Unlocking the ice house

Antarctica and its role in climate change

ALPHA 120

Tim R. Naish

Institute of Geological & Nuclear Sciences Limited

Antarctica New Zealand
New Zealand Antarctic Institute

Foundation for Research Science & Technology
Tūāpapa Rangahau Pūtaiao

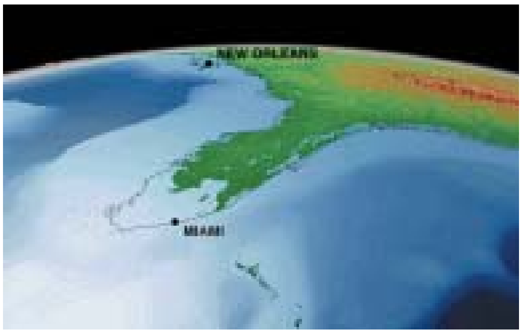
the Royal Society of New Zealand

Introduction

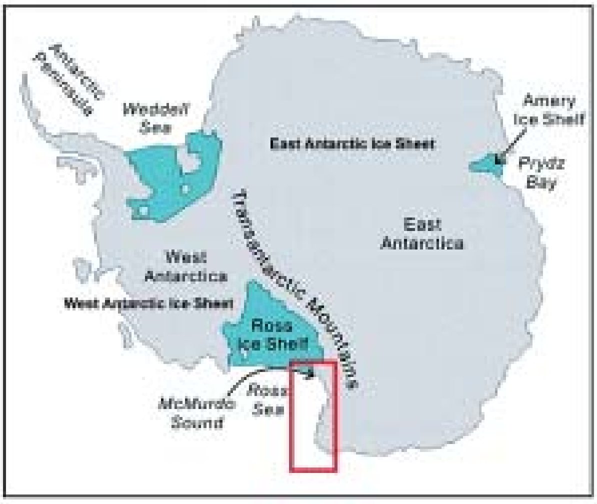
Antarctica – key to global climate jigsaw

Antarctica is a remarkable continent. Remote, hostile and uninhabited, it is the highest, driest, coldest and windiest place on Earth. For the early explorers, Antarctica was the ultimate survival contest. For today's scientists, it is of key importance in trying to understand and predict global climate change.

Antarctica sits over the Earth's southern pole and is covered by an ice sheet up to 4 km thick and over 4000 km across. It contains 70% of Earth's fresh water and 90% of its ice, and has existed in roughly its present form for around 15 million years. The ice sheet is bisected into two unequal parts by the Transantarctic Mountains. The larger East Antarctic Ice Sheet (EAIS) contains 12 million m^3 of ice – enough to raise global sea level by 60 m if it melted. The less stable West Antarctic Ice Sheet (WAIS) contains 2 million m^3 of ice and could contribute 5 m to global sea level rise.



The effect of a 5 m sea-level rise on Florida.



Antarctica – Area in red box shown in more detail over page.

Within the ice sheets is a climate record from the past 500,000 years – trapped bubbles in the ice hold an archive of atmospheric gases, including evidence for levels of global pollution by industry, agriculture and atomic bombs. Equally important is the geological evidence of changing ice sheets and past warm climate extremes that are preserved in sediments hundreds of metres beneath the sea floor around Antarctica.

Climate scientists from New Zealand and many other nations belong to the Intergovernmental Panel on Climate Change (IPCC), whose aim is to better predict our planet's future climate as a consequence of global warming. Knowledge of Antarctica's role in climate change is a key issue being addressed by the IPCC, whose scientific findings are being used to develop international policy for controlling future greenhouse gas emissions under the "Kyoto Protocol" agreement.

