British Antarctic Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL

SCIENCE BRIEFING

Ice cores and climate change

Slices of ice core, drilled from the depths of the Earth's ice sheets reveal details of the planet's past climate

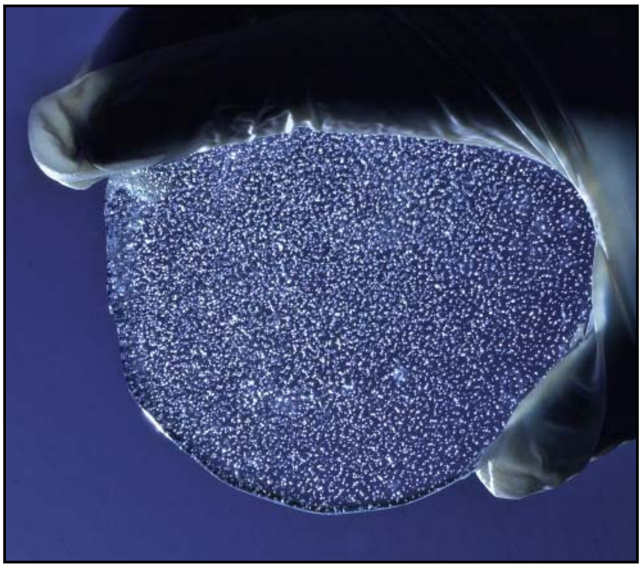
Introduction

Ice cores are cylinders of ice drilled out of an ice sheet or glacier. Most ice core records come from Antarctica and Greenland, and the longest ice cores extend to 3km in depth. The oldest continuous ice core records to date extend 123,000 years in Greenland and 800,000 years in Antarctica. Ice cores contain information about past temperature, and about many other aspects of the environment. Crucially, the ice encloses small bubbles of air that contain a sample of the atmosphere – from these it is possible to measure directly the past concentration of gases (including carbon dioxide and methane) in the atmosphere.

Greenhouse gases and the recent past

Direct and continuous measurements of carbon dioxide (CO_2) in the atmosphere extend back only to the 1950s. Ice core measurements allow us to extend this way back into the past. In an Antarctic core (Law Dome) with a very high snowfall rate, it has been possible to measure concentrations in air from as recently as the 1980s that is already enclosed in bubbles within the ice. Comparison with measurements made at South Pole station show that the ice core acts as a faithful recorder of atmospheric concentrations (see Fig. 1 overleaf), although we do have to be cautious, as artefacts can arise at sites with high concentrations of other impurities.

Antarctic ice cores show us that the concentration of CO_2 was stable over the last millennium until the early 19th century. It then started to rise, and its concentration is now nearly 40% higher than it was before the industrial revolution (see Fig. 2 overleaf). Other measurements (e.g. isotopic data) confirm that the increase must be due to emissions of CO_2 from fossil fuel usage and deforestation. Measurements from older ice cores (discussed below) confirm that both the magnitude and rate of the recent increase are almost certainly unprecedented over the last 800,000 years. The fastest large natural increase measured in older ice cores is around 20ppmv (parts per million by volume) in 1,000 years (a rate seen during Earth's emergence from the last ice age around 12,000 years ago). CO_2 concentration increased by the same amount, 20ppmv, in the last 11 years! Methane (CH_4), another important greenhouse gas, also shows a huge and unprecedented increase in concentration over the last two centuries. Its concentration is now much more than double its pre-industrial level. This is mainly due to the increase in emissions from sources such as rice fields, ruminant animals and landfills, that comes on top of natural emissions from wetlands and other sources.



▲ *A slice of ice core containing tiny bubbles of ancient air*

Natural climate changes: glacial-interglacial cycles

By measuring the ratios of different water isotopes in polar ice cores, we can determine how temperature in Antarctica and Greenland has changed in the past. The oldest ice core we have was drilled by the European Project for Ice Coring in Antarctica (EPICA) from Dome C on the Antarctic plateau. It extends back 800,000 years and shows a succession of long cold 'glacial' periods, interspersed roughly every 100,000 years by warm 'interglacial' periods (of which the last 11,000 years is the most recent). This succession of events is well-known from other records, and the coldest periods in Antarctica are the times when we had ice ages. Ice sheets extended over North America as far south as Wisconsin, and over Britain to south of The Wash.

