



**Australian
ClimateChange
ScienceProgramme**

**Australia's
changing climate**

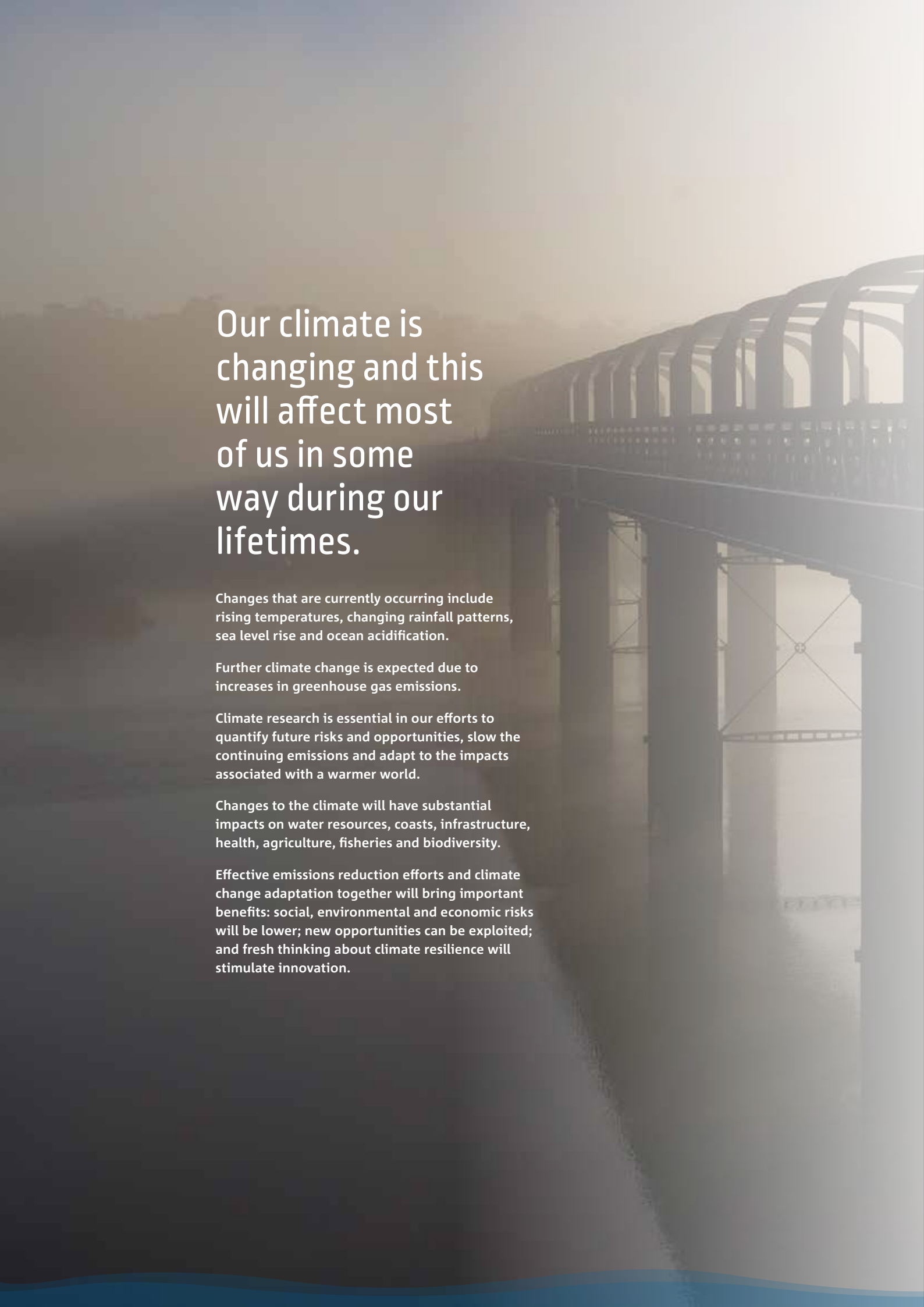


Australian Government

Department of the Environment and Energy

Bureau of Meteorology





Our climate is changing and this will affect most of us in some way during our lifetimes.

Changes that are currently occurring include rising temperatures, changing rainfall patterns, sea level rise and ocean acidification.

Further climate change is expected due to increases in greenhouse gas emissions.

Climate research is essential in our efforts to quantify future risks and opportunities, slow the continuing emissions and adapt to the impacts associated with a warmer world.

Changes to the climate will have substantial impacts on water resources, coasts, infrastructure, health, agriculture, fisheries and biodiversity.

Effective emissions reduction efforts and climate change adaptation together will bring important benefits: social, environmental and economic risks will be lower; new opportunities can be exploited; and fresh thinking about climate resilience will stimulate innovation.

Global climate change

OBSERVED CLIMATE CHANGE

We have a good understanding of the climate system and what drives change. Climate variability and change are influenced by natural factors such as the El Niño Southern Oscillation, volcanic eruptions and solar output, as well as human factors that have increased atmospheric concentrations of greenhouse gases and aerosols and changed the land-surface. Key points from the latest global assessment¹ of observed and future climate change include:

- Warming of the climate system is unequivocal, and since the 1950s, many of the observed changes are unprecedented over decades to millennia.
- The atmosphere and ocean have warmed, the amounts of snow and ice have diminished, sea level has risen and the concentrations of greenhouse gases have increased.
- The surface global warming was 0.85 °C in the period 1880–2012 (Figures 1 and 2), and 2015 was the warmest in the instrumental record.
- During 1901–2010, global average sea level rose by 190 mm. Since the early 1970s, glacier mass loss and ocean thermal expansion from warming together explain about 75% of the observed sea level rise.
- It is very likely that the number of cold days and nights has decreased and the number of warm days and nights has increased on the global scale.
- It is likely that the frequency of heat waves has increased in large parts of Europe, Asia and Australia.
- There are likely more land regions where the number of heavy precipitation events has increased than where it has decreased.