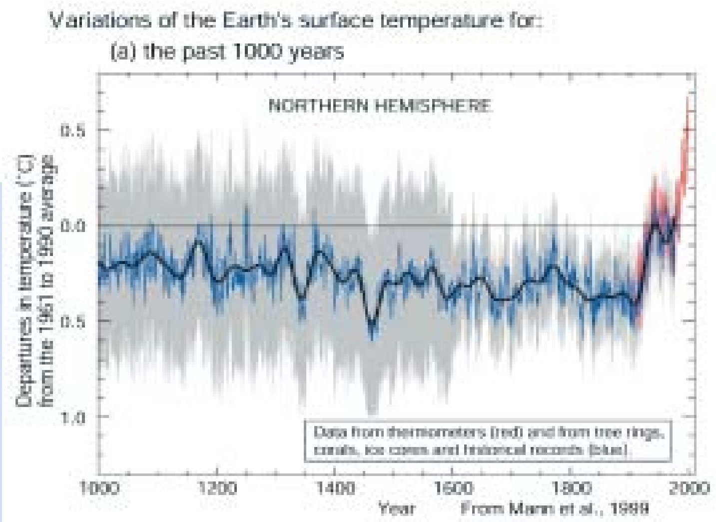
Photo P Barrett

From "greenhouse" to "icehouse" world

Fifty million years ago our planet was on average 6°C warmer, and atmospheric "greenhouse" gases, such as carbon dioxide (CO_2), were four times that of current levels. Temperature changes at the poles were probably twice the global average. Antarctica did not have an ice sheet, but may have had small regions of alpine glaciation and a temperate climate that supported large areas of forest-like vegetation including palms, ferns, and rainforest trees (much like western South Island and Chile today).

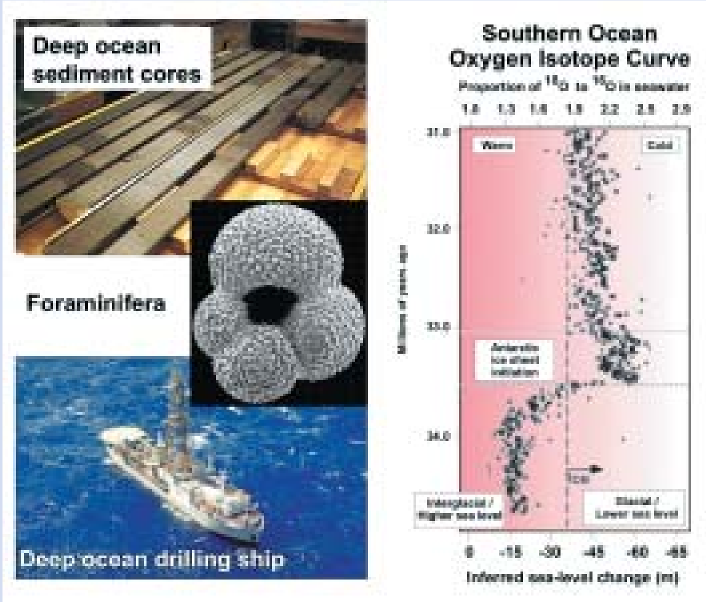
About 34 million years ago, at the end of the Eocene Period, a "sudden" (in just 200,000 years) fall in global temperature of 3–4°C occurred. This cooling led to the expansion of ice on Antarctica by up to 10 million km^3, and a corresponding fall in global sea level of up to 40 m as ocean water was incorporated into the continental ice sheet. The development of an ice sheet on

Antarctica is one of the most significant changes to Earth's climate known in the geological record. It marks the abrupt end of the so-called "greenhouse" world, and the beginning of the "icehouse" world.

