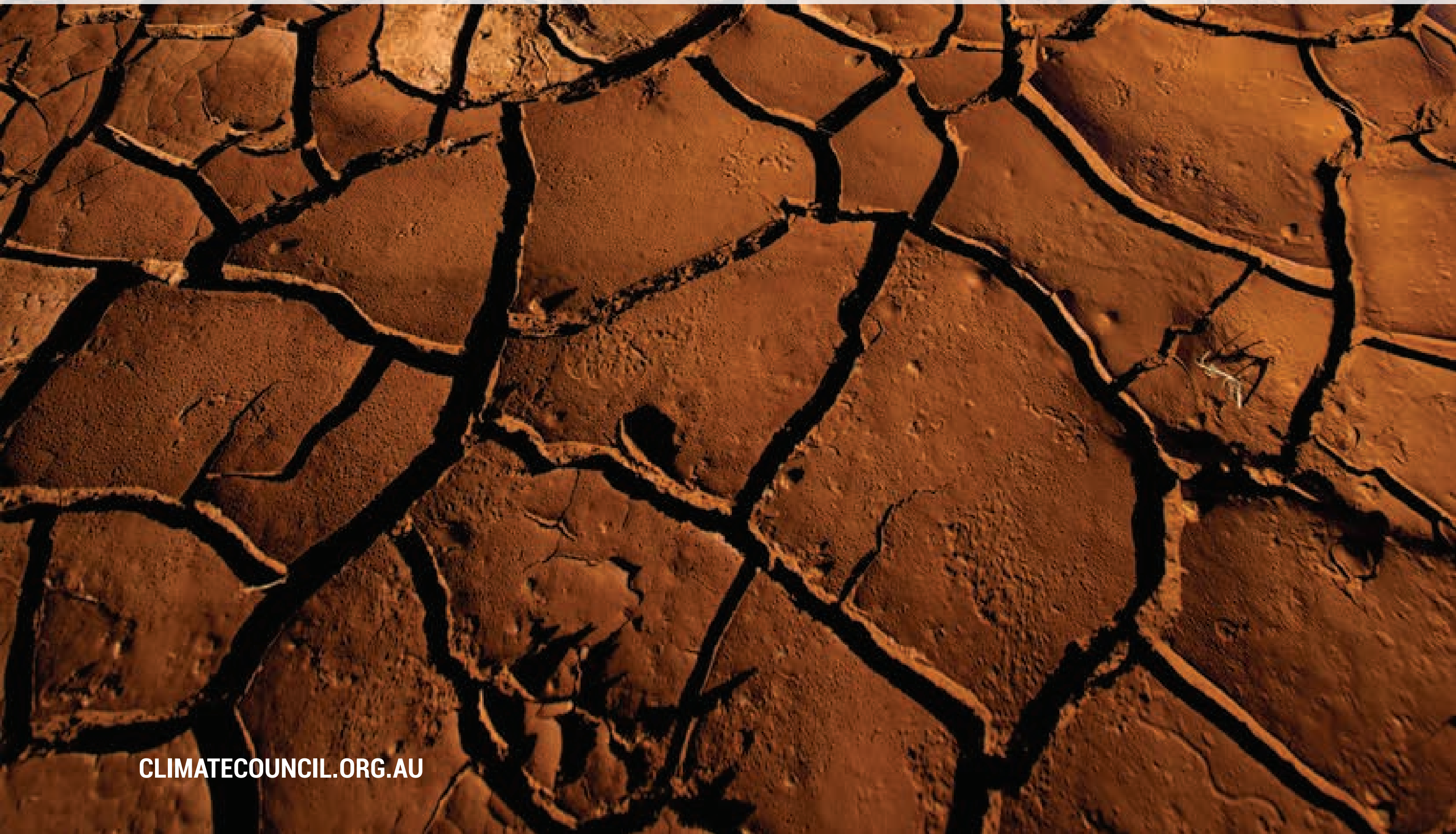
CLIMATE COUNCIL

CLIMATE CHANGE 2015: GROWING RISKS, CRITICAL CHOICES



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Preface

The Climate Council is an independent, non-profit organisation, funded by donations from the public. Our mission is to provide authoritative, expert information to the Australian public on climate change.

Halfway through the Critical Decade for climate action and four years after the Climate Commission released its report, 'Critical Decade: Climate science, risks and responses', this latest Climate Council report provides an update of climate change science, impacts and risks. This report draws from the massive body of evidence that human activities - primarily from the burning of coal, oil and gas - are driving dramatic changes in our climate system. The report outlines how the changing climate poses substantial and escalating risks for health, property, infrastructure, agriculture and natural ecosystems in Australia. Compared to our understanding when the last Critical Decade report was published, the risks of climate change for our well-being now look more serious at lower levels of climate change, strengthening the case for urgent action. Finally, the report describes why it is in Australia's national interest to play a leadership role in the global move for strong climate action leading up to the Paris climate conference at the end of 2015.

The Climate Council is extremely grateful to our team of reviewers whose comments and suggestions improved the report. The reviewers were: Prof. Jon Barnett (University of Melbourne), Dr Linda Beaumont (Macquarie University), Dr Elizabeth Hanna (Australian National University), Prof. David Karoly (University of Melbourne), and Prof. Barbara Norman (University of Canberra). We also appreciate the invaluable contributions of several anonymous reviewers. This report was also made possible thanks to the efforts of Climate Council research volunteers, Zak Ballie, Lily Barnett and Max Newman.

The authors retain sole responsibility for the content of this report.

Professor Will Steffen
Climate Councillor

Professor Lesley Hughes
Climate Councillor

Alix Pearce
Climate Council
Research Officer

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Key Findings

1 Our understanding of climate change continues to strengthen, with dramatic changes of the climate system happening across the globe.

- It is beyond doubt that human activities, primarily the emission of greenhouse gases from the combustion of fossil fuels like coal, oil and gas, are driving the dramatic changes of the climate system.
- Climate change is increasing the frequency and severity of many extreme weather events, including heatwaves and extreme bushfire conditions.
- Hot days have doubled in the last 50 years, while heatwaves have become hotter, last longer and occur more often.
- Over the last 30 years extreme fire weather has increased in the populous southeast region of Australia - southern NSW, Victoria, Tasmania and parts of South Australia.
- Extreme sea-level events have tripled at Sydney and Fremantle since the middle of the 20th century.

2 The changing climate poses substantial and escalating risks for health, property, infrastructure, agriculture and natural ecosystems.

- Further increases in extreme heat in Australia are likely with more frequent and more intense hot days and longer and more severe heatwaves. Deaths from heatwaves are projected to double over the next 40 years in Australian cities.
- More than $226 billion in commercial, industrial, road, rail and residential assets around Australian coasts, most of them in urban areas, are potentially exposed to flooding and erosion hazards at a sea-level rise of 1.1 m.
- From 2020 onwards, the predicted increase in drought frequency is estimated to cost $7.3 billion annually, reducing GDP by 1% per year.
- If global temperatures reach 3°C above pre-industrial levels, an estimated 8.5% of species globally are at risk of extinction, and under a "business as usual" scenario, leading to global warming of 4°C or more, a staggering one in six species could be lost.

3 The risks of climate change for our well-being now look more serious at lower levels of climate change, strengthening the case for urgent action.

