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Tropical rainforest in Hawaii

Simon Fraser/SPL

Forests, carbon and climate

GCSE key words
Photosynthesis
Respiration
Carbon cycle
Climate change
Greenhouse gas

Scientists are only beginning to understand just how complex and fascinating the relationship between trees, the carbon cycle and climate really is. Here, Mathias Disney shows how aspects of your GCSE science course relate to his current research.

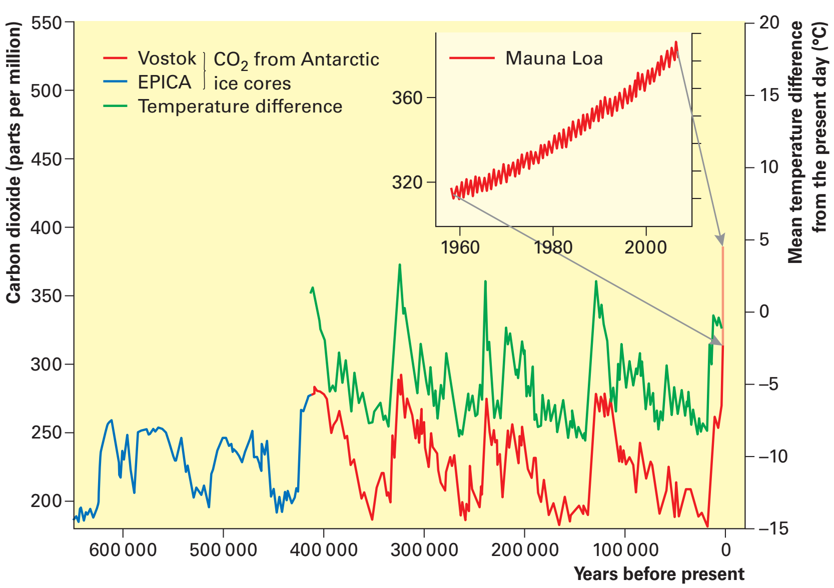

Figure 1 *Atmospheric carbon dioxide concentrations over the last 650 000 years from Antarctic ice cores. The inset shows atmospheric carbon dioxide in more detail from 1958 to the present measured in Mauna Loa, Hawaii. The green line shows historical temperature variations relative to the present day (right hand axis). (Sources: all data publicly available from NOAA — see Box 2)*

Trees are vital to life on Earth. They provide fuel, fibre, food and shelter for humans, and habitats for a vast range of animals. One of the most important functions of trees is their ability to use atmospheric carbon dioxide (CO_2), a greenhouse gas, in photosynthesis:

$$6CO_2 + 6H_2O \xrightarrow[\text{chlorophyll}]{\text{light}} C_6H_{12}O_6 + 6O_2$$

The biomass produced stores large amounts of carbon, and oxygen is released.

Carbon dioxide levels

Reconstructions of Earth's past climate, and the observed impact of vegetation on global atmospheric carbon dioxide levels, have changed the way we perceive the Earth's system. Figure 1 shows past atmospheric carbon dioxide and temperature variations measured from tiny air bubbles trapped up to 3 km deep in Antarctic ice. Although there are major variations over glacial cycles of around 100 000 years, atmospheric temperature and carbon dioxide follow each other — we say that there is a close correlation between temperature and carbon dioxide levels. Notably, carbon dioxide remained below 300 parts per million (ppm) until the twentieth century.

The inset in Figure 1 shows atmospheric carbon dioxide levels from 1958 to the present, measured at Mauna Loa in Hawaii. These measurements highlight the link between vegetation and climate, as well as human influence. They show the annual rise and fall