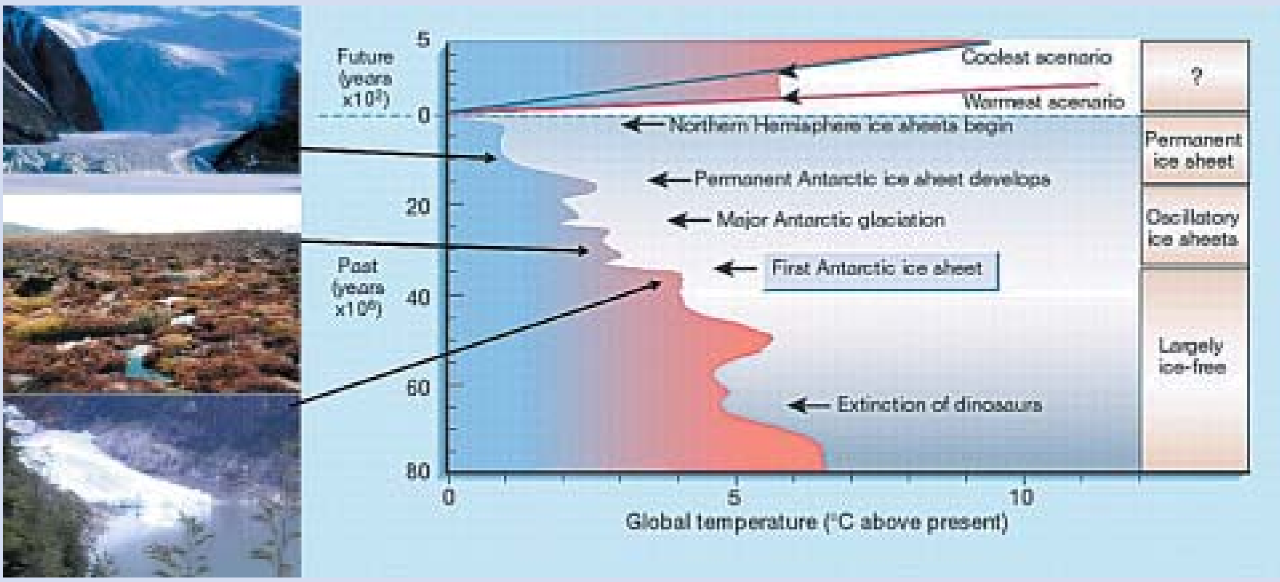


What is the geological evidence for the freezing of Antarctica?

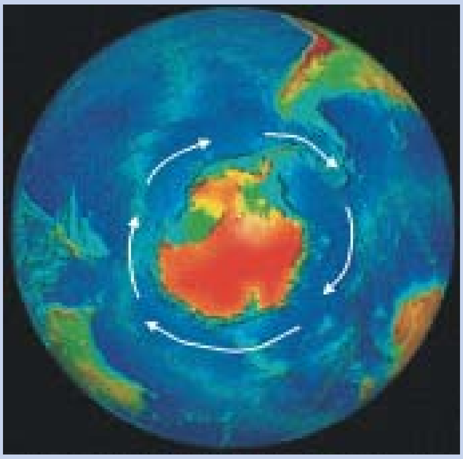
The main evidence for cooling and sudden growth of ice on Antarctica comes from chemical measurements of tiny fossilised plankton, called foraminifera, in deep ocean sedimentary drill cores. The oxygen isotope chemistry of the foraminifera can be used to reconstruct the temperature of the ocean water they once lived in and the amount of ice that existed on continents at the time. When conditions are cold enough for ice sheets to form on land, the light isotope of oxygen (^{16}O) is preferentially removed from the ocean to the atmosphere through photosynthesis by surface-dwelling plankton. It is then incorporated into snow, leaving the ocean enriched in the heavier isotope (^{18}O). It is the measurement of the relative amounts of the heavy and light isotopes of oxygen that provide the evidence for a rapid drop in temperature and ice growth on Antarctica about 34 million years ago.



The Deep Sea Drilling Project ship, the *Glomar Challenger*, began drilling sea floor sediments off the edge of Antarctica in the mid-1970s. Sediment cores show that the first appearance of significant iceberg activity began about 34 million years ago. The existence of icebergs is recorded in the sediment cores by stones (called dropstones) with scratches (called striations). These striated stones were transported by a glacier, and then by icebergs calving at the coastline, to be eventually dropped into mud in the deep ocean as the icebergs melted. The deep sea cores also showed a dramatic change in plant pollen originating from the continent, which indicated that the lush temperate forests were replaced by colder climate tundra at the same time as glaciers were reaching the coastline.



Variation in global average temperature during the last 80 million years and important events in the development of ice sheets on Earth's poles. Also shown are global warming scenarios for the next 500 years based on Intergovernmental Panel on Climate Change (IPCC) 3rd Assessment Report (after Barrett 2003, Nature, 421).

