# 2 The need for action

Failure to reduce global greenhouse gas emissions will result in changes to our climate that will challenge our ability to adapt human settlements and agriculture, and will bring very high risks of widespread species extinctions and irreversible environmental damage.

Over the past two decades, Australian climate change science has contributed to a robust understanding of the Earth's climate system and the impacts of human-induced greenhouse gas emissions. Climate change is a major economic, social and environmental challenge for Australia and the world that will need to be addressed by this generation and those to come.

This chapter is organised as follows:

- Section 2.1 describes the state of climate change science.
- Section 2.2 explains three scenarios used for comparisons—without emissions mitigation, and with greenhouse gas concentrations stabilised at 450 parts per million (ppm) and 550 ppm.
- Section 2.3 outlines global impacts under the three scenarios.
- Section 2.4 discusses observed and projected climate change in Australia.
- Section 2.5 outlines the effects of projected climate change on Australia's economy, society and security.

## 2.1 Climate change science

In 2007, the Intergovernmental Panel on Climate Change (IPCC) concluded that global warming is 'unequivocal' and that it is very likely that human activity has been the main driver of rising global temperatures since the 1950s.[1]

The science of climate change presented in the IPCC's Fourth Assessment Report is strong. There are multiple lines of evidence in the report showing that the earth's average surface temperature has risen nearly 0.76°C (degrees Celsius) since 1850, the earliest year for which we have reliable records. Many other changes in climate have been observed—in wind patterns, precipitation, sea ice and ice sheets, and in aspects of extreme weather.[2] Because of the accumulation of greenhouse gases already in the atmosphere, the world is now committed to centuries of warming, shifting weather patterns and rising seas.

The comprehensive information in the IPCC reports is based on peer-reviewed, published scientific evidence from relevant experts from all regions. Each new assessment report is probably the most scrutinised scientific document in the world, and reflects a progressive strengthening of our understanding of climate change.

New data and scientific understanding compiled since last year's Fourth Assessment Report are starting to paint an even more worrying picture of climate change.

Recent research has found that global greenhouse gas emissions have grown rapidly in the early twenty-first century and are tracking above the upper bounds of the scenarios modelled by the IPCC.[3] Global mean temperature and sea-level rise are at the upper end of the range of projections. There is also increasing concern about the stability of the Greenland and west Antarctic ice sheets, with major implications for sea-level rise over the longer term.

Modelling by the Treasury and the in the Garnaut Final Report shows that, if emissions continue to increase without effective mitigation, by the end of the century, the concentration of long-lived greenhouse gases in the atmosphere will be around 1565 ppm $CO_2$-equivalent ($CO_2$-e), with carbon dioxide ($CO_2$) concentrations of over 1000 ppm, compared to 383 ppm in 2007 and 280 ppm in pre-industrial times. The best estimate of associated temperature increases over pre-industrial levels would be 2.5°C by 2050 and 5.6°C by the end of the century.

## 2.2 Greenhouse gas stabilisation scenarios

While it is too late to stop all human-caused climate change, warming can be substantially slowed by prompt action. The sooner we stabilise[4] atmospheric concentrations of greenhouse gases, the sooner we reduce our impact on the climate and minimise the risk of dangerous change.

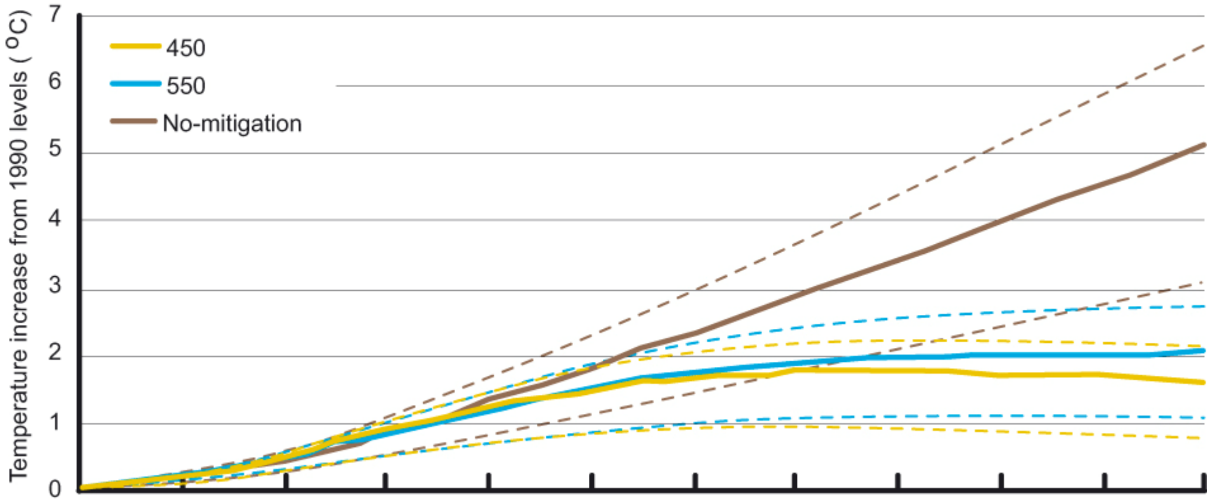
The Garnaut Final Report modelled two stabilisation strategies: the 550 ppm $CO_2$-e stabilisation ('550') scenario, and the 450 ppm $CO_2$-e stabilisation ('450') scenario:

- Stabilisation at 450 ppm $CO_2$-e would result in around a 50 per cent chance of limiting the global mean temperature increase to 1.6°C above 1990 levels. [5] For a target of 450 ppm to be achieved, global emissions would have to peak and then fall at a high rate almost immediately.

- Stabilisation at 550 ppm $CO_2$-e is likely to produce an equilibrium global mean temperature increase of 2°C above 1990 levels.

Even with the 550 and 450 stabilisation scenarios, end-of-century temperature increases above 1990 of 2.7°C and 2.1°C, respectively, are still likely. Figure 2.1 and Table 2.1 show the expected increases in global temperature associated with each of the modelled scenarios, as well as the possible maximum temperature in the 'likely' range defined by the IPCC.

**Figure 2.1: Global average temperature outcomes for three emissions cases 1990-2100**



Note: Solid lines show best estimate temperature outcomes. The range of likely temperatures for each scenario lies within the dotted lines. It is unlikely that temperature increases will fall below the lower dotted line for each scenario. Temperatures are derived from the MAGICC climate model. TML Wigley, MAGICC/SCENGEN 4.1: Technical Manual, National Center for Atmospheric Research, Colorado, 2003).
Source: R Garnaut, *The Garnaut Climate Change Review: Final report, Cambridge University Press*, 2008.
Note: Add 0.5°C to projected future temperatures if comparing to 1850 temperatures.

**Table 2.1: Temperature increases above 1990 levels under the no-mitigation, 550 and 450 scenarios**

| **Scenario** | **2050** | | **2100** | |
|---|---|---|---|---|
| | Best estimate | Upper end of *likely* range | Best estimate | Upper end of *likely* range |
| No mitigation | 2.3 | 2.9 | 5.1 | 6.6 |
| 550 ppm | 1.7 | 2.2 | 2.0 | 2.7 |
| 450 ppm | 1.6 | 2.1 | 1.6 | 2.1 |

Note that 1990 levels are already about 0.6°C above pre-industrial (1850) levels.
Source: Interpreted from: R Garnaut, *The Garnaut Climate Change Review: Final report, Cambridge University Press*, 2008.

