

State of the Climate 2012



Australian Government
Bureau of Meteorology

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This *State of the Climate* is the second produced by CSIRO and the Australian Bureau of Meteorology. It provides a summary of observations of Australia's climate and analysis of the factors that influence it.

The previous *State of the Climate*, released in March 2010 (www.csiro.au/Outcomes/Climate/Understanding/State-of-the-Climate.aspx) highlighted a multi-decadal warming trend over Australia's land and oceans, an increase in record hot days and decrease in record cold days across the country, a decrease in rainfall in southwest and southeast Australia, an increase in global sea level, and increases in global greenhouse gas concentrations.

State of the Climate 2012 provides an updated summary of long-term climate trends. It notes that the long-term warming trend has not changed, with each decade having been warmer than the previous decade since the 1950s. The warming trends observed around Australia are consistent with global-scale warming that has been measured during recent decades, despite 2010 and 2011 being the coolest years recorded in Australia since 2001. Global-average surface temperatures were the warmest on record in 2010 (slightly higher than 2005 and 1998). 2011 was the world's 11th warmest year and the warmest year on record during a La Niña event. The world's 13 warmest years on record have all occurred in the past 15 years.

There has been a general trend towards increased spring and summer monsoonal rainfall across Australia's north during recent decades, and decreased late autumn and winter rainfall across southern Australia. The summary shows that the very strong La Niña event in 2010 followed by another in 2011 brought the highest two-year Australian-average rainfall total on record.

State of the Climate 2012 also highlights the increase in global sea level and notes sea-level rise around Australia since 1993 is greater than, or equal to, the global average. Our observations show that sea-surface temperatures around Australia have increased faster than the global average. The concentrations of long-lived greenhouse gases in the atmosphere reached a new high in 2011. Annual growth in global fossil-fuel CO₂ emissions between 2009 and 2010 was 5.9 per cent, reversing a small decline of 1.2 per cent recorded between 2008 and 2009 during the global financial crisis.



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The Bureau has been observing, reporting and researching Australia's weather since 1908. CSIRO has been undertaking atmospheric and marine research for more than 60 years. Together our scientists continue to build the body of knowledge that allows people to understand the changes in our climate that we are observing and prepare for any future changes.

1 Temperature

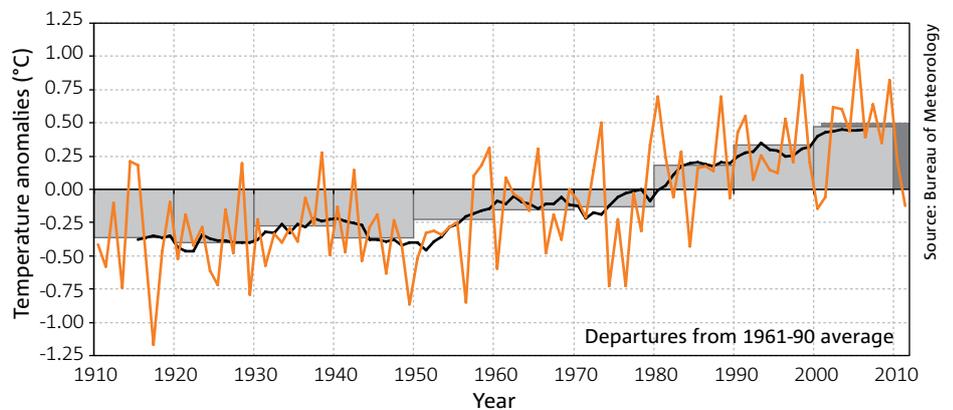
Key points:

- ▶ Each decade has been warmer than the previous decade since the 1950s.
- ▶ Australian annual-average daily maximum temperatures have increased by 0.75 °C since 1910.
- ▶ Australian annual-average daily mean temperatures have increased by 0.9 °C since 1910.
- ▶ Australian annual-average overnight minimum temperatures have warmed by more than 1.1 °C since 1910.
- ▶ 2010 and 2011 were Australia's coolest years recorded since 2001 due to two consecutive La Niña events.

Australian average temperatures over land

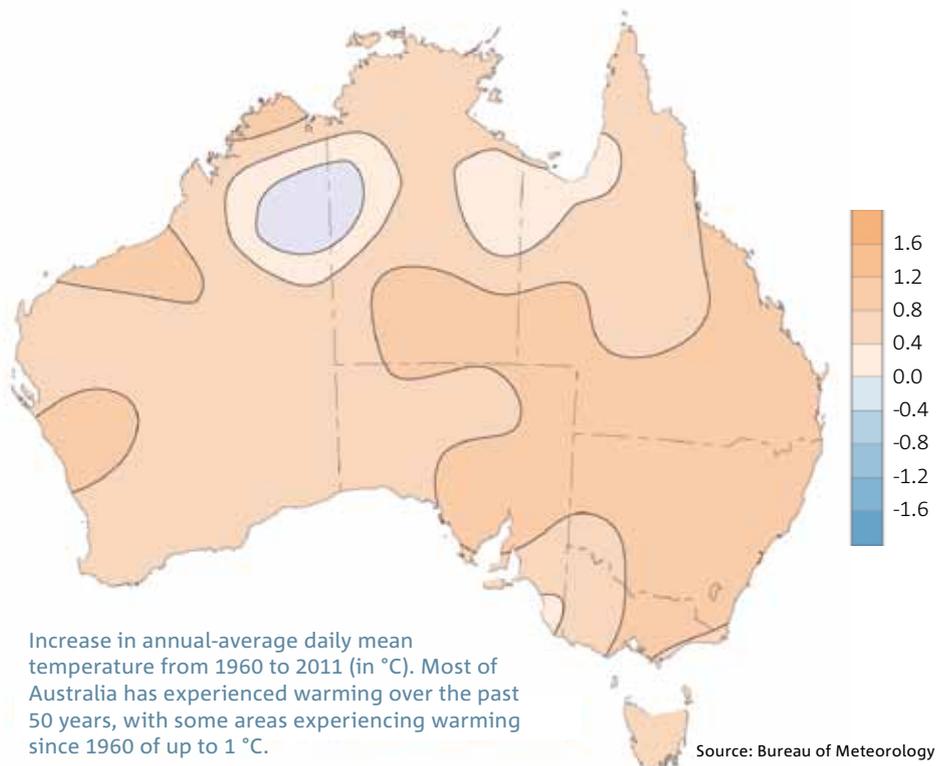
Australian annual-average daily mean temperatures showed little change from 1910 to 1950 but have progressively warmed since, increasing by 0.9 °C from 1910 to 2011. The average temperature during the past ten years has been more than 0.5 °C warmer than the World Meteorological Organization's standard 1961-1990 long-term average. This increase continues the trend since the 1950s of each decade being warmer than the previous.