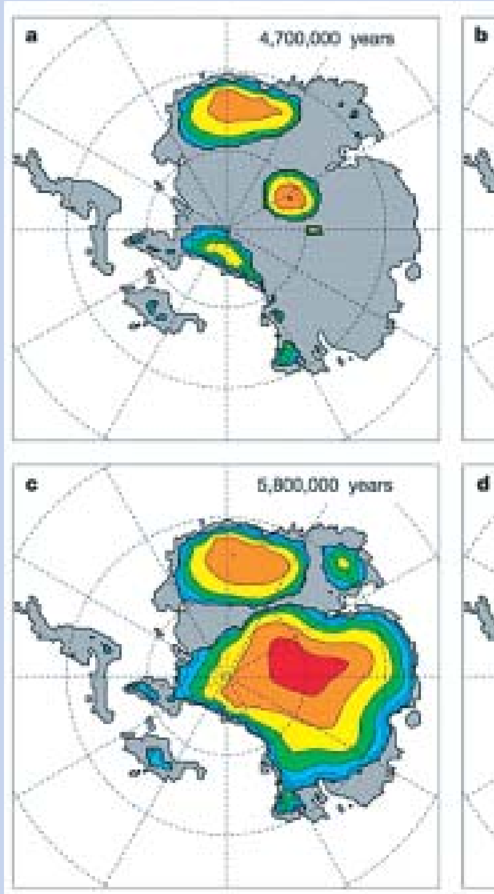


Antarctica's thermal isolation by the Antarctic Circumpolar Current in the Southern Ocean.

What caused the freezing of Antarctica?

For many years scientists believed that the freezing of Antarctica was caused by a series of movements in Earth's major tectonic plates, because the timing of ice sheet growth coincided with sea-floor spreading that pushed Antarctica away from Australia and South America. The opening of these "ocean gateways" produced a strong circumpolar current in the Southern Ocean that is thought to have "thermally isolated" the Antarctic continent, cooling it to a level where an ice sheet could rapidly grow.

However a new theory (based on a sophisticated computer model) indicates that atmospheric greenhouse gas concentrations, particularly a long-term decline in atmospheric CO_2, was the major influence on polar cooling 34 million years ago. The global climate model (GCM) uses ocean and atmospheric circulation, greenhouse gas levels, and the past geography of the continents and oceans to produce an ice sheet. The values for Earth's past CO_2 levels, which have been reconstructed from geological records, show a decline between 50 and 34 million years ago from 1200 parts per million (ppm) to about 600 ppm – a decrease from 3 times present day CO_2 levels. Since the mid 19th century, the concentration of CO_2 has increased in Earth's atmosphere from 280 ppm to 380 ppm, causing a temperature increase of about 1°C. So, like current global warming, CO_2 has had a major influence on past temperature changes. The opening of tectonic ocean gateways, although important, is now considered to have played a secondary role to that of CO_2. During the "global cooling" that led to the glaciation of Antarctica, a CO_2-temperature threshold was crossed (at about today's CO_2 concentration of 380ppm), which led to rapid continent-wide glaciation of Antarctica. So, will future global warming cause the unfreezing of Antarctica?



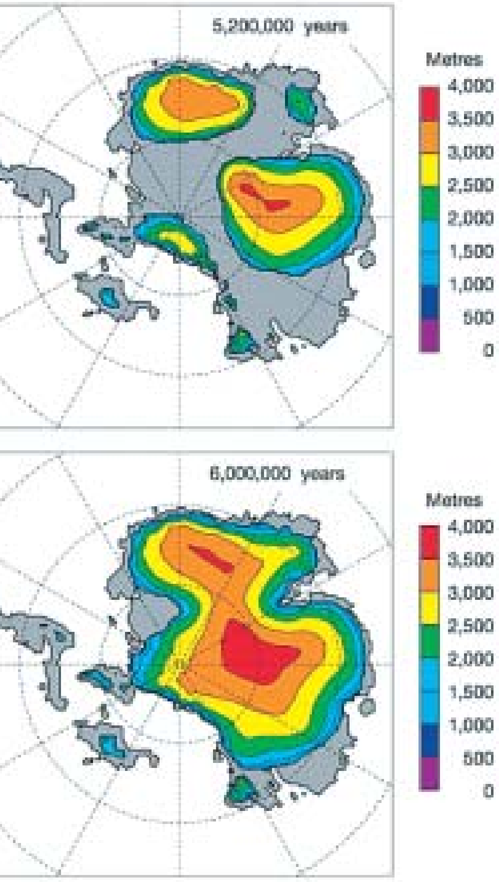
Output of a computer sim
Antarctica 34 million ye
development of a cont
between Figs b and c. (Se
2003, Nature,431).

Southern McMurdo Sound, Western Ross Sea and location of geological drill sites. Cape Roberts Project (CRP). Courtesy of Antarctic New Zealand

Have the ice sheets always been stable?