## 2.3 Global impacts of climate change

Unmitigated climate change is very likely to result in environmental and social disruption, including significant species extinctions around the globe, threats to food production and severe health impacts, with dramatic increases in morbidity and mortality occurring from heatwaves, floods and droughts. Developing countries are especially vulnerable to climate change.

Impacts of climate change at the global scale in the no-mitigation scenario include:

- *Sea-level rise*. Many millions of people are likely to be flooded every year due to sea-level rise. The hardest hit regions will be the deltas of Asia and Africa and small islands.[6] Recent research indicates a sea-level rise of up to 1.4 m is plausible by 2100.[7]

- *Melting of the Himalayan glaciers*. These glaciers feed several of the most important rivers in Asia, which underpin the livelihoods of some of the most populous nations. Decreased freshwater availability could affect more than a billion people in Asia by 2050.[8]

- *Destruction of coral reefs*. Coral reefs are highly sensitive to increasing temperatures and ocean acidification, which both result from rising carbon dioxide concentrations in the atmosphere.

- *Extinction of plant, animal and other species*. The quality of many natural habitats and ecosystems is being compromised by changes in patterns of temperature and precipitation. The expected pace of climate change will be too fast to allow many species to adapt.

Many important processes within the climate and other earth systems appear to be stable until a threshold is crossed. But once that threshold is crossed, the response may be rapid and/or severe, with long-term, irreversible consequences. Important thresholds include:

- *Melting of the Greenland and west Antarctic ice sheets*. If these were to melt completely, they would add 7 m and 6 m, respectively, to global sea level.[9] Under a no-mitigation scenario, it is highly likely that the point of irreversible melting of the Greenland ice sheet will be reached during this century.[10] It would take centuries for the ice sheet to be lost.

- *Exacerbation of global warming from positive (reinforcing) feedbacks in the oceans and terrestrial systems*. The ability of the oceans and the terrestrial biosphere to absorb carbon dioxide may be reduced. Large quantities of the greenhouse gas, methane, could be unlocked from melting permafrost and from methane hydrates in the ocean.[11]

- *A possible increase in the intensity of the El Niño—Southern Oscillation*. An increase in intensity would have consequences for temperature and rainfall patterns for nations in the Pacific region.[12]

Serious global impacts become more likely with each increment of temperature increase. The Garnaut Final Report illustrated the likelihood of these global impacts occurring by 2100, given greenhouse gas stabilisation scenarios of 450 ppm $CO_2$-e, 550 ppm $CO_2$-e and no mitigation (Table 2.2).

**Table 2.2: Summary of extreme climate responses, high-consequence outcomes and ranges for tipping points for the three emissions cases by 2100**

| Extreme climate response or impact | 450 ppm | 550 ppm | No mitigation |
|---|---|---|---|
| **Temperature outcomes** | **1.6 (0.8–2.1)°C** | **2 (1.1–2.7)°C** | **5.1 (3.0–6.6)°C** |
| Species at risk of extinction[a] | 7 (3–13)% | 12 (4–25)% | 88 (33–98)% |
| Likelihood of initiating large-scale melt of the Greenland ice sheet[b] | 10 (1–31)% | 26 (3–59)% | 100 (71–100)% |
| Area of reefs above critical limits for coral bleaching[c] | 34 (0–68)% | 65 (0–81)% | 99 (85–100)% |
| **Estimated lower threshold exceeded by 2100** | | | |
| Threshold for initiating accelerated disintegration of the west Antarctic ice sheet[d] | No | No | Yes |
| Threshold for changes to the variability of the El Niño—Southern Oscillation[e] | No | No | Yes |
| Threshold at which terrestrial sinks could become carbon sources[f] | Possibly | Possibly | Yes |

(a) The percentages of all species ‘committed to extinction’ due to shifts in habitat caused by temperature and climate changes, from sample regions covering 20 per cent of the Earth’s land surface. The upper limit is based on less comprehensive datasets and is therefore more uncertain. Source: P Sheehan, R Jones, A Jolley, B Preston, M Clarke, P Durack, S Islam & P Whetton, ‘Climate change and the new world economy: Implications for the nature and timing of policy responses’, *Global Environmental Change*, doi:10.1016/j.gloenvcha.2008.04.008.

(b) Cumulative probability based on four estimates from the literature. The percentage represents the likelihood of triggering the commencement of partial or complete deglaciation. This is considered virtually certain under the best estimate temperature outcomes in the no-mitigation case. Source: Sheehan et al., ‘Climate change and the new world economy’.

(c) Percentage of reef area in which there is widespread mortality in slow-growing, tolerant reef species on a frequency of less than 25 years, based on a range of studies from the literature. Source: Sheehan et al., ‘Climate change and the new world economy’.

(d) A range in which the threshold for initiating accelerated disintegration of the west Antarctic ice sheet is expected to occur. The outcomes combine a literature review and expert judgment. Source: TM Lenton, H Held, E Kriegler, JW Hall, W Lucht, S Rahmstorf & S Schellnhuber, ‘Tipping elements in the Earth’s climate system’, *Proceedings of the National Academy of Sciences of the United States of America*, vol. 105, no. 6, 2008, pp. 1786–1793.

(e) A range in which the threshold for changes to the variation of El Niño—Southern Oscillation is expected to occur. The outcomes combine a literature review and expert judgment. Source: Lenton et al., ‘Tipping elements in the Earth’s climate system’.

(f) A range in which the threshold at which terrestrial sinks could be damaged to the extent that they become carbon sources is expected to occur. This includes a combination of outcomes from Lenton et al., ‘Tipping elements in the Earth’s climate system’, relating to the threshold for extensive damage to the Amazon rainforest and boreal forest systems; and R Warren, ‘Impacts of global climate change at different annual mean global temperature increases’, in HJ Schellnhuber, C Cramer, N Nakicenovic, T Wigley and G Yohe (eds), *Avoiding dangerous climate change*, Cambridge University Press, Cambridge, 2006, pp. 94–131, relating to desertification leading to widespread loss of forests and grasslands.

Note: The temperatures shown are increases from 1990 levels.

Source: R Garnaut, *The Garnaut Climate Change Review: Final report*, Cambridge University Press, 2008.

## 2.4 Observed and projected climate change in Australia

Changes in Australia’s climate and its effects on human and natural systems are observable already, and the magnitude of impacts will grow as the climate continues to change.

