Australian Government
Department of the Environment and Heritage
Australian Greenhouse Office

CLIMATE CHANGE SCIENCE

Questions Answered

This booklet has been published by the Australian Greenhouse Office, in the Department of the Environment and Heritage.

The Australian Greenhouse Office acknowledges assistance from CSIRO, the Bureau of Meteorology and the Intergovernmental Panel on Climate Change in the development of this booklet.

ISBN 1 920840 79 6

Reprinted in 2005

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This booklet is available electronically at www.greenhouse.gov.au
Copies of this booklet may be obtained by phoning 1300 130 606.

Design: RTM Design www.rtmdesign.com.au

Contents

Note: *A number of the graphs in this booklet have been adapted and simplified from the Intergovernmental Panel on Climate Change Third Assessment Report, 2001. The original graphs can be accessed at: www.ipcc.ch/*

Minister's Foreword

Climate change is having far-reaching impacts globally and in our region.

It is one of the most talked-about issues of our time as, almost weekly, we hear about new scientific research highlighting the potential effects of this change.

But climate change can be a complex issue and we all need help to understand the science behind it.

That is why the Australian Government has produced *Climate Change Science—Questions Answered*.

Australian scientists are at the forefront of enhancing global understanding of climate change, particularly as it is affecting our region.

So it is great to know that some of Australia's leading climate change scientists from the CSIRO, the Bureau of Meteorology and the Intergovernmental Panel on Climate Change have contributed to this useful publication.

These scientists are helping to take the mystery out of climate change as they answer many commonly asked questions such as 'What is the greenhouse effect?' 'Will sea levels rise if the world heats up?' and 'What are the potential impacts of climate change?'

Readers will gain not only a deeper understanding of climate change but also an appreciation of the significance of the scientific research being carried out by our Australian scientists in this area.

Over four years, through its $30.7 million Australian Climate Change Science Programme, the Australian Government is investing strongly in this research effort.

This initiative is part of our $1.8 billion climate change strategy through which we are taking action to reduce our national greenhouse gas emissions, working to develop an effective global response to climate change and helping to prepare communities, industries and regions to adapt to unavoidable impacts of climate change.

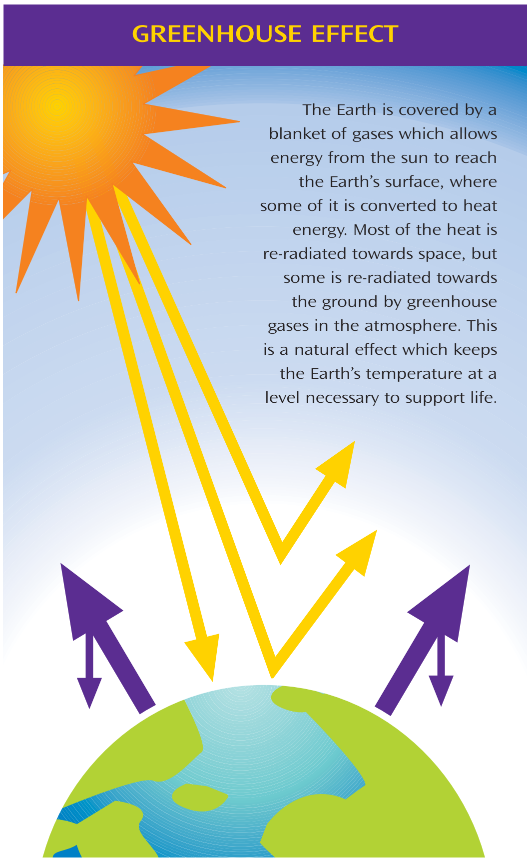
Please enjoy this practical and informative guide to climate change—an issue that is having an increasing impact on the lives of all Australians.

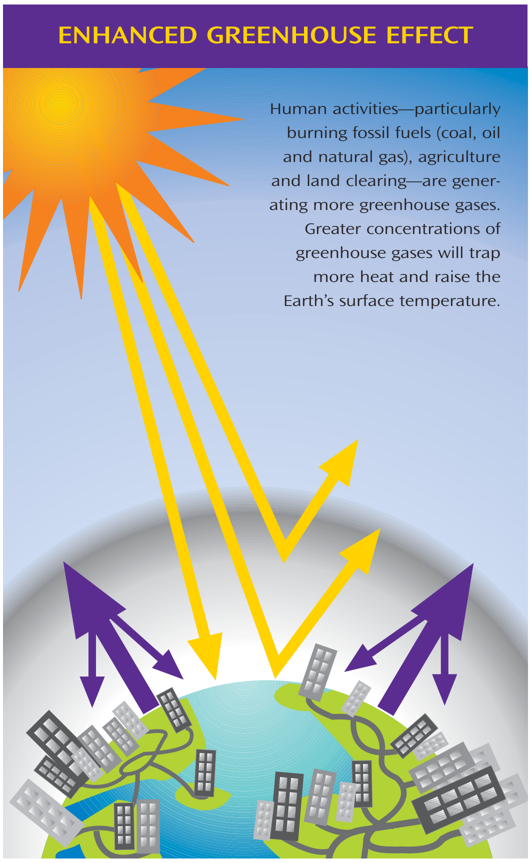
Senator the Hon. Ian Campbell
Australian Minister for the Environment and Heritage

Q1: What is the greenhouse effect?

Greenhouse gases are a natural part of the atmosphere. They absorb and re-radiate the sun's warmth, and maintain the Earth's surface temperature at a level necessary to support life. The problem we now face is that human actions—particularly burning fossil fuels (coal, oil and natural gas), agriculture and land clearing—are increasing the concentrations of the gases that trap heat. This is the enhanced greenhouse effect, which is contributing to a warming of the Earth's surface.

Water vapour is the most abundant greenhouse gas. Its concentration is highly variable and human activities have little direct impact on its amount in the atmosphere. Humans have most impact on carbon dioxide, methane and nitrous oxide. Various artificial chemicals such as halocarbons also make a small contribution to the enhanced greenhouse effect.





Q2: Is the Earth's climate really hotting up?

The global average surface temperature has increased since 1861. (Before this date there were few reliable thermometer measurements.)

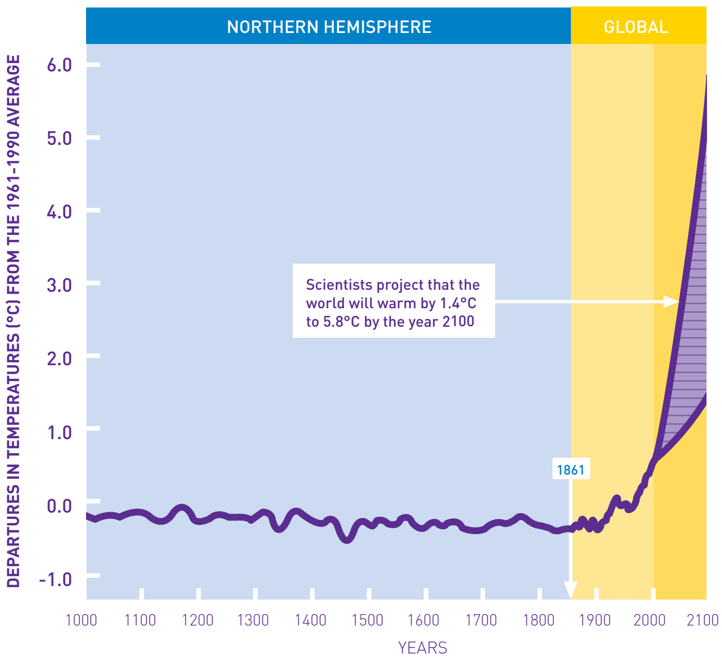
During the past 100 years, global average surface temperature increased by about 0.6°C. Tree rings and other records tell us that in the 1700 years before this, the Earth's temperature remained relatively stable. The 20th century was the warmest of the past 1800 years in the northern hemisphere. Globally, the 10 warmest years on record have all occurred since 1990.

In addition to warming of the Earth's surface, there has been an increase in heatwaves, warming of the lower atmosphere and deep oceans, fewer frosts, retreat of glaciers and sea ice, a rise in sea level of 10–20 cm and increased heavy rainfall in many regions. Some plants and animals have changed their location or the timing of seasonal activities in ways that provide further evidence of global warming.

Although many natural factors influence the Earth's climate, a majority of the worlds' scientists are confident that greenhouse gas increases were the main factor contributing to global warming in the last 50 years. Increases in carbon dioxide, methane, tropospheric (lower atmosphere) ozone, halocarbons and nitrous oxide have all contributed to global warming.