- Changes in the climate system are occurring more rapidly than previously projected with larger and more damaging impacts now observed at lower temperatures than previously estimated.
- The scientific underpinning for the 2°C policy target being a "safe" level of climate change is now weaker than it was a decade ago. The scientific case for a 1.5°C limit is more consistent with our current level of understanding, bolstering the case for even more urgent action.
- As the global average temperature rises further above the pre-industrial level, so does the risk of crossing thresholds or tipping points in the climate system, such as the loss of the Greenland ice sheet, the partial conversion of the Amazon rainforest to a savanna or grassland, and the large-scale emission of carbon dioxide (CO_2) and methane from thawing permafrost. Crossing these thresholds would cause further disruptions to the climate system, with potentially catastrophic knock-on effects for human societies.

4 The action we take in the next five years will largely determine the severity of climate change and its long-term impact on human societies. While action is building worldwide, Australia is lagging behind.

- It is in Australia's national interest to tackle climate change, as a country on the front line of climate change impacts and as one of the world's largest per capita emitters of greenhouse gases.
- There is growing global action to tackle climate change with the rapid uptake of solutions, such as renewable energy, and countries are pledging stronger emissions reduction targets.
- Australia is out of step with the rest of the developed world in climate action; by any indicator used to measure level of effort, Australia is at or near the bottom of the list of developed countries.
- A very strong and rapid decarbonisation of the global economy could stabilise the climate system below 2°C, while a business-as-usual scenario could lead to temperature rises of 4°C or above by the end of the century, threatening the viability of modern society.

1. Introduction

Four years ago, the Climate Commission released a major report, The Critical Decade: Climate science, risks and responses. The report, a comprehensive synthesis of the most recent climate change science, received significant traction in Australia and overseas. The phrase, 'the Critical Decade', has become the defining mantra for what is now the Climate Council, emphasising the clear imperative of significant Australian and global action this decade to tackle climate change.

As world leaders prepare to meet in Paris later this year to negotiate a new climate agreement, this update of the landmark Critical Decade report provides an up-to-date synthesis of climate change science. The result is an even stronger basis for action for our leaders, as the evidence that our climate system is changing because of human activities is stronger than ever before.

The climate change landscape today stands in stark contrast to where it stood four years ago. Halfway through the Critical Decade, many consequences of climate change are already evident, and the risks posed by further climate change are better understood. It is clear that global society must almost completely decarbonise in the next 30-35 years, or sooner if possible, to tackle the climate change challenge effectively. This means that the vast majority of fossil fuels must stay in the ground

The more we learn about climate change, the riskier it looks. A 2°C rise in temperature above pre-industrial levels has been established as a policy target, but this level of warming may already drive significant impacts. As scientific knowledge improves, it is becoming clear that risks previously considered to lie only above 2°C may well occur at lower temperatures.

With just 0.85°C of warming globally we have already witnessed adverse consequences. In Australia the incidence of extreme temperatures has increased markedly over the last 50 years, while heatwaves have become hotter, are lasting longer and occur more often. Ground-breaking scientific research that can now tell us how much influence climate change has on a single heatwave or heat record has shown that many of the most extreme weather events, such as Australia's record hot year in 2013, were virtually impossible without climate change.

The decisions we make in the next five years will largely determine the severity of climate change our children and grandchildren will experience.

The constraints to moving to a low or no-carbon future are no longer technological or economic. They are political, institutional and ideological.

Projections of the escalating risks of climate change under a business-as-usual, high emissions scenario are becoming more reliable and more disturbing. More extreme heat is virtually certain across the continent, and southern and eastern Australia will experience harsher fire weather. Extreme rainfall will likely become even more intense. Time in drought is projected to increase in southern Australia, with a greater frequency of severe droughts. Coastal flooding is very likely to increase as sea level rises at an increasing rate. But this future can be avoided.

While our understanding of climate change and the risks of a high emissions future have increased, so too has the range of solutions to the problem. Not only are these solutions more feasible and less costly than ever before, some are already being implemented. In fact, we can already envisage a low or no-carbon future that is healthier, more resilient, more equitable, and more economically viable than a business-as-usual future.

The constraints to moving to this future are no longer technological or economic. They are political, institutional and ideological (based on belief systems). The rest of the world is now moving seriously on climate change and Australia is being left behind.

Australia must cut its greenhouse gas emissions much more deeply and rapidly to contribute its fair share in meeting the climate change challenge. The government has recently announced that Australia's goal will be to cut emissions by 26-28% compared to 2005 levels, by 2030. This is considerably less ambitious than the targets recommended by the Climate Change Authority (CCA), advising Australia's post-2020 target should include: (i) a 2025 target of a 30% reduction in its emissions below 2000 levels (or a 36% reduction if the government opts for 2005 as its preferred base year); and (ii) further reductions within a range of 40 to 60% below 2000 levels by 2030 (or a range of approximately 45 to 65% below 2005 levels). It is important to note that the CCA's recommendations are based on a two-thirds chance of avoiding 2°C warming. For a stronger chance, the target should be greater emission reductions. Therefore, if global average temperature is to stay below 2°C then the CCA recommendations should be seen as a bare minimum for Australia's contribution to tackling climate change in concert with the rest of the world.

The scientific basis for urgent action is set out clearly in this report. The decisions we make in the next five years, particularly decisions about long-term investments in energy, transport and built infrastructure, will largely determine the severity of climate change our children and grandchildren will experience. Failing to take sufficient action entails potentially catastrophic risks to our economy, environment, society and health. This is the critical decade for action and Australia must join the rest of the world in making deep and rapid cuts to our emissions if we are to protect our way of life into the future.

2. THE SCIENCE OF CLIMATE CHANGE

The scientific understanding of climate change - its causes, consequences and future projections - provides the underpinning for assessing the risks posed to our well-being and provides guidance as to the magnitude and rate of actions required. Our understanding of climate change has advanced enormously over the past decade. The most recent assessment by the Intergovernmental Panel on Climate Change (IPCC), published as a series of reports in 2013 and 2014, provides even stronger evidence than ever before that significant changes to the climate system have already occurred, with significant consequences for our health, communities, infrastructure, economy, livelihoods, and environment.

In early 2015, CSIRO and the Bureau of Meteorology published a comprehensive update on the scientific understanding of climate change in Australia – the nature of Australia's climate and its variability, observations of changes in our climate over the last century, the influence of human-driven climate change on these climatic shifts, and projections of further change over the rest of this century (CSIRO and BoM 2015).

It has been well established for nearly two decades that human activities, primarily the emission of greenhouse gases from the combustion of fossil fuels – coal, oil and gas - are driving the changes of the climate system observed since the mid-20th century. The fundamental physics of the greenhouse effect has been known for nearly two centuries, the observations of a changing climate confirm this understanding, and our capability to model the nature and magnitude of the human influence on climate has become more sophisticated and reliable (IPCC 2013). Our ability to project future changes in climate – increases in temperature, changes in precipitation, sea-level rise and the increase in the frequency and intensity of many extreme weather events – has improved markedly over the past decade or two.

Recent science provides even stronger evidence for significant changes to the climate system.

It has been well established that the burning of fossil fuels – coal, oil and gas - is driving the changes in the climate.

This brief overview of the science of climate change focuses on the major features of the climate that are changing as a result of human activities: land and ocean warming, changing rainfall patterns, sea-level rise and melting of the ice, snow and frozen soil. The influence of climate change on extreme weather events is also included, as this knowledge is crucial for understanding the risks that climate change poses for our well-being (Section 3). Unless otherwise stated, the source for the information at the global level is the IPCC Fifth Assessment Report (IPCC 2013) and references therein, and at the Australian level the CSIRO and BoM report "Climate Change in Australia: Projections for Australia's NRM (Natural Resource Management) Regions" (CSIRO and BoM 2015) and references therein. These reports, along with the Australian Academy of Science report "The science of climate change: Questions and answers", are excellent sources for more detailed information on climate change science.