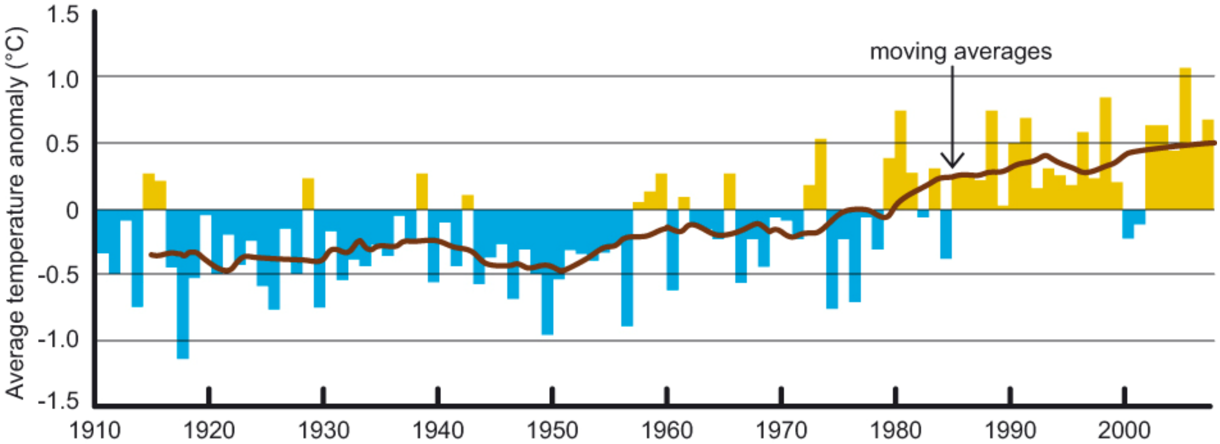
### 2.4.1 Temperature

Figure 2.2 shows that the annual average temperature in Australia has increased by 0.9°C since 1910.[13]

Figure 2.3 shows that the warming trend since the middle of last century has not been uniform across the country. The greatest warming has occurred in central Australia[14], with high warming also in eastern Australia. In south-eastern Australia, average maximum temperatures have increased, resulting in hotter droughts. This in turn affects rainfall, evaporation and, more generally, water availability for human use.

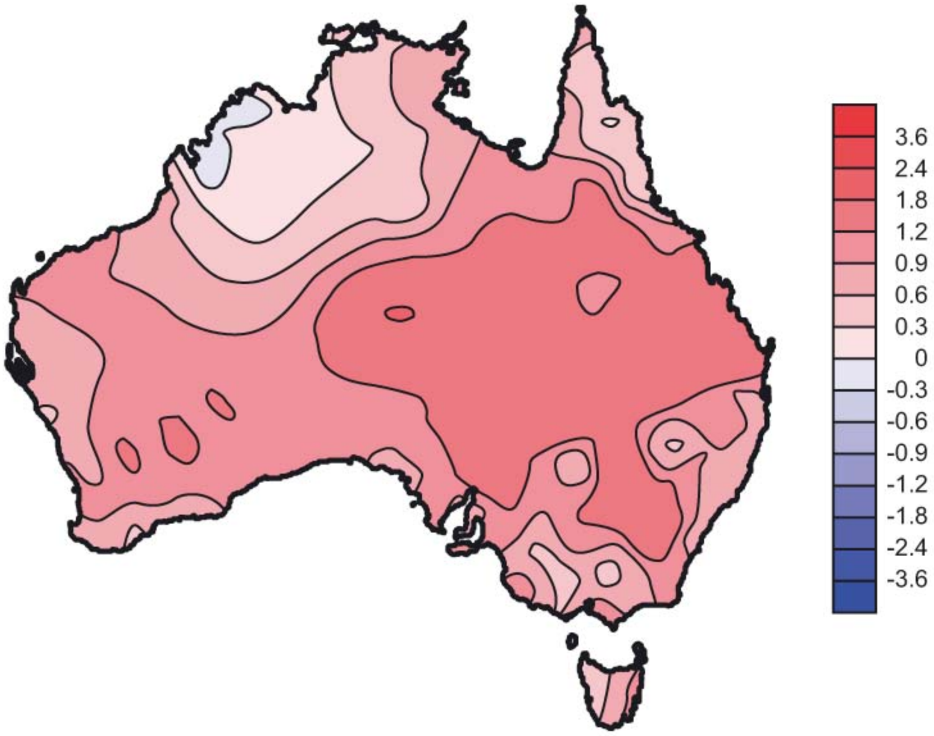
Ocean temperature has changed at a slower pace, due to the ocean's large buffering capacity. However, substantial warming has occurred in the oceans surrounding Australia, particularly the Indian Ocean.[15]

**Figure 2.2: Australian annual mean temperature anomalies**



Note: The data shows temperature differences from the 1961–90 average. The black line shows 11-year running averages.
Source: Bureau of Meteorology, Prepared for R Garnaut, *The Garnaut Climate Change Review: Final report*, Cambridge University Press, 2008.

**Figure 2.3: Trend in annual mean temperature, 1950–2007 (°C per decade)**



Source: Bureau of Meteorology, 2008.
http://www.bom.gov.au/cgi-bin/silo/reg/cli_chg/trendmaps.cgi?variable=tmean&region=aus&season=0112&period=1950.

By 2030, annual average temperature over Australia is expected to be around 1°C above 1990 levels. Coastal areas will experience slightly less warming (0.7–0.9°C), whereas inland Australia will experience greater warming (1.0–1.2°C).[16] To place this change in perspective, a 1°C rise in temperature may lead to a 15 per cent reduction in stream flow in the Murray-Darling Basin due to factors such as increased evaporation.[17]

For the period 1900 to 2007, exceptionally hot years were recorded on average once every 22 years. Projections indicate that comparably hot years will occur every one to two years for the period 2010 to 2040.[18]

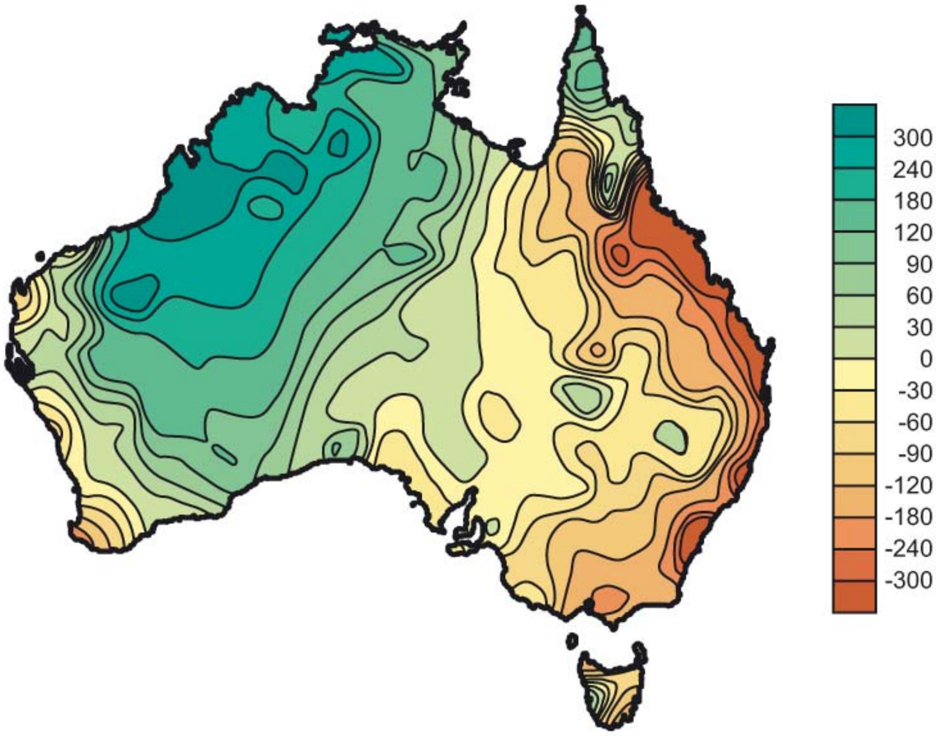
From 2030 until the end of the century, the global emissions pathway will exert a strong influence over temperature change. By 2100, with no mitigation, there will be marked temperature increases across Australia. A temperature increase of more than 3°C (compared to 1990) is very likely for most of the country, increasing to 4.9°C over an extensive area of north-western Australia. The upper end of the projections indicates that there is a 10 per cent chance of temperature increases of more than 7°C in some areas.[19]

### 2.4.2 Rainfall

Since the 1950s, Australia has experienced major change in rainfall patterns, with large geographic variation (Figure 2.4). North-western Australia has seen a significant increase in annual rainfall, whereas most of the eastern seaboard and south-western Australia have seen a significant decrease.[20]

The rate of change in the frequency and intensity of rainfall extremes is greater than the rate of change for average rainfall.[21] This is marked by both an increase in exceptionally dry years and a near absence of very wet years, giving rise to drier soils and decreased river and dam inflows.