The warming trend has occurred against a backdrop of natural, year-to-year climate variability. Most notably, El Niño and La Niña events during the past century have continued to produce the hot droughts and cooler wet periods for which Australia is well known. 2010 and 2011, for example, were the coolest years recorded since 2001 due to two consecutive La Niña events.



Source: Bureau of Meteorology

Changes in average temperature for Australia for each year (orange line) and each decade (grey boxes), and 11-year average (black line – an 11-year period is the standard used by the Intergovernmental Panel on Climate Change). Anomalies are the departure from the 1961-1990 average climatological period. The average value for the most recent 10-year period (2002–2011) is shown in darker grey.



Increase in annual-average daily mean temperature from 1960 to 2011 (in °C). Most of Australia has experienced warming over the past 50 years, with some areas experiencing warming since 1960 of up to 1 °C.

Source: Bureau of Meteorology

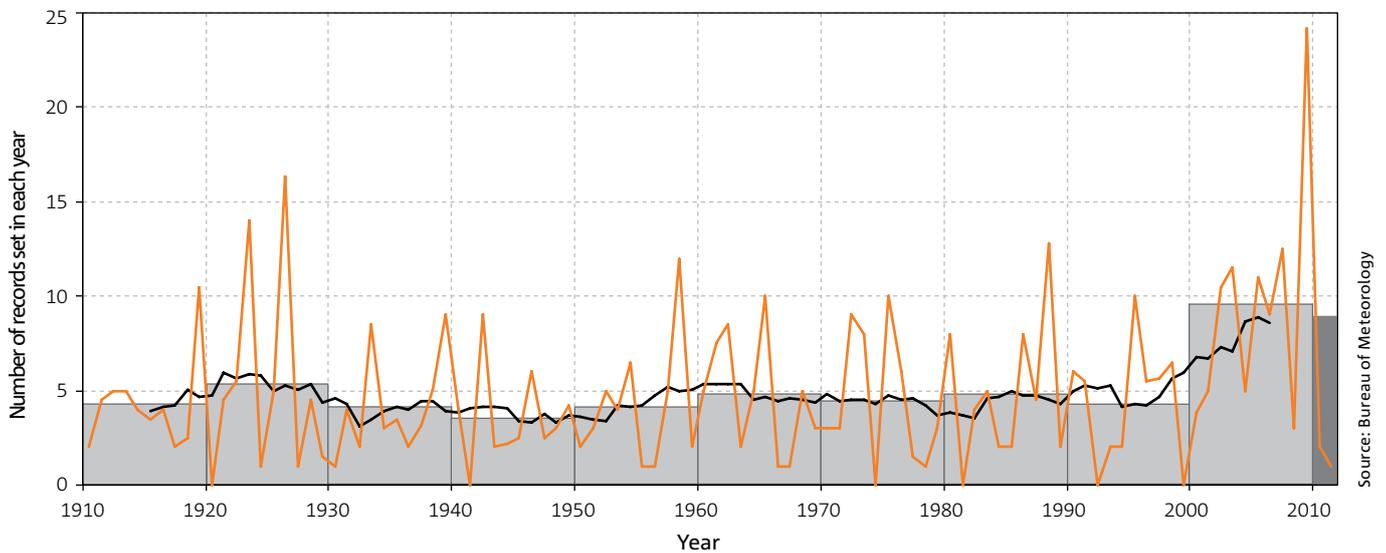
Australian annual-average daily maximum temperatures have increased by 0.75 °C since 1910, with most of the warming trend occurring since 1970. There has been an increase in the frequency of warm weather and decrease in the frequency of cold weather.

Consecutive La Niña events in the past two years, however, have kept average maximum temperatures below the long-term average – by 0.24 °C in 2010 and 2011. Very few extreme hot maxima were recorded during these two years,

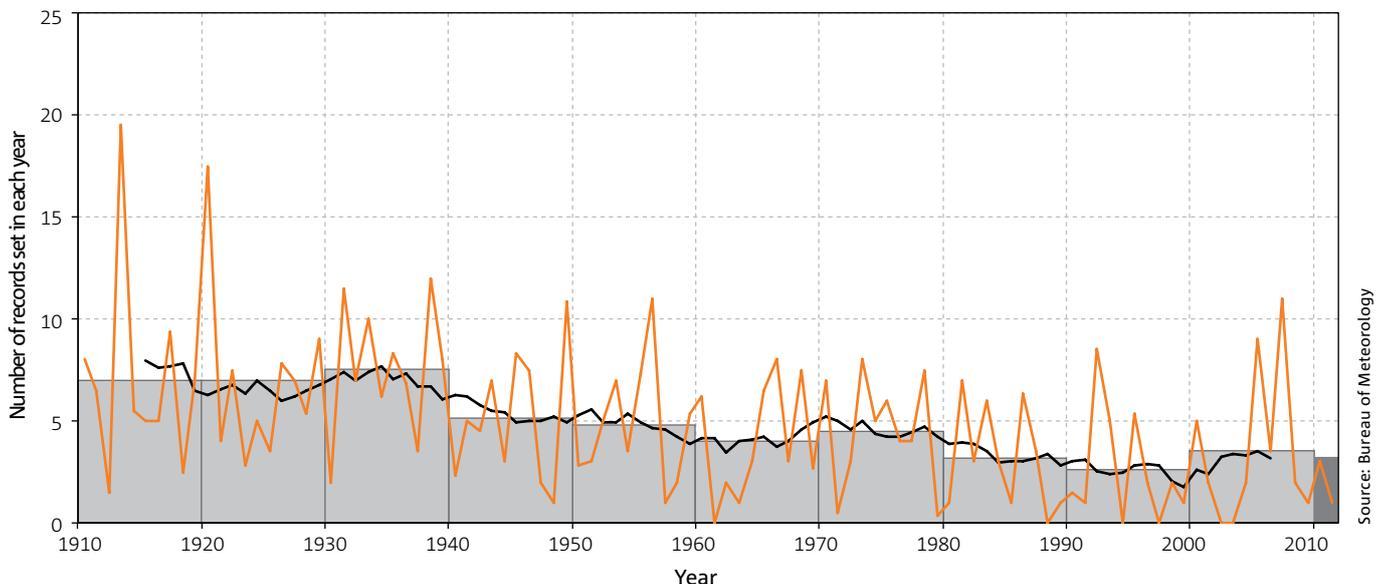
with the exception of three heat waves in 2011 in southeast Western Australia and central South Australia in January and February, southeast Australia in August, and in northwest Western Australia in December.