In its Third Assessment Report released in 2001, the Intergovernmental Panel on Climate Change—an international body that assesses the latest science of climate change—stated that "there is new and stronger evidence that most of the warming observed over the last 50 years is attributable to human activities".

Earth's Temperature 1000–2100



This graph indicates how the Earth's surface temperature has increased since the mid 19th century. From 2000, scientists have projected a range of possible temperatures based on a number of future greenhouse gas emission scenarios. Scientists believe that the Earth's average temperature will rise by 1.4°C to 5.8°C by 2100 if nations around the world do not act to control greenhouse emissions.

This graph has been adapted and simplified from the Intergovernmental Panel on Climate Change Third Assessment Report 2001. The original graph can be accessed at: www.ipcc.ch/

Q3: But hasn't the Earth's climate always been erratic—with ice ages and interglacial periods?

Throughout history, the Earth has experienced cold and warm periods, known as ice ages and interglacial periods. In the past million years, these natural climate changes were due to periodic variations in the Earth's orbit that affect the amount of sunlight received at the surface. Ice ages historically have extended over about 90,000 years and the warmer interglacials have lasted about 10,000 years or less. Globally averaged, ice ages have been about 10°C cooler than present, while interglacials have been about the same temperature as today.

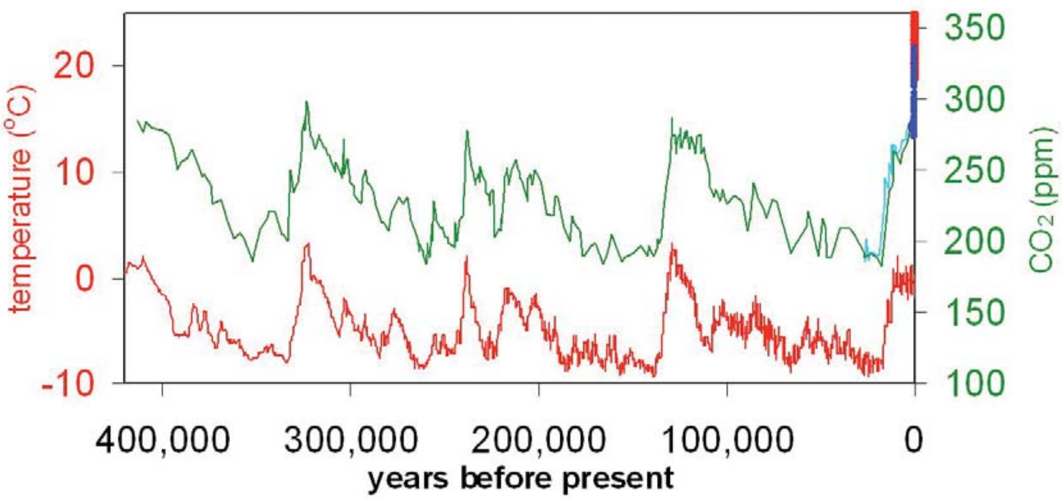
The past 11,000 years is known as the Holocene Warm Period. Over the past 2000 years, regional fluctuations of 1.0–1.5°C have occurred. For example, northern Europe was cold until the 7th century, after which temperatures warmed to a peak, known as the Medieval Warm Period (900–1300 AD).

These complex natural fluctuations are still affecting the Earth's surface temperature and climate over long timescales. However, simulations using sophisticated computer-based climate models confirm that global warming during the past 50 years was mainly caused by human activities that have increased atmospheric concentrations of greenhouse gases.

Present carbon dioxide and methane concentrations are the highest they have been for at least 420,000 years, as shown from analysis of air bubbles trapped in ice in Antarctica. A recent analysis shows that these levels are unprecedented in the last 740,000 years. The current rate of increase in carbon dioxide concentrations has not been experienced for at least 20,000 years.

Climate models driven by scenarios of greenhouse gas emissions indicate that, over the next century, a global warming of 1.4 to 5.8°C could occur. This rate and magnitude of warming are significant in the context of the past 400,000 years. History has shown us that a warming of 1–2°C can have dramatic consequences. Even the 0.6°C warming in the past 100 years has been associated with increasing heat waves and floods, fewer frosts, more intense droughts, retreat of glaciers and ice sheets, coral bleaching and shifts in ecosystems. A further warming of 1.4 to 5.8°C could challenge the adaptive capacity of a range of human and natural systems.

CO_2 and temperature over the last 420,000 years



Temperature and carbon dioxide concentrations from the Vostok ice core in Antarctica. The current global concentrations of CO_2 in the atmosphere (approaching 380 parts per million) are the highest in the last 420,000 years.

This graph is from the Intergovernmental Panel on Climate Change Third Assessment Report 2001. www.ipcc.ch/

Q4: How do we know that most global warming is attributable to human activities rather than natural causes?

The present atmospheric concentration of carbon dioxide has not been exceeded for the past 420,000 years, and possibly not for 20 million years. Ice core records that go back 420,000 years show that carbon dioxide levels in the atmosphere varied between 180 and 280 parts per million (ppm) due to glacial cycles. For the past 10,000 years global atmospheric carbon dioxide has been quite stable at between 260 and 280 ppm, and level at about 280 ppm from 1000 to 250 years ago. However, since the beginning of the Industrial Revolution, some 250 years ago, the concentrations of greenhouse gases in the atmosphere have increased dramatically. Human activities, such as burning fossil fuels (coal, oil and gas), land clearing and agricultural practices have increased carbon dioxide by more than a third (to about 380 ppm), nitrous oxide levels by about 17 per cent and methane concentrations have more than doubled. The current rate of increase in carbon dioxide is unlikely to have been experienced during at least the past 20,000 years.

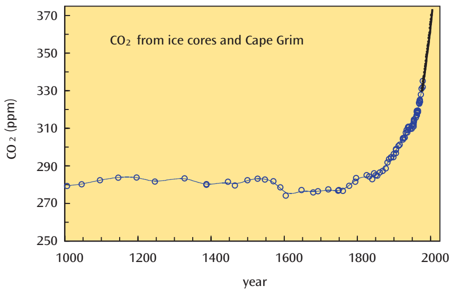
The observed changes in climate, especially temperature increases since about 1970, cannot be explained by natural causes such as solar activity. Reconstructions of climate data for the past 1000 years indicate that this recent warming is unusual and is unlikely to have resulted from natural causes alone.

Scientists use computer models to simulate past and future climate variations. Simulations of the 20th century have been driven by observed changes in various factors that affect climate. When only natural factors, such as volcanic and solar activity, are included in the models, the simulations do not explain the observed warming in the second half of the century. Natural factors contributed to the observed warming of the first half of the 20th century. However, most of the observed warming over the past 50 years is likely to have been due to the human-induced increase in greenhouse gas concentrations.

Indicators of the human influence on the atmosphere during the industrial era

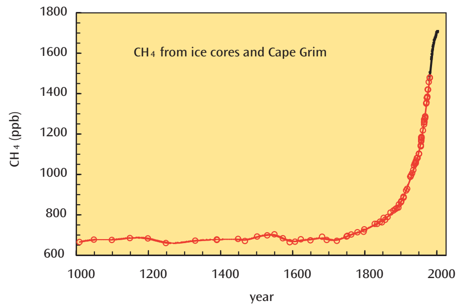
Global atmospheric concentrations of three greenhouse gases

Carbon Dioxide



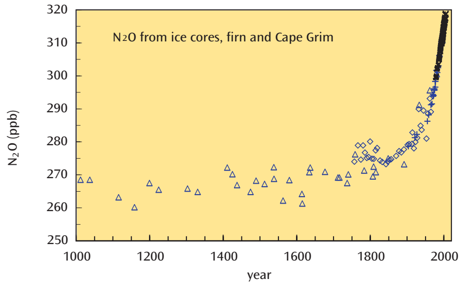
Etheridge et al., J. Geophys. Res. 1996

Methane



Etheridge et al., J. Geophys. Res. 1998

Nitrous Oxide



Machida et al., 1995; Battle et al. 1996,
Fluckiger et al., 1999; Langenfelds et al., 2004

Q5: What is the carbon cycle? How does human activity contribute to the carbon cycle?

Carbon, in various forms, continuously circulates between the living world, the atmosphere, oceans and the Earth's crust. There are many different processes by which carbon is exchanged between these locations. Activities, such as fires, which release carbon dioxide into the atmosphere, are known as 'sources'. The oceans and growing trees remove carbon dioxide from the atmosphere and are known as 'sinks'.

Each year human activity adds several billions of tonnes of carbon in the form of carbon dioxide to the atmosphere. A little over half of this carbon dioxide remains there, while the rest is absorbed by plants and the oceans (and ultimately some of this is returned to the Earth's crust).