**Figure 2.4: Trend in annual total rainfall, 1950–2007 (mm per decade)**



Source: Bureau of Meteorology, 2008.
http://www.bom.gov.au/cgi-bin/silo/reg/cli_chg/trendmaps.cgi?variable=rain&region=aus&season=0112&period=1950.

Rainfall patterns are influenced by a combination of factors, not just climate change. The rainfall decline in south-western Western Australia has been attributed to a combination of an increase in greenhouse gas concentrations, natural variability and land use changes. The rainfall decline observed in south-eastern Australia shares many characteristics with the decline in the south-west.[22] However, this region is affected to a greater extent by major climate phenomena such as the El Niño—Southern Oscillation and the subtropical ridge, which is a belt of high pressure that has been linked to the drying trend across southern Australia.[23] The increased rainfall in the north-west of Australia may be attributable to localised cooling associated with aerosols drifting south from Asia.[24] However, considerable uncertainty still surrounds the attribution of the causes in the change rainfall patterns.

With global warming, there is likely to be a decrease in rainfall for much of Australia, particularly in the south and east. However, the localised nature of influences on rainfall will produce considerable regional variation, with some areas expected to experience an increase in rainfall.

The projected changes in annual average rainfall for 2030 are minimally different in each of the greenhouse gas stabilisation scenarios, but later in the century the rainfall outcomes are more dependent on the level of mitigation. The changes under the 550 and 450 global mitigation cases follow the same patterns, and the reductions are considerably more subdued compared to the no-mitigation case.[25] Table 2.3 shows the best estimate annual average rainfall outcomes for Australia in a no-mitigation case in 2030, 2070 and 2100.[26]

**Table 2.3: Projected changes to state-wide annual average rainfall, best estimate outcome in a no-mitigation case (percentage change relative to 1990)**

| | NSW | Vic. | Qld | SA | WA | Tas. | NT | ACT |
|---|---|---|---|---|---|---|---|---|
| **2030** | –2.5 | –3.5 | –2.4 | –4.2 | –4.1 | –1.4 | –2.5 | –2.8 |
| **2070** | –9.3 | –12.9 | –8.6 | –15.5 | –14.9 | –5.1 | –9.0 | –10.3 |
| **2100** | –13.7 | –19.0 | –12.7 | –22.8 | –21.9 | –7.6 | –13.3 | –15.2 |

Source: CSIRO, '*Regional rainfall projections in Australia to 2100 for three climate cases*', data prepared for the Garnaut Climate Change Review, CSIRO, Aspendale, Victoria, 2008.

The best estimate outcomes do not reflect the extent of the uncertainty in potential rainfall outcomes for Australia under climate change. Table 2.4 shows the average annual changes in rainfall in Australia for the 'dry' (10th percentile) and 'wet' (90th percentile) ends of projections in 2030, 2070 and 2100.

**Table 2.4: Projected changes to state-wide average rainfall, dry and wet outcomes in a no-mitigation case (percentage change relative to 1990)**

| | NSW | Vic. | Qld | SA | WA | Tas. | NT | ACT |
|---|---|---|---|---|---|---|---|---|
| **Dry outcome (10th percentile)[a]** | | | | | | | | |
| **2030** | –10.1 | –8.3 | –11.5 | –13.1 | –12.7 | –5.2 | –11.4 | –8.2 |
| **2070** | –37.0 | –30.3 | –42.0 | –48.0 | –46.5 | –19.2 | –41.8 | –30.1 |
| **2100** | –54.6 | –44.7 | –61.8 | –70.8 | –68.5 | –28.3 | –61.6 | –44.4 |
| **Wet outcome (90th percentile)[b]** | | | | | | | | |
| **2030** | 4.2 | 0.9 | 6.0 | 4.0 | 4.2 | 2.6 | 6.0 | 2.0 |
| **2070** | 15.5 | 3.4 | 22.0 | 14.8 | 15.5 | 9.5 | 22.0 | 7.4 |
| **2100** | 22.8 | 5.1 | 32.5 | 21.9 | 22.8 | 14.0 | 32.4 | 10.9 |

(a) There is a 10 per cent chance that the *decrease* in rainfall will be greater than indicated here.
(b) There is a 10 per cent chance that the *increase* in rainfall will be greater than indicated here.
Source: CSIRO, '*Regional rainfall projections in Australia to 2100 for three climate cases*', data prepared for the Garnaut Climate Change review, CSIRO, Aspendale, Victoria, 2008. The methodology for the preparation of these distributions is described in CSIRO & Bureau of Meteorology, *Climate Change in Australia: Technical Report 2007*, CSIRO, Melbourne, 2007.

Changes in annual average rainfall often mask significant seasonal and local patterns. There are likely to be changes in seasonal rainfall patterns across Australia. In winter and spring, rainfall will likely decline in the south-west and south-east; in summer and autumn, rainfall decline will be more limited, and rainfall may even increase in some areas.[27] It is projected that in future there may be longer dry spells broken by heavier rainfall events. The considerable variability Australia experiences in interannual and decadal rainfall may mask or exaggerate changes that are due to high greenhouse gas concentrations.

## 2.4.3 Sea-level rise

In recent decades, the rate of increase in sea level has been an order of magnitude faster than the average rate of rise over the previous several thousand years, and the rate is increasing. From 1993 to 2003 global sea level rose by 3.1 mm a year, compared to 1.8 mm a year when averaged from 1961 to 2003. Global average sea-level rise during the twentieth century was 1.7 mm a year, which was slightly higher than the 1.2 mm a year rise recorded around Australia for the period.[28]

The IPCC estimated sea-level rise in 2100 to be in the range of 26–59 cm for a scenario similar to the no-mitigation case.[29] This figure does not include the potential for rapid dynamic changes in ice flow from icesheets such as those in Greenland and west Antarctica, which could add up to 20 cm to the upper bound of the sea-level rise estimate for 2100. A key conclusion of the IPCC sea-level rise projections is that larger values above the upper estimate of 79 cm by 2100 cannot be excluded. Recent modelling suggests that a maximum rise of 140 cm is plausible by 2100.[30]

## 2.4.4 Cyclones and storms

Studies for the Australian region indicate a likely increase in the proportion of tropical cyclones reaching the more intense categories, with a possible decrease in the total number of cyclones. Projections indicate that the regions of cyclone genesis and decay on the east coast could shift 200 km and 300 km southwards, respectively, by 2050.[31]

The limited modelling that has been done indicates a dramatic increase in the risk from very large hail along the south-eastern coastline of Australia, with a decrease in hail risk and severe thunderstorms along the southern coast.[32]

## 2.5 Impacts of climate change in Australia

Australia is highly exposed to the impacts of climate change. Under a no-mitigation emissions scenario, average temperatures across Australia are expected to rise by 5.1°C (compared to 1990) by 2100.[33] Australia's water resources, coastal communities, natural ecosystems, energy security, health, agriculture and tourism will have much increased vulnerability if global temperatures rise by 3°C or more.[34]

To place these changes in perspective, a 1°C rise in average temperature will make Melbourne's temperatures resemble those currently experienced in Wagga Wagga, a 4°C rise like that of Moree and a 6°C rise like that just north of Roma in Queensland.