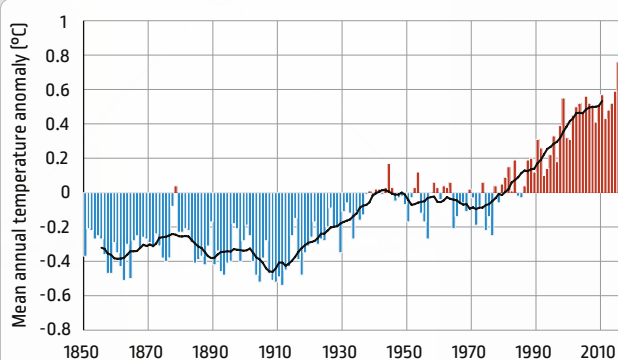


FIGURE 1 Global mean surface air temperature 1850 to 2015 (bars), shown as the anomaly relative to the 1961–1990 average, with an 11-year running average (black line) showing variability about an upward overall trend (source: UK HadCRUT4)⁴.

- Changes in greenhouse gas and aerosol concentrations have been caused by human activities.
- It is extremely likely that human influence has been the dominant cause of the observed global warming since the mid-20th century.
- Human influence has also been detected in warming of the atmosphere and the ocean, in changes in the global water cycle, in reductions in snow and ice, in global mean sea level rise, and in changes in some climate extremes.

PROJECTED CLIMATE CHANGE

- Continued net emissions of greenhouse gases will cause further warming and changes in all components of the climate system. For the period 2081–2100, relative to 1986–2005, expected changes include:
 - Global warming of 0.3 °C –1.7 °C under a low emissions scenario² through to 2.6 °C –4.8 °C under a high emissions scenario³.
 - Sea level rise of 0.26 to 0.55 m under a low emissions scenario through to 0.45 to 0.82 m under a high emissions scenario.
 - More and longer heat waves.
 - More intense and more frequent extreme rainfall over most of the mid-latitude land masses and over wet tropical regions.

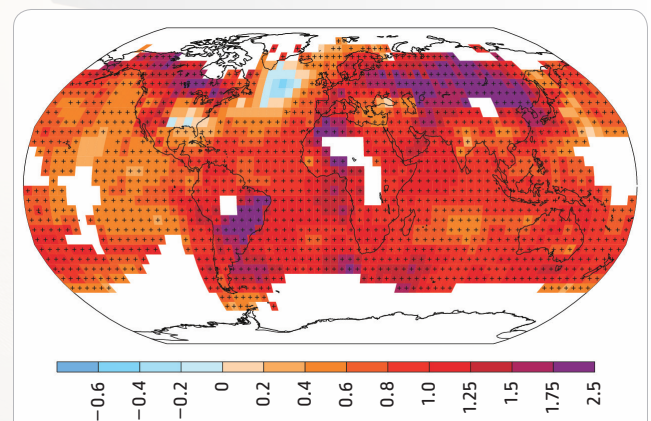


FIGURE 2 Change in mean annual surface temperature between 1901 and 2012, showing warming over almost all regions. Trends significant at the 10% level are shown by plus symbol, areas with insufficient data are white (source: IPCC 2013)⁴.

¹ The Intergovernmental Panel on Climate Change (IPCC), Working Group 1 Fifth Assessment Report, 2013

² RCP2.6 – see page 3

³ RCP8.5 – see page 3

⁴ Figure 1 and 2 use the UK Hadley Centre and Climate Research Unit Temperature series version 4 (UK HadCRUT4) dataset, plus symbols in Figure 2 show where changes are statistically significant

Climate variability and change in Australia over the past 100 years⁵

TEMPERATURE

- Australian average surface air temperature has increased by around 1 °C since 1910 (Figure 3), with warming over most areas since 1950 (Figure 4).
- In recent decades, months warmer than average have occurred more often than months colder than average.
- Heat waves have increased in duration, frequency, and intensity in many regions.
- Since 2001, the number of extreme heat records in Australia has outnumbered extreme cool records by about 3 to 1 for daytime maximum

temperatures and about 5 to 1 for night-time minimum temperatures.

- Many heat extremes have been shown to be much more likely due to human influence, including numerous heat records set from 2013 onwards.

RAINFALL

- Atmospheric circulation has changed, partly due to human influence: in some seasons the edge of the tropical zone and the weather band in southern Australia known as the 'storm track' have both moved south. In other words, the tropics are expanding.

- Annual-average rainfall in many regions of southern and eastern Australia has decreased since the 1950s, particularly in southwest Western Australia (Figure 5).
- Annual-average rainfall increased in much of northern Australia since the 1950s (Figure 5).
- Decreases in heavy rainfall have tended to occur in southern and eastern Australia, while increases have occurred in northern Australia.
- Heavy daily rainfall has accounted for an increased proportion of total annual rainfall over an increasing fraction of the Australian continent since the 1970s.

