ATMOSPHERIC RESEARCH

The Antarctic atmosphere: barometer on a changing world

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Precision instruments and extensive international and local collaboration are the hallmarks of NIWA's atmospheric research in Antarctica.

Ozone depletion and increasing greenhouse gases both feature regularly in the news media these days and the connection between ozone and Antarctica is well known. We can also learn much about greenhouse gas concentrations from studies in the Antarctic. NIWA's atmospheric research in Antarctica is aimed mainly at understanding these two important issues. Because the atmosphere has no national boundaries, the research involves scientists from many countries.

Ozone

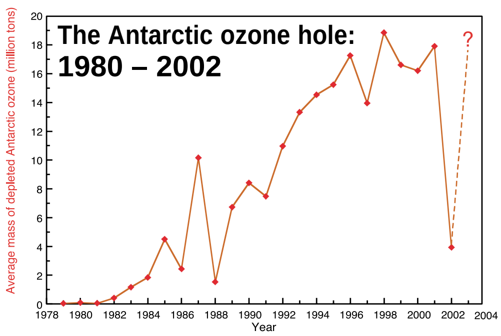
The ozone depletion that occurs over Antarctica each spring – the Antarctic ozone hole – is a striking example of human influence on the atmosphere. In the space of a few weeks most of the ozone in the lower **stratosphere** over Antarctica disappears. This is due to a remarkable combination of dynamics and chemistry in the cold Antarctic atmosphere that makes industrial chemicals far more effective in depleting ozone (see *Water & Atmosphere 9(2)*: 12–13).

In the 1980s international action resulted in a treaty – the Montreal Protocol – to limit and ban the chemicals responsible for the damage. Although the Montreal Protocol is now proving effective, it will be decades before some of these gases recover to pre-ozone-hole concentrations. Over the past few years the ozone hole has varied considerably in size and severity (see graph below and *Water & Atmosphere 9(2)*: 12–13 and *10(4)*: 4). To confirm the predicted ozone recovery, we need to demonstrate a consistent decrease in the extent and intensity of the ozone hole over many years.

Greenhouse gases

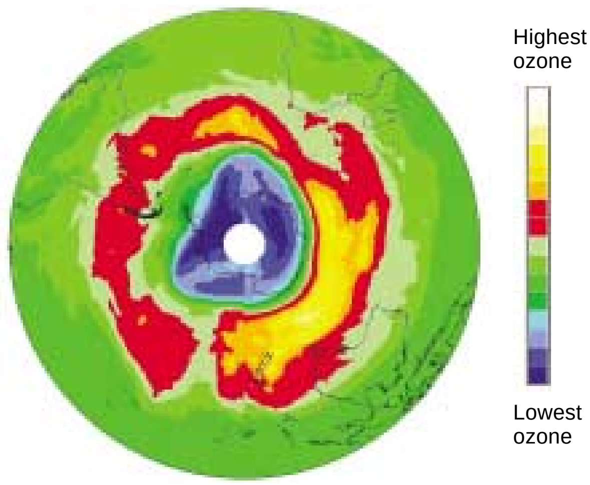
Although it is widely accepted that increases in greenhouse gases in the atmosphere are causing the Earth's surface to warm on a global scale, we still do not fully understand where the gases come from and where they end up. Carbon dioxide (CO_2), the most important greenhouse gas, has increased by more than 30% since pre-industrial times (see *Water & Atmosphere 8(1)*: 14–16). We know that about half of the CO_2 emissions remain in the atmosphere, enhancing the Earth's natural greenhouse effect, and that the remainder probably gets incorporated into land-based and ocean ecosystems. But how much goes into each of these reservoirs?

The Southern Ocean is thought to be the world's largest **sink** of carbon, but we still have to determine how large. As a step towards quantifying this, NIWA has made high-precision **stable isotope** measurements of



The values plotted above are calculated from the amount of depleted ozone in the ozone hole area, averaged from 19 July to 1 December each year. In 2002 the size and lifetime of the ozone hole were unusually low. In 2003 the ozone hole developed early and has already been nearly as large in area as any recorded in the past (right), though its duration (and therefore the total amount of ozone depletion) is not known at the time of printing.

The ozone hole: 17 September 2003



The blue area is the ozone hole, which covers almost all of Antarctica. The white circle at the centre is an area with no data.

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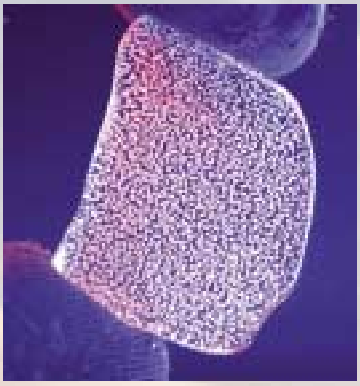
atmospheric CO_2 and oxygen in the Antarctic (*Water & Atmosphere 4(2)*: 11–12, *5(2)*: 16–17). The differences in stable isotope levels can be used to estimate how much CO_2 is absorbed by the southern oceans. Early results show a significant effect of ocean circulation and upwelling events on atmospheric CO_2 and O_2 concentrations. This project is part of an ongoing international research effort to work out the proportions of carbon from human activities absorbed by the oceans and by the land.