Geological evidence shows that global sea level has risen and fallen by 10 to 40 m many times during the last 34 million years, with each cycle of sea-level change lasting 40,000 or 100,000 years. The sea-level changes imply that Antarctica had extensive periods when its ice sheets were highly unstable, fluctuating in volume by up to 80%. This is thought to be particularly true between 34 and 15 million years ago when atmospheric CO_2 levels were twice as high and global average temperatures were 2°C warmer, than in the year 1900. These are similar to CO_2 and temperature conditions predicted for the next few hundred years!

A second major cooling step occurred about 15 million years ago when the Antarctic ice sheets are thought to have expanded to their present size.



ulation of the glaciation of ars ago. Note the rapid inental-scale ice sheet ource DeConto & Pollard,

There is widespread debate between scientists as to how stable the ice sheets have been in the last 15 million years. Some scientists, known as the "stablists", argue that the ice sheets have been cold and have not changed significantly in size. Others, the "dynamicists", believe that the oxygen isotope records support unstable dynamic ice sheets with changes of up to 50% of present day volume driving global sea-level changes of up to 30 m. Evidence for the latter view is provided by marine microfossils found in glacial deposits at a number of locations high in the Transantarctic Mountains. It is proposed that the diatoms originated from an inland sea that existed during warm periods when the ice sheets had melted, subsequently to be eroded by glaciers and transported to their present-day sites. However the "stablists" have argued that the diatoms could have been carried by winds from the Southern Ocean, and in fact numerous species of wind-transported marine diatom are found today at the South Pole. This debate continues.

Cape Roberts Project drill cores provide first direct evidence of an unstable ice sheet when Antarctica was once warmer!

In the mid-1980s, Victoria University professor Peter Barrett, and a largely New Zealand team, were amongst the first to discover that Antarctica had been glaciated since the late Eocene, when they drilled the deepest sedimentary record (at that time) in western Ross Sea. During the late 1990s the Cape Roberts Project, also led by Peter, and including scientists from six other nations (United States, Germany, Italy, United Kingdom, Australia, and the Netherlands), drilled three more holes about 100 km north of the previous drilling site. They tapped into a remarkably complete, 1.5 km-deep "sedimentary tape recorder" of ice sheet behaviour between 34 and 17 million years ago. This provided the first direct evidence that the EAIS had been highly dynamic in a past, warmer world and closely matched the deep sea oxygen isotope records which predicted major ice volume changes equivalent to 20-30 m of sea-level rise and fall every 40,000 and 100,000 years.

Peter Barrett

Cape Roberts drill rig and camp

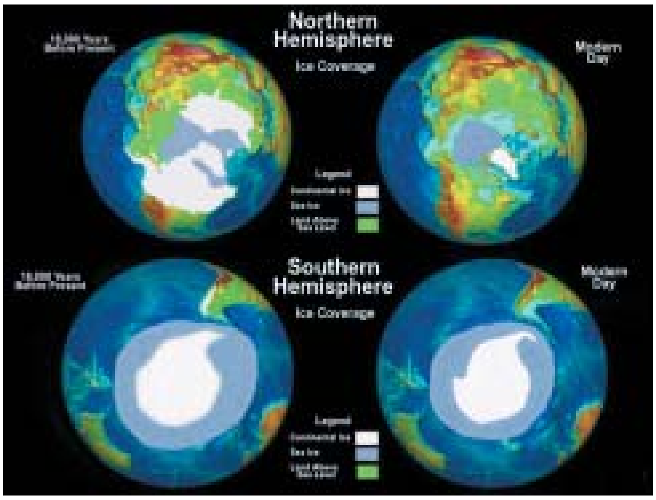
Photos P Barrett

Photos T Naish

Drill core of sediments deposited by a glacier entering the sea

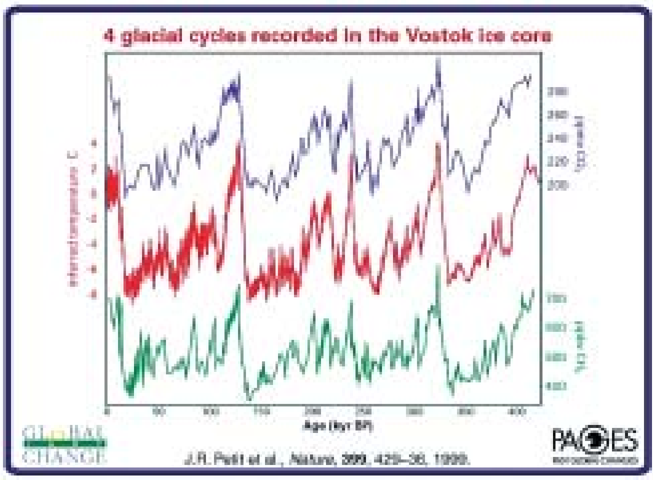
Cape Roberts project scientists discuss the sediment cores

