ATMOSPHERIC RESEARCH

Antarctic ice: the world's air museum

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Air bubbles trapped in ice hundreds or even thousands of years ago are providing vital information about past levels of greenhouse gases in the Earth's atmosphere.

IT'S A FACT: the chemical composition of the atmosphere is changing rapidly, worldwide. Since the pre-industrial era, the concentrations of important greenhouse gases (see panel) have all increased significantly. NIWA maintains the longest continuous measurements of atmospheric carbon dioxide (CO_2) in the Southern Hemisphere at Baring Head (see *Water & Atmosphere* 8(1):14–16). In the 30 years since measurements began there, atmospheric CO_2 has increased by about 15%.

But even the longest available dataset for atmospheric CO_2 goes back less than 50 years. So how do we know how CO_2 concentrations were changing before this? And what were the levels of greenhouse gases in the atmosphere before emissions from modern industry and agriculture started to change things?

Drilling for ice

Fortunately, over 20 years ago, scientists made an important discovery. Near the surface of ice sheets, snowfall eventually turns into ice containing air trapped in tiny bubbles (above, right). This ice provides a remarkable museum of the chemical state of the atmosphere.

The most successful investigations so far have been at the polar ice caps. Here, snow traps air in the firn, a permeable surface layer about 40–100 m thick. As more snow falls, the firn is buried deeper and deeper until it is compressed into solid ice, with the trapped air enclosed in bubbles. Layer after layer of ice is built up, burying in the ice cap a history of past atmospheric composition. Because the ice is both impermeable and inert, it is a remarkably good storage container for many of the important gases in air.

To retrieve this atmospheric information, researchers drill into the ice cap and remove cores of ice. The cores are kept frozen until the air trapped in them can be analysed.

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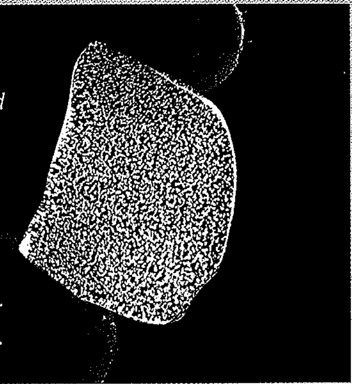
Methane increases over 1000 years

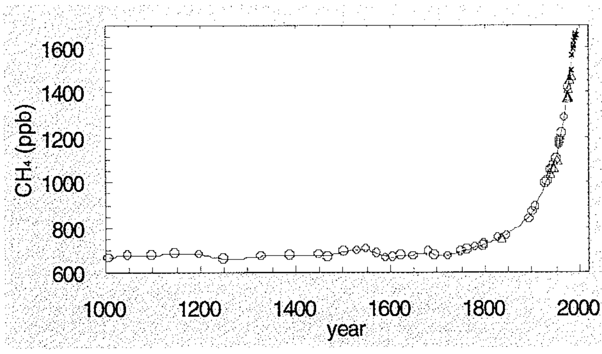
Australian researchers have been particularly successful with cores extracted from Law Dome, an ice cap 200 km across and up to 1200 m thick near the coast of the Australian Antarctic Territory. This area was especially suitable because of its rapid ice formation and very cold temperatures, averaging –20°C. Fast ice formation means that trapped air bubbles cover a shorter time span. Changes over as little as 10 years can be detected. Also, the most recent air available is quite young, allowing comparison with modern atmospheric measurements.



A sliver of ice from a core drilled from a depth of several hundred metres at Law Dome in Antarctica. The bubbles containing the air are clearly visible.

The ice cores on Law Dome extended right down to the bedrock. At this depth the trapped air is over 1000 years old.

Analysis of the methane (CH_4) content of the trapped air (below) shows small variations in atmospheric methane since 1000 AD. However, from 1800 to the present atmospheric methane has



Atmospheric methane over the last 1000 years. The plot shows small variations in atmospheric methane during the natural climatic events: the medieval warm period (1000–1300 AD) and Little Ice Age (1550–1800 AD). These contrast with the dramatic increase in methane over the last 200 years. The blue symbols are measurements from ice; the red line at the end of the record is from recent atmospheric measurements from Cape Grim, Tasmania. (Adapted from Etheridge et al. *1998.* Journal of Geophysical Research *103(D13): 15,979–15,993.)*

