Climate change and carbon dioxide

There is a wide range of scientific evidence which shows that the Earth's climate has always been changing. Over the last few hundreds of thousands of years, there have been periods of global warming and global cooling. The cooler periods correspond to ice ages when much of the northern hemisphere land was covered with sheets of ice many kilometers thick. It is only in the last few decades that some of the changes in the last 200 years have been attributed to the consequences of human activity. These are called anthropogenic changes.

The temperature of the Earth is determined by a balance between the energy coming in from the Sun, and the energy being re-radiated into space. Carbon dioxide is known to be a greenhouse gas: it absorbs infrared energy emitted from the Earth.

Change in the last century
Since the industrial revolution, carbon containing fuels (and particularly fossil fuels) have been burnt on a scale never known before. These fuels produce carbon dioxide which goes into the atmosphere.

1. Explain why burning fossil fuels produces carbon dioxide. Use at least one equation in your answer.

Carbon dioxide is naturally present in the atmosphere and has a lifetime of about 50-100 years. This means that a molecule will spend on average this amount of time in the atmosphere before being removed. Processes which add carbon dioxide to the atmosphere are known as sources and those which remove it are known as sinks.

2. Suggest some natural sources and sinks of carbon dioxide in the atmosphere.

When all the sources are adding carbon dioxide to the atmosphere at the same rate that all the sinks are removing it, then the total concentration of carbon dioxide will remain constant (it will be in equilibrium). At present, carbon dioxide from human activity is going into the atmosphere faster than the sinks can remove it. As a consequence the concentration of carbon dioxide in the atmosphere is rising. At Mauna Loa in Hawaii, the concentration of carbon dioxide in the air has been measured regularly since the middle of the last century and this rise can be seen clearly.
Figure 1. This graph shows the carbon dioxide concentration in the air. Data are reported as a dry mole fraction which is defined as the number of molecules of carbon dioxide divided by the number of molecules of dry air multiplied by one million (ppm). The black line shows the seasonal (6 monthly) average. The information is obtained by passing a stream of air through an infrared gas analyser which has a water vapour freeze trap attached. The machine is regularly calibrated by passing reference samples, which contain a known concentration of carbon dioxide, through it.
Mauna Loa in Hawaii is a barren lava field a long way off the coast of the USA in the Pacific Ocean. Although there are other places where CO₂ is measured, this is considered to be one of the most reliable records.

3. Why is this data more reliable than if were recorded somewhere like mainland Britain?

4. Why is regular calibration of the infrared gas analyser important?

5. The concentration rises and falls in a regular pattern which matches the seasons. Would you expect the summer or the winter to have the higher value? Explain your answer.

6. What is the percentage of carbon dioxide in the air by volume? (Assume the concentration is 380 ppm.)

7. What is happening to the rate of the increase in concentration of carbon dioxide in the air?

Temperatures have been measured directly in a number of places around the globe since about 1850. These can be used to show how the average global temperature has changed in that time.
Figure 3. This graph shows how the global temperature has changed since the mid-1800s (when records began.) The axis on the right shows the average global temperature; the one on the left shows how this temperature differs from the average temperatures measured during the period from 1961-1990. The circles show the yearly values and the red line the averaged values over a ten year period. The pink shaded areas are the estimated uncertainties in the values.

8. Describe how the temperature changed between 1900-2000.

9. What has happened to the thickness of the pink line as the century has progressed? What does this show?

10. Is there a direct correlation between the change in the concentration of carbon dioxide and the change in temperature?

The differences in the shapes of the temperature and carbon dioxide graphs suggest that the link between temperature and carbon dioxide is not straightforward. Carbon dioxide is not the only factor which can cause temperature change. Many other factors can also cause warming (such as the gas methane); some cause cooling. Small particles in the atmosphere called aerosols can cause cooling. The aerosols contain sulfate ions which can come from natural sources such as volcanic eruptions or they may come from burning fuels without controls on emissions. It is widely accepted that the cooling in the middle of the 20th century was caused by these particles.
Climate Change over much longer time scales
To help in the search for information about climate change in the past, ice cores have been drilled in both the Arctic and the Antarctic. These ice cores are long, thin cylinders of ice which go down several kilometers into the glaciers near the poles. As snow is successively laid down, bubbles of air become trapped and can be analysed to find out historical concentrations of gases including carbon dioxide. In addition, by examining the ratios of $^{16}\text{O}$ and $^{18}\text{O}$ as well as $^1\text{H}$ and $^2\text{H}$, the temperature of the Earth at the time can be calculated. The ice cores at Vostok have yielded data going back more than 400 000 years; those at EPICA Dome C nearly 800 000 years.

