Module One

Open the spreadsheet for module one and click on the tab for the first exercise. Each exercise has two tabs: one for the data, and a second with some graphical analysis to help you with your answer these questions.

Exercise One: The Phanerozoic Record of Global Sea-Level Change

This exercise uses data from ocean cores that have been used to estimate how much sea level in the past has changed relative to the current day.

- Look at the data sheet for this exercise.
  - What is being measured?
  - How is this determined?
  - What time span do they cover?
- Look at the frequency of variation in the sea level curve
  - Over what interval is the frequency highest?
  - Over what interval is the frequency lowest?
  - What is the reason for this difference?
- What is the general trend in sea level between 170 mya and 55 mya?
  - Can you explain this trend?
- Look at the two major cycles that occur between 82 mya and 70 mya
  - What is the duration of each cycle?
  - What is the most likely reason for each cycle?
  - Why is global glaciation not likely to be the answer?
- When does the maximum peak in sea level occur in this record?
  - What happened in the geological record at this time?
  - What was the most likely cause of sea level rise?
  - Describe what happened to sea level after this pronounced maximum.
  - What is the most likely cause of this change?

Exercise One: Estimated Global Sea Level

- What time span does this expanded section of these data cover?
- Describe what happens to average sea level over this interval
- Look at how the amplitude of the sea level curve changes
  - What is the range between maximum and minimum from 8 mya to 6.2 mya?
  - What is the range between 6.2 mya and 3.4 mya?
  - What is the range between 1 mya and the start of the record?
  - What do these changes in amplitude actually represent?

Exercise One: Estimate Global Sea Level (II)

- Graph Number Three
- What time span does this cover?
- Look at the amplitude and frequency of this curve

- What happens to the frequency from around 1 mya to the start of the record?
- What happens to the amplitude of the signal over this same period?
- Can you explain the changes?

Exercise Two: Estimate Global Temperature

The second exercises uses data from the combined record of a number of Ocean Drilling Project (ODP) cores. The first two graphs are the ODP data at different scales. The third graph is a copy of the sea level data from the first exercise for comparison.

Exercise Two: L404 Benthic Stack

- Look at the data sheet for this exercise.
  - What is being measured?
  - How is this determined?
  - What time span do they cover?
  - What has been measured on the Y-Axis?
- What was the overall trend in temperature between 6 mya and around 3.4 mya?
- What happened to the overall trend in temperature between 3.4 mya and the start of the record?

Exercise Two: L404 Benthic Stack (II)

- Compare the range in amplitude of this data record between 2 mya and the start of the record
- How does this compare with the sea level record from the previous exercise?
- Do both records record the same changes?
- What is the average duration of each cycle before 1 mya?
- What was the average duration of each cycle from 0.8 mya to the start of the record?
- Compare the minimum range on the Y-axis both before and after 1 mya
- What does this change signify?
- Why is this represented in the isotope data from foraminifera?

Exercise Three: The NGRIP Greenland Ice Core

This graph is based on data from the Northern Greenland Ice Core Project spanning an interval from 120,000 during the last Eemian interglacial period to the modern era. Be sure to locate this core on the map provided before starting the exercise.

- Look at the NGRIP Graphs tab on the spreadsheet.
  - What is this graph measuring?
  - How is this related to temperature?
- How would you describe the overall pattern of temperature change?
  - Would you say that rapid climate change was unusual during this period?
  - Which was most common: a rapid rise in temperature or a rapid fall in temperature?
  - How many major shifts in climate occurred over the last 80,000 years?

    - What is the difference in $\delta^{18}O$ between the warmest period during this interval and the coldest period?
- Using the graph provided, estimate the change in temperature this represents
- Look at the interval between 50,000 and 30,000 years ago. These are Dansgaard Oeschger cycles.
    - What was the change in temperature on the ice sheet during this time?
- Estimate the change in temperature over the interval between 12,000 and 10,000 years ago?
    - What was the average rate of change per decade over this interval?
    - How does this compare to the rate of change in temperature over the last 50 years?
- Are all the cycles you observe in this data of the same length?
    - Is there a clear pattern to the cycles you see?
    - How does the interval between these visible cycles match the intervals of known Milankovitch cycles?

Exercise Four: The GISP Greenland Ice Core

This data is from the Greenland Ice Sheet Project and focuses on the record of climate change at the end of the most recent glacial period. Be sure to locate this core on the map provided before starting the exercise.

- What time interval do these data span?
- What is measured on the y-axis?
- How many Dansgaard Oeschger cycles can you identify in the interval between 50,000 and 10,000 years ago
- How does this compare to the data from the NGRIP ice core?
- Use the original data from this ice core to estimate how rapidly the temperature rose at the start of the Bölling-Allerød event
- How long did it take the temperature to fall from the Bölling-Allerød maximum to the minimum of the Younger Dryas event?

Exercise Four: The GISP Greenland Ice Core (II)

This graph is taken from the same data as the last, but covers a much shorter interval during the end of the last glaciation.

- What was the average rate of warming over the interval 10,000 to 11,000 years ago?
- What was the maximum rate of warming over the interval 11,857 to 11,594 year ago?
- What was the average rate of cooling from 14,500 to 12,700 years ago?
- What was the maximum rate of cooling during this same interval?