Australian annual-average overnight minimum temperatures have warmed more rapidly than daytime maximum temperatures. Minimum temperatures have warmed by more than 1.1 °C since 1910 – with more than 0.8 °C of that warming occurring since 1960.

The number of climate reference stations recording warm (top ten per cent) night-time temperatures and the frequency with which this occurs have increased since the mid 1970s. The rate of very hot (greater than 40 °C) daytime temperatures has been increasing since the 1990s. The frequency of extreme (record) hot days has been more than double the frequency of extreme cold days during the past ten years.



Number of hottest-day-of-the-month (highest maximum) records at 43 Australian climate reference stations with daily data from 1910; for each year (orange line) and each decade (grey boxes), and the 11-year average (black line). The average for the most recent 10-year period (2002-2011) is shown in darker grey.



Number of coldest-day-of-the-month (lowest maximum) records at 43 Australian climate reference stations with daily data from 1910; for each year (orange line) and each decade (grey boxes), and the 11-year average (black line). The average for the most recent 10-year period (2002-2011) is shown in darker grey.

Key points:

- ▶ Southwest Western Australia has experienced long-term reductions in rainfall during the winter half of the year.
- ▶ There has been a trend over recent decades towards increased spring and summer monsoonal rainfall across Australia's north; higher than normal rainfall across the centre, and decreased late autumn and winter rainfall across the south.

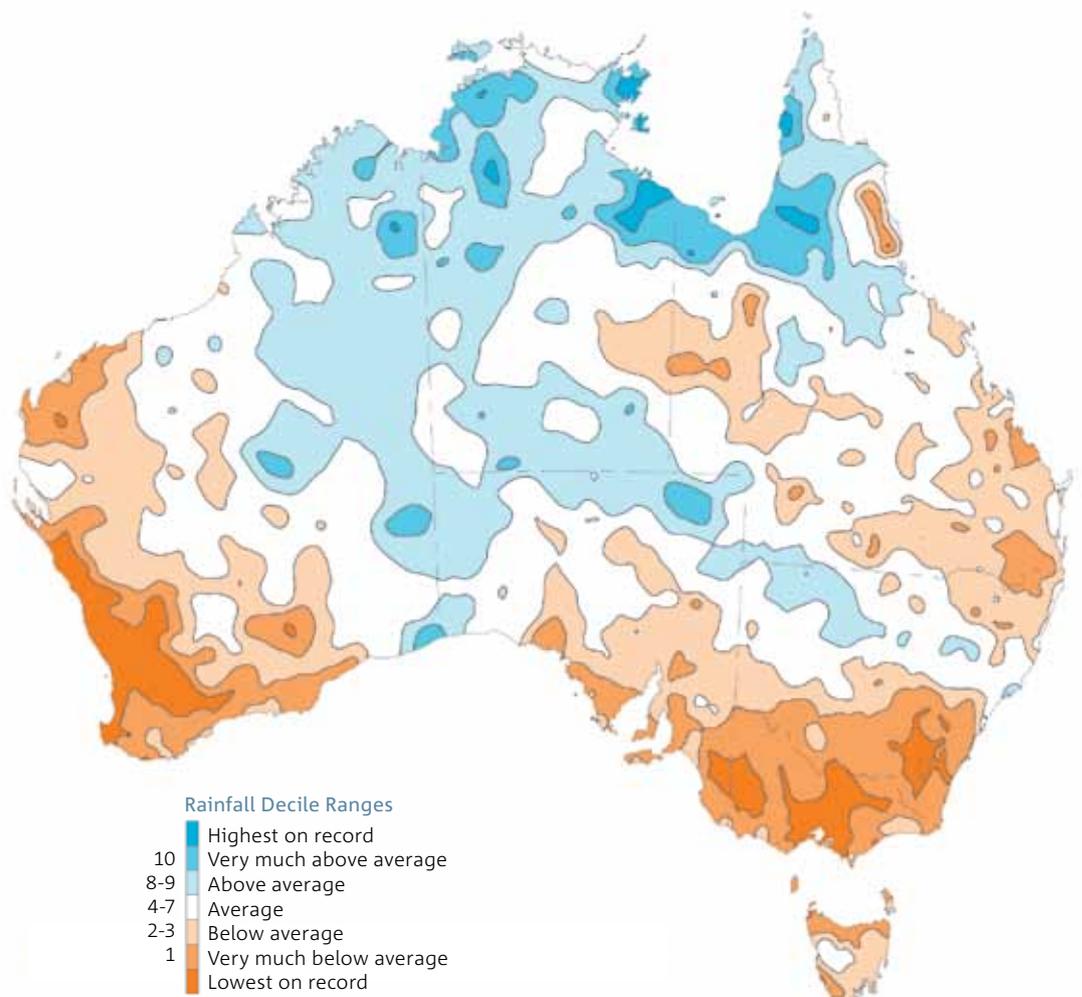
Rainfall

Australia's rainfall is highly variable. During recent decades, there has been a general trend towards increased spring and summer monsoonal rainfall across Australia's north, higher than normal rainfall across central parts of the continent, and decreased late autumn and winter rainfall across the south.

A very strong La Niña event in 2010, followed by another La Niña event in 2011, brought the highest two-year Australian-average rainfall total on record. Many rainfall records were broken during this period.