More than 120 billion tonnes of carbon are exchanged each year between all living things during photosynthesis and respiration. Plants absorb about 61 billion tonnes of carbon and respire about 60 billion tonnes. Plants grow by absorbing carbon dioxide from the air or water and converting it to plant tissue through photosynthesis. Some of this carbon is used to supply the plant with energy. This process, known as respiration, releases carbon dioxide back into the atmosphere. The carbon from carbon dioxide absorbed by a tree may be stored as wood for hundreds of years. Or the carbon may become part of a leaf that dies and decomposes, with the carbon returning to the atmosphere relatively quickly.

The surfaces of the oceans release about 90 billion tonnes of carbon to the atmosphere and absorb about 92 billion tonnes each year. This absorption occurs when carbon dioxide in the air dissolves in the top layer of sea water and through photosynthesis by marine plants.

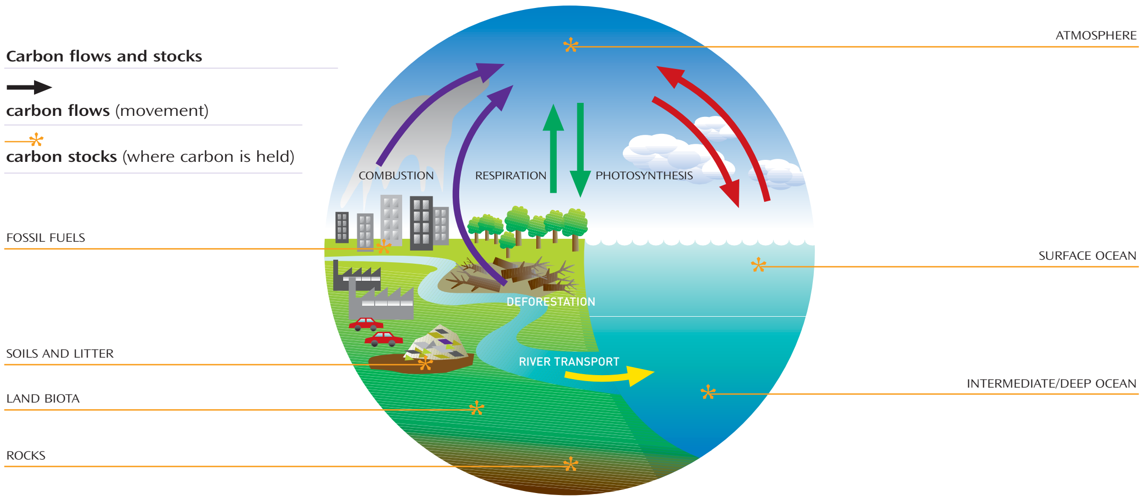
The amount of carbon dioxide that people add to the atmosphere may seem very small in comparison to the amounts being added and absorbed by natural processes, but it only takes a small change to upset the balance.

The burning of fossil fuels by humans adds about 6.5 billion tonnes of carbon each year in the form of carbon dioxide. Land clearing, reduced soil humus and the erosion of topsoil account for one to two billion tonnes of carbon a year.

Proof that more carbon dioxide is being added to the atmosphere than removed is the fact that concentrations of the gas continue to rise. Higher atmospheric concentrations of carbon dioxide and other greenhouse gases are likely to have led to the surface temperature increases and changing climate that are being experienced globally.

We still do not fully understand the carbon cycle. Scientists are carefully studying the extent to which different parts of the climate system absorb and release greenhouse gases.

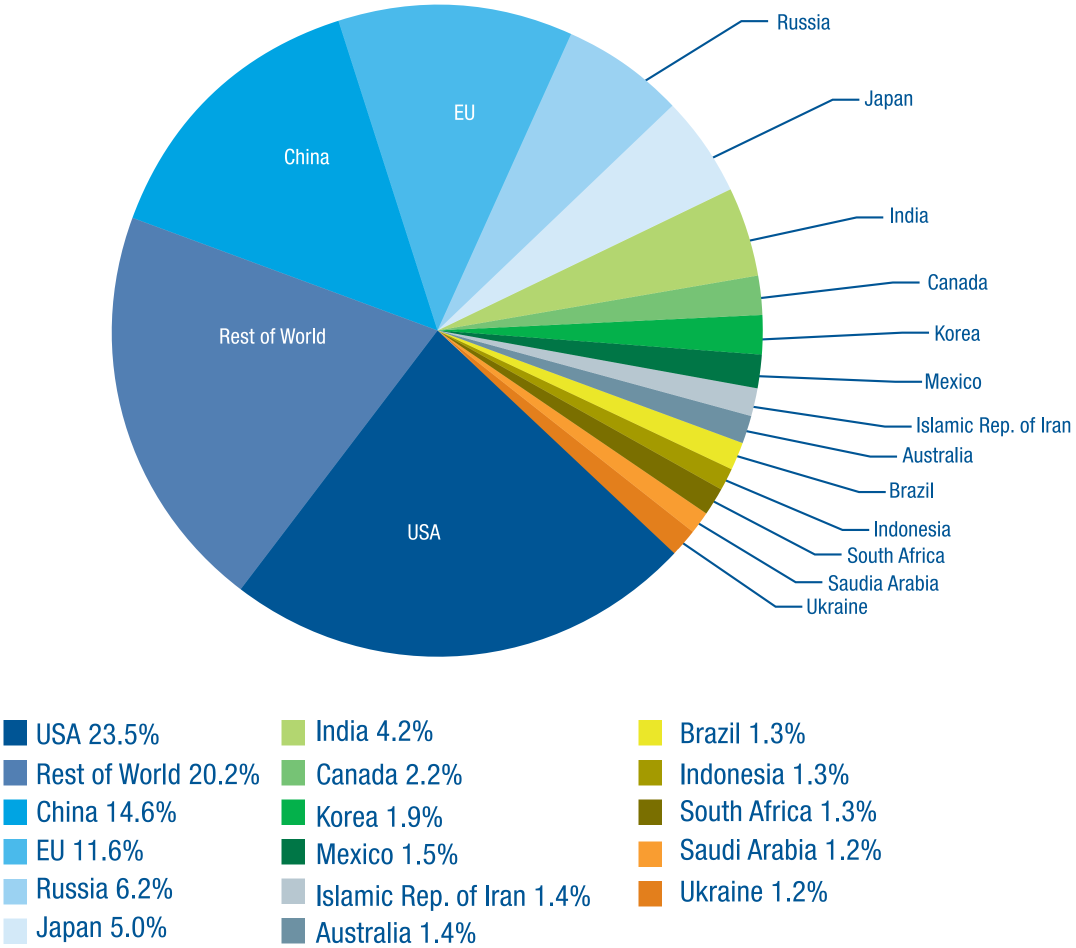
The carbon cycle



Q6: How much does Australia contribute to global greenhouse gas emissions?

According to the International Energy Agency Australia contributes only 1.4 per cent to world emissions.

2002 World Energy Related CO_2 Emissions



Source: *2002 World Energy-Related CO2 Emissions*, International Energy Agency

Australia contributes just 1.4 per cent of global greenhouse gas emissions. To put it another way, if Australia switched off all our power stations today—shutting down all schools, hospitals, factories, heaters and air conditioners—the greenhouse gas savings would be completely replaced by increased emissions from China's booming power sector in less than 12 months.

Q7: Will a few degrees warming have a significant impact on our climate?

The world has warmed 0.6°C in the past century. Scientists are confident that the world will get warmer in the 21st century due to further increases in greenhouse gas concentrations, with globally-averaged surface temperatures likely to increase by 1.4 to 5.8°C from 1990 to 2100. Warming of a few degrees may seem minor compared with day-to-day or seasonal variations in temperature. However, in global climate terms it is much larger than any of the climatic changes experienced during the past 10,000 years. For example, with a global temperature increase of 4°C, the temperatures experienced in Melbourne could be similar to those now experienced in Moree in northern New South Wales.