While climate change is usually thought of as involving incremental change, for many locations the main risk from climate change will be an increase in damage from specific events, such as severe storms, heatwaves, intense cyclones, drought and fire.

If global development continues without effective mitigation, the impacts on Australia are likely to be severe. But if greenhouse gas concentrations were stabilised at 450 ppm $CO_2$-e, or even 550 ppm $CO_2$-e, the impacts on Australia could be much reduced (Table 2.5).

**Table 2.5: Differences between probable unmitigated and mitigated futures at 2100**

| | | **Mitigation** | **Mitigation** |
|---|---|---|---|
| **Sector** | **No mitigation** | **550 ppm $CO_2$-e** | **450 ppm $CO_2$-e** |
| Irrigated agriculture in the Murray–Darling Basin | 92% decline in irrigated agricultural production in the basin, affecting dairy, fruit, vegetables, grains. | 20% decline in irrigated agricultural production in the basin. | 6% decline in irrigated agricultural production in the basin. |
| Natural resource–based tourism (Great Barrier Reef) | Catastrophic destruction of the Great Barrier Reef. Reef no longer dominated by corals. | Disappearance of reef with high impact on reef-based tourism. Three-dimensional structure of the corals largely gone, and system dominated by fleshy seaweed and soft corals. | Mass bleaching of the coral reef twice as common as today. |
| Natural resource–based tourism (alpine areas) | Snow-based tourism in Australia likely to have disappeared. Alpine flora and fauna highly vulnerable because of retreat of snowline. | Moderate increase in artificial snowmaking. | Moderate increase in artificial snowmaking. |
| Water supply infrastructure | Up to 34% increase in cost of supplying urban water, due largely to extensive supplementation of urban water systems with alternative water sources. | Up to 5% increase in the cost of supplying urban water. Low-level supplementation with alternative water sources. | Up to 4% increase in the cost of supplying urban water. Low-level supplementation with alternative water sources. |
| Buildings in coastal settlements | Significant risk to coastal buildings from storm events and sea-level rise, leading to localised coastal and flash flooding and extreme wind damage. | Significantly less storm energy in the climate system. Reduced risk to coastal buildings from storm damage. | Substantially less storm energy in the climate system. Greatly reduced risk to coastal buildings from storm damage. |

**Table 2.5: Differences between probable unmitigated and mitigated futures at 2100 (continued)**

| | | | |
|---|---|---|---|
| Temperature-related death | Over 4000 additional heat-related deaths in Queensland each year. A ‘bad-end story’ (10% chance) would lead to more than 9500 additional heat-related deaths in Queensland each year. | Fewer than 80 additional heat-related deaths in Queensland each year. | Fewer deaths in Queensland than at present because of slight warming leading to decline in cold-related deaths. |
| Geopolitical stability in the Asia–Pacific region | Sea-level rise beginning to cause major dislocation in coastal megacities of South Asia, South-East Asia and China and displacement of people in islands adjacent to Australia. | Substantially lower sea-level rise. Greatly reduced risk to low-lying populations. Displacement of people in small island countries of South Pacific. | |

Note: The assessment of impacts in this table does not build in centrally coordinated adaptation. The median of the probability distribution is used for the scenarios considered.
Source: R Garnaut, *The Garnaut Climate Change Review: Final report*, Cambridge University Press, 2008.

### 2.5.1 Water security

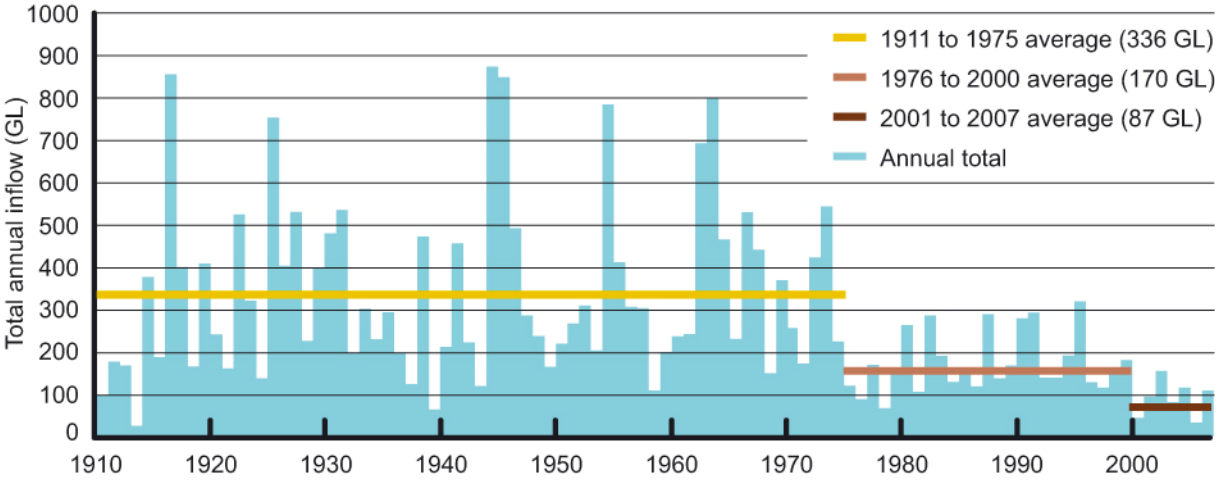
Water security is already a major challenge in southern parts of the continent, and the costs of meeting this challenge under climate change will be significant. Reductions in rainfall result in proportionately larger declines in the amount of water flowing into rivers and dams (‘stream flow’). Generally, a decrease in rainfall can result in a twofold to threefold decrease in stream flow.[35]

In the Murray–Darling Basin, a 10 per cent change in rainfall has already contributed to a 35 per cent reduction in stream flows.[36] This effect is exacerbated by higher temperatures. The reduction in water availability has limited production from cropping and irrigated systems, and is threatening aquatic ecosystems and the viability of towns and farming communities throughout the basin.

Low stream flows have been recorded in the rivers supplying most major urban water storage systems over the past decade.[37] Over that period, stream flows into water storages have been 43 per cent of the long-term average in Canberra, 65 per cent in Melbourne, 62 per cent in Adelaide, 42 per cent in Brisbane and 40 per cent in Sydney.