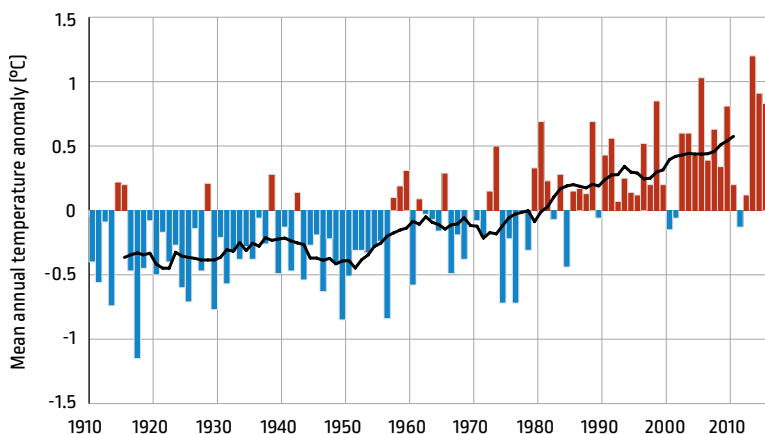


FIGURE 3 Australian mean annual surface air temperature anomalies (bars), shown as the anomaly relative to the 1961–1990 average, with an 11-year running average (black line) showing variability but an upward overall trend (source: Bureau of Meteorology).

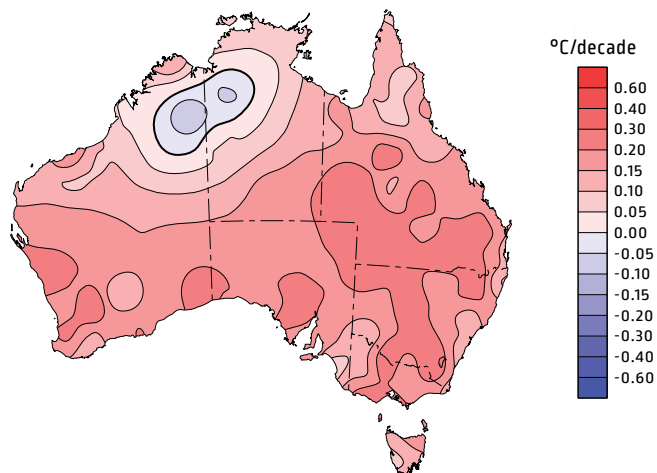


FIGURE 4 Trend in annual mean temperature (°C/decade) from 1950–2015, showing warming over most of the continent (source: Bureau of Meteorology)⁶.

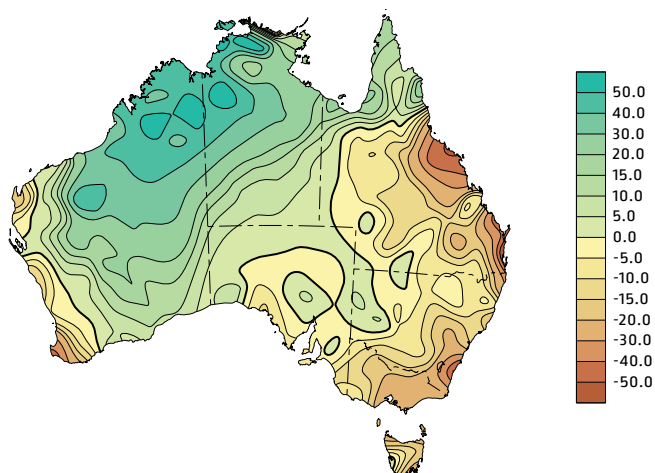


FIGURE 5 Trend in annual-average rainfall (mm/decade) from 1950–2015, showing an increase in rainfall in much of the north and a decrease in many southern areas (source: Bureau of Meteorology, see website for other time periods).

⁵ For more information, see www.bom.gov.au, www.climatechangeinaustralia.gov.au and State of the Climate (2016)

⁶ Both Figure 3 and 4 use the Australian Climate Observations Reference Network – Surface Air Temperature (ACORN-SAT) dataset, see www.bom.gov.au

Australian climate projections for the 21st century

ABOUT CLIMATE PROJECTIONS

Projections use the latest climate science to provide detailed pictures of plausible future climates. They are not predictions, but they illustrate the effect of different scenarios of human activity, including demographic change, economic development and technological advances. They assist us in understanding the likely impact of future socio-economic pathways on the climate system. The main place to find extensive information on Australian climate projections is the website:

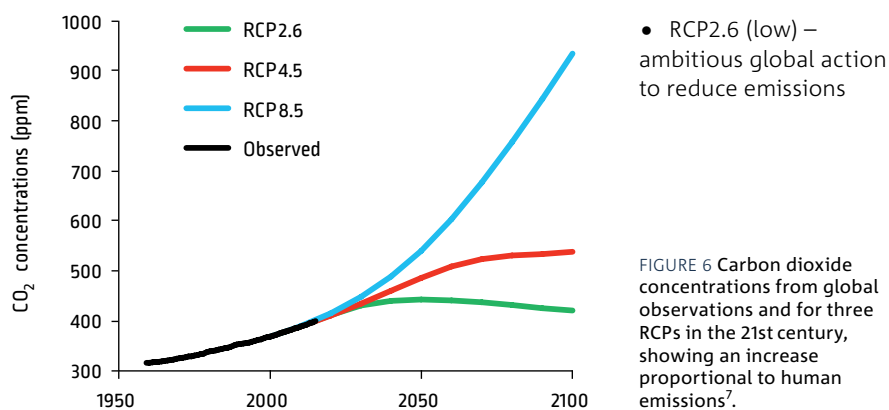
www.climatechangeinaustralia.gov.au

The climate we experience for a given future period depends on three main factors:

1. Natural climate variability – this is always present year-to-year (e.g. the El Niño Southern Oscillation) and decade-to-decade, and this will continue as the underlying climate changes (see box below).
2. Greenhouse gas and aerosol emissions – explored using Representative Concentration Pathways (RCPs). The RCP number refers to the amount of extra radiative impact on the climate system by the end of the century. All the RCPs are quite similar up to 2030, but grow increasingly different after that (Figure 6):
 - RCP8.5 (high) – little global action to reduce greenhouse gas emissions
 - RCP4.5 (medium) – strong global action to reduce emissions towards end of century

3. Climate response – the range of possible changes in the climate system for each RCP given our current understanding of how processes and feedbacks react to emissions. Scientists use computer models of the climate system to simulate the climate response to different RCPs. These global climate models are based on the laws of physics and are verified against historical climate records. Simulations from 40 different models give a range of possible climate responses.

Australian climate change projections account for these three factors, presenting a range of results for a given climate variable, region, year and scenario from different global climate models and additional dynamical and statistical downscaling. Results in Figures 7–10 and Table 1 show the range of possible change from different models and the effect of different emissions scenarios (which becomes marked by 2090). Figure 7 shows the projected changes in average temperature in Australia relative to past temperatures. It also indicates United Nations Framework Convention on Climate Change (UNFCCC) Paris Agreement targets (2 °C and 1.5 °C global warming since the pre-industrial era). Note these targets have been converted to the relevant thresholds for Australia (2.4 °C and 1.8 °C) and warming to the baseline period has been subtracted, giving the values of 2.05 °C and 1.45 °C.



CLIMATE VARIABILITY AND CHANGE

Warming of the climate system over the past century is a well-established fact, and the long-term trend in surface temperature is clear for the globe (Figure 1) and for Australia (Figure 3). A good indicator of heat in the climate system is the temperature of the oceans: since 1971, 90% of the extra energy accumulated in the climate system has gone into the oceans, and the temperature of the upper 700 m of the ocean has risen.

However, the climate has always varied from year to year and from decade to decade, and always will. This is due to drivers of natural variability such as the El Niño Southern Oscillation, volcanic eruptions, and variations on the sun's output. In addition to natural variability, increases in greenhouse gases and aerosols due to human activities contribute to global warming and other climatic trends. Since trends

are combined with natural variability, there are periods of rapid change and periods of little change. For example, the global warming trend in Figure 1 shows periods of rapid warming from 1910–1940 and 1970–2015, separated by a period of little change. Trends calculated over short periods, such as 10–20 years, are very sensitive to the choice of start and end years.

⁷ Adapted from Van Vuuren D, et al. 2011. The representative concentration pathways: an overview. *Climatic Change*, 109, 5–31



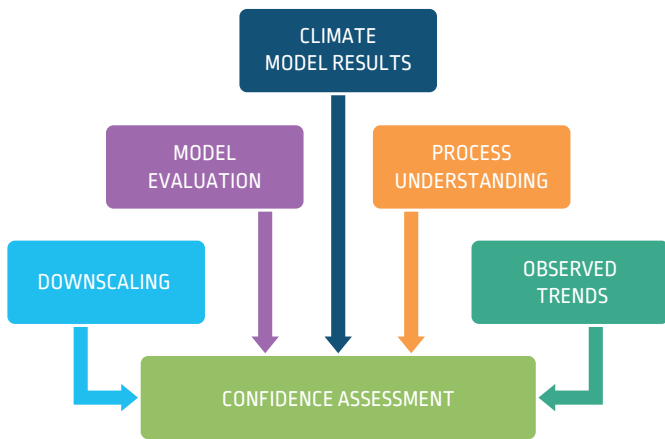
CONFIDENCE IN THE PROJECTIONS

Confidence in the direction and range of projected change is key information when viewing and using climate projections. Confidence ratings have been derived for different climate variables, regions, emissions scenarios and time periods, based on five lines

of evidence. Ratings range from *very high* to *low*, depending on the amount of evidence and the level of agreement between the different lines of evidence.

The confidence ratings are important considerations when using the projections for adaptation and mitigation activities. These activities must use a decision-making framework

that accounts for uncertainty and risk. Projections with *high* or *very high* confidence can be used to develop management decisions, whereas projections with *low* to *medium* confidence require a more cautious approach, with more emphasis on flexible management, monitoring and general building of climate resilience to an uncertain future.



Lines of evidence used to assess confidence.

AGREEMENT	High agreement Limited evidence	High agreement Medium evidence	High agreement Robust evidence	CONFIDENCE SCALE
	Medium agreement Limited evidence	Medium agreement Medium evidence	Medium agreement Robust evidence	
	Low agreement Limited evidence	Low agreement Medium evidence	Low agreement Robust evidence	
	EVIDENCE [type, amount, quality, consistency]			

Table used to assign confidence ratings.



Australian climate projections at a glance

TEMPERATURE

- Australia's average temperature will increase, with more hot extremes and fewer cold extremes (*very high confidence*).