Core scanning equipment measures the physical properties of the drill core



Earth's polar ice sheets during the present day and 18,000 years ago during the last ice age.

Cartoon illustrating the ocean circulation system known as the 'great ocean conveyor'.



Cycles of greenhouse gas concentration and temperature recorded in the 400.000 year long Vostok Ice Core.


Scientists from Russia, United States of America and France hold sections of ice core at Vostok Station. Photo Rob Dunbar

Why do ice sheets and sea-level "yo-yo"?

During the last 3 million years Earth has experienced "bi-polar" glaciations – both polar regions having ice sheets. The warmer Northern Hemisphere ice sheet is more unstable than Antarctica and is currently restricted to Greenland. However 18,000 years ago during the last ice age, most of North America, Asia, and Europe were covered by ice, and Antarctica may have had 25% more ice than today. There was so much water frozen in ice sheets that sea level was about 120 m lower than today. The beach would have been about 100 km east from Christchurch and people could have walked from South East Asia to Australia.

So what caused these ice volume and sea-level changes? The answer was discovered by a Serbian mathematician, Milutin Milankovitch, at the beginning of the 20th century. From observations of the solar system, he predicted that regular changes in Earth's orbit should cause regular changes in the amount of the Sun's heat received at the Earth's surface, and that this could affect the climate over long cycles, such as 40,000 years. He concluded that the last ice age was caused by one of his orbital cycles. However it took until the mid-1970s before "Milankovitch cycles" were properly recognised in geological records and his theories proven.

Antarctic sea-ice drives the great "ocean conveyor"

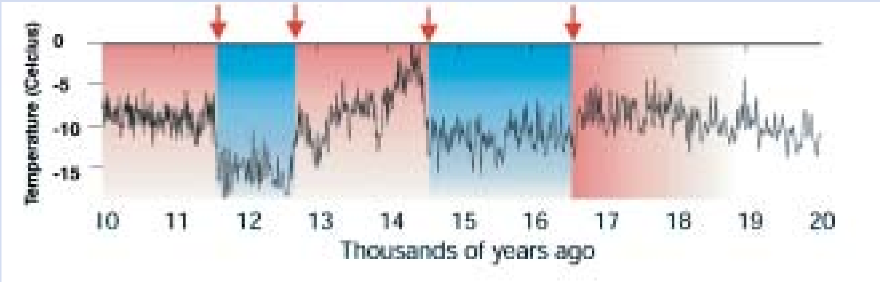
Low temperatures and strong persistent winds generated over the interior of the Antarctic ice sheet, cool surface waters of the surrounding Southern Ocean to form sea-ice. Each year, sea-ice around Antarctica grows to nearly 60°S at its peak extent during late austral winter (September), doubling the area of the continent! The annual sea-ice apron plays an important role in the generation of cold "Antarctic Bottom Water". Salty brines form below the sea-ice. Because they are denser than sea water, they sink to the bottom of the Southern Ocean. This newly formed saline bottom water spins around Antarctica before flowing north along Eastern New Zealand into the Pacific where it warms and returns to the surface, ultimately to flow as a warm current through the Indian Ocean and up into the North Atlantic as the "Gulf Stream". Northern Hemisphere seasonal sea-ice then cools the water, returning it to the deep ocean where it flows south to Antarctica again. This process of ocean circulation was named the "great oceanic conveyor", by famous United States oceanographer Wally Broecker. The ocean conveyor is an important feature of Earth's climate as it redistributes heat between the equator and the poles. Antarctica is the major "pump" in the conveyor. Therefore, changes in Antarctic ice volume not only affect sea level, but can significantly affect the seasonal production of sea-ice with the potential to slow or shut down the ocean circulation with dramatic consequences for Earth's climate (see "Abrupt Climate Change" below).