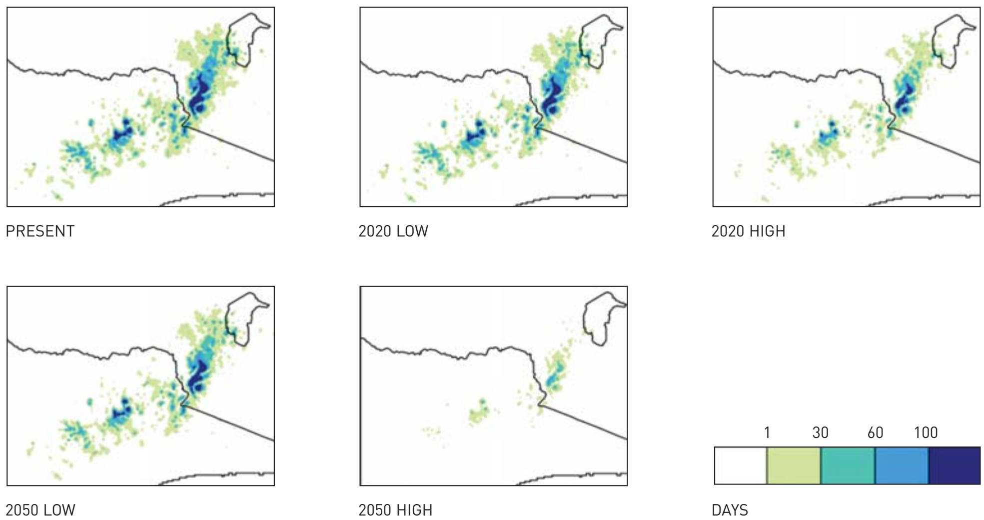
During the last ice age, which was at its maximum about 70,000 years ago, surface temperatures were on average about 5°C lower than today, and much colder in the polar regions. Sheets of ice covered almost one-third of the world's land.

The projected global warming of a few degrees in the 21st century would occur at a time that is already one of the warmest for hundreds of thousands of years, with current levels of carbon dioxide not exceeded for the past 420,000 years, and not likely during the past 20 million years.

A few degrees of global warming will lead to more heat waves and fewer frosts. In Australia, the projected average warming of 0.4 to 2.0°C by the year 2030 would lead to a 10–50 per cent increase in days over 35°C at many places, and a 10–80 per cent decrease in frosts.

More fires and droughts are expected in some regions of the world and more intense rainfall and resultant flooding in other areas. Australia's alpine regions are expected to have less snow cover (see figure below). Higher latitudes of the globe would receive more rainfall while middle latitudes, including parts of Australia, would likely receive less. Tropical cyclones may become stronger and sea level may rise 9 to 88 cm by the year 2100. Some low-lying coastal areas and islands could be more prone to inundation from storm surges. Human-induced climate change is another major stress in a world where natural and social systems are already experiencing pollution, increasing resource demands and unsustainable management practices.

Simulated snow-cover duration (days) for present, 2020 and 2050



A low impact climate change scenario for 2020 leads to a 10% reduction in the area with at least one day of snow cover, while a high impact climate change scenario leads to a 40% reduction in area. By 2050, there may be a 20–85% reduction in area.

Graphic courtesy of CSIRO

Q8: How do scientists measure global surface temperatures?

The Earth's surface temperature is measured in many ways. Thermometers have recorded air temperature at weather stations or surface seawater temperature from ships for many decades, with almost global coverage extending back to 1861. Instruments on satellites have monitored infrared radiation for many years, which is then converted to temperature to provide global records back to 1979. In addition, proxy records—data relating to climate, such as tree rings and ice cores—extend the global surface temperature record back hundreds and even thousands of years.

Urbanisation, with its heat-absorbing structures and materials such as concrete, can change the local climate, for example by raising local temperatures. Researchers take into account such locational changes when looking for long-term trends in regional and global temperatures.

Measurements from satellites and weather balloons record average temperature in the lowest eight kilometres of the atmosphere, including the surface. Satellite-derived estimates of temperatures are subject to errors and biases and care needs to be taken in interpreting these data. For example, adjustments are required to account for changes in satellite orbits and comparisons between measurements from different satellites.

Early analyses showed that satellite data appeared not to support the surface warming data, causing concern that perhaps, the surface data were biased or contaminated. However, corrections to the satellite data, comparison with balloon measurements, and longer satellite records have led to measurements that generally support the evidence of a recent increase in surface temperature of 0.17°C per decade.

Q9: How reliable are climate models?

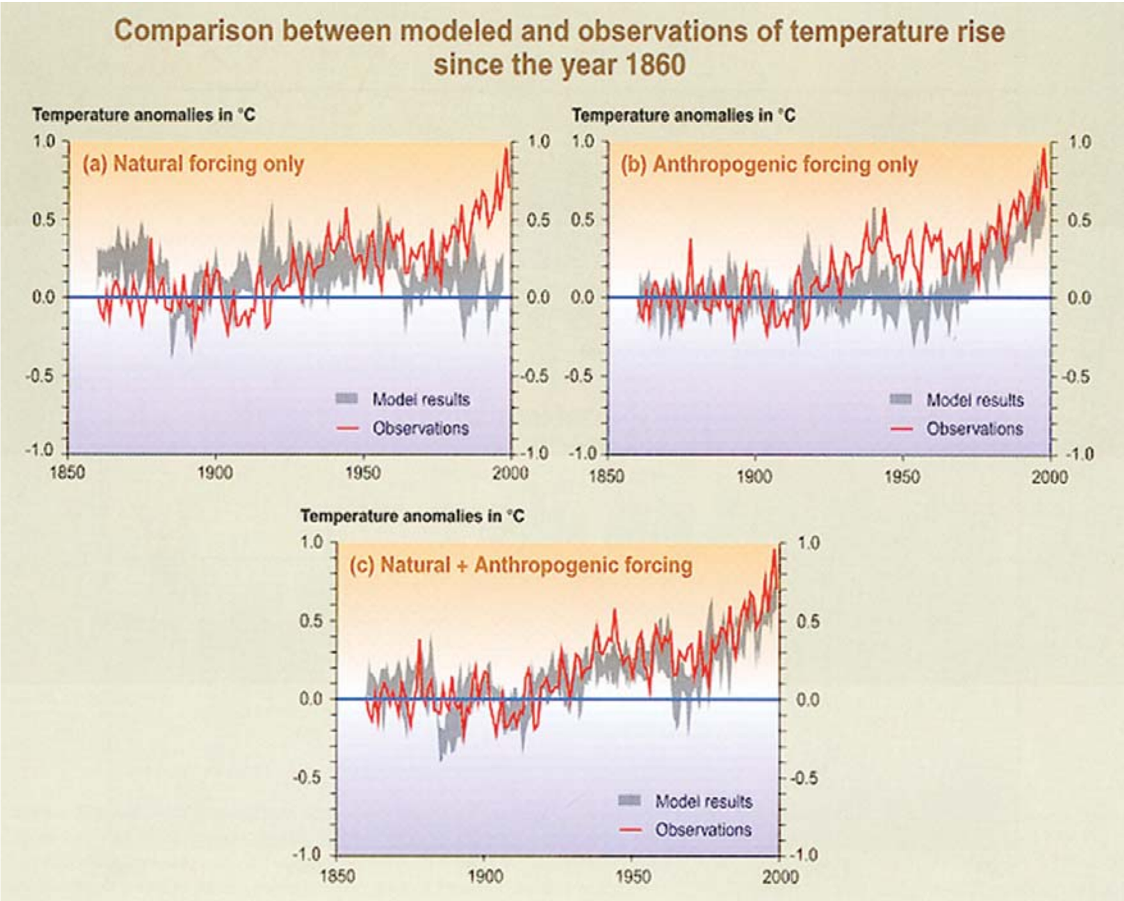
Climate models are the best tools available for making climate change projections. Over the past five years, scientists have improved their understanding of important climate processes and the representation of these processes in climate models. Climate models represent the climate system remarkably well. Confidence in the reliability of these models for climate projections has also improved, based on tests of the ability to simulate the present average climate, including the annual cycle of seasonal changes; year-to-year variability; and extreme events such as storms and heatwaves. Models can also simulate past climate.

Average temperature and atmospheric pressure are well simulated down to sub-continental scales, but rainfall simulations need to be improved. There is good consistency between observed changes in global average surface temperature over the 20th century and model simulations that include natural variability as well as human-induced warming and cooling (see diagrams, below). Other aspects of model simulations have improved, including their ability to reproduce variability due to monsoons, the El Niño—Southern Oscillation (a see-saw of atmospheric pressure and ocean temperature in the Pacific affecting climate in many regions, including

Australia) and the North Atlantic Oscillation (a see-saw in atmospheric pressure and ocean temperatures influencing climate from central North America to Europe and much of Northern Asia).

Australian scientists are working towards developing better capacity in models to represent such things as the effects on climate of clouds and airborne particles (aerosols), ocean circulation, biogeochemical processes such as the exchanges of carbon dioxide and water between the land surfaces and the atmosphere, and the uptake and release of carbon dioxide by oceans. Other important work is on the development of 'downscaling' techniques that will allow better regional simulations of climate and extreme weather.

Climate Model Simulations



Comparison of observed changes in global average surface air temperature over the 20th century with that from an ensemble of climate model simulations. When models simulate both natural and anthropogenic (human-induced) changes, they simulate well the temperature ranges we have observed in the past.