RAINFALL

- In southern Australia, winter and spring rainfall is projected to decrease over the whole century (*high confidence*), although increases are projected for Tasmania in winter (*medium confidence*).
- In northern Australia, substantial changes to wet-season and annual rainfall is possible over the century, but there is *low confidence* in the direction of future rainfall change.
- Southwest Western Australia has already seen reductions in rainfall due to human influence, and further drying in winter is a particularly confident projection.

DROUGHT

- The time in drought will increase over southern Australia, with a greater frequency of severe droughts (*high confidence*).

EVAPORATION AND SOIL MOISTURE

- A projected increase in evaporation rates will contribute to a reduction in soil moisture in southern Australia (*high confidence*).

HUMIDITY

- There is *high confidence* that inland humidity will decrease in winter and spring as well as annually, and there is *medium confidence* in declining relative humidity in summer and autumn.

FIRE WEATHER

- Southern and eastern Australia are projected to experience harsher fire weather (*high confidence*).

SNOW

- There will be a decrease in snowfall, an increase in the melting of snow that does fall and thus reduced snow cover (*high confidence*).

EXTREME EVENTS

- Extreme rainfall events that lead to flooding are likely to become more intense (*high confidence*).
- The number of tropical cyclones is projected to decrease but with a greater proportion of intense cyclones (*medium confidence*). Higher sea levels and rainfall intensity will affect their impact.

OCEANS

- Sea levels will continue to rise throughout the 21st century and beyond (*very high confidence*).
- Oceans around Australia will warm and become more acidic (*very high confidence*).
- There is *medium confidence* that long-term viability of corals will be impacted and that there will be harm to marine ecosystems.

Projections of change are for all scenarios, with greater change under higher scenarios.

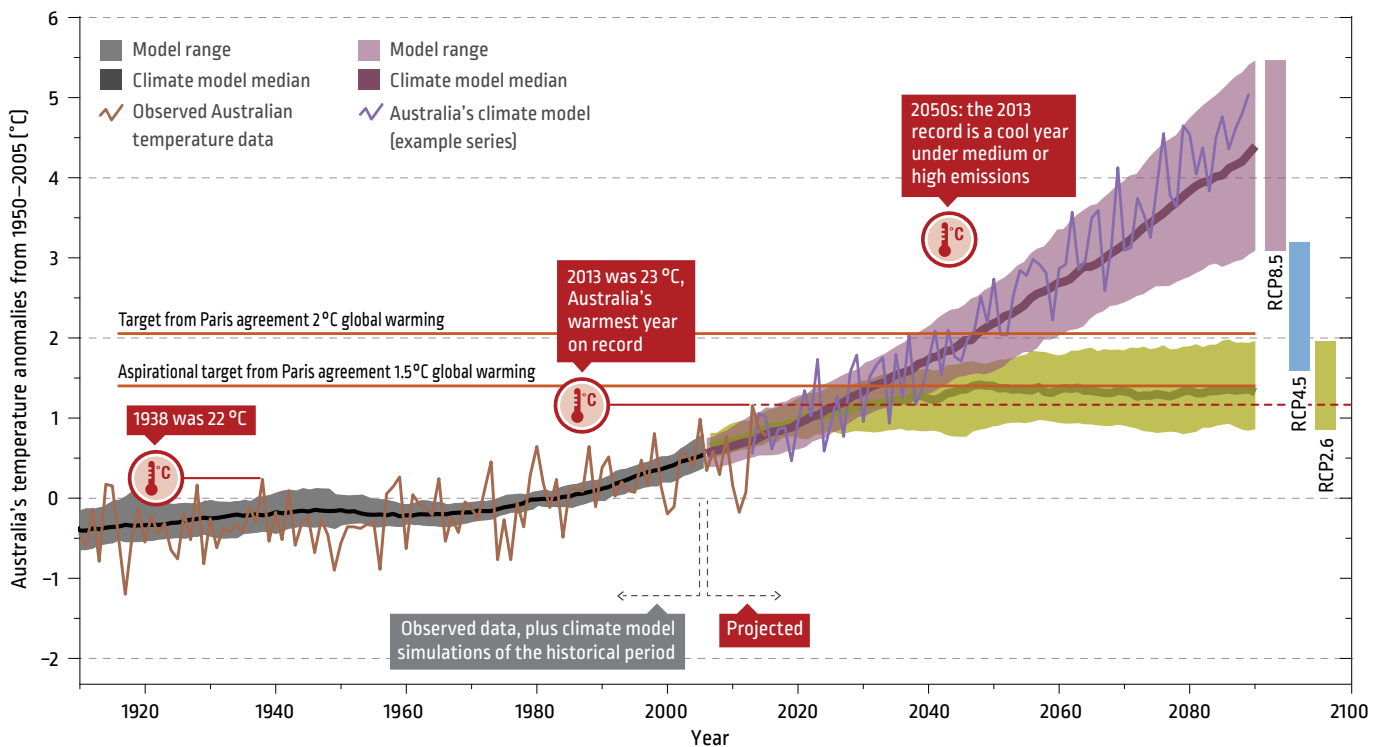


FIGURE 7 Australian mean annual surface warming in the past and for future emissions pathways. Series are relative to the 1950–2005 average: brown is observations⁸, shading is the range of 20-year averages from up to 40 climate models, thick lines are the median of the models, purple is a simulation from Australia's community climate model (ACCESS) showing what a future time series may look like for high emissions including year-to-year variability. Global warming targets from the Paris Agreement are shown relative to pre-industrial temperature and converted to a relevant temperature band for Australia.