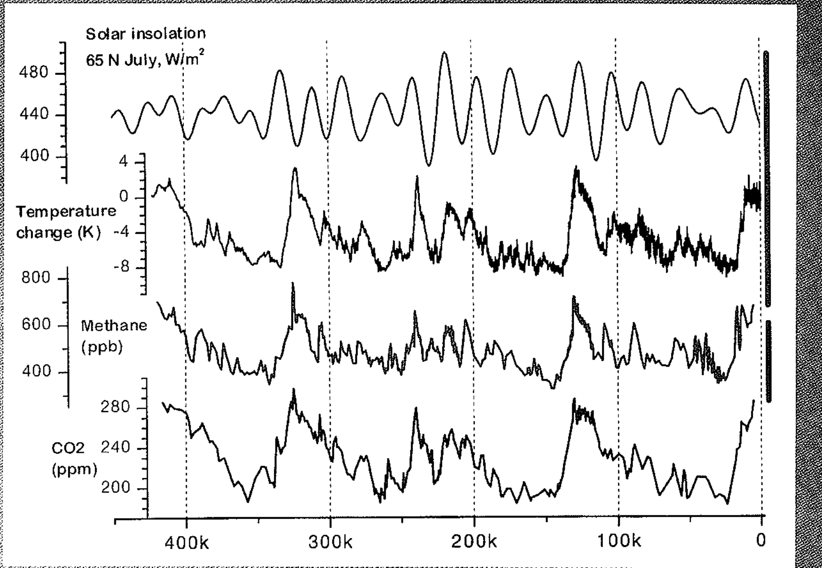
more than doubled. This dramatic rise has been caused by increased emissions associated with human activity.

A different climate

We currently live in a warm inter-glacial period known as the Holocene, which has lasted about 10,000 years. Before this, the earth was gripped in glaciation for about 100,000 years. Temperatures averaged 10–15°C cooler than today and ice sheets were much more extensive. How did the atmosphere change during these different natural climatic events?

The answer has come from an extraordinary series of ice cores drilled at Vostok, a Russian station in the remote centre of Antarctica. French, Russian and American scientists have worked together to produce a climate history from these cores, spanning over 400,000 years and covering four complete glacial and inter-glacial periods (see graph, right).

Atmospheric CO_2 and CH_4 data are clearly correlated with temperature through the record. We know that the climate changes were initially triggered by changes in the amount of solar radiation (insolation) reaching the earth due to wobbles in its orbit. The response of the greenhouse gases, however, was to feed back and amplify the temperature changes by a factor of about two. Nowhere in the over 400,000 years of record do the CO_2 or CH_4 concentrations approach today's levels. Current greenhouse gas levels, which have developed in only the last 200 years, mean that the world now faces a climate different from anything during the last 400,000 years.



Simultaneous records of solar radiation or insolation, temperature, and atmospheric CH_4 and CO_2 concentrations over the last 400,000 years derived from Antarctic ice at Vostok. The parallel changes in CO_2 and CH_4 are believed to have caused about half the amplitude of the temperature changes, with the other half probably due to changes in solar insolation. Today's levels are indicated by the solid lines at the right-hand side. (Adapted from Petit et al. *1999.* Nature 399*: 429–436.)*

Isotopes, gas measurements, models

A joint NIWA/CSIRO project is currently measuring air extracted directly from the Antarctic firn layer to look at sources of atmospheric methane over the last 100 years. NIWA has used isotopic techniques to distinguish different sources of methane (see *Water & Atmosphere* 5(2): 16–17). Levels of the naturally occurring radioactive isotope carbon 14 in methane, for example, can indicate whether the methane is derived from fossil fuels or from natural sources like swamps. Already the work has shown that 60 years ago up to 15% of atmospheric methane was derived from fossil sources.

The study of atmospheric greenhouse gas records in Antarctic ice will clearly provide a large amount of information about past climatic changes. However the data are also essential for testing how well global climate models can simulate observed climate change in the past.

The study of air bubbles trapped in Antarctic ice goes hand in hand with measurements of current greenhouse gas levels and the development of climate models to predict the future state of the atmosphere.

All three kinds of research are currently being carried out by NIWA and CSIRO. ■

Greenhouse gases and predicting climate change

Greenhouse gases – mainly carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) – make up a relatively small proportion of the earth's atmosphere. However, because they absorb strongly in the infrared part of the solar spectrum and retain heat, they play a significant role in the radiation balance of the earth and hence its climate. Increases in their concentration are viewed with concern, and intense international activity is focused on predicting the consequences of changing atmospheric composition and its impact on the earth's climate. Many of these studies are based on the use of global climate models to predict, for example, the effects of doubling atmospheric CO_2. The models use measurements of greenhouse gases as input data but are restricted because data are needed over long time periods for long-lived gases like CO_2.

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