Southwest Western Australia experienced its lowest rainfall on record in 2010 and only average rainfall during 2011, in contrast to the rest of the continent.

The record rainfall of 2010 and 2011 fell in spring and summer in the southeast of the continent. Rainfall was below average for the period April to July 2011, continuing the longer-term drying trend observed over the winter half of the year for this region. Recent drying trends across southern Australia in autumn and winter have been linked to circulation changes. The causes of these changes are an area of active research.



Source: Bureau of Meteorology

April to September (autumn and winter) rainfall deciles from 1997 to 2011 for Australia (a decile rainfall map shows whether the rainfall is above average, average or below average for the most recent 15-year period, in comparison with the entire rainfall record from 1900). Areas of highest on record and lowest on record are also shown.

2 Oceans

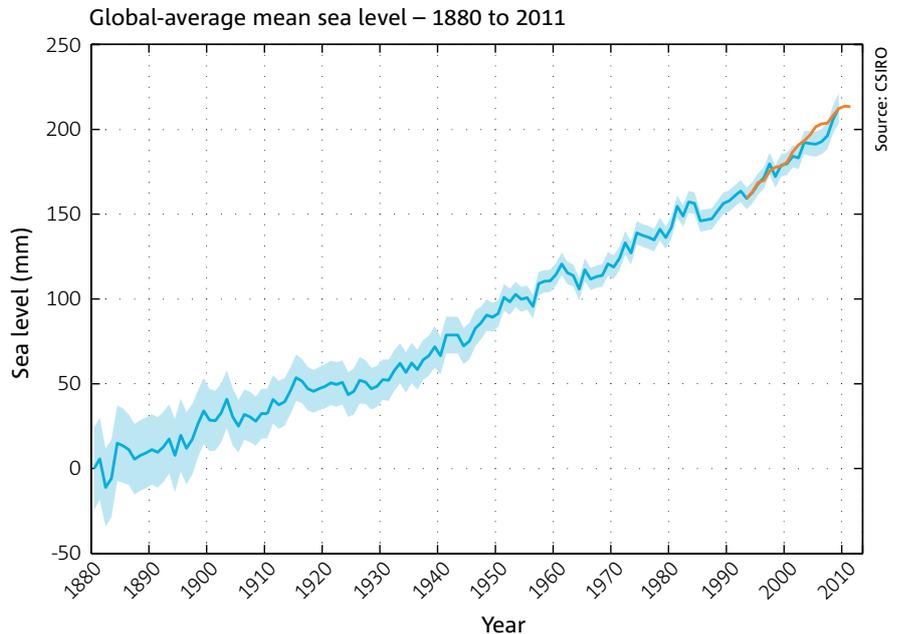
Key points:

- ▶ Global-average mean sea level for 2011 was 210 mm above the level in 1880.
- ▶ Global-average mean sea level rose faster between 1993 and 2011 than during the 20th century as a whole.

Rising global-average mean sea level

Global-average mean sea level for 2011 was 210 mm (± 30 mm) above the level in 1880, the earliest year for which robust estimates of global-average mean sea level are available.

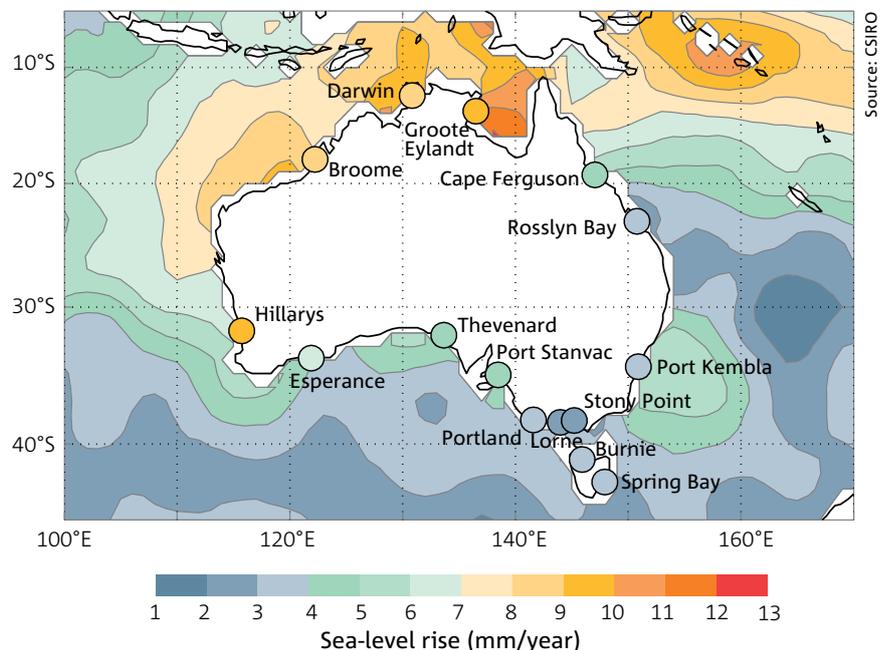
The observed global-average mean sea-level rise since 1990 is near the high end of projections from the 2007 Intergovernmental Panel on Climate Change Fourth Assessment Report.



High-quality global sea-level measurements have been available from satellite altimetry since the start of 1993 (red line), in addition to the longer-term records from tide gauges (blue line, with shading providing an indication of the accuracy of the estimate). Sea level rose at a global-averaged rate of about 3 mm per year between 1993 and 2011, and 1.7 mm per year during the 20th century as a whole.

Rising sea level around Australia

Rates of sea-level rise are not uniform around the globe and vary from year to year. Since 1993, the rates of sea-level rise to the north and northwest of Australia have been 7 to 11 mm per year, two to three times the global average, and rates of sea-level rise on the central east and southern coasts of the continent are mostly similar to the global average. These variations are at least in part a result of natural variability of the climate system.



The rate of sea-level rise around Australia as measured by coastal tide gauges (circles) and satellite observations (contours) from January 1993 to December 2011.