The role of greenhouse gases in glacial-interglacial cycles

From the air in our oldest Antarctic ice core, we can see that CO_2 changed in a remarkably similar way to Antarctic climate, with low concentrations during cold times, and high concentrations during warm periods (see Fig. 3 overleaf). This is entirely consistent with the idea that temperature and CO_2 are intimately linked, and each acts to amplify changes in the other (what we call a positive feedback). It is believed that the warmings out of glacial periods are paced by changes in Earth's orbit around the Sun, but the tiny changes in climate this should cause are amplified, mainly by the resulting increase in CO_2, and by the retreat of sea ice and ice sheets (which leads to less sunlight being reflected away). Looking at the warming out of the last glacial period in detail, we can see how remarkably closely Antarctic temperature and CO_2 tracked each other. It is often said that the temperature 'leads' the CO_2 during the warming out of a glacial period. On the most recent records, there is a hint that the temperature started to rise slightly (at most a few tenths of a degree) before the CO_2, as expected if changes in Earth's orbit cause an initial small warming. But for most of the 6,000-year long 'transition', Antarctic temperature and CO_2 rose together, consistent with the role of CO_2 as an important amplifier of climate change (see Fig. 4 overleaf). In our modern era, of course, it is human emissions of CO_2 that are expected to kick-start the sequence of events. We see no examples in the ice core record of a major increase in CO_2 that was not accompanied by an increase in temperature. Methane concentration also tracks the glacial-interglacial changes, probably because there were less wetlands in the colder, drier glacial periods.

Abrupt climate changes

The climate changes described above were huge, but relatively gradual. However, ice cores have provided us with evidence that abrupt changes are also possible. During the last glacial period, Greenland experienced a sequence of very fast warmings (see Fig. 5 overleaf). The temperature increased by more than 10°C within 40 years. Other records show us that major changes in atmospheric circulation and climate were experienced all around the northern hemisphere. Antarctica and the Southern Ocean experienced a different pattern, consistent with the idea that these rapid jumps were caused by sudden changes in the transport of heat in the ocean. At this time, there was a huge ice sheet (the Laurentide) over northern North America. Freshwater delivered from the ice sheet to the North Atlantic was able periodically to disrupt the overturning of the ocean, causing the transport of tropical heat to the north to reduce and then suddenly increase again. While this mechanism cannot occur in the same way in today's world, it does show us that, at least regionally, the climate is capable of extraordinary changes within a human lifetime: rapid switches we certainly want to avoid experiencing.

Summary

Ice cores provide direct information about how greenhouse gas concentrations have changed in the past, and they also provide direct evidence that the climate can change abruptly under some circumstances. However, they provide no direct analogue for the future because the ice core era contains no periods with concentrations of CO_2 comparable to those of the next century.

FACTFILE

- **Ice core.** Cylinder of ice drilled out of an ice sheet or glacier. Most ice core records come from Antarctica and Greenland.
- Ice cores contain information about past temperature, and about many other aspects of the environment.
- Atmospheric carbon dioxide levels are now nearly 40% higher than before the industrial revolution. This increase is due to fossil fuel usage and deforestation.
- The magnitude and rate of the recent increase are almost certainly unprecedented over the last 800,000 years.
- Methane also shows a huge and unprecedented increase in concentration over the last two centuries.

Fig 1: *Measurements of CO_2 from the Law Dome ice core[1] fall onto the line of annual average atmospheric measurements from South Pole[2]*