Figure 1: Smokestacks in Alberta, Canada. Major features of the climate are changing as a result of human activities.

2.1 Warming of the Earth’s Surface

A commonly used indicator for climate monitoring purposes is the globally averaged combined land and ocean surface temperature, shown in Figure 3 (top panel). While there is considerable variability from year-to-year, there is a clear warming trend since the middle of the 20th century. Over the period 1880 to 2012, the average surface temperature has risen by 0.85°C, with much of that warming occurring since about 1970. 2014 was the hottest year on record. It was also the 38th year in a row that the global average temperature was hotter than the 20th century average (NOAA 2015).

The 1980s, 1990s and 2000s were all hotter than any other decade in recorded history.

Figure 2: A floodway shimmers in the heat in Ashburton, Western Australia.

The bottom panel of Figure 3 shows this warming trend as decadal averages, which remove much of the short-term variability. The 1990s were warmer than the 1980s and the 2000s were warmer than the 1990s. All three decades were hotter than any preceding decade since 1850. A comparison of these recent trends to palaeo-climatic records indicates it is likely that the 1983-2012 period was the warmest 30-year period during the last 1400 years in the Northern Hemisphere, where longer and more extensive temperature data exist.

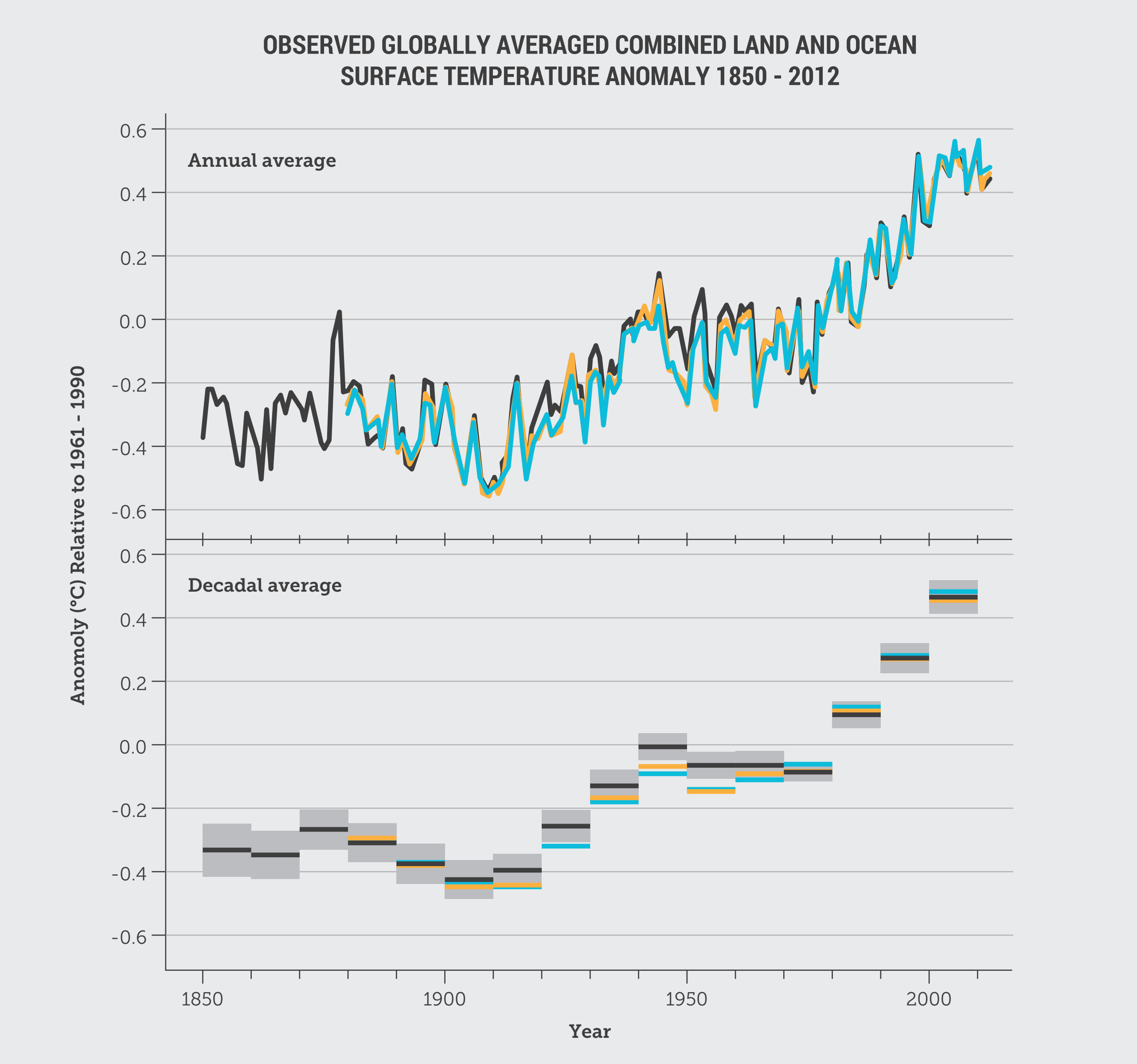

Figure 3: Observed global mean combined land and ocean surface temperature anomalies, from 1850 to 2012 from three data sets. Top panel: annual mean values: Bottom panel: decadal mean values including the estimate of uncertainty for one data set (black). Anomalies are relative to the mean of 1961-1990. **Source:** IPCC 2013.

Average surface temperature over the Australian continent has increased by 0.9°C since 1910, with higher increases in night-time minimum temperatures than in daytime maximum temperature. Figure 4 shows that this warming trend is apparent in all states and territories. 2013 was Australia's warmest year on record.