Key points:

- ▶ The heat content of the world's oceans has increased during recent decades, increasing the volume of ocean waters and contributing to sea-level rise.
- ▶ Sea-surface temperatures around Australia have increased faster than the global average.
- ▶ Sea-surface temperatures in the Australian region in 2010 were the highest on record.
- ▶ Sea-surface temperatures have increased by about 0.8 °C since 1910.

Increasing sea-surface temperatures

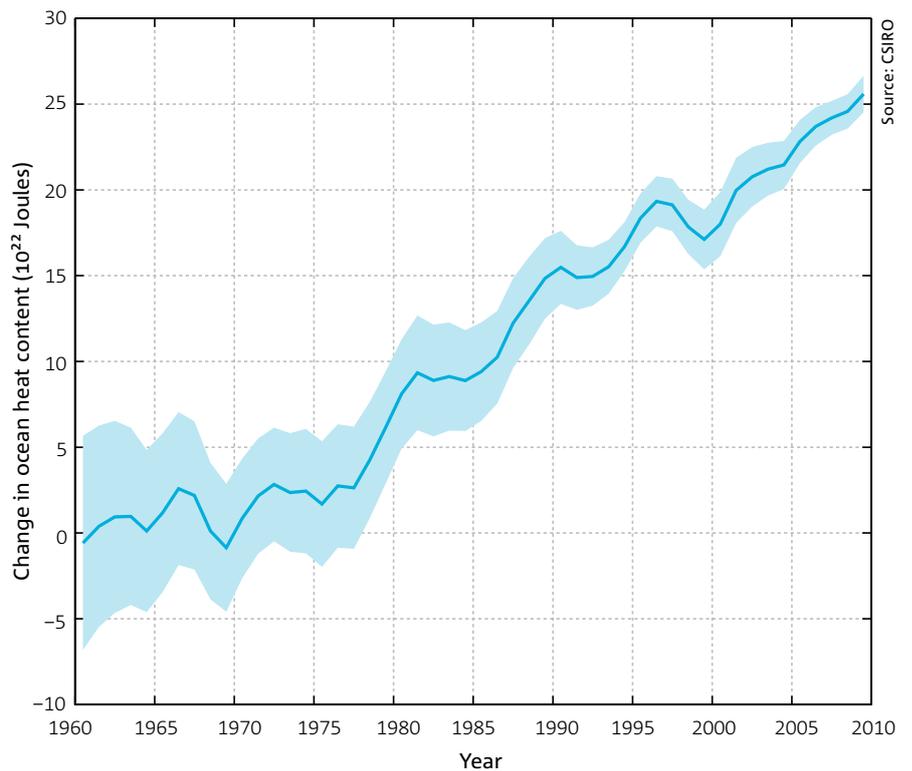
Sea-surface temperatures in the Australian region in 2010 were the highest on record, with nine of the months during 2011 ranked in the top ten warmest months on record. Sea-surface temperatures averaged over the decades since 1900 have increased for every decade. Sea-surface temperature datasets are separate to land temperature datasets, but both terrestrial and ocean surface temperatures have shown very similar warming trends over the last century, confirming that temperatures are rising.

The warm sea-surface temperatures in 2010-11 were strongly influenced by La Niña. La Niña events are typically associated with warmer-than-average ocean temperatures in the Australian region. Ocean temperatures around Australia were warmer during 2010-11 than for any previously identified La Niña event, likely due to the influence of the long-term warming trend of the past century.

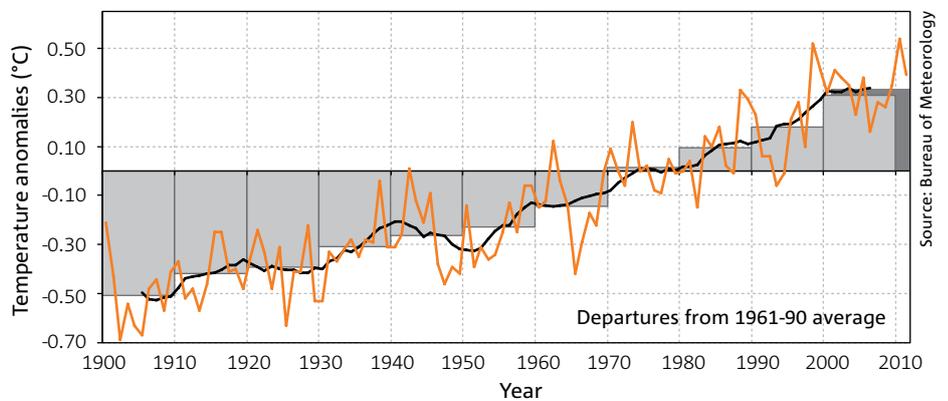
Ocean heat content

One of the best indicators of changes in the climate system is the amount of heat stored in the oceans. The heat content of the world's oceans has increased during recent decades and accounts for more than 90 per cent of the total heat accumulated by the land,

air and ocean since the 1970s. This warming increases the volume of ocean waters and is a major contribution to sea-level rise. Ocean warming is continuing, especially in the top several hundred metres of the ocean.



Ocean heat-content change from 1960 to 2009, relative to 1970. Shading provides an indication of accuracy of the estimate.



Annual (line) and decadal (box) mean sea-surface temperature anomalies for the Australian region relative to the 1961–1990 average. The average value for the most recent 10-year period (2002–2011) is shown in darker grey.

3 Greenhouse gases

Key points:

- ▶ Fossil-fuel CO₂ emissions increased by more than three per cent per year from 2000 to 2010.
- ▶ The concentration of CO₂ in the atmosphere in 2011 was 390 parts per million – higher than at any time for the past 800,000 years.
- ▶ The main cause of the observed increase in CO₂ concentration in the atmosphere is the combustion of fossil fuels since the industrial revolution.

Greenhouse gas concentrations

Global CO₂, methane (CH₄), and nitrous oxide (N₂O) concentrations have risen rapidly during the past two centuries. The amount of these long-lived greenhouse gases in the atmosphere reached a new high in 2011. The concentration of CO₂ in the atmosphere in 2011 was 390 parts per million (ppm) – much higher than the natural range of 170 to 300 ppm during the past 800,000 years.