Within another international programme, NIWA is investigating changes in the isotope composition of greenhouse gases like methane and CO_2 (see *Water & Atmosphere 9(1)*: 22–23). We know that the atmosphere is changing quickly. A key benchmark is the composition of the atmosphere before human activity dramatically changed it.

When snow falls it traps air; over time, as the snow turns to ice, the trapped air remains as tiny bubbles within the ice. The deeper the bubble in the ice, the older is the air within it. The ice sheets in Antarctica thus provide a remarkable museum of the chemical state of the atmosphere extending over millennia. For example, the naturally occurring radioactive isotope carbon-14 in methane trapped in these bubbles can tell us whether the gas came from fossil fuels or from natural sources like swamps. Initial results show that 60 years ago up to 15% of atmospheric methane was derived from fossil sources. Higher percentages imply a larger industrial component in sources of atmospheric methane.



Air bubbles trapped in Antarctic ice can provide information about past atmospheric conditions. (Photo: David Etheridge)

Gas measurements and modelling

To measure atmospheric **trace gases**, especially those in the stratosphere, we rely on the fact that different gases absorb light in different parts of the spectrum. We use specialised ground-based equipment to measure quantities of ozone and several other gases active in ozone depletion chemistry, such as HCl, ClO and BrO. These instruments can also be used to determine greenhouse gases and other gases in the **troposphere**, such as the products of fires in the tropics.

Most of our measurements use sunlight, though it is possible to use moonlight for some measurements in the dark winter months. A perennial task is to refine our measurement and analysis techniques to improve the information retrieved (see panel above).

Bromine on Ice

Robyn Schofield in Antarctica.

Investigating the future of the Antarctic ozone hole brought a PhD student from the University of Auckland to Scott Base for the 2002 season. Robyn Schofield, a University of Otago honours graduate and FRST Bright Futures Scholarship recipient, has pioneered a new measurement technique in partnership with NIWA scientists and successfully applied it to bromine monoxide, BrO.

Knowing how much bromine is in the **stratosphere** is critical to predicting the future severity of the ozone hole. Chlorine-containing gases (which derive from breakdown of CFCs) are controlled under international agreements and rapid decreases are expected. However, bromine-containing gases also play a major role in ozone loss, and will decline more slowly. The more bromine in the stratosphere, the longer the ozone hole will persist.

For some years NIWA has been measuring total volumes in the atmosphere of BrO, nitrogen dioxide (NO_2), and chlorine dioxide (OClO), all of which are involved in ozone depletion. We have now developed a “direct-sun” spectrometer to separate tropospheric from stratospheric information. The new technique combines two different viewing methods with a computer model developed by Robyn. In the first method, looking directly at the sun results in a long light path through the **troposphere**; in the second, looking at scattered light from the zenith produces a similar enhancement in the stratosphere.

After successfully applying the new technique to BrO measurements at Lauder (45 °S), Robyn went on campaign in the Antarctic. She operated a direct-sun instrument from early September to late October every clear morning and evening. Robyn then used these observations to measure stratospheric and tropospheric BrO.

A high variability was observed for the stratosphere, partly because of the unusual stratospheric warming in spring 2002. Robyn measured a background concentration of 0.3 parts per trillion (ppt) BrO in the troposphere. On 24 and 25 October 2002 there was a “bromine explosion”, equivalent to 7 ppt BrO in the lower 2 km of the atmosphere. First measured in the mid 1990s, these events are thought to result from an accumulation of bromine- and chlorine-containing sea salt on the winter ice pack, leading to a rapid release of bromine and consequent severe ozone depletion close to the ground.

Teachers: this article can be used for NCEA Achievement Standards in Geography (1.1, 2.1, 3.1, 1.7, 2.7, 3.7, 1.6, 2.6, 3.6), C&S (1.2), Physics (1.2, 2.2, 2.7). See other curriculum connections at www.niwa.co.nz/pubs/wa/resources

We also measure gas concentrations directly from air samples collected both in Antarctica and during transport flights between Christchurch and McMurdo.

To interpret the measurements of stratospheric gases, we have developed a model that tracks how stratospheric chemistry changes under given conditions. We plan to use the model to separate the effects of gas movement from chemical changes in a series of measurements of trace gases made at regular intervals over time at a single site. A separate modelling project has looked at the effect of spring-time ozone depletion on places at mid-latitudes. The work has shown that more than half of the observed summer time reduction in ozone over New Zealand since pre-ozone-hole times is due to the dilution effect when annual ozone holes dissipate, leading to significant increases in UV over New Zealand in the past two decades (see also *Water & Atmosphere 7(4):* 7–8).