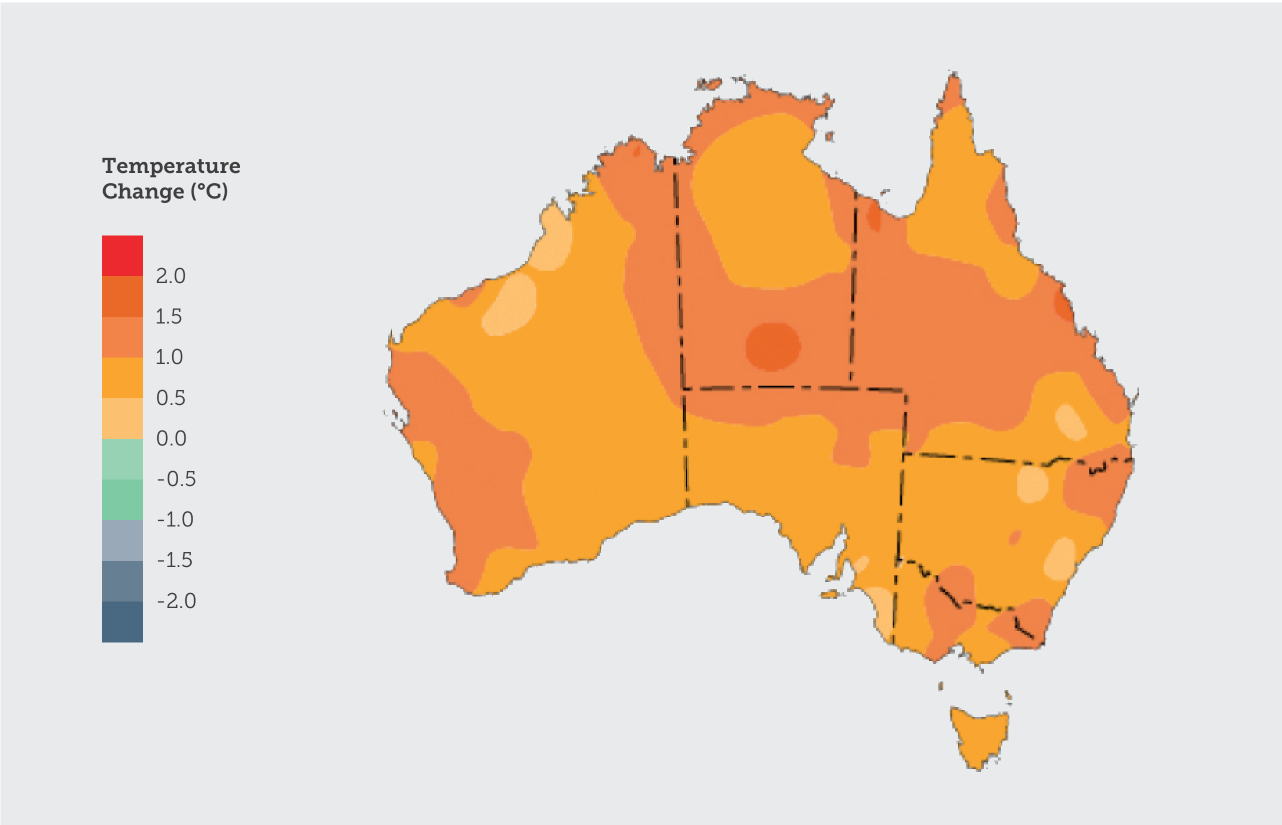

Figure 4: Warming is apparent in all states and territories. Linear trend in Australian mean temperature from the Australian climate observations reference network (ACORN-SAT) calculated for the entire period 1910 to 2013. **Source:** BoM 2014a.

2.2 Warming of the Climate System

To understand how the climate is changing, the climate system as a whole, not only the atmosphere just above the Earth's surface, must be considered. The climate system consists of the entire atmosphere, the oceans, the land surface, and the cryosphere (the frozen parts of the Earth). The climate system also includes the physical, chemical and biological processes that transport and store energy, carbon and other elements. All of these parts and processes need to be monitored to understand how the entire climate system is changing.

The Earth is warming strongly. The air, the ocean, and the land surface are all warming.

Despite the focus on air temperature, warming of the air accounts for only 1% of the additional energy stored in the climate system as a result of the increase in greenhouse gases in the atmosphere. More than 90% of the total energy accumulated between 1971 and 2010 has been absorbed by the world's oceans (Figure 5). More than 60% of the net energy increase in the climate system during that period is stored in the upper ocean (0-700 m). The upper 75 m has warmed by 0.11°C per decade over the period 1992 to 2010. It is likely that the deeper ocean has also warmed, though somewhat unevenly. Observations from 1957 to 2009 show ocean warming at depths between 700 and 2000 m below the surface, but there has likely been no significant warming of the layer 2000 - 3000 m below the surface for this period. However, significant warming has likely occurred even deeper, below 3000 m, with the largest increase observed in the deep waters of the Southern Ocean.

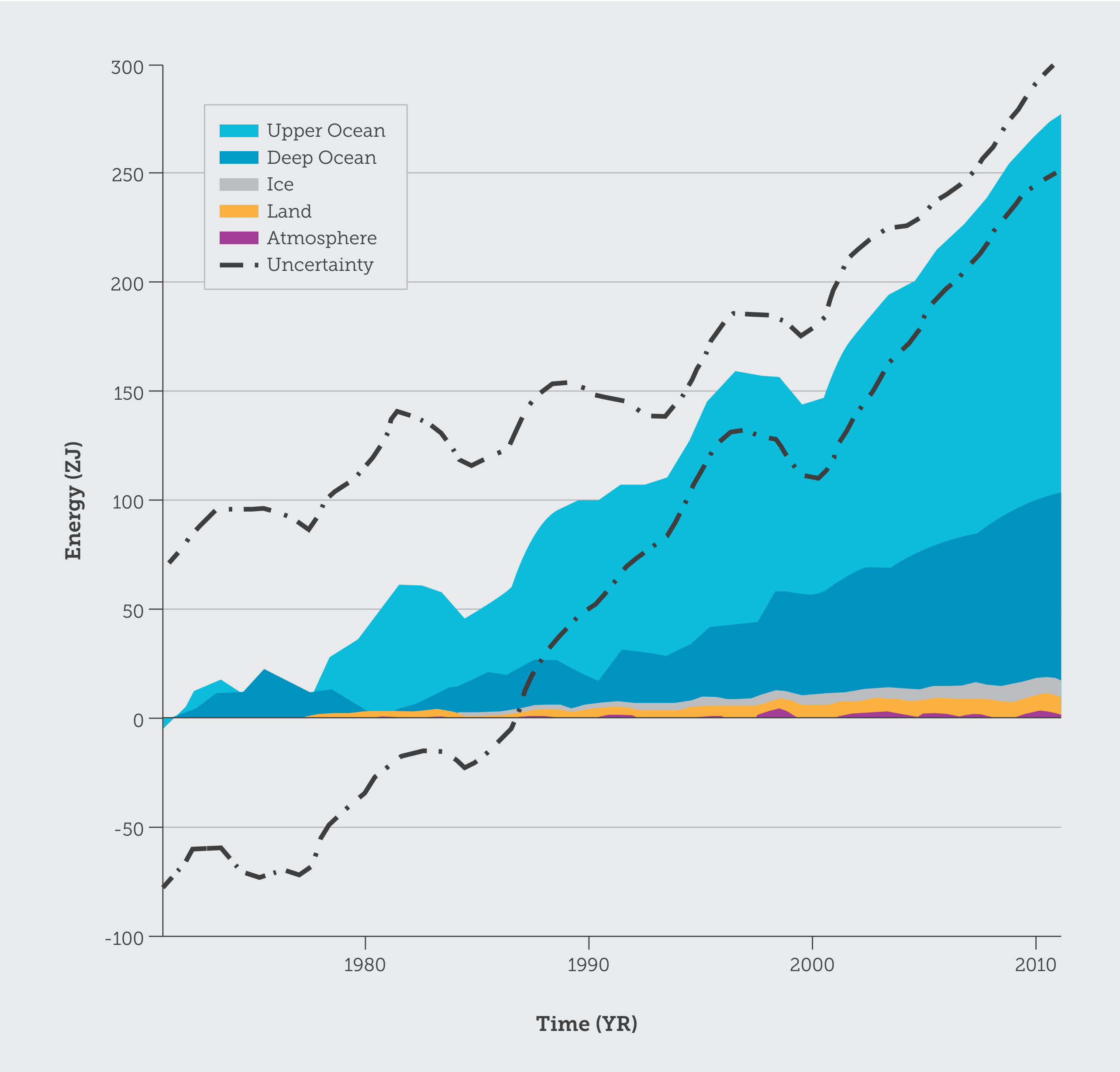

Figure 5: The ocean is warming strongly. Plot of energy accumulation in ZJ (1 ZJ is 10^{21} J (Joules)) within distinct components of Earth's climate system relative to 1971 and from 1971-2010 unless otherwise indicated. Ocean warming (heat content change) dominates, with the upper ocean (light blue, above 700 m) contributing more than the deep ocean (dark blue, below 700 m; including below 2000 m estimates starting from 1992). Ice melt (light grey, for glaciers and ice caps, Greenland and Antarctic ice sheet estimates starting from 1992, and Arctic sea ice estimate from 1979-2008); continental (land) warming (orange); and atmospheric warming (purple, estimate starting from 1979) make smaller contributions. Uncertainty in the ocean estimate also dominates the total uncertainty (dot-dashed lines about the error from all five components at 90% confidence intervals). **Source:** Rhein et al. 2013.