Global CO₂ concentrations in the atmosphere increased from 2009 to 2011 at 2 ppm per year. Over the same period, nitrous oxide increased at nearly 1 part per billion (ppb) per year and the synthetic greenhouse gases (CFCs, HFCs and so on) increased at nearly ten parts per trillion per year. Methane has increased by about 6 ppb per year from 2009 to 2011 after a temporary pause in growth from 1998 to 2005.

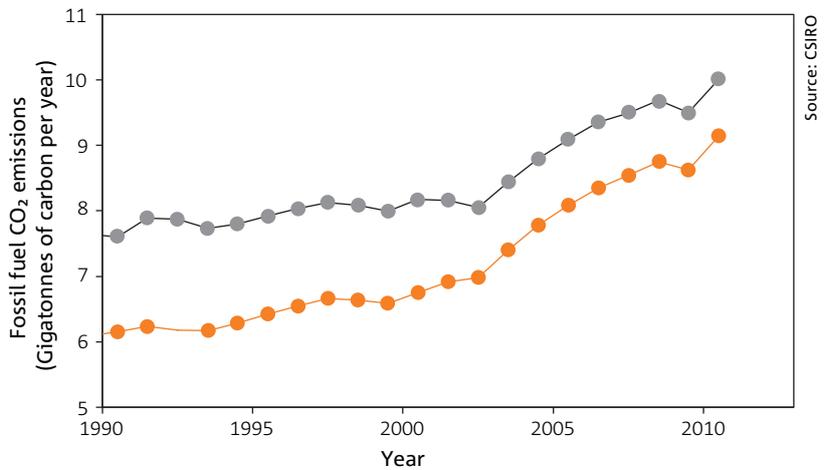
The temporary pause was due to an overall reduction in methane sources (likely to be a combination of natural gas, agricultural and wetland emissions). The cause(s) of the recent methane increase are at present unidentified, but again likely to be a combination of the above sources.

The relative contributions to the enhanced greenhouse effect from pre-industrial times to 2011, due to the long-lived greenhouse gases, are: CO₂ (64 per cent), CH₄ (18 per cent), synthetics (12 per cent) and N₂O (six per cent).

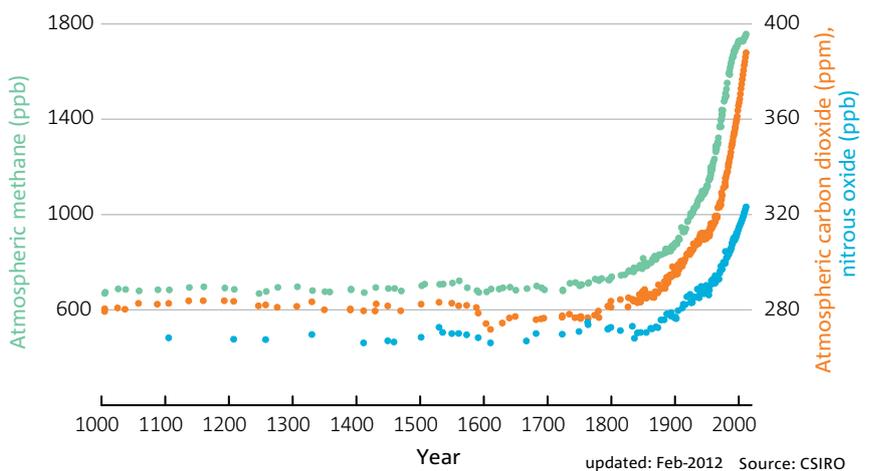
Carbon dioxide emissions

Carbon dioxide (CO₂) emissions account for about 60 per cent of the effect from anthropogenic greenhouse gases on the earth's energy balance over the past 250 years. These global CO₂ emissions are mostly from fossil fuels (more than 85 per cent), land use change, mainly associated with tropical deforestation

(less than ten per cent), and cement production and other industrial processes (about four per cent). Australia contributes about 1.3 per cent of the global CO₂ emissions. Energy generation continues to climb and is dominated by fossil fuels – suggesting emissions will grow for some time yet.



Fossil-fuel CO₂ emissions (orange) increased from 2000 to 2010 at more than 3 per cent per year. The growth from 2009-2010 was 5.9 per cent, reversing a small decline of 1.2 per cent the previous year related to the global financial crisis. Observations of total CO₂ emissions (from fossil fuel burning and land-use change – grey) are tracking along the higher end of expected emissions.



1000-year records of southern hemisphere background concentrations of CO₂ parts per million (ppm – orange), N₂O parts per billion (ppb – blue) and CH₄ (ppb – green) measured at Cape Grim Tasmania and in air extracted from Antarctic ice and near-surface levels of ice known as firn.