⁸ Bureau of Meteorology ACORN-SAT

Some of the largest projected climate change impacts will be felt through changes to extreme weather. For example, an increase in extremely hot days (Figure 8) will lead to greater energy demand for air conditioning, more black-outs, more heat-related deaths, increased fire risk and transport disruption. Fewer extremely cold nights will lead to reduced energy demand for heating, less cold-stress, less frost-damage to crops, less snow and reduced yield for stone fruit and apples.

Annual total rainfall varies substantially from year to year. Rainfall is projected to increase in some areas and seasons, and decrease in others, and in some areas substantial change is possible but the direction of change is unclear. Projected changes are generally larger for the higher emissions scenarios. Southern Australian rainfall is projected to decrease, mainly in the cooler months, but with some regional exceptions. Substantial increase or decrease is possible in northern Australia, but more research is needed to understand which is more likely.

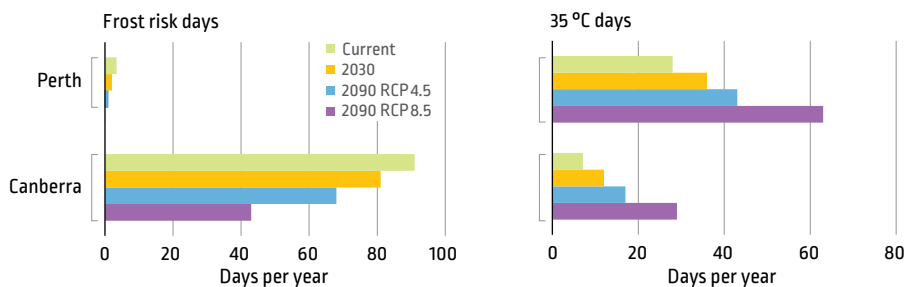


FIGURE 8 Projected changes in the annual-average number of frost risk days (nights below 2 °C) and days over 35 °C for Perth and Canberra stations relative to the 1981–2010 period for 2030 (where emissions scenarios are similar), and for 2090 for medium and high emissions. The graph shows a reduction in cold extremes and an increase in hot extremes with time, proportional to the emissions scenario.

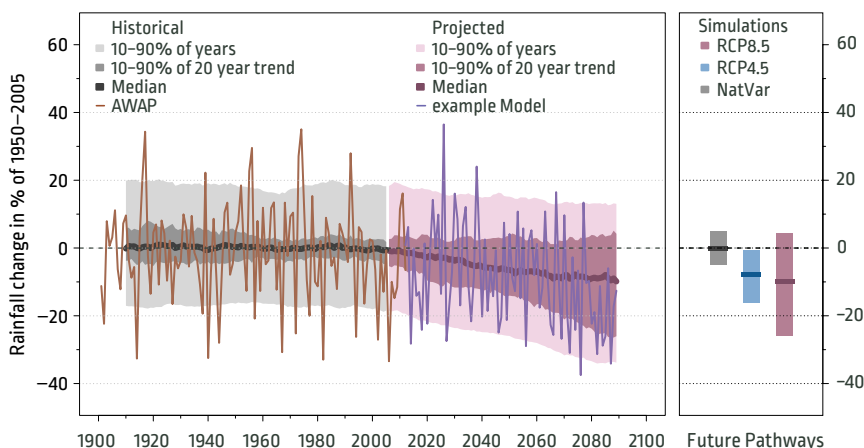


FIGURE 9 Southern Australian rainfall variability and change relative to the 1950–2005 average. Observations⁹ (brown) show the substantial variability experienced. The range between 40 climate model results (coloured bands) shows large variability but with a projected decrease simulated by most models. The dark line gives the central estimate of models. Lighter shading indicates year-to-year variability. An example of Australia's climate model (ACCESS-1.0) shows what an actual time series may look like, with year-to-year variability. Bars to the right show the range at 2090 relative to 1986–2005 for natural variability only, medium emissions and high emissions.

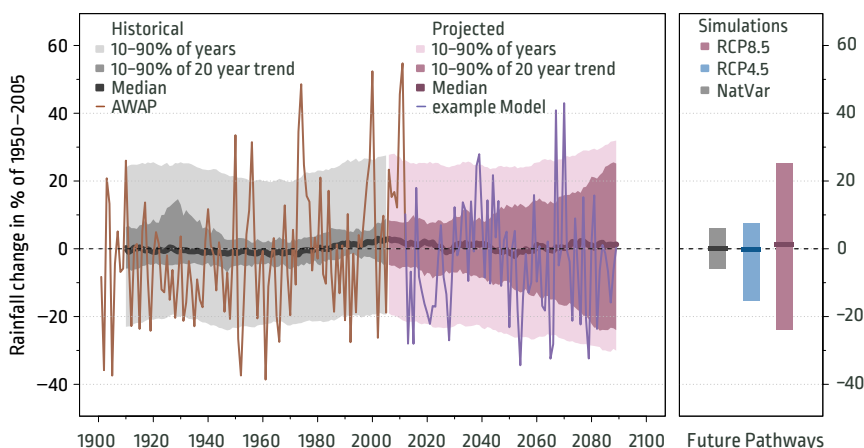
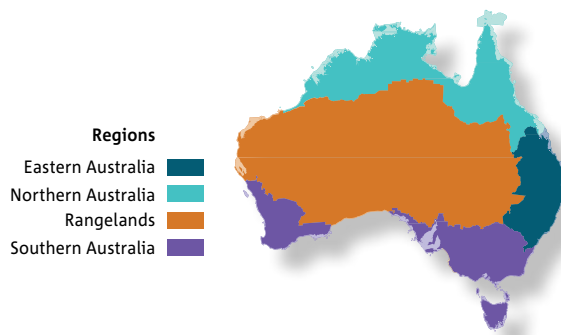