2.3 Changes in the Water Cycle

The focus here is on changes in precipitation averaged over global land areas (Figure 6), as this is important for availability of water for human societies. Averaged over the mid-latitudes of Northern Hemisphere land areas, precipitation has increased since 1901 and especially since 1951 (with high confidence). For other latitudes in both hemispheres, area-averaged, long-term trends in precipitation are difficult to discern with any confidence.

Global rainfall patterns are changing with rainfall increasing in some areas and decreasing in others.

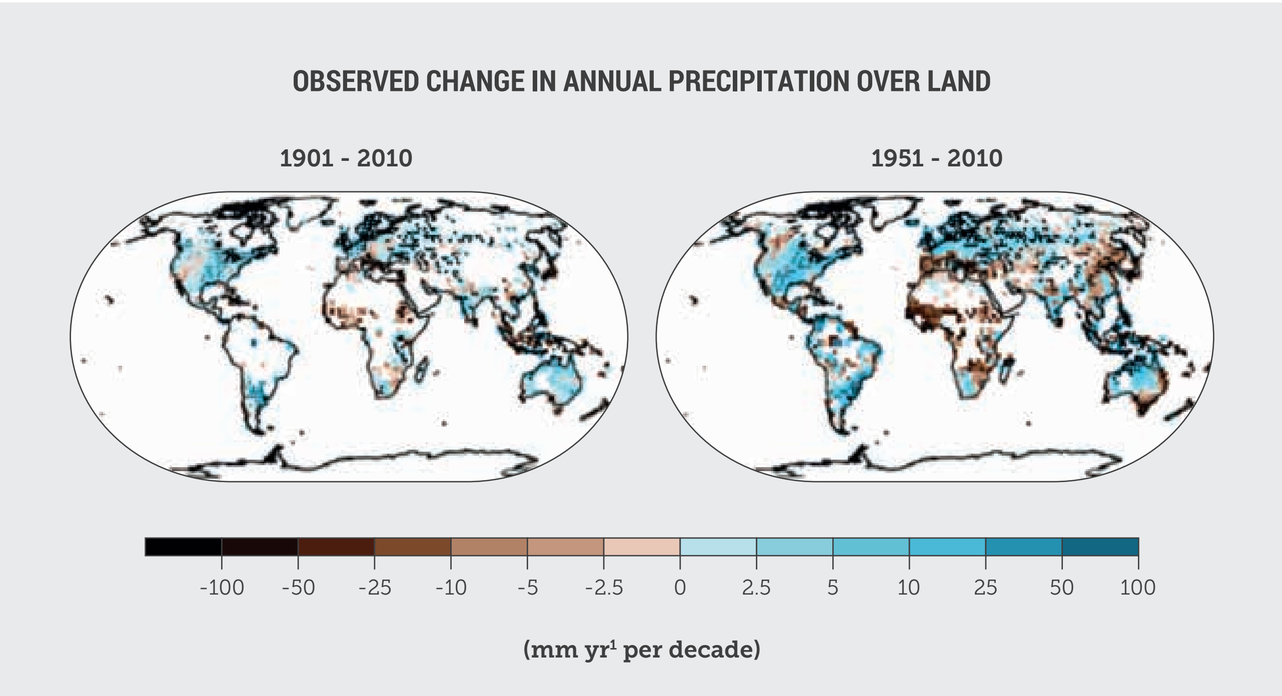

Figure 6: Maps of observed precipitation change from 1901 to 2010 and from 1951 to 2010 (trends in annual accumulation) from one data set. **Source**: IPCC 2013.

Changes in the water cycle are especially important for Australia, as our climate is prone to both extensive, prolonged droughts and heavy rainfall and associated flooding. Recent changes in precipitation patterns across Australia are shown in Figure 7 for the 1997-2013 period. Rainfall during October to April over this period was very much above average over large parts of the continent (Figure 7a); the period 2010 to 2012 recorded the highest 24-month rainfall totals for Australia as a whole. The trend of increased warm-month rainfall has become most apparent since the early 1970s, and has intensified since the mid-1990s.

In contrast, southern Australia has experienced a drying trend (Figure 7b) over the past few decades, characterised by a 10-20% reduction in cool-season (April-September) rainfall. The reduction is most pronounced in southwest Western Australia from the late-1960s (IOCI 2011) and in southeast Australia from the mid-1990s. Climate change is likely a contributing factor to the observed rainfall declines via its influence in the southward shift of the rain-bearing fronts from the Southern Ocean, which normally account for much of the cool-season rainfall in southern Australia.

Southern Australia has experienced a drying trend over the past few decades, characterised by a 10-20% reduction in cool-season rainfall.

