old, and 500,000 years is 0.0005 billion years!

Tracking temperatures over longer periods of time is less precise, but scientists have provides some estimates.

Figure 8.3 shows estimates of temperature change over the last 500 *million* years. Note that the scale on the horizontal axis is not linear in time! The data we have been looking at appears in the rightmost two panels, but the more recent times are stretched out compared to older times. The same is true as one goes farther back in time on the plot, as you can see from the axis labels.

29. Has the Earth been significantly hotter than it is now at any point in the past? When? **(2 points)**

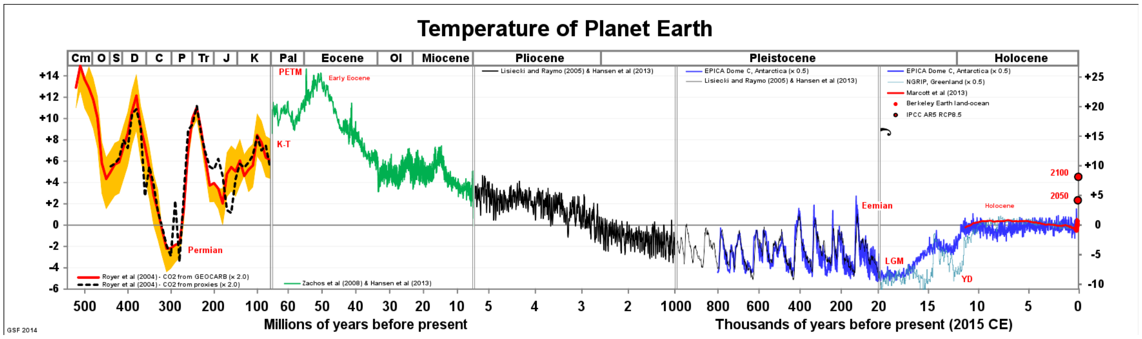



Figure 8.3: Long term temperature changes on Earth

30. If the Earth was warmer in the past, does that mean that we shouldn't be concerned about a rise in temperature now? Why or why not? **(3 points)**

## 8.7 Individual summary

**Individually**, write up a lab summary for this lab, and submit as a separate individual assignment. Remember to include all of the requested components!

## 8.8 References

*The exercises in this lab were largely drawn from*


- https://cimss.ssec.wisc.edu/wxfest/Milankovitch/earthorbit.html
- https://cimss.ssec.wisc.edu/wxfest/Milankovitch/MilankovitchCycleWorksheet.pdf
- https://serc.carleton.edu/eslabs/cryosphere/4b.html
- https://ncse.ngo/sites/default/files/TMEO%20Lesson%203%20-%20Past%20and%20Present.pdf

Other references

- https://www.globalchange.umich.edu/globalchange1/current/lectures/kling/paleoclimate/index.ht
- https://serc.carleton.edu/microbelife/topics/proxies/paleoclimate.html
- https://en.wikipedia.org/wiki/Paleoclimatology
- https://en.wikipedia.org/wiki/Timeline_of_glaciation