Source: IPCC Synthesis Report (2001) www.grida.no/climate/ipcc_tar/vol4/english/022.htm

Q10: How do scientists project future climate?

Our climate is the result of the interaction of the Sun's radiation with the atmosphere, oceans, polar ice and the land. Many processes contribute to the climate, including the absorption and emission of heat by different materials such as gases and water, the reflection of heat from different surfaces such as snow and trees and the circulation of the oceans and atmosphere.

Climate models are the best tools we have for forecasting weather and climate. A common application is in daily weather forecasting. Models are also used for seasonal climate forecasts, which can assist agribusiness and other industries plan for the months ahead. Another application is projecting the effect of human activities on climate over the coming decades, and explaining the causes of climate change over past decades.

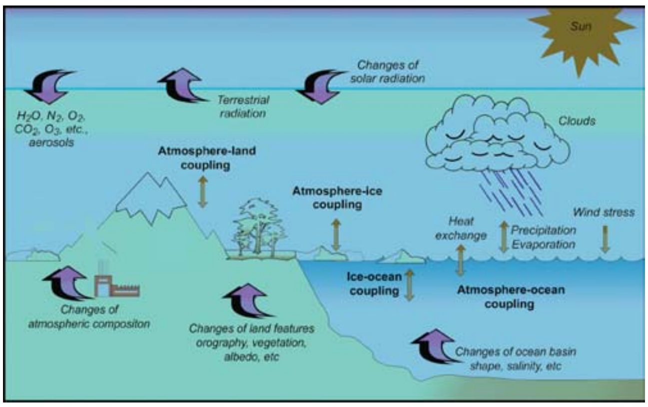
A climate model is a simplified mathematical representation of the Earth's climate system. Models have a three-dimensional grid of points over the globe, extending into the ocean and the atmosphere. Present computer power restricts the spacing of the grid points to about 300–500 km, with 10–20 layers in the atmosphere and 20–30 layers in the ocean.

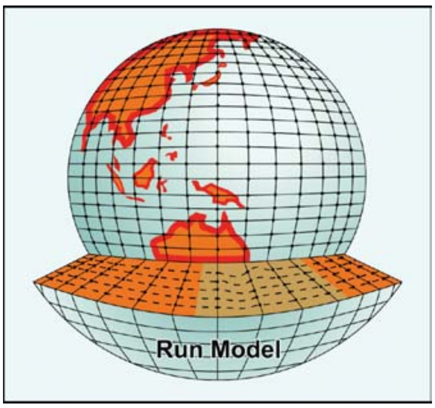
Regional models can provide more detailed information over a small area. The spacing of grid points is often 30–60 km. Since regional models operate at finer resolution than global models, they give a much better representation of the effect of topographic features such as mountain ranges and local variations in climate.

International validation of climate models has shown that they reproduce present climatic features reasonably well, along with past climates such as the last Ice Age and the global warming of the 20th century.

Economists and other experts have developed a number of scenarios for how the world might develop over the next century based on a set of assumptions, such as how fast population might increase and how quickly renewable energy sources might replace fossil fuels. In 2000, a set of 40 greenhouse gas and aerosol emission scenarios for the 21st century were developed for use in climate model simulations. Many research groups around the world used these scenarios to project climate changes. The results were featured in the report of the Intergovernmental Panel on Climate Change, (www.ipcc.ch/).

A wide range of scenarios for global temperature rise is possible, the lowest are the most likely to be exceeded and the highest the least likely to be reached. However, even the most optimistic scenario for stabilising CO_2 in the atmosphere would lead to a warming of 1 to 3°C by the year 2100. This level of warming is considered by some scientists to represent a threat for some regions and some ecosystems. Other systems may benefit from warming. The challenge facing us now is to determine how much we need to reduce our emissions to minimise the risk of dangerous climate change.





Schematic representation of a climate model. Various physical quantities such as temperature and rainfall are typically computed in half-hour time steps over a three-dimensional grid.

Q11: What contributions do volcanic eruptions make to global warming?

Volcanoes emit water vapour and carbon dioxide, but contribute little to global changes in atmospheric greenhouse gas concentrations.

Large volcanic eruptions, however, can blast huge amounts of sulfur dioxide into the upper atmosphere (the stratosphere). There, the sulfur dioxide transforms into tiny particles of sulfate aerosol. These particles reflect energy from the sun back into space, preventing some of the sun's rays from heating the Earth.

Conversion of sulfur dioxide to sulfuric acid aerosol in the stratosphere takes some months, so maximum cooling occurs up to a year after the eruption. It may take as long as seven years before the cooling influence of the volcanic aerosol disappears completely.

When Mt Pinatubo in the Philippines erupted in 1991 it blasted up to 26 million tonnes of sulfur dioxide into the stratosphere. This led to a global surface cooling of 0.5°C one year after the eruption. This cooling offset the warming effects of both El Niño and human-induced greenhouse gases from 1991 to 1993.

As well as cooling the lower atmosphere (troposphere), volcanic aerosol can absorb both thermal radiation from the ground and solar radiation, leading to a warming of the stratosphere.

Q12: What is thermohaline circulation?

The world's oceans transport massive amounts of heat. Differences in seawater density, which depend on differences in temperature (thermo) and salinity (haline), drive global ocean currents known as the thermohaline circulation. Part of the thermohaline circulation is the Gulf Stream, which warms Western Europe.

The Atlantic thermohaline circulation acts like an oceanic conveyer belt, carrying heat from the tropics to the North Atlantic. As warm water moves into the northern Atlantic, it cools, sinks to the ocean floor, and then returns southward.

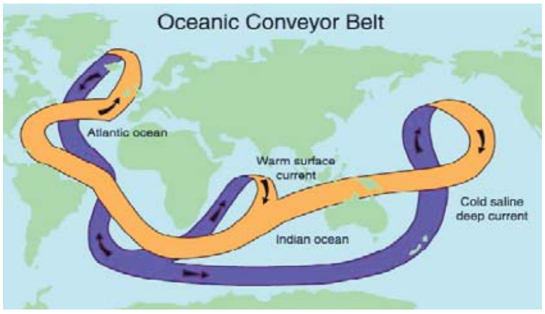
The Southern Ocean is also a significant contributor to the thermohaline circulation, linking the shallow and deep 'limbs' of the ocean conveyor belt, and playing a key role in the heat engine that influences global climate patterns.

There are concerns that global warming may slow or even halt the thermohaline circulation. This could occur through changing salinity of the oceans due to greater rainfall and influxes of fresh water from melting ice. Surface ocean waters are becoming less salty in some places, and a key current in the North Atlantic appears to have slowed.

The thermohaline circulation has changed abruptly in the distant past; disruption of the thermohaline circulation could lead to rapid changes in the Earth's climate.

A shut down in thermohaline circulation within decades is most unlikely. However, according to the Intergovernmental Panel on Climate Change, beyond the year 2100, some climate models suggest that the thermohaline circulation could completely, and possibly irreversibly, shut down in either hemisphere if the warming caused by rising concentrations of greenhouse gases is large enough.

Schematic diagram of the global ocean circulation pathways



Schematic diagram of the global ocean circulation pathways, the 'conveyor' belt (after W. Broecker)

Q13: Will sea levels rise if the world heats up?

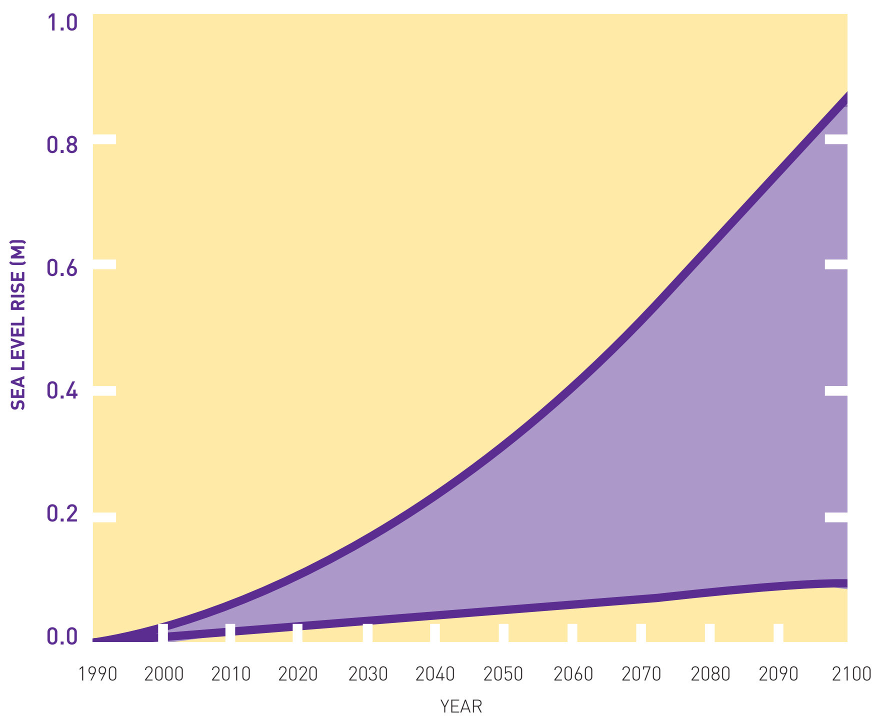
Global average sea level rose between 10 and 20cm during the 20th century. It is very likely that increasing temperatures in the 20th century contributed to this sea level rise through thermal expansion of sea water and widespread loss of land ice (retreating glaciers).