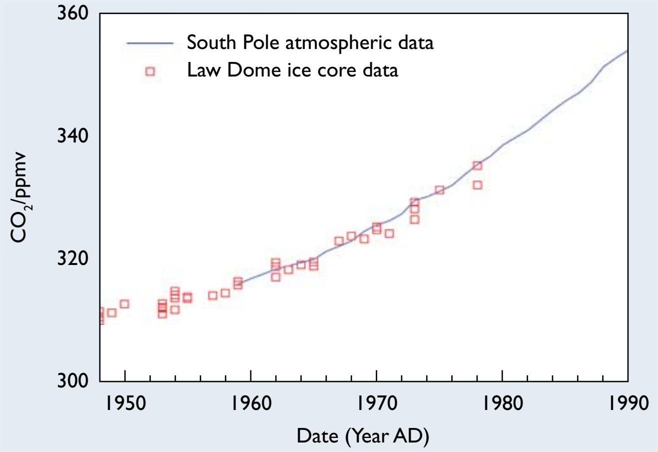


Fig. 2: *CO_2 and CH_4 over the last 1,000 years[1-4]*

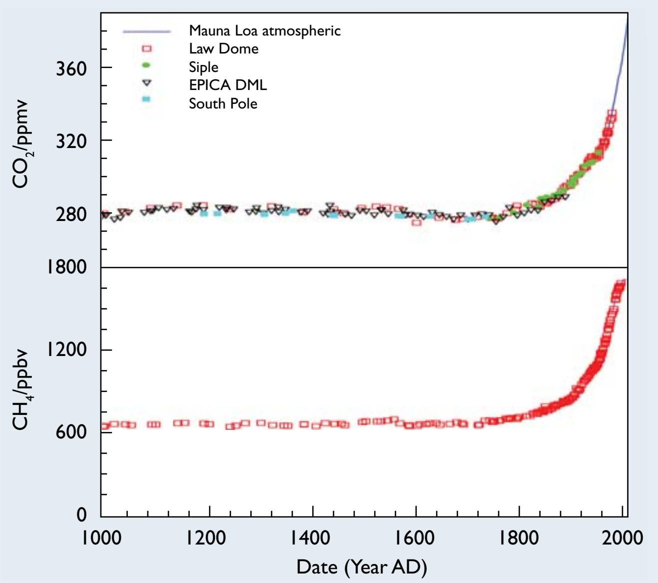


Fig. 4: *Close-up of deuterium (temperature proxy) and CO_2 from the EPICA Dome C ice core over the warming from the last glacial period[7]*

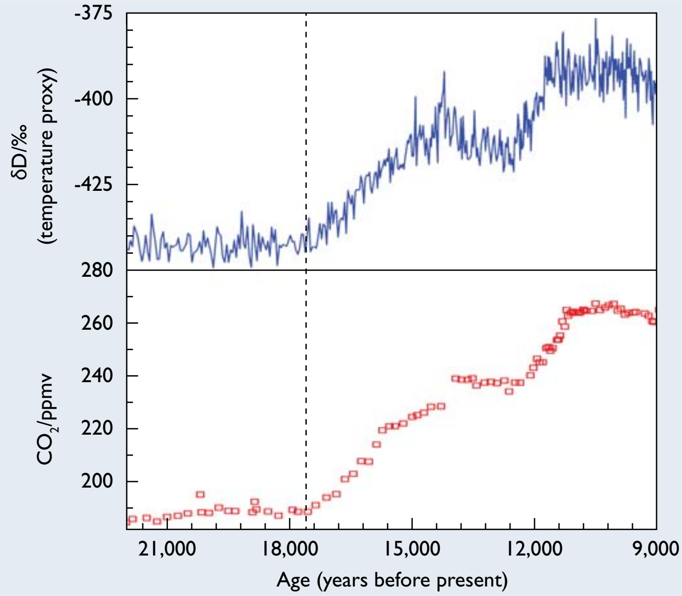


Fig. 5: *Oxygen isotope ratio (temperature proxy) from the NorthGRIP (Greenland) ice core showing a sequence of rapid temperature jumps[8]*