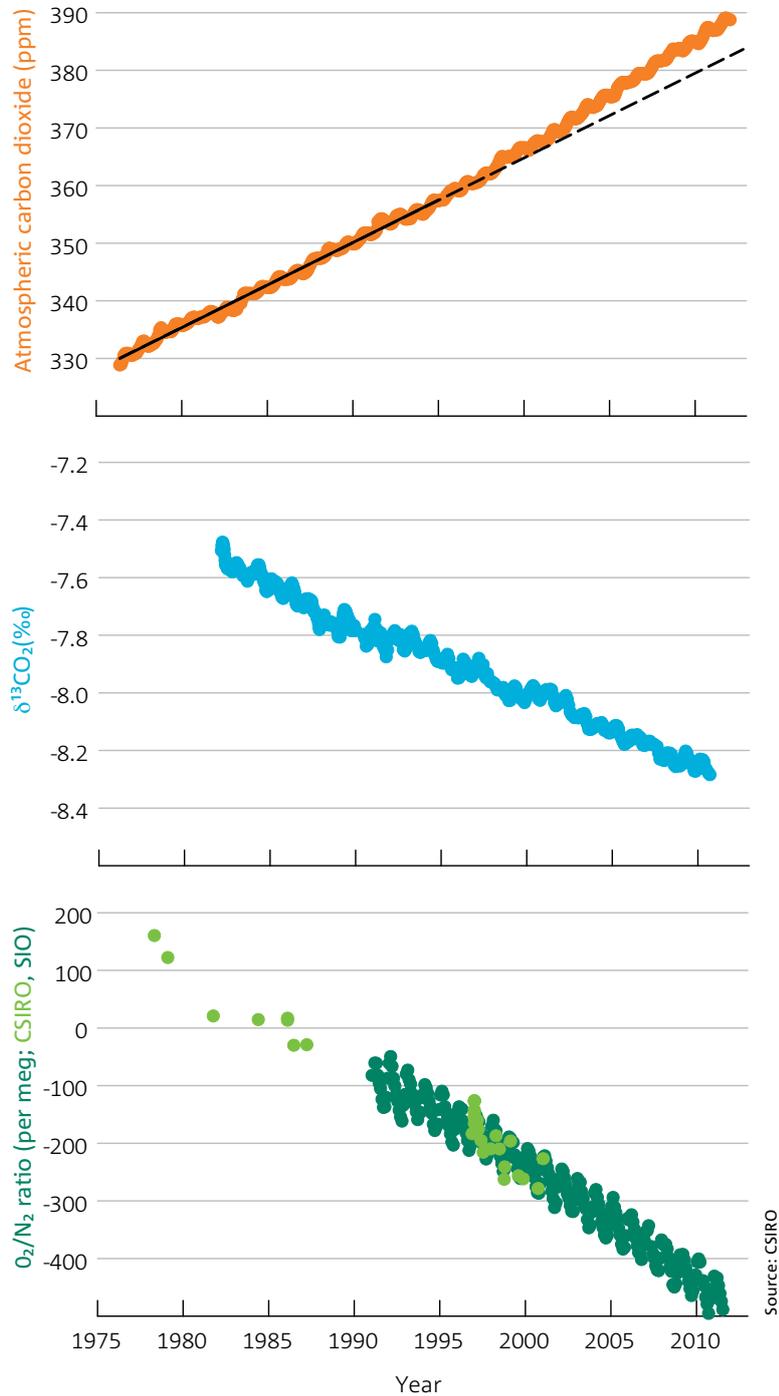
Sources of carbon dioxide

CO₂ levels are rising in the atmosphere and ocean.

About 50 per cent of the amount of CO₂ emitted from fossil fuels, industry, and changes in land-use, stays in the atmosphere. The remainder is taken up by the ocean and land vegetation, in roughly equal parts.

The extra carbon dioxide absorbed by the oceans is estimated to have caused about a 30 per cent increase in the level of ocean acidity since pre-industrial times.

The sources of the CO₂ increase in the atmosphere can be identified from studies of the isotopic composition of atmospheric CO₂ and from oxygen (O₂) concentration trends in the atmosphere. The observed trends in the isotopic (¹³C, ¹⁴C) composition of CO₂ in the atmosphere and the decrease in the concentration of atmospheric O₂ confirm that the dominant cause of the observed CO₂ increase is the combustion of fossil fuels.



Measurements from Cape Grim, Tasmania, showing: increasing monthly-mean, background concentrations of CO₂ (parts per million, top) showing that the CO₂ growth rate has increased above the linear trend (dashed line) through the measurement period; the decreasing ratio of ¹³CO₂/¹²CO₂ in the atmosphere (expressed as $\delta^{13}\text{C}_{\text{CO}_2}$ in units of per mille, centre); and decreasing concentration of oxygen in the atmosphere (expressed as the ratio of oxygen to nitrogen, bottom), including measurements at Cape Grim from both CSIRO (light green) and Scripps Institution of Oceanography (dark green).

4 Understanding global warming

Key points:

- ▶ Both natural and human influences affected climate over the past 100 years.
- ▶ It is very likely that most of the surface global warming observed since the mid 20th century is due to anthropogenic increases in greenhouse gases.
- ▶ Human activities also have influenced ocean warming, sea-level rise, and temperature extremes.
- ▶ The warming around Australia is consistent with the global pattern and cannot be explained by natural variability alone.
- ▶ There is evidence of changes in extreme temperatures globally.
- ▶ No significant trends in the total numbers of tropical cyclones or in the occurrence of the most intense tropical cyclones have been found in the Australian region.

Australia in the context of global warming

Warming in Australia is consistent with warming observed across the globe during recent decades. Global-average surface temperatures were the warmest on record in 2010 (slightly higher than 2005 and 1998). 2011 was the world's 11th warmest year, and the warmest year on record during a La Niña event. The world's 13 warmest years have all occurred in the 15 years since 1997. The planet's average surface temperature has increased by about 0.8 °C, and Australia's by about 0.9 °C, during the past century.

It is very likely (at least 90 per cent likelihood) that most of the observed global warming since the mid-20th century is due to increases in greenhouse gases from human activities. Human activities also have influenced ocean warming, sea-level rise, and temperature extremes. It is very unlikely (less than ten per cent likelihood) that 20th century warming can be explained by natural variability alone.

