

Climate change is a hot topic in these times. Almost daily we are presented with claims and counter claims in a torrent of information of variable reliability. From some quarters we hear each and every extreme weather event cited as evidence of climate change, while others suggest that nothing is amiss, or that any changes to climate will be benign or beneficial. Rather like the extreme weather, extreme opinions can mask the underlying story, making it difficult to understand what is really occurring.

Modern climate science is global and multidisciplinary, and covers such a diversity of fields that maintaining a deep understanding across its breadth can be a challenge, even for professional scientists. The good news is that even without specialist training, the broad scientific issues are not so hard to appreciate and the main arguments can be readily understood.

What follows is an overview of some of the basics of climate change, with an emphasis on Antarctic issues. The Antarctic and Southern Ocean regions are key components of the global climate system, and regular readers of this magazine will be aware that climate research is a major component of Australia's Antarctic science programme.

The fundamental issue in climate change is of course the greenhouse effect: the well-known fact that the atmosphere traps some of the heat that would otherwise radiate away from our planet into space. This effect is not at all contentious – without it, the average temperature of the planet would be about 33 degrees cooler than its actual value of about 14°C. But this is the *natural* greenhouse effect. The real issue is the degree to which human activity is strengthening the greenhouse effect.

We know that our use of fossil fuels and changes in land use have added large quantities of carbon dioxide (CO₂) and methane to the atmosphere, and that concentrations have reached levels not seen for several hundred thousand years or longer. In fact, Australian Antarctic research has provided the clearest proof of this change in atmospheric composition, which is revealed in the analysis of bubbles of past atmosphere trapped in Antarctic ice (see figure).

We also know that the CO₂ and other emissions have a powerful greenhouse impact. The effect has been likened to piling extra blankets on the planet. As long ago as 1896, a Swedish Nobel Prize winning chemist, Svante Arrhenius, raised the idea that fossil fuel emissions would have this effect, although interestingly, he drastically underestimated the 20th century growth in emissions, suggesting that it would take perhaps 3000 years for atmospheric CO₂ to double in concentration. In fact, depending on various social and economic assumptions, doubling is likely to occur mid to late this century.

Since Arrhenius first raised the issue, the real problem has been determining the strength of this human contribution to the greenhouse effect. In the real-world climate, warming as a result of increased greenhouse gases leads to a range of other

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Climate change: cold,

Sea smoke

climatic changes – some that tend to reinforce and accelerate warming and others that tend to counteract warming. For example, in a warmer climate, retreat of ice and snow cover leaves a darker surface, which absorbs more heat and drives further warming. Conversely, a warmer atmosphere carries more moisture that may cause increased clouds in some areas, which reflect sunlight before it reaches the Earth's surface, reducing surface warming. The net result quickly becomes too complicated for manual calculation and requires the use of computer models that use known physics to quantify the processes.

Identifying all the processes that need to be modelled and getting accurate mathematical representations is a central activity in modern climate studies. Observations of current and past climate behaviour help to refine understanding of climate processes and allow us to test and improve the climate models.

While there is a wide variety of modern climate models, all confirm the net warming effect of human greenhouse emissions, despite the fact that the various models adopt quite different approaches to their internal representation of the climate system. The models indicate warming over the course of the 21st century in the range of 1.4 to 5.8 degrees; about half this range comes from the uncertainties in the models themselves and the remaining half is from uncertainty in projected emissions.

A major part of testing models is to see how they reproduce, or 'hindcast', past changes, including the closely monitored changes during the 20th century. The best of these 20th century hindcasts closely reproduce the observed rate of warming and total global average increase of 0.6 degrees. Tellingly though, they can only do so if known human emissions of greenhouse gases are included as drivers, providing strong evidence that not only are the models capturing major climatic behaviour well, but that the emissions

hard facts on a hot topic

are indeed the cause of warming.

Climate observations are important in building and testing models. Observations also show us just how climate changes are being manifest. The task of detecting human-induced changes is difficult however, because the climate system has natural variability. We know that the climate has changed in the past - very dramatically over timescales of hundreds of thousands of years. Even over short timescales, the climate shows natural variations which can

be substantial, especially over limited regions. The result is that it can be difficult to determine if an observed change is just part of the natural behaviour.

So how *do* we know that the 0.6 degree warming in the last 100 years is significant? Aside from the modelling evidence, the answer comes from looking at past climate indicators from tree rings, ice cores, corals, ocean sediments and other sources. Several different studies have produced reconstructions of global climate over past centuries, some extending back some 2000 years. The evidence is strong that today's global climate is warmer than at any time in this period. Glaciers are in retreat, arctic sea ice is declining and there are changes, particularly at the margins of Antarctica and Greenland, that all suggest a warming outside what could be explained by natural variability.

Some have argued that climate changes were much more drastic in the past but, to the best of our knowledge, the climate has never been much warmer than present; that is, unless you look so far back that the whole geology, chemistry and biology of the planet was radically different. In more recent periods, over the past several hundred thousand years, temperatures in the warm intervals between ice ages may have reached a degree or two warmer than present. However, for ice age cycles, we know that temperature changes arise from slow variations in the Earth's orbit, which are not the cause of present warming. What's more, these ice age changes are much slower than current warming and happened in an environment with only about 280 ppm (parts per million) CO₂ and not the approximately 380 ppm we see today.