11. What is the difference between $^{16}\text{O}$ and $^{18}\text{O}$ atoms?
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Figure 5. A scientist operating an ice core drill in a pit.

Figure 6. Scientists examining an ice core in Antarctica.
12. In Figure 6, the scientists are seen to be wearing a lot of protective gear including full body suit, gloves and masks. Explain why this is necessary.

![Graph showing CO₂ concentration and temperature variation](image)

*Plots courtesy of EPICA. Data from Luethi et al 2008 (CO₂) and Jouzel et al 2007 (temperatures). Thanks to Eric Wolff of British Antarctic Survey (BAS) for supplying the information.*

Figure 7. Antarctic Ice Core Data.

13. What do you notice about the pattern of temperature rises and falls (shown in blue)?

14. Does the carbon dioxide concentration (shown in red) show a similar pattern to the temperature rises?

15. Which appears to rise first – temperature or carbon dioxide concentration?

Issues with dating the ice cores (and in particular, dating the temperature and carbon dioxide measurements relative to each other) mean that it is not possible to be completely certain which rises first, but it appears to be the temperature. Current thinking is that the temperature began to rise which caused the carbon dioxide concentration to rise. The extra carbon dioxide in turn helped to heat up the Earth, which caused more carbon dioxide to enter the atmosphere. This is what is known as feedback and it can amplify a small change into a much larger one. The carbon dioxide could come from a number of sources including the oceans; as the temperature rises, carbon dioxide becomes less soluble and comes out of solution.

The exact nature of the relationship between temperature and carbon dioxide concentration is still not well understood and there is no one fully-accepted explanation for the patterns seen in
The regular shape of the temperature graph suggests an almost mathematical function which in turn suggests that one of the causes of the temperature variations might be astronomical in nature. In the 1920s a Serbian astronomer called Milutin Milankovitch developed the theory that ice ages were controlled by the amount of solar energy reaching high northern latitudes in midsummer because this was the area where ice would begin to advance if solar energy dropped. Milankovitch proposed that variations in solar energy were caused by the orientation of the Earth as it moved around the Sun. Combinations of three factors in the Earth’s motion (eccentricity, precession and obliquity or amount of tilt) altered the amount of energy received by the Earth at different latitudes and seasons giving rise to what are known as Milankovitch cycles. The Milankovitch Theory of ice ages is generally accepted today.

The graph below shows the amount of solar energy in watts per square metre reaching latitude 65 deg N calculated over the last 160 thousand years.

If this is superimposed on the Vostok ice core data (Figure 7) the peaks in the two curves seem to coincide (see Figure 9) and this is also true further back in time. Milankovitch obviously did not have the ice core data and so the match between it and what his theory predicts is particularly striking.
This offers a hypothetical explanation of why the temperature varies as it did over half a million years, although it is still difficult to understand the magnitude of the temperature reaction.

16. Carbon dioxide concentrations today are about 380 ppm. Has the concentration been higher than this in the last 400 000 years?

17. Why is this high concentration of carbon dioxide a concern?

It seems from the Antarctica data that the temperature there has been higher than at present in the last half a million years. It is not clear, however, whether the average temperature of the Earth has ever been higher as the ice cores give a local not a global picture.

Sunspots
In addition to the Milankovitch cycles, the amount of solar energy reaching the Earth is dependent on the number of 'sunspots' on the Sun’s surface. Roughly, the higher the number of sunspots the hotter the Sun is and therefore more energy will reach us. The number of sunspots also affects how much solar wind reaches Earth and reflects changes in the Sun’s magnetic field. Exactly how and how much this affects the climate of the Earth is still a subject for much debate and research. A team of scientists in Zurich have recently shown that the number of sunspots is at a 1000-year high and say that anthropogenic climate change is amplifying the warming already being produced by the sun.
Summary

Summarise the possible causes of climate change:

a. Over the last half a million years
b. Over the last 150 years

In your own words, explain the relationship between changes in the climate and concentration of carbon dioxide in the atmosphere. Indicate where the areas of uncertainty are and suggest what further research is required. Explain why what is happening now is different to the changes in climate which have occurred in the Earth’s past.