FIGURE 10 Northern Australian rainfall variability and change, showing ongoing large variability and an uncertain projection – substantial increase or decrease is possible. Details as for Figure 9.

⁹ Australian Water Availability Project (AWAP) data, see www.bom.gov.au

TABLE 1 Projected climate changes by 2090, relative to 1995, averaged over the four regions shown in the map: Northern, Southern, Eastern and Rangelands for RCP8.5 (purple), RCP2.6 (Yellow), or where RCP2.6 results are not available, RCP4.5 (blue). Results are the range of change from the available climate models (the 10–90% range, so excluding the 10% outliers), emphasising the range of possibilities rather than a single ‘best estimate’.

See www.climatechangeinaustralia.gov.au for more information



	SOUTHERN	EASTERN	NORTHERN	RANGELANDS
Annual temperature	2.7 to 4.2 °C 0.5 to 1.4 °C	2.8 to 5 °C 0.6 to 1.6 °C	2.7 to 4.9 °C 0.5 to 1.6 °C	2.9 to 5.3 °C 0.6 to 1.8 °C
Sea level rise	Geelong 0.38 to 0.82 cm 0.22 to 0.53 cm	Newcastle 0.46 to 0.88 cm 0.22 to 0.54 cm	Darwin 0.41 to 0.85 cm 0.22 to 0.55 cm	Port Hedland 0.40 to 0.84 cm 0.22 to 0.55 cm
Annual rainfall	-26 to 4 % -15 to 3 %	-25 to 12 % -19 to 6 %	-26 to 23 % -12 to 3 %	-32 to 18 % -21 to 3 %
Summer rainfall	-13 to 16 % -22 to 6 %	-16 to 28 % -20 to 13 %	-24 to 18 % -16 to 4 %	-22 to 25 % -22 to 8 %
Autumn rainfall	-25 to +13 % -17 to 11 %	-33 to 26 % -25 to 15 %	-30 to 26 % -18 to 11 %	-42 to 32 % -26 to 18 %
Winter rainfall	-32 to -2 % -9 to 4 %	-40 to 7 % -24 to 9 %	-48 to 46 % -32 to 13 %	-50 to 18 % -31 to 12 %
Spring rainfall	-44 to -3 % -23 to +4 %	-41 to 8 % -26 to 11 %	-44 to 43 % -32 to 13 %	-50 to 23 % -32 to 15 %
Evapotranspiration	8 to 17 % 2 to 5 %	9 to 18 % 3 to 7 %	8 to 17 % 2 to 6 %	6 to 16 % 0 to 4 %
Extreme rainfall (20-year average recurrence interval)	5 to 30 % 1 to 19 %	13 to 45 % 0 to 28 %	3 to 65 % 0 to 31 %	8 to 42 % 4 to 20 %
Fire weather – days over McArthur forest fire danger index 50	Baseline: 2.8 5.3 3.8	Baseline: 1.2 3.2 1.9	Changes less clear	Changes less clear

RCP8.5 RCP2.6 RCP4.5

USING CLIMATE PROJECTIONS

Climate projections can be used at the global, national or local scale to address a range of questions about climate risks and opportunities. Different levels of detail are useful for different activities and stakeholders:

- Simple qualitative statements are sufficient for raising awareness.
- Quantified ranges of change in specific climate variables can be used in impact assessments.
- Interactive web-based tools allow people to explore information in different ways.
- Tailored climate products and services may be needed for specific decisions.

It is important to seek guidance from experts to find information that is fit for purpose.

There are several steps and numerous inputs when assessing climate risks and opportunities. Information is needed about current climate and projected climate change, but also climate exposure (what is at risk) and the adaptive capacity (what can be done to reduce risk). Various risk assessment frameworks¹⁰ are available. The aim is to develop robust “adaptation pathways”, where different actions are implemented depending on when critical thresholds are crossed.

The National Climate Resilience and Adaptation Strategy¹¹ provides a number of examples in which climate projections have been used to assess impacts and guide decision-making.



¹⁰ <http://www.climatechangeinaustralia.gov.au/en/climate-campus/modelling-and-projections/using-projections/impact-assessment/>

¹¹ <https://www.environment.gov.au/climate-change/adaptation/strategy>

Climate impacts in Australia

Extreme weather and climate events significantly affect the vulnerability of our economy, society and environment. Some changes to extreme events have already been observed in Australia – notably an increase in fire weather, record-breaking temperatures and heatwaves. Understanding the causes of *individual* extreme events is difficult, and is a field of active research.¹²

- High sea surface temperatures have repeatedly bleached coral reefs in north-eastern Australia since the late 1970s and more recently in Western Australia. The 2016 bleaching event was the most severe on record and affected most of the reef¹³.
- Widespread drought in southeast Australia (1997–2009) resulted in substantial economic losses¹⁴.
- The southeast Australian heatwave in late January 2009 resulted in 374 more deaths in Victoria than would be expected normally¹².
- The Victorian bushfires in early February 2009 killed 173 people and more than 1 million animals, destroyed

more than 2000 homes, burnt about 430,000 hectares, and cost about \$4.4 billion¹².