Catastrophic collapse of the Larsen B ice shelf in March 2002 due to warming of the Antarctic Peninsula

Icehouse to greenhouse once again?

Geological records of Earth's past climate provide a valuable context for predicting our climatic future. Scientists study past periods of global warmth because they provide realistic examples, or analogues, of how Antarctic ice sheets, global sea level and ocean circulation might change as global temperatures and CO_2 continue to rise.

Ice cores tell an amazing tale of how humans have changed Earth's climate. They allow changes over the last few centuries to be directly compared to natural climate variations of the last few hundred thousand years. The longest ice core record available today was drilled near the Russian station of Vostok in the centre of the East Antarctic ice sheet. It was drilled to a depth of over 3000 m and recovered an uninterrupted record of the last 400,000 years. Air bubbles trapped in the ice of the Vostok record contain a remarkable annual inventory of changing levels of atmospheric greenhouse gases (carbon dioxide, methane, nitrous oxide). Temperatures can be accurately estimated using oxygen and hydrogen isotopes in the ice. The record shows that both temperature and greenhouse gases have varied over the last 400,000 years. When greenhouse gas concentrations increase, temperature follows suit. Conversely, a drop in temperature always occurs when the greenhouse gas concentrations fall. There are four large fluctuations in temperature and greenhouse gases in the Vostok record. Each corresponds to a natural 100,000-year climate cycle. Of significance is that maximum CO_2 levels in each cycle never exceeded 300 ppm until the 20th century where CO_2 is now at a record 380 ppm and climbing. Carbon dioxide and methane have increased by 31% and 150%, respectively, since the beginning of the industrial age (1750).



Abrupt climate change as shown by the remarkable swings in Northern Hemisphere temperature, as recorded in the Greenland ice core.

Will global warming unlock the icehouse?

A critical question facing humanity is, **"will human-induced global warming return us to a greenhouse world within the next few centuries"?** and, if so**, "what will be the consequences of unlocking the Antarctic icehouse?"**.

So what are the facts concerning global warning? The IPCC, in their 3rd assessment report published in 2001 came to the following conclusions about 20th century climate:

- global average surface temperature has increased by 0.6°C
- snow and ice cover has reduced by 10%
- global average sea level has risen by 0.2 m
- CO_2 has increased by 31% since 1750
- CH_4 has increased by 151% since 1750
- greenhouse gas concentrations are the highest they have been in the last 400,000 years (from ice core evidence)
- present changes in climate have not occurred naturally in the past
- present warming is not part of the natural climate cycle
- warming is a result of human activities.

IPCC predictions for the next 100 years include:

- global average sea level will rise by at least 1 m
- global average surface temperature will increase between 1.4 and 5.8°C
- CO_2 will increase by 90–250%
- the ocean conveyor may slow down.

So IPCC scientists have answered the first question. The current and predicted increases in temperature and greenhouse gases will take Earth's climate back to the same conditions that existed in the greenhouse world over 34 million years ago – a time when Antarctica did not have an ice sheet. Before we all run off in search of higher ground it is important to understand that large uncertainties surround the likely response of Antarctic ice sheets to this warming over the next few centuries. It is unlikely that Antarctica's ice sheet will melt in the very near future. Even with sustained warming for the next 200–300 years, major loss of Antarctica's ice would probably take thousands of years. However, scientists are growing increasingly concerned about the future stability of the smaller West Antarctic Ice Sheet (WAIS). A large part of the WAIS sits on bedrock below sea level and as sea and air temperatures increase it could collapse much sooner than the larger more stable EAIS. Could this happen in the next few hundred years? We don't know, but should the WAIS melt, it would raise global shorelines by 5 m – enough to drown one third of Florida!

Could global warming cause a mini ice age?