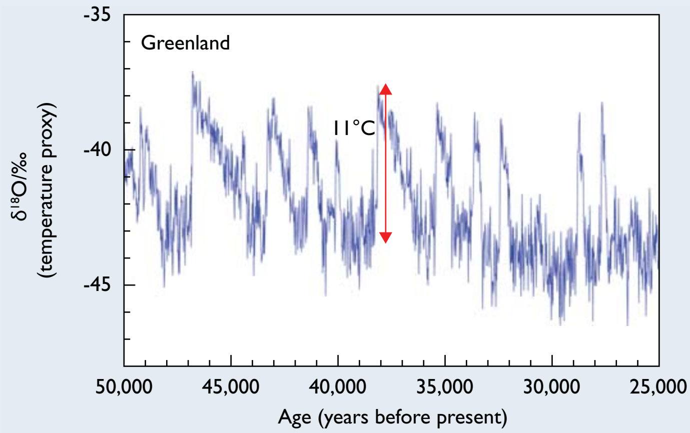
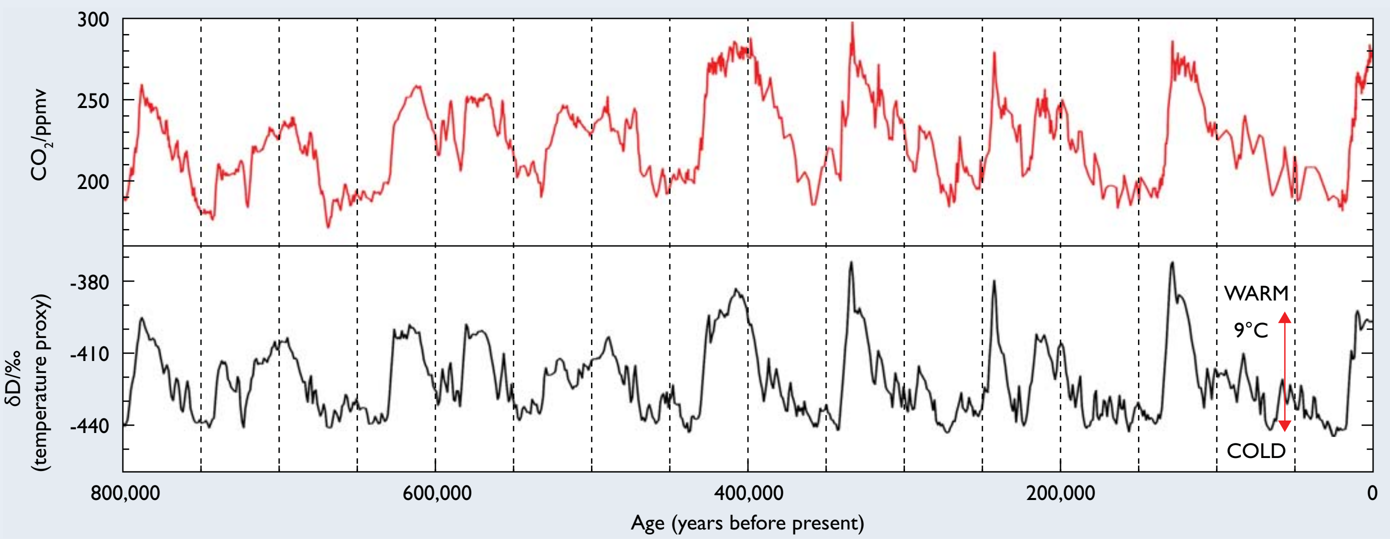


Fig. 3: *Ice core data from the EPICA Dome C (Antarctica) ice core: deuterium (δD) is a proxy for local temperature; CO_2 from the ice core air[5,6]*



Data sources: [1] *MacFarling Meure, C., and others: Law Dome CO_2, CH_4 and N_2O ice core records extended to 2,000 years BP, Geophys. Res. Lett., 33, L14810, doi:10.1029/2006GL026152, 2006*

[2] *Atmospheric data supplied by NOAA/ESRL*

[3] *Friedli, H., and others: Ice core record of the 13C/12C ratio of atmospheric CO_2 in the past two centuries, Nature, 324, 237-238, 1986*

[4] *Siegenthaler, U., and others: Supporting evidence from the EPICA Dronning Maud Land ice core for atmospheric CO_2 changes during the past millennium, Tellus Ser. B-Chem. Phys. Meteorol., 57, 51-57, 2005*

[5] *Jouzel, J., and others: Orbital and millennial Antarctic climate variability over the last 800,000 years, Science, 317, 793-796, 2007*

[6] *Lüthi, D., and others: High-resolution carbon dioxide concentration record 650,000-800,000 years before present, Nature, 453, 379-382, 2008*

[7] *Monnin, E., and others: Atmospheric CO_2 concentrations over the last glacial termination, Science, 291, 112-114, 2001 with data converted to the age scale of Parrenin, F., and others: The EDC3 chronology for the EPICA Dome C ice core, Climate of the Past, 3, 485-497, 2007*

[8] *North Greenland Ice Core Project Members: High-resolution record of Northern Hemisphere climate extending into the last interglacial period, Nature, 431, 147-151, 2004*