The evidence for human-driven climate change is now well established and the tasks ahead are both political and scientific. As we look for ways to respond, we are ever more reliant on our understanding of the climate system in all its complexity. The question of 'what to expect?' is a pressing one that demands continued scientific effort. Models are

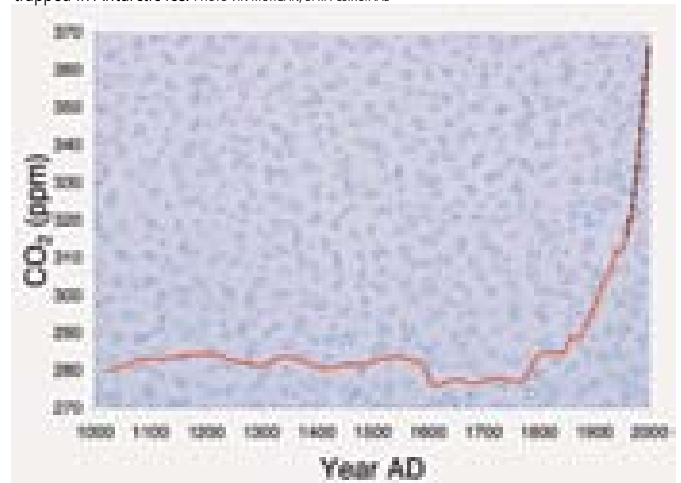
improving, but are generally limited in their ability to predict changes at continental and regional scales. We know that the climate changes will not be felt uniformly across the planet. Better understanding of the detailed workings of climate will be needed to reduce uncertainties.

In this century we will continue to see loss of temperate glaciers, increases in sea level in the range of 10 to 80 cm, average warming of about 1.4 to 5.8°C, and significant changes to the ice margins of Greenland and Antarctica. Popular reports of complete loss of ice in either Greenland or large portions of Antarctica, with metres of sea level rise, are inconceivable in less than centuries to millennia. The Antarctic interior is so cold that even the strongest projected warming will not lead to complete melting. But this is cold comfort, for even more realistic climate changes will have major impacts.

There is much to be done in Antarctic and Southern Ocean climate research. The systems of high southerly latitudes interact with the global climate system in powerful ways. The annual cycle of sea ice formation generates cold salty water masses (so-called Antarctic bottom water) that have major impacts on global ocean circulation. Monitoring these ocean water masses and understanding changes is just one aspect of ongoing research.

The response of sea ice formation to a warmer climate is likely to have large impacts on ocean circulation and the whole Southern Ocean ecosystem. Integrated research on the combined physical and biological components of this system is a major aspect of research at the Antarctic Climate and Ecosystems Cooperative Research Centre. The Antarctic ice sheet itself is a major target of study. Even small changes in the size of this ice sheet will have significant consequences for sea level, and changes are already being seen as warming alters the balance between water accumulation as snow, and water loss by iceberg calving and melting.

Atmospheric CO₂ concentrations over the past 1000 years from Law Dome ice cores. The ice core measurements overlap with direct atmospheric measurements at South Pole, available since 1958 (black dashed line). The background photograph shows bubbles trapped in Antarctic ice. PHOTO VIN MORGAN; DATA CSIRO/AAD



The Antarctic is a region where the climate records from observations are both short and sparsely distributed. To address this limitation, the ice sheet and ocean floor will continue to be probed for information about past climate, by drilling ice cores and ocean sediment cores. Antarctic ice core records are providing new information on climate changes on the continent, the surrounding sea ice and Southern Ocean, and even Southern Australia.

FURTHER READING:

Barrie Pittock. *Climate Change: Turning up the heat*. CSIRO Publishing, 2005.
Spencer Weart. *The Discovery of Global Warming*. Harvard University Press, 2003.
Also online at <<http://www.aip.org/history/climate/>>
RealClimate Website: <<http://www.realclimate.org/>>

Given this concentrated, multi-faceted effort and the clear imperative for understanding the climate changes we face in the future, Australian Antarctic science is set to continue its record of major contributions to international climate research.

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A new international programme for Antarctic climate research

A new scientific programme called 'Antarctica and the Global Climate System' (AGCS), will focus research attention on the Antarctic climate and its interaction with the global climate.

The programme is one of five flagship activities of the Scientific Committee on Antarctic Research, and 12 nations, including Australia, have submitted plans to address issues covering four main themes.

The first theme will look at climatic change across Antarctica and the Southern Ocean and try to better describe and understand climate variability over decadal time spans. The work will largely rely on observational data and computer modelling. Research will investigate, for example: changes in the El Niño Southern Oscillation that might relate to Antarctica and the Southern Ocean; shifts seen in many post-1970s climate indicators; and recent trends in atmospheric pressure and winds around Antarctica (connected with a phenomenon known as the Southern Annular Mode).

The second theme aims to use ice cores to better reconstruct the climate since the peak of the last ice age, and particularly over the last 10 000 years (the Holocene Period).

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A key activity, and one in which Australia has played a significant role, is the calibration and understanding of the relationships between typical climate parameters (such as temperature) and the dozens of properties that are measured from ice cores.

The third AGCS theme aims to separate the Antarctic climate response to natural and human influences. To do this, researchers will develop climate models and run simulations to evaluate Antarctic and Southern Ocean climate responses under different scenarios of natural variation and human activities.

Australian researchers will focus on the response of the ice sheet to warming and its consequent impact on sea level. This work will involve enhancing climate models, by adding interactions between the ocean and ice shelves, which are currently not included.

The fourth theme of the programme looks at how Antarctic climate processes influence the global climate. We know, for example, that the formation of deep, salty, cold ocean water around Antarctica has a global impact. Computer model simulations and direct oceanographic observations will help us study these processes.

The AGCS programme runs from 2005–2010. It will include a number of international activities throughout the International Polar Year (2007–2009) and will provide a valuable forum for the development of Antarctic climate science into the future.

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