Of more immediate concern is the prospect of "abrupt climate change". Abrupt switches in Earth's climate have occurred on average every 2000 years during and following the last ice age 60,000–10,000 years ago. This natural instability is recorded in polar ice cores which indicate that changes in temperature of up to 8°C occurred in a decade! In fact 12,500 years ago the Northern Hemisphere was plunged into a mini "ice age" as temperatures over Greenland plummeted 8°C in only 20 years. The cold "glacial" conditions lasted for only 1000 years before reversing just as quickly back to the warm climate that has existed to this day. It is widely accepted from the abruptness and size of this event that the global ocean conveyor, which redistributes heat between tropical and polar regions, either slowed down or stopped entirely. The north flowing, warm ocean current known as the "Gulf Stream", which brings warm air masses into eastern North America and Europe, may have stopped. Climate scientists are concerned that global warming could return our climate to the past pattern of wild and crazy jumps. Relatively small amounts of ice melting at key locations around Antarctica and the Arctic could "shut down" ocean currents such as the Gulf Stream within a decade or two causing catastrophic change to Earth's climate.

Four good reasons to keep doing climate research in Antarctica

It's really fascinating … yet because this amazing continent and its enormous ice sheets sit isolated by ocean at the bottom of the world we still know relatively little about Antarctica's influence on global climate.

The Earth is warming. At the rate humans are pumping greenhouse gases into the atmosphere the Earth will soon have warmed to a level it has not experienced for 35 million years – a time when there was no ice on Antarctica. If today's ice sheets completely melted sea level would rise by 65 m. Although most scientists agree that this is unlikely to happen, some melting will happen in the next few centuries – what can we expect? How much will sea level rise? How will changes to Antarctica's fringing sea-ice and the Southern Ocean affect Southern Hemisphere climate?

We learn more about New Zealand's climate. Cyclonic weather systems that circulate around Antarctica have as much influence on our climate as the tropical systems which bring El Niño and La Nina climatic patterns to New Zealand. The more we can understand about Antarctica's icy grasp on our climate the better we can plan for the consequences of future climate change in New Zealand, such as droughts, storms, floods, and water shortages in our hydro-lakes.

So New Zealand can fulfil its international research obligations. As a signatory nation of the Antarctic Treaty our government has made a commitment to co-operate with other nations to do scientific research that will help us to better understand Antarctica and its place in the Earth's system. We have also made a commitment as a member of the IPCC to contribute research to understanding the science of climate change. Research on New Zealand and Antarctica will be used as a basis for implementing future greenhouse gas emissions strategy under the Kyoto Protocol agreement.

Further reading

Alley, R. 2001. The two mile time machine: ice cores abrupt climate change and our future. Princeton University Press. 240 p.

Broecker, W. 1993. Glacial world according to Wally. Eldigio Press, Lamont-Doherty Geological Observatory, Columbia University, New York.

Houghton, J.; Ding, Y.; Griggs, D.; Noguer, N.; van der Linden, P.; Xiaosu D. (ed.) 2001. Climate Change 2001: The Scientific Basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change (IPCC). Cambridge University Press, United Kingdom. 944 p.

Mayewski, P.; White, F.; Margulis, L. 2002. The ice chronicles: the quest to understand global climate change. University Press of New England. 264 p.

Web resources

Antarctica New Zealand
http://www.antarcticanz.govt.nz/

British Antarctic Survey
www.antarctica.ac.uk/ or www.nerc-bas.ac.uk/public/

US National Science Foundation Office of Polar Programs(Antarctica) http://www.nsf.gov/od/opp/antarct/start.htm

Institute of Geological and Nuclear Sciences
http://www.gns.cri.nz/what/earthhist/antarctica/index.htm

Victoria University of Wellington Cape Roberts Project http://www.geo.vuw.ac.nz/croberts/

National Institute of Water and Atmospheric Research (NIWA)
http://www.niwa.cri.nz/rc/antarctica/

Acknowledgements

Author: Dr Tim Naish, paleoclimatologist, Institute of Geological and Nuclear Sciences (GNS).

Resources and information generously donated by Emma Reid (Antarctica New Zealand), Dr Rob Dunbar (Stanford University), Dr Peter Barrett and Alex Pyne (Victoria University of Wellington), Lionel Carter (NIWA), Richard Levy (ANDRILL Science Management Office, University of Lincoln, Nebraska).

Reviewed by Julian Thompson, Raphael House, Rudolph Steiner School, New Zealand Science, Technology, and Mathematics Teacher Fellow 2004.

Sponsored by the GNS Global Change Through Time Programme (Foundation for Research, Science and Technology Contract CO5X0202) and Antarctica New Zealand.

the ROYAL SOCIETY of NEW ZEALAND