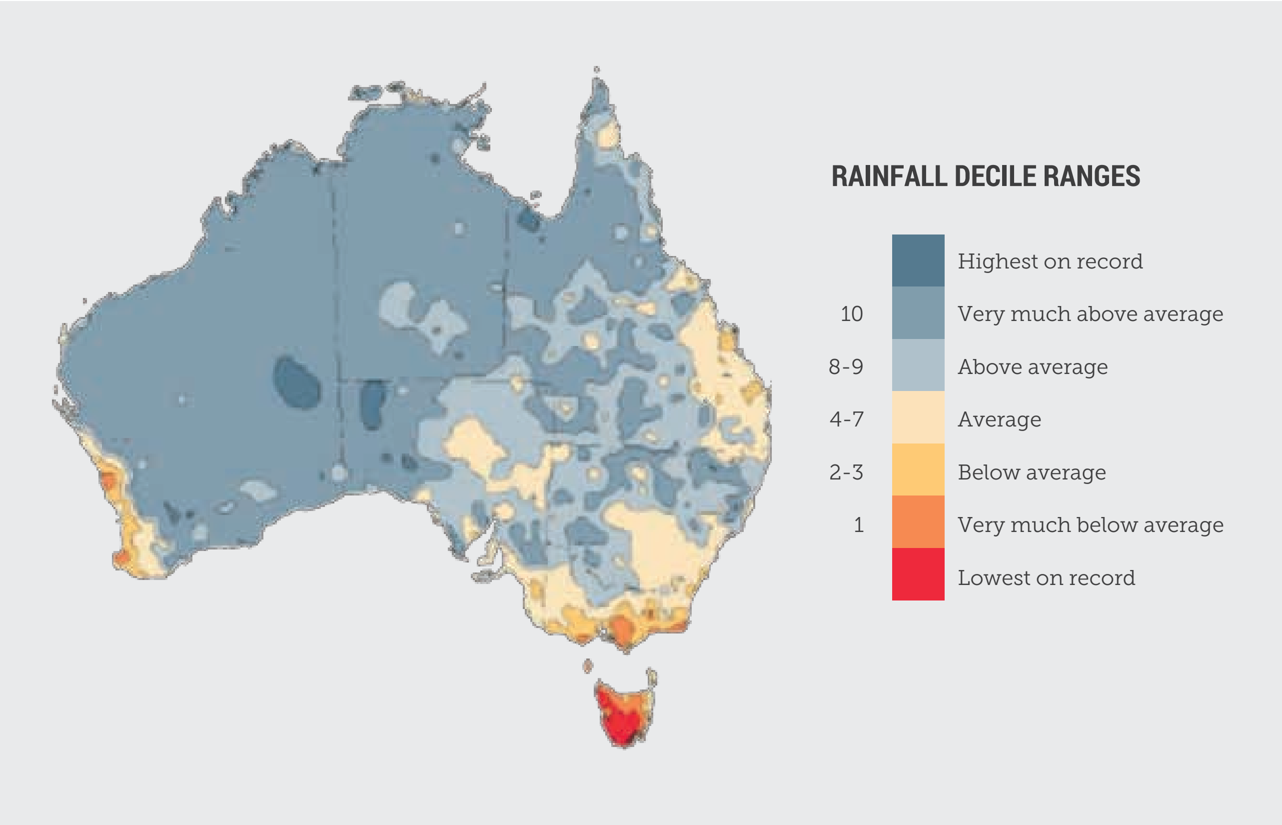

Figure 7a: Rainfall deciles for October to April (the Northern wet season) 1997 to 2013, relative to the reference period 1900-2013, based on AWAP data. **Source:** BoM 2014a, cited in CSIRO and BoM 2015.

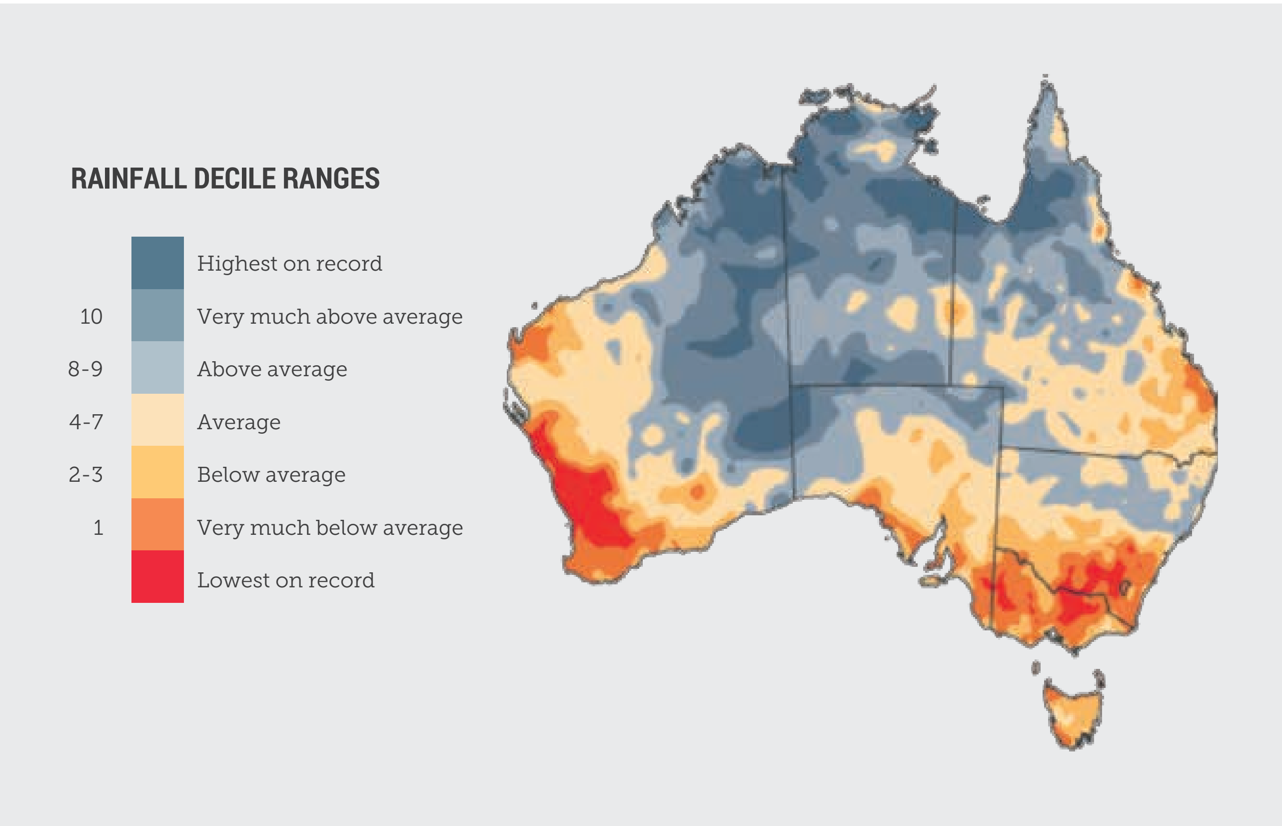

Figure 7b: Rainfall deciles for April to September (Southern wet season) 1997-2013, relative to the reference period 1900-2013, based on AWAP data. **Source:** BoM 2014a.

2.4 Change in the Cryosphere

The cryosphere comprises the frozen part of the climate system – the polar ice sheets, continental glaciers (e.g. Figure 8), sea ice, permafrost (frozen soil) and seasonal snow cover. As the Earth warms, an increasing loss of ice and frozen soil has become clear over the past several decades.

The average rate of ice loss from glaciers around the world was 226 Gt (billion tonnes) per year from 1971 to 2009, increasing to 275 Gt per year in the period 1993-2009. The average rate of ice loss from the large polar ice sheets has increased sharply over the past two decades, with important consequences for sea-level rise (Section 2.5). Ice loss from Greenland has risen substantially, from 34 Gt per year in the 1992-2001 period to 215 Gt per year in the 2002-2011 period, an increase of more than six-fold, while the net losses from the Antarctic ice sheet over the comparable periods were 30 and 147 billion tonnes per year, respectively (Figure 9). The extent of Northern Hemisphere snow cover has decreased since the mid-20th century, permafrost temperatures have increased in most regions since the early 1980s, and a considerable reduction in permafrost thickness and areal extent has been observed over the period 1975-2005 in the Russian European North.

Figure 8: the Athabascan Glacier in the Canadian Rockies.

Ice loss from Greenland has increased more than six-fold between 1992 and 2001.