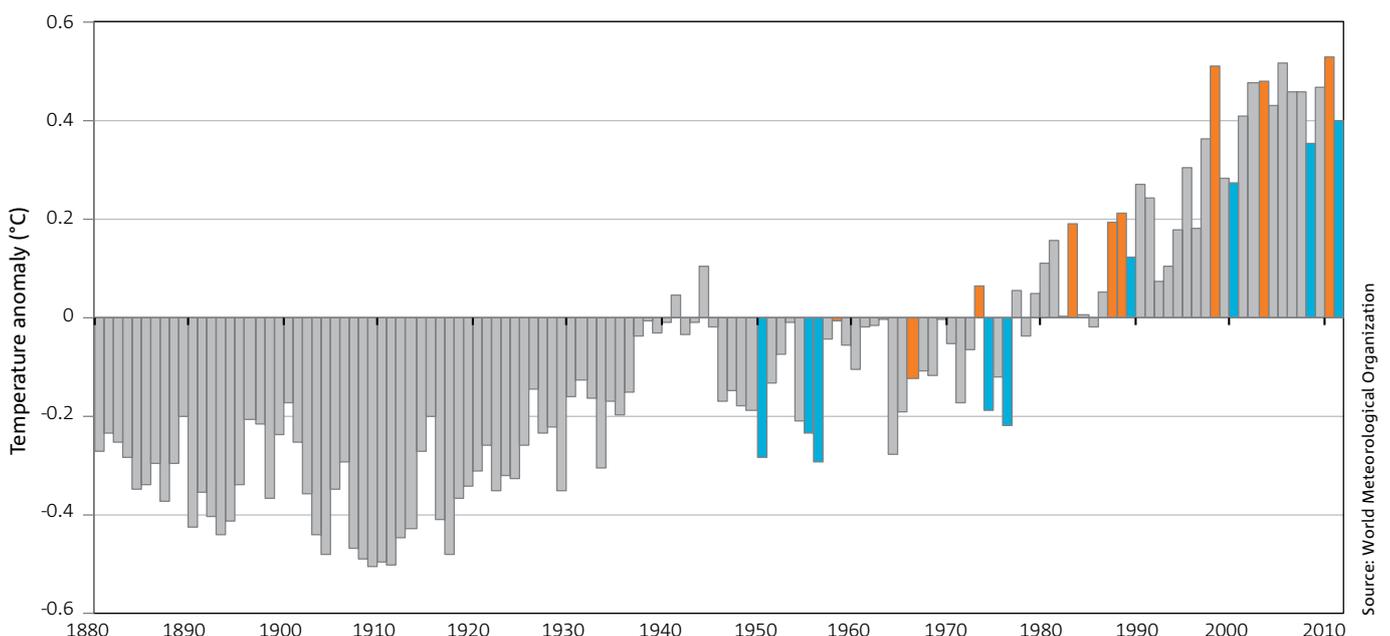
Changes in extreme weather events

Extreme events are relatively rare and identifying changes in intensity or frequency is more difficult than for changes in averages.

There is evidence of changes in some aspects of extreme weather patterns, including fewer cold days and nights and more hot days, hot nights and heatwaves globally in the past 50 years. It is likely that warming of extreme daily minimum and maximum temperatures on the global scale has been influenced by human activities.

Weather associated with high fire danger has shown a rapid increase in the late 1990s to early 2000s at many locations in southeastern Australia.

Heavy rainfall events have increased in frequency over some areas of the globe, with medium confidence that human influences have contributed to this. Long-term global climate trends are occurring alongside natural weather variations. For example, recent Australian heavy rainfall and flooding can be explained largely by strong La Niñas. However, sea-surface temperatures off the western Australian coast have also been at or near record high values as part of a significant warming of the oceans in the past 50 years. No significant trends in the total numbers of tropical cyclones or in the occurrence of the most intense tropical cyclones have been found in the Australian region.



NASA, the US National Climatic Data Centre, and the UK Hadley Centre have each produced global temperature datasets. The graph shows the annual means calculated from the three datasets. Years beginning with an El Niño (orange) and La Niña (blue) are shown after suitable data became available in 1950 (note: 2010 began with an El Niño, and a La Niña then started mid-year).

5 Future changes

Key points:

- ▶ Australian average temperatures are projected to rise by 1.0 to 5.0 °C by 2070 when compared with the climate of recent decades.
- ▶ An increase in the number of droughts is expected in southern Australia but it also is likely that there will be an increase in intense rainfall events in many areas.

Future Australian temperature, rainfall and extreme weather events

Australian average temperatures are projected to rise by 0.6 to 1.5 °C by 2030 when compared with the climate of 1980 to 1999. The warming is projected to be in the range of 1.0 to 5.0 °C by 2070 if global greenhouse gas emissions are within the range of projected future emission scenarios considered by the Intergovernmental Panel on Climate Change. These changes will be felt through an increase in the number of hot days and warm nights, and a decline in cool days and cold nights.

Climate models suggest long-term drying over southern areas during winter and over southern and eastern areas during spring. This will be superimposed on large natural variability, so wet years are likely to

become less frequent and dry years more frequent. Droughts are expected to become more frequent in southern Australia; however, periods of heavy rainfall are still likely to occur.

Models generally indicate an increase in rainfall near the equator globally, but the direction of projected changes to average rainfall over northern Australia is unclear as there is a lack of consensus among the models.

For Australia as a whole, an increase in the number of dry days is expected, but it is also likely that rainfall will be heavier during wet periods.

It is likely (with more than 66 per cent probability) that there will be fewer tropical cyclones in the Australian region, on average, but the proportion of intense cyclones is expected to increase.

Climate change is continuing

Multiple lines of evidence show that global warming continues and that human activities are mainly responsible.

The fundamental physical and chemical processes leading to climate change are well understood. CSIRO and Bureau of Meteorology observations provide further evidence that climate change is real. The scientific understanding and the observations show that global trends in temperatures and sea-level rise since the mid-20th century have been caused predominantly by human activities. Natural climate variability also affected global-mean temperature and sea level during the past century, but much less than increasing greenhouse gases.

It is clear that increasing greenhouse gas concentrations will result in significant further global warming. Uncertainties remain regarding future levels of greenhouse gas concentrations, and the precise timing and magnitude of changes, particularly at regional scales. Further uncertainties relate to tipping points in the climate system, such as the break-up of ice-sheets, which can lead to rapid climate change. Unless greenhouse gas emissions decrease, we expect to see the temperature of the atmosphere and the oceans continue to warm and sea levels continue to rise at current or even higher rates than reported here.

CSIRO and the Bureau of Meteorology will continue to provide observations, projections, research, and analysis so that Australia's responses are underpinned by science of the highest quality.

Further information

The Bureau of Meteorology produces an extensive range of regular climate products and reports. Some, such as rainfall, temperature and solar exposure maps, are produced daily for every State. Detailed climate statements and weather reviews are produced monthly. Special climate statements are released for significant events. Annual statements are released after each year. All of these reports, and many others, can be found on the Bureau's website at www.bom.gov.au/climate.

CSIRO provides comprehensive, rigorous science to help Australia understand, respond to and plan for a changing climate. Go to www.csiro.au/Climate-Change-Book for a free copy of the eBook *Climate Change: Science and Solutions for Australia* and to www.csiro.au for our web page 'Climate Questions, Science Facts' and other information about climate science, adaptation and mitigation. Telephone **1300 363 400** or email enquiries@csiro.au.

A list of peer-reviewed references underpinning *State of the Climate 2012* can be found at www.csiro.au/Outcomes/Climate/Understanding/Snapshot-reference.aspx.