The earliest significant decline in stream flows of rivers supplying major water storages was observed in Perth (see Figure 2.5). There has been a marked decline since the 1970s, with average annual dam inflows from 1976 to 2000 being about half those from 1911 to 1975. From 2001 to 2007, average inflows were about a quarter of the longer term average. The decline in rainfall in the region, which occurred at approximately the same time, has been partly attributed to human-induced climate change.[38]

Figure 2.5: Annual stream flow into Perth's dams



Note: Annual totals are from May-April.
Source: Water Corporation of Western Australia, Prepared for R Garnaut, *The Garnaut Climate Change Review: Final report*, Cambridge University Press, 2008.

### 2.5.2 Extreme sea events

The increased magnitude of storm events and sea-level rise under a no-mitigation case is likely to exert significant pressure on coastal infrastructure and natural resources through storm damage and flooding.

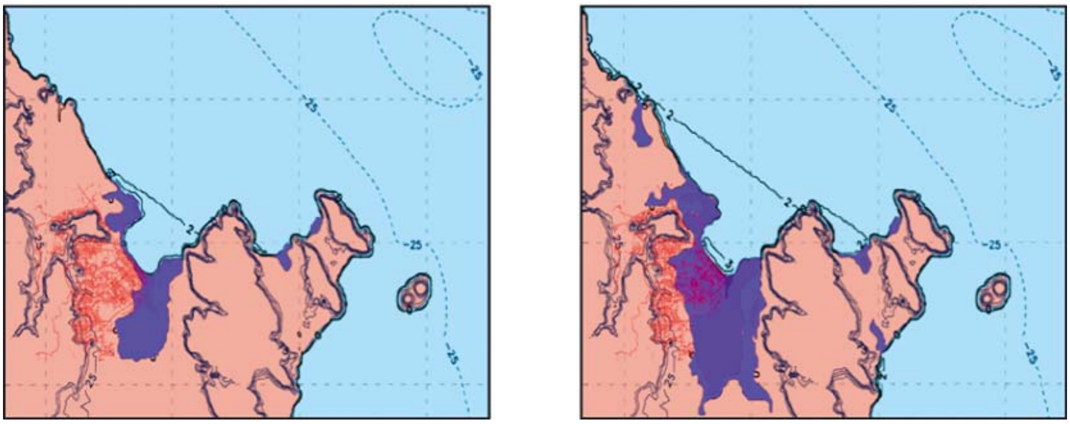
The frequency of extreme events can increase many times for even modest changes in mean sea level. For a mid-range (0.5 m) sea-level rise over the twenty-first century, would result in the present one-in a hundred year event becoming an annual or more frequent event by 2100.[39] Larger increases may occur in many places, such as Sydney, Brisbane and Bass Strait.

Shoreline recession can happen at a rate of up to 100 times the amount of sea-level rise, depending on the topography of the coastline. This equates to around 50 m landward erosion for a sea-level rise of 0.5 m.[40] Erosion of this magnitude will have significant impacts on coastal ecosystems, infrastructure, land tenure and public beaches.

### 2.5.3 Settlements and infrastructure

The Australian trend towards coastal living means that the community's exposure to extreme climatic events, such as severe storms and storm surges, will continue to increase. Around 80 per cent of Australians now live in coastal areas, and that percentage is increasing rapidly. There have been major developments and expansions of settlements in areas known to be subject to a high risk of flooding (see Figure 2.6). Australia wide 711 000 addresses and many billions of dollars worth of assets are at risk from rising sea levels and changes in storm surge.[41]

**Figure 2.6: A doubling of carbon dioxide levels would double the area of Cairns inundated during a 1 in 100 year flood**



Current 1-in-100 year storm surge extent

1-in-100 year storm surge extent under $2xCO_2$ conditions

Source: B Pittock (ed), *Climate change: An Australian guide to science and potential impacts,* prepared for the Australian Greenhouse Office, Canberra, 2003.

Climate change will have wide-ranging and significant impacts on the infrastructure critical to the operation of settlements and industry across Australia. Changes in temperature, rainfall and wind may accelerate the degradation of materials, structures and foundations of buildings, thereby reducing their life expectancy and increasing their maintenance costs. Higher temperatures put greater stress on materials such as asphalt and steel. For example, under a 2-3°C increase in temperature, road maintenance costs will rise by roughly 17 per cent.[42] Sustained dry periods can cause increased ground movement, which accelerates the degradation of materials, structures and foundations.

Intense extreme weather events, which are expected to occur more frequently under climate change, will damage or compromise infrastructure, increase the costs of clean-up operations and increase insurance premiums:

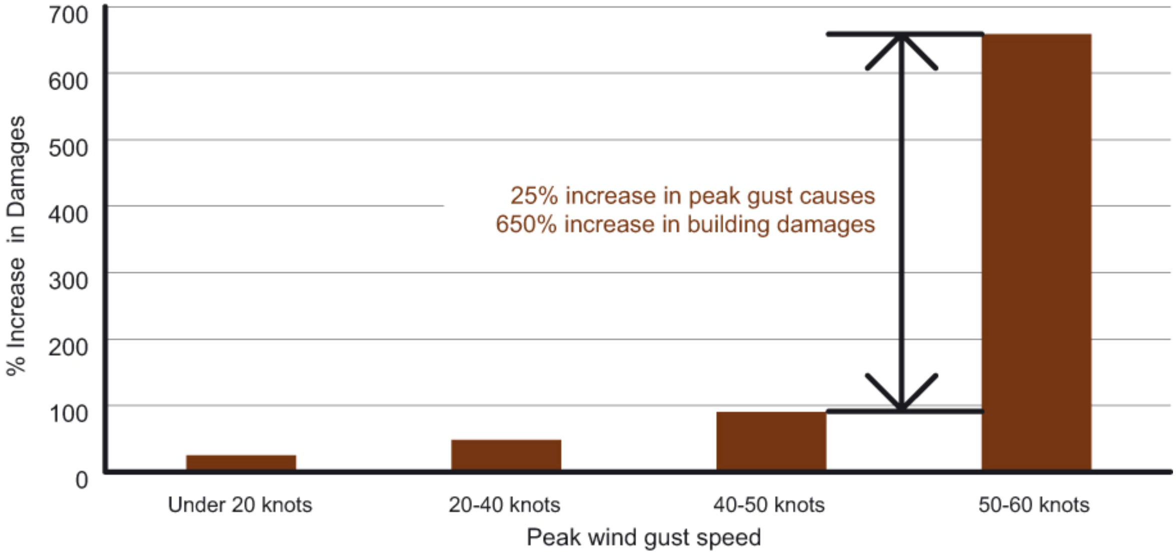
- Drought has the potential to disrupt electricity generation capacity and affect the reliability of electricity supplies. Reduced water availability affects coal-fired power stations, which require water for cooling, and hydro-electric stations because of low storage dam levels. Prices in the National Electricity Market in 2007 were highly variable as a result of drought conditions in Australia.

- Drought threatens water security. Infrastructure projects to boost water supply will be costly. For example, to address current water supply problems in south-east Queensland, a $1.2 billion desalination plant is being constructed as a part of a $9 billion upgrade to the south-east Queensland water grid.[43]

- Hailstorms lead to extensive property damage and insured losses. The 1999 Sydney hailstorm resulted in $1.7 billion insured losses and 500 people left homeless.[44]

- Changes in the intensity and geographical distribution of cyclones will place additional infrastructure at risk. A 25 per cent increase in wind gust speed can lead to a dramatic increase in damage costs for buildings, largely because existing building or engineering standards have been exceeded (Figure 2.7).