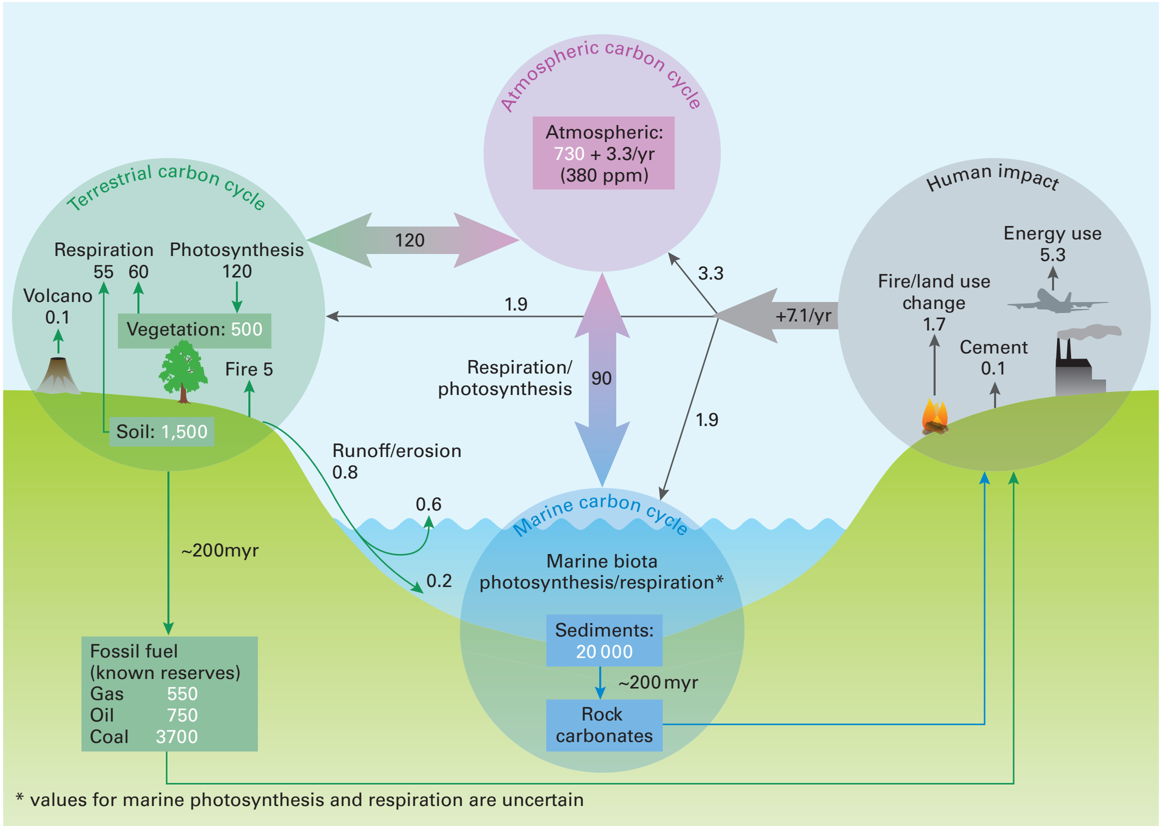

Figure 2 *The global carbon cycle showing the reservoirs (white) of carbon in billion tonnes (gigatonnes, Gt) of carbon. Fluxes are in GtC/year. Geological changes are measured in millions of years (myr)*

- **Can you manage the global carbon cycle and climate? Have a go using this simple online model: www.sei.se/forests/breathingforests.htm**

of carbon dioxide caused by the vegetation in the northern hemisphere growing up during summer and dying back during winter; the whole Earth is 'breathing'. There is much less land mass supporting vegetation in the southern hemisphere. Figure 1 also shows there has been an increase of nearly 20% in carbon dioxide levels since 1958. This rapid increase is mainly due to burning fossil fuels (gas, oil, coal). There is strong evidence that this is having a measurable impact on climate.

Box 1 The history of the greenhouse gas concept

1827 Fourier developed the greenhouse gas concept in which carbon dioxide raises the atmosphere's temperature by about 15 °C.
1860 Tyndall found that water vapour makes the largest contribution to greenhouse warming.
1896 Arrhenius calculated that doubling atmospheric carbon dioxide would bring about a 5°C temperature increase.

Trees and climate

So how do trees fit into the picture? Figure 2 shows the stores of carbon and the fluxes (flows) that make up the global carbon cycle. The soil/plant system acts as a huge store for carbon. It contains three times as much carbon as the atmosphere. The land and ocean each absorb approximately a quarter of all fossil fuel emissions; the other half remains in the atmosphere. As atmospheric carbon dioxide concentration rises, trees grow more rapidly (so-called carbon dioxide fertilisation) and hence absorb more carbon dioxide. At a certain concentration of carbon dioxide, however, this increase will level off as other factors become limiting.

Figure 2 also shows that soils are a vital part of the carbon cycle. Microbes in the soil decompose dead organic plant matter, storing huge quantities of carbon. But they respire while doing so, releasing carbon dioxide. As global temperatures rise, these microbes will become more active, releasing more carbon dioxide and further increasing warming.

This is just one of many feedbacks between the forest system and climate, some positive (reinforcing warming) and some negative (slowing down warming). One of the most fascinating and important challenges facing scientists is how to measure the carbon balance of forest systems over many life cycles and predict how this may alter with changing climate.

Measuring how forests 'breathe'

Each year a large amount of carbon cycles through the Earth's vegetation and soil. Because forests are not closed systems, measuring the carbon balance of a forested region is difficult. We need to know how much carbon flows in and out over a given time period. To do this, scientists draw an imaginary box around the forest system and, using instruments mounted on towers above the forest canopy (see pages 18–19), measure the flux of carbon dioxide, resulting from flow, into the system (due to photosynthesis) and out of it (due to plant and soil respiration).