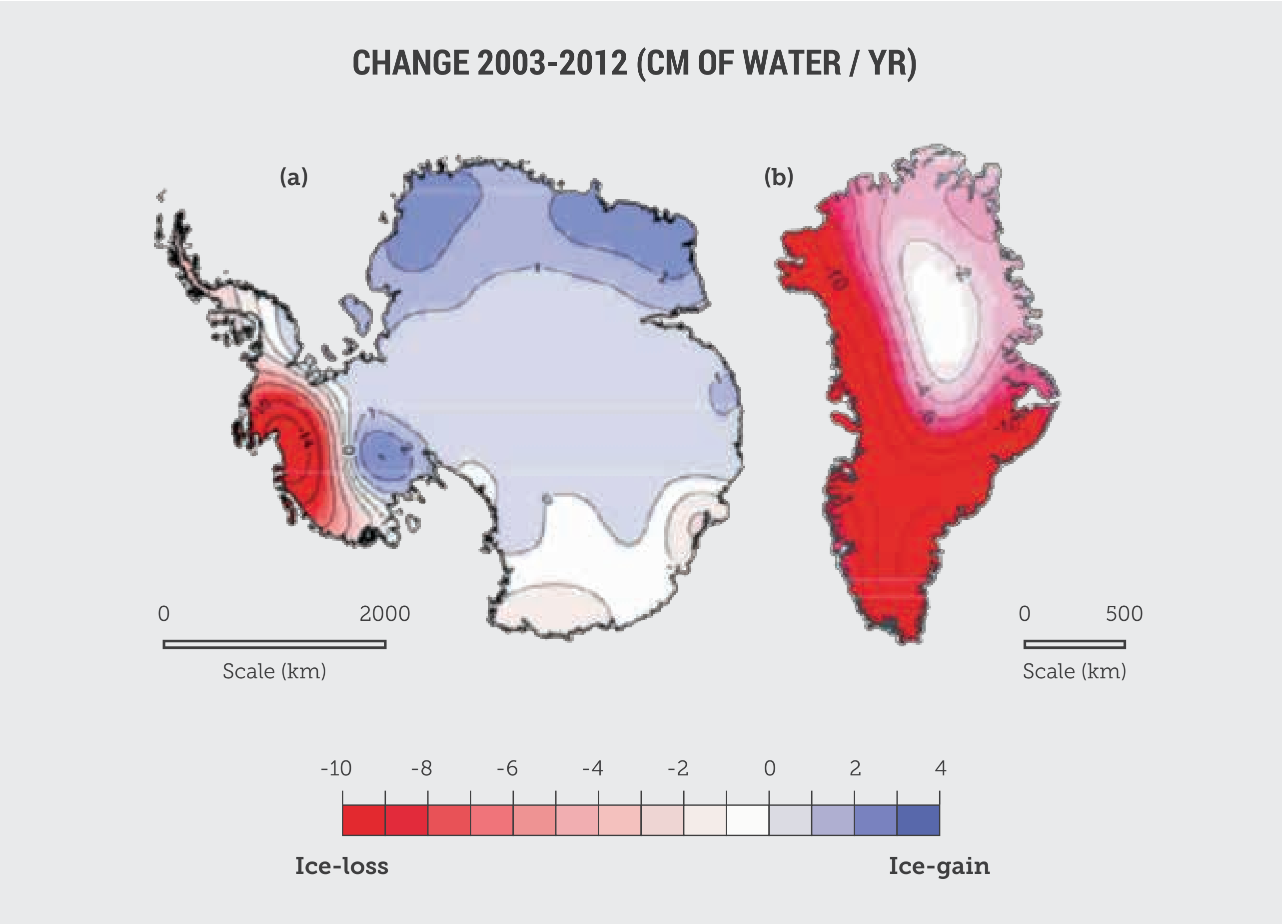

Figure 9: Substantial ice loss from Greenland and Antarctica. Distribution of ice loss for (a) Antarctica and (b) Greenland shown in cm of water per year (cm of water yr-1) for the period 2003 to 2012. **Source:** Stocker et al. 2013.

The annual average extent of Arctic sea ice – ice floating on the surface of the Arctic Ocean – decreased by 3.5-4.1% per decade over the 1979-2012 period, and the summer sea ice minimum, which represents perennial ice, decreased by 9.4-13.6% per decade over that period. Based on comparisons with palaeo-climate data, Arctic sea ice retreat over the past three decades was unprecedented in at least the last 1,450 years. By contrast, there has been a slight increase (1.2 to 1.8% per decade) in sea-ice extent around Antarctica over the 1979-2012 period. There are, however, strong regional differences around Antarctica in terms of where the ice-free season has lengthened and where it has decreased. Data are inadequate to make any assessment of changes in sea-ice thickness and volume.

The changes in sea-ice extent in both the Arctic (Figure 10) and Antarctic are consistent with a warming planet. In the Arctic region, which has been warming at a rate considerably greater than the global average, loss of sea-ice in summer increases the area of darker ocean water, in turn leading to an increase in absorption of sunlight that further enhances regional warming and loss of sea ice, thus forming a reinforcing feedback loop. In the Antarctic region, the small increases in sea-ice extent are due to changes in ocean circulation and the freshening of surface waters from continental ice melt and runoff, both of which are consistent with warming.

Arctic sea ice retreat over the past three decades was unprecedented in at least the last 1,450 years.

Figure 10: Arctic sea ice melt.

2.5 Sea-level Rise

Sea level is rising due to increasing ocean heat content and consequent thermal expansion as well as loss of water from land-based ice sheets and glaciers to the ocean. Over the period from 1901 to 2010, global average sea level rose by 0.19 m (Figure 11). It is likely that the average rate of sea-level rise between 1901 and 2010 was 1.7 mm per year, increasing to 3.2 mm per year between 1993 and 2010.

Since the early 1970s, glacier mass loss and the thermal expansion of the ocean are the most important factors driving the observed sea-level rise, with the loss of polar ice from Greenland and Antarctica increasing in importance since the 1990s.

Sea-level rise around Australia was, on average, 2.1 mm per year for the 1966-2009 period and 3.1 mm per year for the 1993-2009 period, close to the global averages (White et al. 2014).