NIWA will continue to recognise the importance of the Antarctic atmosphere in the global system with a strong measurement programme, backed up with modelling and analytical research and increased collaboration with overseas researchers. ■

Most of NIWA's experimental work in Antarctica is carried out at Arrival Heights, a small laboratory on Hut Point Peninsula near Scott Base (see map below). The site has good viewing horizons and is remote from local atmospheric emissions. The laboratory usage has grown over the last 20 years, so Antarctica New Zealand is planning to replace the building over the 2004/05 and 2005/06 seasons, with some assistance from NIWA. (Photo: Stephen Wood)

Acknowledgements
This work is supported by the FRST programme "Drivers and Mitigation of Global Change" under contract C01X0204 and relies on technical and logistic support from Antarctica New Zealand. It has strong collaboration with overseas groups such as the Universities of Heidelberg and Denver, The State University of New York, NOAA in Boulder, CSIRO in Melbourne, and the Scripps Institution of Oceanography in California. The programme benefits from joint work with universities in a range of PhD students: Rona Thompson (Victoria University); Rebecca Batchelor (University of Canterbury); Jelena Ajtic (University of Canterbury); and Robyn Schofield (University of Auckland – see panel, page 21).

For explanations of terms in **bold**, see glossary on page 23.

Ross Island and the McMurdo Dry Valleys in southern Victoria Land, Antarctica. (Reproduced with permission, from: Waterhouse, E. (2001). Ross Sea Region 2001. A state of the environment report for the Ross Sea region of Antarctica. Antarctica New Zealand)

Glossary of terms (printed in **bold** in articles in this issue)

Anoxic: without oxygen.

Antarctic Cold Reversal: a period between 14,800 and 12,800 years ago when the warming trend since the peak of the last ice age (23,000 years ago) temporarily halted.

Conductivity: a measure of a water sample's capacity to conduct electricity, often used to approximate the amount of dissolved salts. Units are Seimens (S) per unit length. Conductivity of tap water is typically 50–150 µS/cm (where µS = S/1000,000).

Cyanobacteria: microscopic plants (blue-green algae) that photosynthesise but are more closely related to bacteria than to other plants. They often contain blue-green pigments and were probably one of the earliest forms of life on Earth.

Diatoms: single-celled algae with ornamented silica cell walls. Diatoms are very common in both marine and fresh waters.

Fast ice: sea ice attached to the shore, generally in the position where it first formed.

Katabatic: describes a wind directed down a slope, caused by downhill drainage of cooler, dense mountain air. Katabatic winds in Antarctica tend to flow from the central ice dome down valleys and can be very strong.

Nematodes: small, unsegmented worms common in soils and sediments.

Nototheniid: belonging to the Nototheniidae, a family of typical spiny-finned fishes. Nototheniids have anti-freeze properties in their blood and include most of the fish inhabiting the ocean surrounding Antarctica.

Pack ice: sea ice made up of a floating mosaic of plates of ice that is free to drift with currents, tides and wind (cf. fast ice).

Pelagic: living within the upper part of the ocean, away from the shore.

Precambrian: the oldest geological era, comprising all geological time before about 600 million years ago. The last era of the Precambrian saw the emergence of organised life in the form of stromatolites (layered microbial communities).

Primary production: the conversion of solar energy into chemical energy through photosynthesis in plants. Carbon dioxide and water are converted into organic material.

Production: the accumulation of biomass by plants or animals before any losses from, for example, predation, migration.

Sink: refers to a location where chemicals or nutrients eventually end up.

Snowball Earth: the theory that the Earth was completely frozen over for 10 million years and then warmed rapidly about 600 million ago as a result of warming from CO_2 entering the atmosphere from volcanoes. Some scientists believe that this rapid warming created the conditions needed for the evolution of complex life on Earth.

Stable isotope: isotopes of an element have the same atomic number, but different atomic mass. Some isotopes undergo spontaneous radioactive decay; stable isotopes do not decay.

Stratosphere: the region of the atmosphere between about 10 and 50 km above the troposphere.

Sublimation: the process in which solids transform directly to a gas or vapour without going through a liquid phase.

Tardigrades: tiny, but cute, aquatic invertebrates with a segmented body and four pairs of legs; also known as water bears.

Trace gases: gases found in minute quantities in the atmosphere.

Troposphere: the part of the atmosphere closest to the Earth's surface, extending up about 10 km. The temperature in the troposphere decreases steadily with increasing altitude.

Water mass: a more or less isolated body of water defined by its temperature and salinity characteristics and created by surface processes at a specific location. Isolation can be by land masses or more frequently by strong density gradients that retard mixing. Water masses are modified as they move and can eventually mix with other water masses.