Although scientists refer to carbon in the environment, it is usually in a compound: carbon dioxide in the atmosphere; hydrocarbons in fossil fuel; carbohydrates, proteins and lipids in plants and animals; and carbonates in rocks.

EPICA is the European Project for Ice Coring in Antarctica. The ice core went to 3190 metres covering 720 000 years. The Vostok ice core went back 420 000 years.

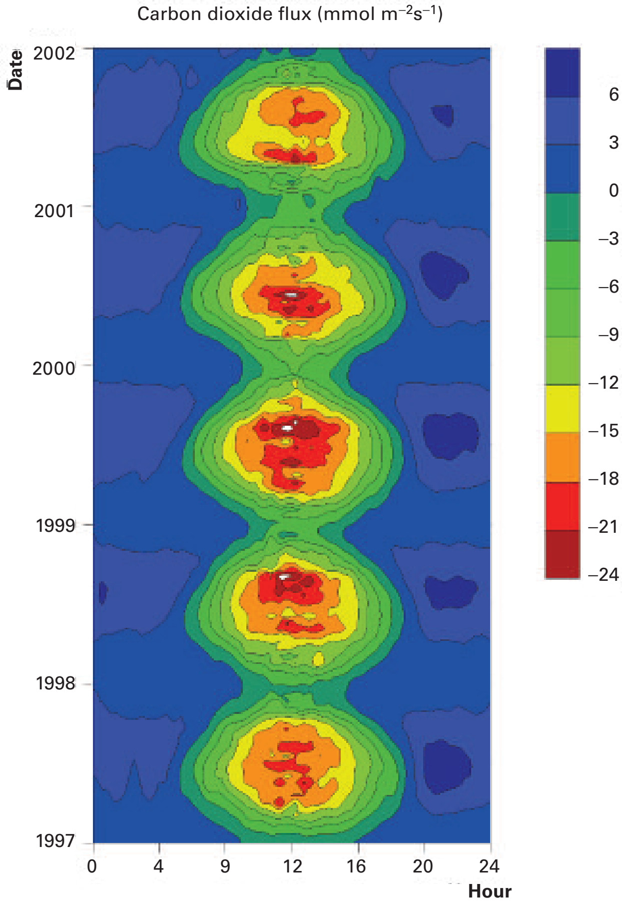

Figure 3 *Daily variations in carbon dioxide fluxes (horizontal axis) measured at Aberfeldy in Scotland, over a 5-year period. We see the forest breathing in carbon dioxide (green to red, negative values) due to photosynthesis during the day and during the summer; and out (blue, positive) due to respiration at night and during the winter. (Source: J. Moncrieff)*

A typical forest

Figure 3 shows a forest breathing (a localised version of the global breathing in Figure 1). From bottom to top it shows 5 years of seasonal variation in the net carbon flux; horizontally it shows variations over each day. Negative values (green to red) indicate where the forest is a **sink** of carbon dioxide, when more carbon dioxide is absorbed through photosynthesis than is released by respiration (during the day and in summer). Positive values (blue) indicate where the forest is a **source** of carbon dioxide (during the night and in winter). By adding up all the positive and negative values we can calculate the forest carbon balance over time.

Biomass is the total dry mass of an organism such as a tree.

Soil respiration

Instruments placed on the soil enable us to measure how much of the total carbon dioxide flux comes from soil respiration. This is vital to understanding how soil respiration will change with climate. Such measurements show that forest systems can be very different from each other, and that the carbon balance of a forest varies over its life cycle.


Robert Brook/SPL

It may take a young forest 15 or 20 years to become a net carbon dioxide sink


David C. Clegg/SPL

Deforestation reduces the amount of carbon dioxide absorbed from the atmosphere

Young and old forests

A young forest may be a net source of carbon dioxide to the atmosphere because the soil disturbed during planting may emit more carbon dioxide than is taken up by the vegetation. It may take 15 or 20 years to become a net carbon dioxide sink. As a forest gets old, the size of the sink may decrease as the trees near the end of their lives. Crucially, after death, tree biomass decomposes, releasing most of its stored carbon back into the atmosphere. So the long-term store lies in the soil.

Satellite observations

Scientists complement their detailed forest measurements with observations from satellites which monitor forest productivity on a global scale. Figure 4 shows satellite estimates of global vegetation productivity over the globe for 1999.