Under global warming scenarios, sea levels are projected to rise between 9 and 88 cm between 1990 and 2100. This may have consequences for low-lying islands and coastal settlements throughout the world.

As the Earth's surface warms, the oceans slowly absorb heat and expand, causing the sea level to rise. This thermal expansion of the ocean will be a major contributor to sea level rise during future centuries.

Melting of non-polar glaciers is also expected to contribute to rising sea levels. Melting ice from Greenland is expected to make a small contribution to rising sea levels, offset in part by increased snow on the Antarctic ice sheet. Very little melting is expected to occur over the Antarctic mainland during the next century because of the very long response time to atmospheric warming and the low temperatures there.

Future Scenarios for Global Warming



Based on a range of possible future scenarios for global warming, scientists predict that sea levels will rise between 9 and 88 cm by the year 2100 as oceans expand and glaciers melt.

This graph has been adapted and simplified from the Intergovernmental Panel on Climate Change Third Assessment Report 2001. The original graphs can be accessed at: www.ipcc.ch/

Q14: What role does El Niño play in climate change?

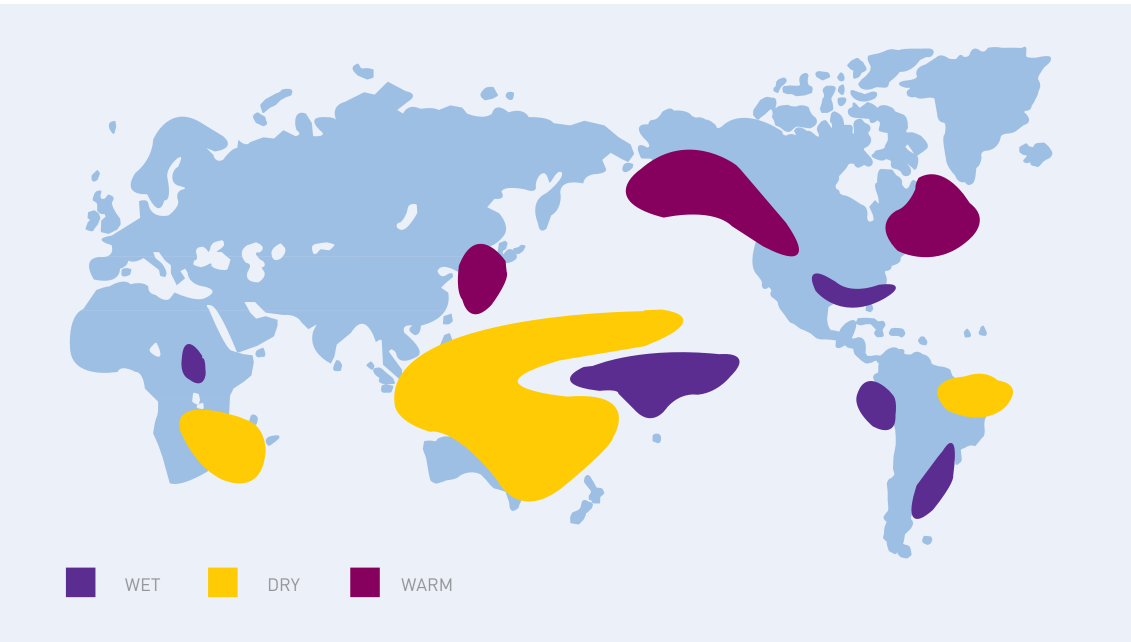
The oceans store a lot of the Sun's energy and transport this heat around the planet through massive currents. A slight temperature change in ocean surface waters can have a large impact on the atmosphere and rainfall patterns over large areas. The El Niño—Southern Oscillation (ENSO), centred in the central eastern tropical Pacific Ocean can cause impacts across large areas of the globe, particularly eastern Australia. The El Niño phase of ENSO can cause severe drought over Australia and other parts of the world, as well as increased rain in Peru and the central Pacific (see figure below). The opposite phase, La Niña, can lead to floods and more tropical cyclones in parts of Australia. Typically, El Niño and La Niña events occur every two to seven years.

Since 1975, Australia has experienced more frequent El Niño events than during previous years of the 20th century. As a consequence of the warming trend in Australia, droughts have become hotter, with the 2003 drought (which coincided with an El Niño event) being the hottest in the past 100 years. The combination of high temperatures and drought resulted in significant economic loss, job losses, major fires, low dam levels and water restrictions.

The relationship between long-term climate change and the short-term climate variability seen in ENSO is complex and unclear. It is a topic of ongoing research.

The El Niño effect

Areas most consistently affected by El Niño



The Southern Oscillation Index (SOI) is a measure of the strength of ENSO. Visit the Bureau of Meteorology's website for the latest SOI data (www.bom.gov.au) . CSIRO has a graph showing SOI monthly values from January 1866 through to the present (www.dar.csiro.au).

Source: Bureau of Meteorology

Q15: Do the satellite data contradict other evidence of global warming?

Although there is solid evidence for global warming, much attention has focussed on the period since 1979 when satellite records became available. These records provide a global measure of temperature in the lower atmosphere. When this was compared with surface temperature measurements, the lower atmosphere appeared to have warmed less than the Earth's surface.

A number of factors need to be taken into account when interpreting satellite measurements. Firstly, the lower atmosphere and the surface are affected differently by factors such as stratospheric ozone depletion, atmospheric aerosols and El Niño. Secondly, the period during which satellites have monitored temperatures is short. Thirdly, like surface-based temperature measurements, satellite measurements have errors associated with them.

The satellite temperature record is made up of measurements from different satellites. There are calibration errors associated with the satellite temperature record and biases due to the satellites slowly falling from their orbits.

When corrections are made, the satellite-measured warming of the lower atmosphere is 0.18°C per decade, which is almost exactly the same as the measured surface warming (0.17°C per decade).

Q16: Does stratospheric ozone depletion have anything to do with climate change?

Global warming and ozone depletion (the 'ozone hole') in the upper atmosphere (stratosphere) are two different problems, but chlorofluorocarbon (CFC) emissions play a role in both. Chemical reactions involving CFCs destroy ozone in the stratosphere. As a result, more of the Sun's ultraviolet radiation reaches the Earth, increasing our risk of skin cancer. The Montreal Protocol, an international agreement to protect the ozone layer, has led to concentrations of atmospheric CFCs and related substances beginning to decrease. Stratospheric ozone is likely to return to 1980 levels by about 2050.

CFCs also act as powerful greenhouse gases in the lower atmosphere by trapping heat energy which would otherwise escape to space. Some CFCs can remain in the atmosphere for many centuries before being broken down, so their contribution to global warming is likely to persist for a long time.

Researchers have suggested that ozone depletion has contributed to the southward shift in Southern Hemisphere weather systems in recent decades, which has reduced rainfall in southern Australia. This possible link is currently being investigated.

Q17: Shouldn't we wait until climate change science is more certain before taking action to reduce greenhouse gas emissions?

Most climate scientists now say that the pivotal question regarding climate change is not whether the climate is changing and will continue to change in response to human activities, but rather how much, how fast and where. While analyses of observations and climate model simulations are providing many of the answers, uncertainties remain. The Rio Declaration (1992) says that "lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation"—this is an interpretation of the Precautionary Principle.

Scientists are certain that climate change is already happening. Global average surface temperature increased over the past 100 years by about 0.6°C. There has also been an increase in heatwaves, a reduction in frosts, warming of the lower atmosphere and deep oceans, retreat of glaciers and sea ice, a rise in sea level of 10–20 cm and increased heavy rainfall in many regions. There is growing evidence of the impacts of global warming on the growth and distribution of plants and animals, as well as changes in events such as floods and droughts in some regions.