**Figure 2.7: Building claims verses peal gust speed showing disproportionate increase in claims cost from small increases in peak wind gust speed**



Source: T Coleman, *The impact of climate change on insurance against catastrophes*, Insurance Australia Group, 2002.

### 2.5.4 Health

The adverse health impacts of climate change will be greatest among people on lower incomes, the elderly and the sick. Indigenous people in remote communities are particularly vulnerable as a result of a lack of basic infrastructure, lower economic and social status and existing health problems.

Climate change will lead to an increase in the number of heat-related deaths through an increase in the number of very hot days (above 35°C). For a temperature increase of 2–3°C, temperature-related deaths among people over 65 may rise by 89–123 per cent. For an increase of 3–4°C, deaths may rise by 144–200 per cent.[45]

Additional health impacts as a result of climate change include the effects of extreme weather events, changes in the distribution of vector-borne diseases, a greater incidence of foodborne and waterborne diseases (such as food poisoning), and mental health consequences.

### 2.5.5 Natural resources

Our diverse natural systems, including those underpinning agriculture and fisheries, are highly exposed to long-term climate changes. These systems have limited capacity to adapt to climate change.

Natural areas particularly at risk include the Wet Tropics and Kakadu wetlands, alpine areas, and tropical and deep-sea coral reefs, including the Great Barrier Reef. Examples of impacts include the following:

- A 1°C (compared to 1990) increase in temperature is likely to destroy the entire habitat of the mountain pygmy possum.[46] This temperature increase could also reduce the upland tropical rainforests of the Wet Tropics by up to 50 per cent.[47]

- A 2–3°C temperature rise could lead to the loss of 80 per cent of freshwater wetlands in Kakadu.[48]

- A 2–3°C temperature increase would result in up to 97 per cent of the Great Barrier Reef being bleached every year. A greater than 3°C temperature increase would give rise to catastrophic mortality of coral species.[49]

- A 5°C increase may result in a loss of 90–100 per cent of core habitat for most native vertebrates.[50]

Climate change will threaten agricultural production through changes in water availability, water quality, temperatures and threats from pests and diseases. For example:

- For a 2–3°C temperature increase, pasture growth will slow by roughly 31 per cent and the national livestock carrying capacity will decrease by approximately 40 per cent.[51]

- A 3°C temperature increase may reduce production from the Murray–Darling Basin by roughly 50 per cent.[52]

In 2100, while Australians will be substantially wealthier in goods and services, despite setbacks from climate change, they are likely to be substantially poorer in environmental amenity of various kinds and in the services provided by well functioning ecosystems.

Australia's scientific research base can help human systems adjust to some degree of climate change. Recent research by the Australian Bureau of Agricultural and Research Economics notes that the 'adaptive capacity' of our agricultural industries will enable them to reduce their potential vulnerability to climate change, but at a cost and within limits of the rate and magnitude of climate change.

### 2.5.6 Indirect impacts

Australia will be affected indirectly by other countries' experiences of climate change.

Modelling conducted for the Garnaut Final Report indicates that climate change will affect Australia's terms of trade (the ratio of Australian export to import prices) much more adversely than any other developed country's. This occurs primarily because our major trading partners in the future, such as China, India, Indonesia and other Asian economies, are expected to be relatively badly affected by climate change.

Climate change threatens geopolitical stability in the Asia–Pacific region. Climate change outcomes, such as the displacement of human settlements by sea–level rise, reduced food production, water scarcity and increased prevalence of diseases, have the potential to destabilise domestic and international political systems in parts of Asia and the south-west Pacific. Australia may be required to intervene in natural, political and humanitarian crises at a large cost.

Australia's level of exposure and sensitivity to the impacts of climate change are high. The extent to which those impacts are realised will depend on the success and timing of global greenhouse gas mitigation, and on national and international adaptation efforts.

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1 Intergovernmental Panel on Climate Change, *Climate change 2007: The physical science basis, Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, S Solomon, D Qin, M Manning, Z Chen, M Marquis, KB Averyt, M Tignor & HL Miller (eds), Cambridge University Press, 2007.

2 Intergovernmental Panel on Climate Change, *Climate change 2007: Impacts, adaptation and vulnerability, Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change,* M Parry, O Canziani, J Palutikof, P van der Linden & C Hanson (eds), Cambridge University Press, 2007.

3 MR Raupach, G Marland, P Cias, C Le Quéré, JG Canadell, G Klepper, & CB Field, 'Global and regional drivers of accelerating CO2 emissions', *Proceedings of the National Academy of Sciences of the USA,* 0700609104, 2007; JG Canadell, C Le Quéré, MR Raupach, CB Field, ET Buitenhuis, P Cias, TJ Conway, NP Gillet, RA Houghton & G Marland, 'Contributions to accelerating atmospheric CO2 growth from economic activity, carbon intensity, and efficiency of natural sinks', *Proceedings of the National Academy of Sciences of the USA*, 0702737104, 2007.

4 'Stabilisation' of a greenhouse gas is reached when its atmospheric concentration remains constant. For a group of greenhouse gases, stabilisation is achieved when the combined warming effect of the gases is maintained at a constant level. Stabilisation of greenhouse gases does not mean the climate will stop changing. Due to the inherent time lag in the system, changes in, for example, temperature and sea levels, will continue for hundreds of years until they reach a new equilibrium.

5 Temperature reference points: Various reports and studies on mitigation may use different points of comparison for temperature increases. Temperature rise may be framed in terms of the increase from pre-industrial times, or from a given year. Unless otherwise specified temperature changes are expressed as the difference from the period 1980-99, usually referred to as '1990 levels' in the IPCC Fourth Assessment report. Following the same convention, temperatures over the period 1850-1899 are often averaged to represent 'pre-industrial levels'. To compare temperature increases from 1990 levels to changes relative to pre-industrial levels, 0.5oC should be added. Projected changes to the end of the 21st century are generally calculated from the average of 2090-99 levels, but are often expressed as '2100'.

6 Intergovernmental Panel on Climate Change, *Climate change 2007: Impacts, adaptation and vulnerability.*

7 S Rahmstorf, "A semi-empirical approach to future sea-level rise", *Science*, vol. 315, 2007, pp 368-370; Rahmstorf et al., 'Recent climate observations compared to projections'

8 Intergovernmental Panel on Climate Change, *Climate change 2007: Impacts, adaptation and vulnerability.*

9 Intergovernmental Panel on Climate Change, *Climate change 2007: The physical science basis*; M Oppenheimer & R Alley, 'Ice sheets, global warming, and Article 2 of the UNFCCC', *Climate Change*, vol. 68, 2005, pp. 257–267.

10 R Garnaut, *The Garnaut Climate Change Review: Final report,* Cambridge University Press, 2008.

11 MR Raupach, G Marland, P Cias, C Le Quéré, JG Canadell, G Klepper, & CB Field, 'Global and regional drivers of accelerating CO2 emissions', *Proceedings of the National Academy of Sciences of the USA,* 0700609104, 2007; JG Canadell, C Le Quéré, MR Raupach, CB Field, ET Buitenhuis, P Cias, TJ Conway, NP Gillet, RA Houghton & G Marland, 'Contributions to accelerating atmospheric CO2 growth from economic activity, carbon intensity, and efficiency of natural sinks', *Proceedings of the National Academy of Sciences of the USA*, 0702737104, 2007.