Exercise Four: The GISP Greenland Ice Core (III and IV)

These graphs show the same data (**note**: in reverse time order) with a simple calculation of the rate of climate change superimposed in red.

- Look at the peaks and troughs that represent rapid climate change
  - Which are most common: rapid rises in temperature of rapid falls in temperature?
  - What is the maximum rate of temperature change you observe?
  - When did this occur?
- Look at the last graph on this page that plots the data over a shorter period of time.
  - Compare the stability of climate before 11,000 years ago with the period from 11,000 to 3,000 years ago.
  - What are the main differences you observe?
  - How would you compare and contrast climate stability during glacial and interglacial periods?

Exercise Five: The GRIP Greenland Ice Core

These data are from three ice cores from the Greenland Ice Cap. Be sure to locate these cores on the maps provided before starting the exercise.

- Look at the data sheet for this exercise.
  - What is being measured?
  - How is this determined?
  - What time span do they cover?
- How well do the data agree?
- Can you find a record of the Younger Dryas event in these data?
- What happens to the record between 8,000 and 8,300 years ago?
  - What change in temperature does this represent?
  - What could be the reason for this temperature change?
  - How does it compare to the Younger Dryas event?
- What is the general trend in climate on Greenland from 8,000 years ago to the present?
- How representative is this likely to be of the overall climate of the northern hemisphere?
- How representative is this likely to be of global climate?

Exercise Six: The GISP Greenland Ice Core and Byrd Antarctic Ice Core

These data are from cores on Greenland and Antarctica. Be sure to locate these cores on the maps provided before starting the exercise.

- Look at the data sheet for this exercise.
    - What is being measured?
    - How is this determined?
    - What time span do they cover?
- How well do the records compare?
    - Find one interval where these is close agreement
    - Find one interval where there is little agreement
    - How do the records compare between 70,000 and 40,000 years ago?
    - What does this tell us about the link between the Arctic and Antarctic?
- Look at the data over the interval between 20,000 and 10,000 years ago
    - Did warming occur at the same time at both sites?
    - At which site did the greatest amount of warming occur?
    - Find the record of the Younger Dryas event on the Greenland data
    - Can you find any record of this event in Antarctica?
    - Why should the record of warming be so different at both sites?

Exercise Seven: The Vostok Antarctic Ice Core

These data are the Vostok core on Antarctica. Be sure to locate this core on the maps provided before starting the exercise.

- Look at the data sheet for this exercise.
    - What is being measured?
    - How is this determined?
    - What time span do they cover?
- How many glacial and interglacial periods can you recognize from this data?
- How long has the present interglacial period lasted compared with previous interglacial periods?
- How well does the carbon dioxide record agree with the temperature record?
- Which tends to fall first: temperature or CO_2?
- Which tends to increase faster: temperature or CO_2?
- Why should this happen?

Exercise Eight: The EPICA Antarctic Ice Core

This data is from the EPICA Antarctic Ice core, the deepest to date. Be sure to locate this core on the map provided before starting the exercise. This chart is data intensive and my take some time to open on an older computer.

- Look at the data sheet for this exercise.
    - What is being measured?
    - How is this determined?
    - What time span do they cover?

- How many glacial and interglacial periods can you recognize from this data?
- How long has the present interglacial period lasted compared with previous interglacial periods?
- The first graph is a measure of the amount of solar radiation arriving at 65°N of the equator as determined by Milankovitch orbital cycles.
  - What is the overall pattern in these data?
  - What is the periodicity of the major cycles you observe?
  - How is the 100,000-year cycle represented on this data?
  - How is the 42,000-year cycle represented on this data?
  - Which Milankovitch cycle is most closely related to interglacial phases?
- Can you find a past pattern in the Milankovitch cycles that closely resembles recent changes?
  - Find the interglacial period associated with this time
  - How long does that interglacial last compared to the next three?
  - What does that tell us about the probable length of the present interglacial period?

Exercise Eight: EPICA: Temperature and CO_2

- Draw a series of lines from points where the temperature starts to increase rapidly to the Milankovitch data curve.
  - Do rapid increases in temperature occur at the same time as more energy is reaching the northern hemisphere?
  - Why is there a difference?
- How well do temperature and CO_2 agree over this interval?
- Can you see any more examples of temperature leading changes in CO_2? (**Note**: you may have to expand this data to look at some sections in more detail)

Exercise Eight: Dust in the ice cores

- Where does dust come from and how does it get into ice cores?
- Compare the dust record with the temperature record
  - When is the record of dust at its greatest?
  - Why should this be so?

Exercise Nine: Global Sea Level

- This data is an estimate of sea level using data from exercise one
  - How well does the sea level curve follow the temperature curve
  - Do closely do sea level maxima coincide with temperature maxima?
  - Why would you expect a difference?

Exercise Ten: The future?

- This diagram illustrates the combined impact of Milankovitch cycles on the amount of solar irradiation that reaches the top of the atmosphere. As these cycles are predictable, they also give us some important clues about probable climate change in the future. Use the space provided on this diagram to predict how global climate is likely to change over the next 800,000 years