Scientists are also confident that most of the global warming of the past 50 years is due to human activities that have increased greenhouse gases. Once carbon dioxide—the main greenhouse gas increasing through human activity—is released into the atmosphere, it stays there for between 50 and 200 years. Hence further warming is already in the pipeline, regardless of what we do in future. This is also because the deep ocean and the polar ice caps have massive thermal inertia, or heat-storing capacity, so they warm and cool more slowly than the atmosphere.

It is likely that the warming will exceed 1°C over the next century. To quantify future warming, scientists have developed scenarios. These represent possible futures based on various assumptions about human behaviour, economic growth and technological change. Some scenarios assume 'business as usual' without actions specifically aimed at reducing net greenhouse gas emissions. These scenarios lead to a projected global-average warming of 1.4 to 5.8°C from 1990 to 2100. Other scenarios include actions to slow global warming by stabilising carbon dioxide concentrations. These scenarios require substantial global greenhouse emissions reductions over the 21st century. For example, to limit global warming to under 2.5ºC by the year 2100, carbon dioxide concentrations would need to be stabilised at 550 parts per million or less. This would require about a 50 per cent reduction of carbon dioxide emissions across the globe by 2100 and further reductions after that.

If the world waits until all the scientific uncertainties regarding climate change are resolved, action to reduce greenhouse emissions may be too late to achieve desired targets for carbon dioxide stabilisation.

The level of action required to address the problem depends on the degree of climate change we are prepared to accept. Article 2 of the United Nations Framework Convention on Climate Change requires stabilisation of greenhouse gases at a level that prevents "dangerous human interference with the climate system". At this stage, dangerous is not well defined and will involve a mixture of scientific, economic, political, ethical and cultural considerations. However, it is clear that greater emission reductions will slow climate change more effectively, leading to a lower probability of dangerous impacts. Some studies have indicated that dangerous impacts may occur if the world warms by 2–3°C. Avoiding this level of warming by the year 2100 would require significant global emission reductions within the next 20–40 years.

Q18: Haven't increases in methane, an important greenhouse gas, levelled out?

Concentrations of the greenhouse gas methane have levelled out in recent years.

From 1999 to 2003 there was essentially no growth in the mean annual atmospheric methane concentration, compared to a 15 per cent rise over the preceding 20 years. Overall, there has been a 150 per cent rise since pre-industrial times.

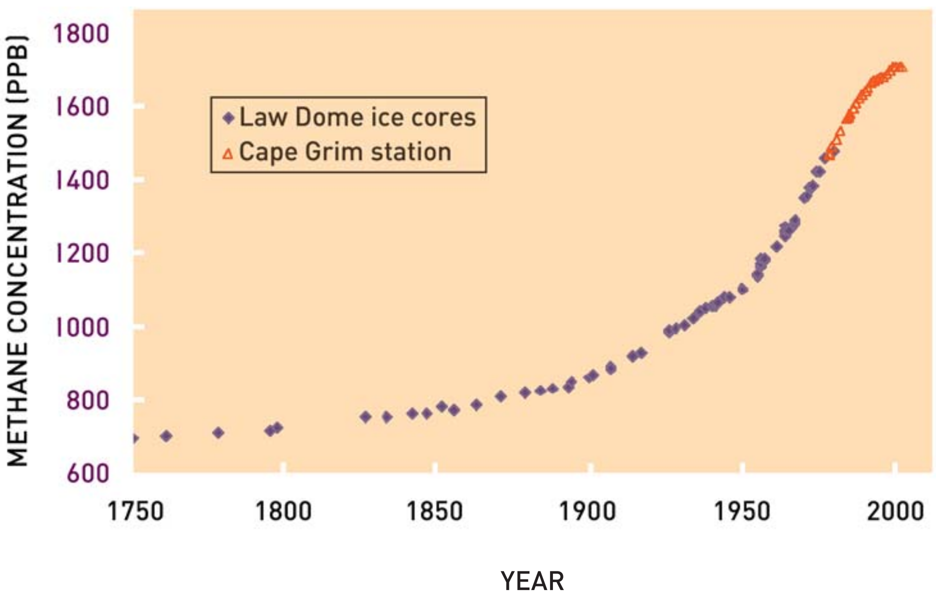
Methane is currently responsible for almost a fifth of the enhanced greenhouse effect, second in importance only to carbon dioxide. Methane has a warming potential more than 20 times greater than carbon dioxide on a volume basis. It is released to the atmosphere from agriculture—rice, cattle and sheep—from landfills, from biomass burning, from the mining and use of fossil fuels—coal, oil and gas—as well as from natural wetlands. Methane has an atmospheric lifetime of about ten years.

Scientists are not certain why methane concentrations have stabilised. A possible cause is reduced emissions from the production and distribution of natural gas, as well as the increasing recovery of landfill methane.

If a global decline in methane emissions continued, global atmospheric methane concentrations would begin to fall. However, until it is known whether the recent stabilisation is a temporary interruption to growth or a sustained change in the methane budget, it is not possible to predict further concentrations with confidence. Furthermore, methane may be released in the future as tundra thaws in the northern hemisphere and perhaps as methane hydrates in ocean sediments destabilise due to oceanic warming.

Greenhouse gas emission scenarios for the 21st century indicate that changes in carbon dioxide will play the dominant role in future global warming. At present, carbon dioxide accounts for 60 per cent of the total greenhouse gas forcing (that is, the extra heat absorbed in the atmosphere as a result of atmospheric composition changes relative to pre-industrial times).

Methane concentrations since pre-industrial time from ice cores from Law Dome, Antarctica, and flasks from Cape Grim, Tasmania



Methane concentrations since pre-industrial time from ice cores from Law Dome, Antarctica, and flasks from Cape Grim, Tasmania.

Source: CSIRO, Australian Antarctic Division, Bureau of Meteorology.

Q19: What contribution do changes in the Sun's energy make to climate change?

The Sun's energy drives the Earth's climate. The amount of energy received by the Earth varies due to changes in the Sun's activity and changes in the Earth's orbit around the Sun.

Annual mean total solar energy varies between the minimum and maximum of the 11-year sunspot cycle by about 0.1 per cent.

During the 20th century, the climatic influence of natural factors probably increased (a warming effect) up to about 1950 due to a period of low volcanism and a small rise in solar radiation. The warming influence of solar variations early in the 20th century was about half of that due to increasing greenhouse gases. Since the 1970s, global temperatures have risen significantly. Solar changes account for just a fraction of this recent warming. Rising concentrations of greenhouse gases are responsible for the bulk of the warming experienced in recent decades.

Q20: What are the potential impacts of climate change?

The effects of climate change are already being felt by natural systems in many places. Glaciers in both the northern and southern hemisphere are shrinking, permafrost is thawing, growing seasons are lengthening and animals are shifting their ranges to higher and cooler ground.

While increases in intense rainfall events and heatwaves have happened in some regions , there is no clear global trend in tropical cyclone activity or smaller-scale severe weather events such as tornadoes, hail or dust storms. Climate models indicate that further increases in greenhouse gases will lead to continued global warming, more heatwaves, fewer frosts, less snow and a rise in sea level. Rainfall over most parts of the world may increase, but some places in the mid-latitudes, including parts of Australia, may become drier. Threatened natural systems, such as alpine fauna and coral reefs, are likely to suffer most as a result of climate change.

In many countries, insurance companies are already reassessing their exposure to extreme weather events as the costs of natural disasters rise. The world's poor and disadvantaged people, and developing countries are likely to be affected much more than developed countries, which have the capacity to adapt to climatic changes. Projections for the 21st century suggest:

- More heat waves could result in heat stress and heat-related deaths in humans and livestock, and damage to crops. The risk of bushfires is likely to increase in some areas.
- Fewer cold and frosty days would reduce cold stress and cold-related deaths in humans and livestock, and reduce frost damage, but may extend the range of pests and diseases. Yields of stone fruit such as apricots and nectarines in some locations may be reduced due to inadequate chilling.
- More intense and sporadic rainfall (including from tropical cyclones) would increase flooding and associated loss of life, property and productivity. It would also affect soil erosion and pollution of rivers and oceans.
- More frequent or intense droughts would increase loss of crops, livestock, fisheries and wildlife, and decrease river flows and water quality.