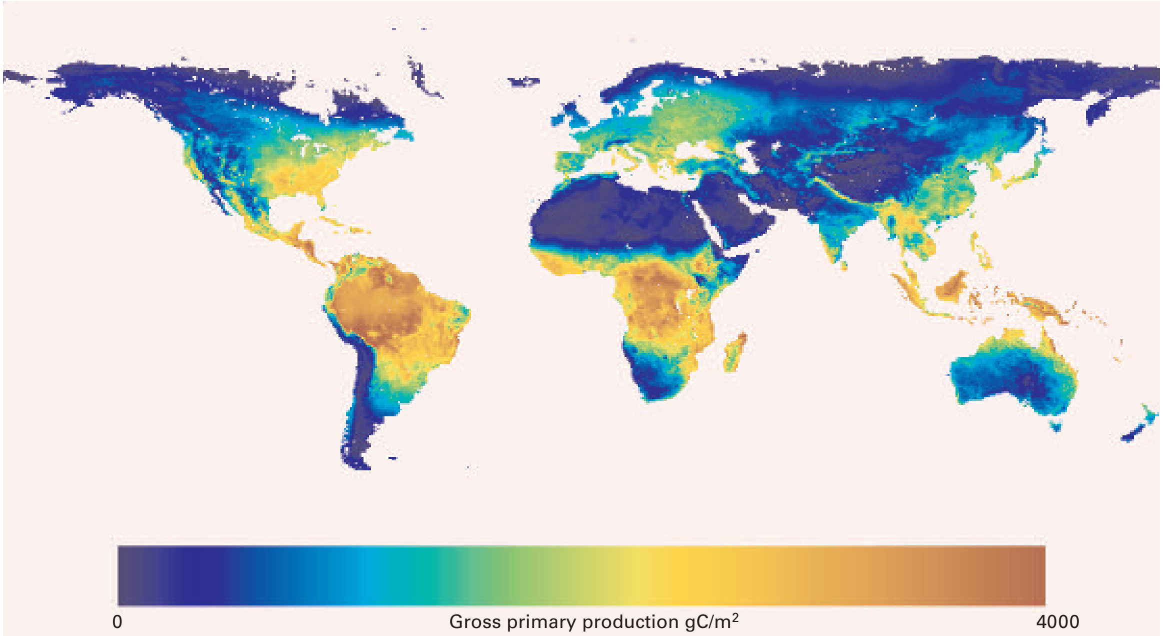

Figure 4 *Satellite-derived map of gross primary production, the total amount of carbon absorbed due to photosynthesis, in grams of carbon per square metre during 1999. Values range from 0 (dark blue) to 4 kg C/m^2 (brown). The heavily productive regions can be clearly seen across the tropical forests in the Amazon and Central Africa (Source: T. Quaife)*

Developing models

All these measurements help us to develop models of how the system works and make predictions about what will happen as climate changes. We can also use such models to make predictions about the impact of actions such as deforestation, increased fossil fuel consumption and planting trees to offset carbon emissions.

Other feedbacks

One of the difficulties in considering how forests and climate interact is that there are many other factors involved, in addition to carbon dioxide. Some of these factors have positive effects, some negative.

Recent research suggests that forests may be a source of methane (CH_4), another important greenhouse gas. Forests, being large and dark, absorb more sunlight energy than light-coloured areas, making the surface warmer. Trees can also encourage the production of clouds both by transpiring water into the atmosphere and through production of compounds which encourage cloud formation. Clouds can reduce heat loss from the ground and atmosphere beneath (clear nights are colder than cloudy ones), but also reflect light from the sun before it reaches the ground. The net impact of forests on climate is a combination of all these (and other) factors, whose complexity scientists are still trying to unravel.

Box 2 Useful websites

- This site shows the way many nations are collaborating in research on the carbon cycle: www.globalcarbonproject.org
- The website of the Intergovernmental Panel on Climate Change is at: www.ipcc.ch
- A great place to learn more about the carbon cycle is at: http://earthobservatory.nasa.gov/Library/CarbonCycle
- You can find ice core data at: www.ncdc.noaa.gov/paleo/icecore/antarctica/vostok/vostok_data.html
- You can find data on carbon dioxide concentrations at: www.cmdl.noaa.gov/projects/web/trends/co2_mm_mlo.dat

A **limiting factor** is one that controls the rate of a process.

Conclusion

At the start of the twenty-first century, it is clear that managing the Earth's carbon cycle is crucial to the planet's wellbeing. Scientists are revealing how much we have left to learn about the subtle interplay between trees, carbon storage and climate. This science is fascinating, because we don't know the answers. It is also urgent if we are to predict the full consequences of humanity's global climate experiment from burning fossil fuel.

Mathias Disney *wrote this article with input from Shaun Quegan, John Grace and Andreas Heinemeyer. All are members of the Centre for Terrestrial Carbon Dynamics research team. Find out about the team's work at* **http://ctcd.group.shef.ac.uk/ctcd.html.** *Click on* People *to read their biographies.*