12 TM Lenton, H Held, E Krieger, JW Hall, W Lucht, S Rahmstorf & HJ Schellnhuber, 'Tipping elements in the Earth's climate system', *Proceedings of the National Academy of Sciences of the USA*, vol. 105, no. 6, 2008, pp. 1786–1793.

13 CSIRO (Commonwealth Scientific and Industrial Research Organisation) & Bureau of Meteorology, *Climate change in Australia: Technical report 2007*, CSIRO, Melbourne, 2007.

14 BF Murphy & B Timbal 2008, 'A review of recent climate variability and climate change in south-eastern Australia', *International Journal of Climatology*, vol. 28, no. 7, 2008, pp. 859–880.

15 CSIRO & Bureau of Meteorology, *Climate change in Australia: Technical report 2007.*

16 CSIRO & Bureau of Meteorology, *Climate change in Australia: Technical report 2007.*

17 W Cai & T Cowan, 'Evidence of impacts from rising temperature on inflows to the Murray–Darling Basin', *Geophysical Research Letters*, vol. 35, L07701, 2008.

---

18 CSIRO & Bureau of Meteorology, *An assessment of the impact of climate change on the nature and frequency of exceptional climatic events: Drought exceptional circumstances,* Commonwealth of Australia, 2008.

19 CSIRO, 'Regional temperature projections in Australia to 2100 for three climate cases', data prepared for the Garnaut Climate Change Review, CSIRO, Aspendale, Victoria, 2008.

20 CSIRO & Bureau of Meteorology, *Climate change in Australia: Technical report 2007*.

21 LV Alexander, P Hope, D Collins, B Trewin, A Lynch, & N Nicholls, 'Trends in Australia's climate means and extremes: A global context', *Australian Meteorological Magazine*, vol. 56, 2007, pp. 1–18.

22 CSIRO & Bureau of Meteorology, *Climate change in Australia: Technical report 2007*.

23 Murphy & Timbal, 'A review of recent climate variability and climate change in south-eastern Australia'.

24 LD Rotstayn, W Cai, MR Dix, GD Farquar, Y Feng, P Ginoux, M Herzog, A Ito JE Penner, ML Roderick, & M Wang, 'Have Australian rainfall and cloudiness increased due to the remote effects of Asian anthropogenic aerosols?', *Journal of Geophysical Research*, vol. 112, JD007712, 2007.

25 R Garnaut, *The Garnaut Climate Change Review: Final report*, Cambridge University Press, 2008.

26 CSIRO, 'Regional rainfall projections in Australia to 2100 for three climate cases'.

27 CSIRO & Bureau of Meteorology 2007, *Climate change in Australia: Technical report 2007*.

28 J Church & NJ White, 'A 20th century acceleration in global sea-level rise', *Geophysical Research Letters*, vol. 33, L01602, 2006.

29 Intergovernmental Panel on Climate Change, *Climate change 2007: The physical science basis, Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, S Solomon, D Qin, M Manning, Z Chen, M Marquis, KB Averyt, M Tignor & HL Miller (eds), Cambridge University Press, 2007.

30 S Rahmstorf, 'A semi-empirical approach to future sea-level rise', *Science*, vol. 315, 2007, pp. 368–370; Rahmstorf et al., 'Recent climate observations compared to projections'.

31 D Abbs, S Aryal, E Campbell, J McGregor, K Nguyen, M Palmer, T Rafter, I Watterson & B Bates, *Projections of extreme rainfall and cyclones*, report to the Australian Greenhouse Office, Canberra, 2006; LM Leslie, DJ Karoly, M Leplastrier & BW Buckley, 'Variability of tropical cyclones over the southwest Pacific Ocean using a high resolution climate model, *Meteorology and Atmospheric Physics*, vol. 97, 2007, pp. 171–180.

32 CSIRO & Bureau of Meteorology, *Climate change in Australia*: *Technical report 2007*.

33 R Garnaut, *The Garnaut Climate Change Review*: *Final report*.

34 Intergovernmental Panel on Climate Change, *Climate change 2007: Impacts, adaptation and vulnerability*.

35 FHS Chiew, 'An overview of methods for estimating climate change impacts on runoff', report for the 30th Hydrology and Water Resources Symposium, Launceston, 4–7 December 2006.

36 R Jones, P Whetton, K Walsh & C Page, *Future impact of climate variability, climate change and land use change on water resources in the Murray–Darling Basin*, overview and draft program of research, CSIRO, 2001.

37 Water Services Association of Australia, *The WSAA report card 2006/07: Performance of the Australian urban water industry and projections for the future*, WSAA, Melbourne, 2007.

38 W Cai & T Cowan, T., 'SAM and regional rainfall in IPCC AR4 models: Can anthropogenic forcing account for southwest Western Australian winter rainfall reduction?', *Geophysical Research Letters*, vol. 33, L24708, 2006.

39 Antarctic Climate & Ecosystems Cooperative Research Centre, *Position analysis: Climate change sea-level rise and extreme events—impacts and adaptation issues*, Antarctic Climate & Ecosystems Cooperative Research Centre, 2008.

---

40 Antarctic Climate & Ecosystems Cooperative Research Centre, *Position analysis: Climate change sea-level rise and extreme events—impacts and adaptation issues*, Antarctic Climate & Ecosystems Cooperative Research Centre, 2008.

41 Intergovernmental Panel on Climate Change, *Climate change 2007: Impacts, adaptation and vulnerability, Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change,* M Parry, O Canziani, J Palutikof, P van der Linden & C Hanson (eds), Cambridge University Press, 2007.

42 CSIRO Marine and Atmospheric Research, *Climate change impacts on Australia and the benefits of early action to reduce global greenhouse gas emissions*, CSIRO, Canberra, 2006.

43 Insurance Australia Group, Submission 19 to the House of Representatives Standing Committee on Climate Change, Water, Environment and the Arts Inquiry into Climate Change and Environmental Impacts on Coastal Communities, 2008, http://www.aph.gov.au/house/committee/ccwea/coastalzone/subs/sub019.pdf.

44 Insurance Australia Group, Submission 19 to the House of Representatives Standing Committee on Climate Change, Water, Environment and the Arts.

45 CSIRO Marine and Atmospheric Research.

46 R Brereton, S Bennett & I Mansergh, ‘Enhanced greenhouse climate change and its potential effect on selected fauna of south-eastern Australia: a trend analysis’, *Biological Conservation*, vol. 72, 1995, pp. 339–354.

47 Allen Consulting Group, *Climate change risk and variability*, Australian Greenhouse Office, Canberra, 2005.

48 W Hare, *Assessment of knowledge on impacts of climate change: contribution to the specification of Article 2 of the UNFCCC*, WGBU, Berlin, 2003.

49 CSIRO Marine and Atmospheric Research.

50 SE Williams & DW Hilbert, ‘Climate change threats to the biological diversity of tropical rainforests in Australia’, in W Laurance & C Peres (eds), *Emerging threats to tropical forests*, University of Chicago Press, 2006.

51 SJ Crimp, NR Flood, JO Carter, JP Conroy & GM McKeon, *Evaluation of the potential impacts of climate change on native pasture production: implications for livestock carrying capacity*, Australian Greenhouse Office, Canberra, 2002.

52 R Garnaut, *Garnaut Climate Change Review*: *Final report*.