- Changes in rainfall patterns and reduced soil moisture in parts of Australia could reduce water supplies for agriculture, domestic and industrial uses, energy generation and biodiversity.
- The net effect of climate change on plant growth is dependent on interactions between carbon dioxide, temperature, nutrients and rainfall. High carbon dioxide concentrations increase plant productivity but higher temperatures and reduced rainfall, likely to occur in mid-latitudes, may decrease plant growth.
- Like agricultural systems, Australia's forests may benefit from a carbon dioxide-enriched atmosphere, but the gains may be offset or even nullified by the impact of rising temperatures.
- In tropical rainforests, even a modest degree of warming is likely to significantly harm high altitude rainforest flora and fauna. In woodland ecosystems in south-western Australia, modest warming may harm most frog and mammal species.
- Projected global warming will contribute additional stress to coral reefs around the world due to ocean warming (causing coral bleaching), stronger tropical cyclones, sea-level rise and higher levels of carbon dioxide which may reduce coral growth rates.
- All natural systems are vulnerable to invasion by exotic species. Disturbance by climate change is likely to increase vulnerability by increasing the stress on established vegetation. Warmer conditions will increase the likelihood of pests and diseases from tropical and sub-tropical Australia spreading southward. Some weeds may benefit from climate change and from reduced competition as unfavourable conditions weaken native species and perhaps crops.
- Less snow and a shorter snow season appear likely, threatening alpine ecosystems. Greater investment in snow-making will be needed by the ski industry.

Further details are available from *Climate change: an Australian guide to the science and potential impacts* (www.greenhouse.gov.au/science/guide)

Q21: How can we live with climate change?

Scientists believe that further climate change is inevitable. Without actions to reduce greenhouse gas emissions, the Earth's surface temperature is likely to rise by 1.4 to 5.8°C by the year 2100 with more heatwaves, fewer frosts, less snow, more storms, stronger tropical cyclones and a 9 to 88 cm rise in sea level. Therefore, strategies enabling adaptation to changes in climate will play an important part in reducing the damages and increasing the opportunities associated with the impacts.

Damages can also be reduced by slowing global warming and sea level rise. This can be achieved by stabilising greenhouse gas concentrations. For example, to limit global warming to under 2.5°C by the year 2100, carbon dioxide concentrations would need to be stabilised at 550 parts per million or less. This would require about a 50 per cent reduction of carbon dioxide emissions across the globe by 2100 and further reductions after that. The reduction in emissions does not translate to an immediate reduction in concentrations because carbon dioxide has an atmospheric lifetime of 50–200 years. Once concentrations eventually stabilise, global temperature and sea levels will continue to rise for centuries because of the heat-holding capacity of the ocean.

Coping with climate change and a warmer world will mean changing the way we live. For example, urban planning in coastal areas will need to consider beach erosion and flooding caused by rising sea levels. In some regions, buildings will need to be designed to cope with more intense tropical cyclones and storm surges. Areas prone to flooding may need to increase their drainage capacity, while drier areas will need to use water more efficiently.

Some farmers may need to adjust their cropping calendar, fertiliser application or varieties of crops to cope with climatic changes. Climate change may affect market prices for some commodities.

Putting in place strategies to adapt to climate change has the potential to reduce the adverse impacts as well as to capture possible benefits. Adapting to climate change will, however, incur costs and will not prevent all damage. The ability of different countries to cope with climate change will vary widely.

Many natural systems will have difficulty coping with climate change, particularly those systems that are already vulnerable. Some Australian species could become endangered or extinct. For example, coral reefs may experience more frequent bleaching as ocean temperatures rise, and the mountain pygmy possum could become extinct.

Q22: What is the Intergovernmental Panel on Climate Change?

Recognising the problem of global climate change, in 1988 the World Meteorological Organization (WMO) and the United Nations Environment Programme (UNEP) established the Intergovernmental Panel on Climate Change (IPCC). The role of the IPCC is to assess the scientific, technical and socio-economic information relevant to understanding the threat of human-induced climate change. The IPCC does not carry out new research nor does it make climate-related measurements. It bases its assessments mainly on published and peer-reviewed scientific literature. The IPCC has produced three comprehensive assessment reports on the status of global climate change, the latest of which was released in 2001. Hundreds of the world's leading climate scientists, including many Australian experts, contributed to the production of these reports, which provide the authoritative, consensus account of global climate change. The Fourth Assessment Report will be completed in 2007.

Q23: What is Australia doing about climate change?

The Australian Government has invested over $1.8 billion to address climate change issues covering reduction of our greenhouse gas emissions, climate change science and adaptation to climate change. Measures to reduce Australia's greenhouse gas emissions encourage low emissions technology, energy efficiency, renewable energy, and support local government, communities and individual households to identify practical ways to reduce their emissions.

The Government supports a range of programmes that cover climate change science and climate impacts and adaptation. The major climate change research effort is undertaken through the Australian Climate Change Science Programme. This programme is a collaboration between Australian Greenhouse agencies; the Australian Greenhouse Office and the Bureau of Meteorology Research Centre, which are part of the Department of the Environment and Heritage, and the CSIRO which is part of the Department of Education, Science and Training. The research programme covers many aspects of the climate system and climate change including:

- Understanding the role of oceans in global and regional climate, the potential impacts of warming on the Southern Ocean thermo-haline circulation and the capacity of the ocean to absorb carbon dioxide;
- Detection and attribution—determining the causes of recent climate shifts in Australia;
- Understanding the impacts of airborne particles and clouds on climate;
- Developing and improving global and regional climate models to provide more certainty in climate projections for Australia;
- Contributing our science to international climate change science forums, especially in the preparation of Intergovernmental Panel on Climate Change assessment reports; and
- Investigating the impacts of climate change and its potential impacts on the frequency and intensity of extreme climate events.

Climate change research is also carried out by many organisations, including Co-operative Research Centres and universities.

The Australian Government's National Climate Change Adaptation Programme is designed to help prepare Australian governments and vulnerable industries and communities for the unavoidable consequences of climate change. The Programme is focused on priority regions and sectors, identified on the basis of vulnerability to climate change impacts, national importance and potential to benefit from early adaptation. It has three streams of activity:

1. Advising government on policy issues related to climate change impacts and adaptation, including key risks to and opportunities for Australia.
2. Increasing Australia's capacity to adapt to climate change by developing tools, raising awareness, education, and encouraging the incorporation of climate change adaptation into relevant policies and programmes.
3. Building research partnerships with stakeholders to assess likely climate change impacts and adaptation options in priority regions and sectors.

At the global level climate change science is assessed approximately every five years by the Intergovernmental Panel on Climate Change (IPCC)—an international body that reviews climate change science. The IPCC's third assessment report was released in 2001 and was written by more than 1000 scientists from around the world, and reviewed by thousands of experts. The IPCC's fourth assessment report will be available in 2007 and will give greater emphasis to regional impacts of climate change and appropriate mitigation and adaptation strategies.

The challenge of climate change is increasing the focus on sustainability as a way of life. Climate change is a global problem that requires a global solution. An effective response to climate change requires action by everyone. Australia became a party to the United Nations Framework Convention on Climate Change (UNFCCC) in 1992.

The aim of this Convention is to stabilise greenhouse gas concentrations in the atmosphere at a level that will prevent dangerous human-induced changes to our climate system.

Australia is participating actively in the development of a comprehensive long-term global response, both through the UNFCCC and by working directly with key regional partners. Australia, the United States, China, India, Japan and South Korea have agreed to form the Asia-Pacific Partnership on Clean Development and Climate.

The Asia-Pacific Partnership will engage countries in our region in a practical partnership to develop, deploy and transfer the cleaner, more efficient technologies that the world will need to make the required deep cuts in global greenhouse gas emissions. Particular areas of focus include low emission electricity generation, renewable energy and energy efficiency, hydrogen, advanced transportation, carbon sequestration and methane capture and use.

For details of other Australian activities and actions refer to the Australian Greenhouse Office website at www.greenhouse.gov.au/science

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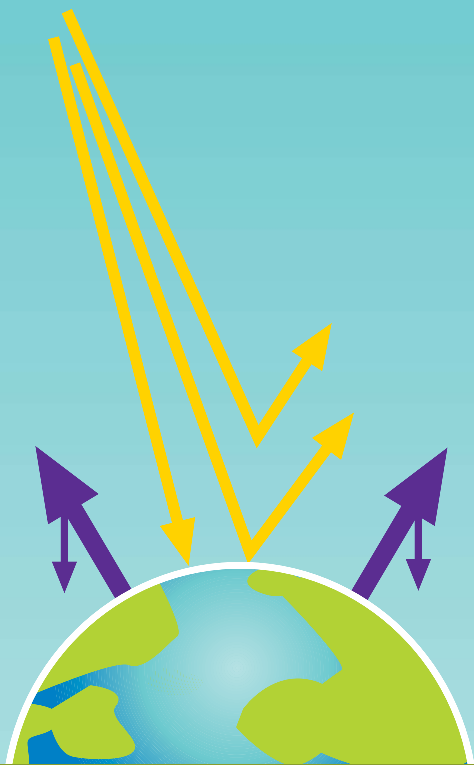

Further information

Australian Greenhouse Office
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Bureau of Meteorology Australia
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