- The floods in eastern Queensland in early 2011 cost more than \$5 billion in lost revenue, and the loss of 33 lives¹².
- Heatwaves in 2013 (Australia's hottest year), 2014 and 2015 had substantial impacts on infrastructure, health, electricity supply, transport and agriculture¹².
- From November 2015 to January 2016, South Australia's Pinery bushfires (26 November), the Sydney tornado (17 December), the Great Ocean Road bushfires in Victoria (26 December) and the bushfires in Western Australia's south west (8 January) cost \$515 million in insured losses¹⁵.
- The June 2016 storm that lashed Queensland, NSW, Victoria and Tasmania caused significant flooding and coastal damage, with insurance losses of \$235 million¹⁵.

The frequency and/or intensity of such events is projected to increase in many locations. Without adaptation, changes

in climate, sea level, atmospheric carbon dioxide and ocean acidity are projected to have substantial negative impacts on water resources, coasts, infrastructure, health, agriculture and biodiversity¹⁶.

Some communities and sectors in some locations have the potential to benefit from projected changes in climate and increasing atmospheric carbon dioxide, for example:

- Reduced winter mortality for people, crops and livestock.
- Reduced energy demand for winter heating in southern parts of Australia.
- Increased forest growth in cooler regions, except where soil nutrients or rainfall are limiting.
- Increased spring pasture growth in cooler regions.

Ongoing research into how the climate is changing at a regional level is critical to identify both the challenges and opportunities associated with climate change, and to inform management and policy decisions.

Managing climate change through adaptation and mitigation

Adaptation and mitigation are complementary strategies for reducing and managing the risks of climate change. Mitigation seeks to reduce net emissions to limit the extent of climate change, while adaptation helps individuals, communities, organisations and natural systems deal with those consequences of climate change that emissions reduction cannot help us avoid.

MITIGATION

Substantial emissions reductions over the next few decades can reduce climate risks in the 21st century and beyond, increase prospects for effective adaptation, reduce the costs and challenges of mitigation in the longer term, and contribute to climate-resilient pathways for sustainable development.

Mitigation actions include enhancing energy efficiency, greater use of renewable energy, improved industrial

processes, greater use of sustainable transport and enhanced carbon uptake in the landscape.

ADAPTATION

Adaptation can involve gradual transformation with many small steps over time, or major transformation with rapid change. There are engineering and built-environment solutions, institutional solutions, technological solutions and ecosystem-based solutions.

¹² ACCSP brochure on Weather extremes and climate change: <http://www.cawcr.gov.au/projects/climatechange/resources.shtml>

¹³ Great Barrier Reef Marine Park Authority: <http://www.gbrmpa.gov.au/media-room/coral-bleaching>

¹⁴ van Dijk A.J., *et al.*, 2013. The Millennium Drought in southeast Australia (2001–2009): Natural and human causes and implications for water resources, ecosystems, economy, and society. *Water Resources Research*, 49, p 1040-1057

¹⁵ Insurance council of Australia. 2016 media releases. www.insurancecouncil.com.au/media-centre

¹⁶ Reisinger, A. *et al.*, 2014. Australasia. In: *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Barros, V.R., *et al.* (eds.). Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 1371-1438.

TOOLS

Decision-support tools are useful for assisting decision and policy makers to assess the climate risks in their region or sector, and to inform the development of climate ready plans and adaptation strategies. For example:

- The National Climate Change Adaptation Research Facility is working closely with governments, businesses, and communities around Australia to develop CoastAdapt¹⁷, an online tool to help local governments and other relevant organisations understand and manage the risks associated with sea level rise, storm surges and other coastal hazards.
- CSIRO's AdaptNRM¹⁸ tool provides support for natural resource managers to develop climate-ready plans.
- The AdaptWater¹⁹ tool quantifies the risk associated with climate change and extreme weather events to water utility assets. The tool performs cost-benefit analyses on proposed adaptation options to inform planning and investment decisions.

The *National Climate Resilience and Adaptation Strategy*²⁰ sets out how Australia is managing the risks of a variable and changing climate. It identifies a set of principles to guide effective adaptation practice and resilience-building, and outlines a vision for a climate-resilient future.

As the strategy highlights, the best mix of climate change adaptation, resilience-building and emissions reduction policies varies from country to country depending on emissions intensity, the cost of reducing

emissions, vulnerability to climate change impacts and tolerance for risk. Some actions, such as energy-efficient building design, water conservation and urban greening, have mitigation and adaptation benefits.

Australia needs a strong foundation in policies, laws, institutions and investments in research and technology to further reduce greenhouse gas emissions and build the resilience of communities, the economy and the environment.



¹⁷ <https://www.nccarf.edu.au/content/coastal-tool-overview>

¹⁸ <http://adaptnrm.csiro.au/>

¹⁹ <https://www.nccarf.edu.au/localgov/case-study/adaptwater%E2%84%A2-online-climate-change-analysis-tool>

²⁰ <https://www.environment.gov.au/climate-change/adaptation/strategy>

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