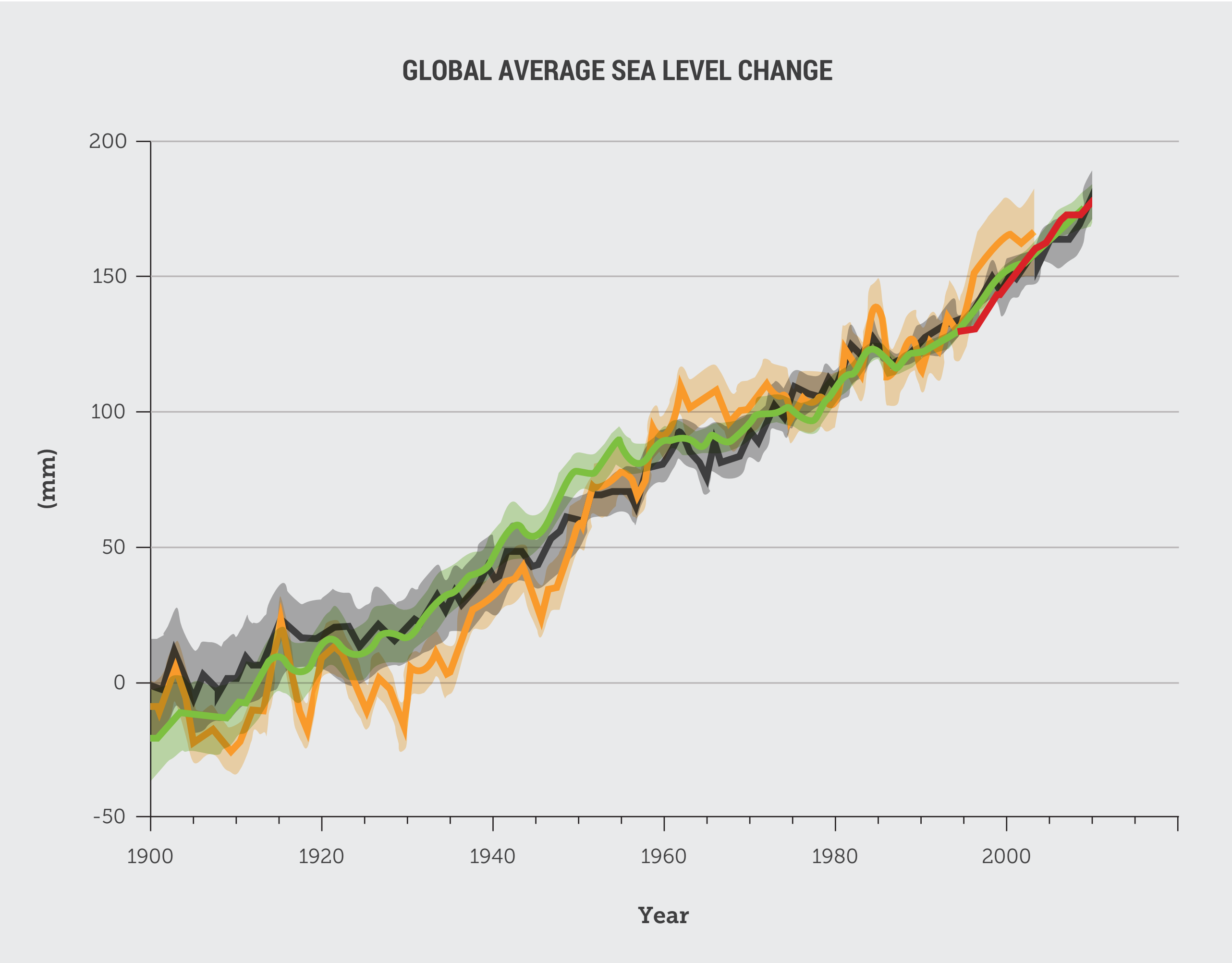

Figure 11: Global mean sea level relative to the 1900-1905 mean of the longest running data set, and with all data sets aligned to have the same value in 1993, the first year of satellite altimetry data. All time series (coloured lines indicating different time series) show annual values, and where assessed, uncertainties are indicated by coloured shading. **Source:** IPCC 2013.

2.6 Extreme Weather Events

Changes in extreme weather events are critically important in terms of risks to our health, communities, infrastructure, economy, livelihoods, and natural ecosystems. Climate change is making many types of extreme weather events more frequent and severe. The influence of climate change on the frequency and severity of many extreme weather events is shown in Table 1, including the level of confidence that human influence on extreme weather is already discernible.

Terms used by the IPCC to describe the likelihood (probability) of an outcome:

Virtually certain	99-100%
Very likely	90-100%
Likely	66-100%
About as likely as not	33-66%
Unlikely	0-33%
Very unlikely	0-10%
Exceptionally unlikely	0-1%

The IPCC also uses "high, medium and low confidence" to describe the confidence in the validity of a finding.

Table 1: Extreme weather and climate events: global-scale assessment of recent observed changes, human contribution to the changes, and projected changes for the future (based on IPCC (2013), Table 1 Summary for Policy Makers).

Extreme event	Observed change	Human contribution	Projected change 2016-2035	Projected change 2081-2100
Warm spells/ heatwaves	Increased frequency and intensity over most land areas (medium confidence)	Likely	Further increases likely	Further increases virtually certain
Heavy precipitation events	Increase in frequency and amount of heavy precipitation: likely more land areas with increases than decreases	Medium confidence	Further increases likely over many land areas	Further increases very likely over most of the mid-latitude land masses and over wet tropical regions
Drought	Increases in intensity and/or duration of drought likely in some regions: low confidence on a global scale	Low confidence	Low confidence	Likely (medium confidence) on a regional to global scale
Tropical cyclones	Increase in intense tropical cyclone activity virtually certain in North Atlantic since 1970 but low confidence in changes elsewhere	Low confidence	Low confidence	Increase in intense cyclone activity more likely than not in Western North Pacific and North Atlantic
Extreme high sea-level events	Increased incidence and magnitude of extreme high sea-level events likely since 1970	Likely	Further increases likely	Further increases very likely

Many changes in extreme weather events have been observed since about 1950 on a global scale. It is likely that the frequency of heatwaves has increased in large parts of Europe, Asia and Australia. There are likely more land areas where the number of heavy precipitation events has increased than areas where it has decreased. The frequency and/or intensity of heavy precipitation events has likely increased in North America and Europe. It is virtually certain that intense tropical cyclone activity has increased in the North Atlantic region since 1970.

Changes in extreme weather events have also been recorded in Australia (Table 2). Heatwaves are becoming hotter, lasting longer and occurring more often in many regions across the continent (Perkins and Alexander 2013). Since 2001 the number of extreme heat records has outnumbered extreme cool records by almost 3 to 1 for daytime maximum temperatures and almost 5 to 1 for night-time minimum temperatures. Very warm months have increased five-fold in the past 15 years.

High fire danger weather is worsening in the southeast of the country. The Forest Fire Danger Index (FFDI) increased significantly at 16 out of 38 measuring stations, with no stations showing decreases, over the period 1973 to 2010; stations showing significant increases in FFDI are concentrated in the southeast. Extreme sea-level events have tripled at Sydney and Fremantle since the middle of the 20th century (Church et al. 2006).

Table 2: Extreme weather and climate events in Australia: assessment of recent observed changes, human contribution to the changes, and projected changes for the future. **Sources:** CSIRO and BoM (2015)[1], references therein, and other references noted in this report.

Extreme event	Observed change	Influence of climate change	Projected change for the future
Extreme heat: hot days and heatwaves	Since 2001 extreme heat records have outnumbered extreme cold records by 3:1. Very warm months have increased 5-fold in last 15 years. From 1971-2008, duration and frequency of heatwaves has increased. The hottest days have become hotter	Increase of mean temperature stacks the odds towards more extreme heat	Further increases very likely: more frequent and hotter hot days; longer and more severe heatwaves
Bushfire weather	Forest Fire Danger Index (FFDI) was originally on a scale 0 to 100. After the 'Black Saturday' fires in Victoria in 2009, the FFDI was revised and the category 'Catastrophic' (FFDI>100) was added	Increase in extreme heat and increasing incidence of high fire danger weather	Longer and hotter fire seasons in southern and eastern Australia
Heavy precipitation events	Little evidence of changes to date, but expected changes in the future	Warming climate increases evaporation and water vapour content in atmosphere	Extreme rain events likely to become more intense
Drought	Still dominated by natural variability in general; however, recent Millennium Drought (1996-2010) was likely influenced by drying trend in southeast since mid-1990s in the cooler months. Pronounced drying trend in southwest Western Australia since late-1960s in the cooler months	Likely climate change influence in drying trends in SW and SE Australia via southward shift of frontal systems from Southern Ocean in cooler months and intensification of sub-tropical ridge	Increase in time in drought in southern Australia, with greater frequency of severe droughts. Possible increase of time in drought and severity of droughts elsewhere
Tropical cyclones	No clear trends in cyclone frequency or intensity (wind speeds) in the Australian region	No clear evidence of climate change influence yet	Increase in intense cyclone activity more likely than not in Australian region later this century; possible southward extension of storm tracks
Extreme high sea-level events	Incidence of extreme high sea-level events increased by factor of 3 at Sydney and Fremantle since mid-20th century	Higher sea levels raise the level of storm surge/high tide events relative to fixed infrastructure and property	Further increases likely

[1] See: http://www.climatechangeinaustralia.gov.au/en/.

2.7 Projections for the Future

Continued emissions of greenhouse gases will cause further warming and changes in all components of the climate system. Over the next decade or two, changes in the climate system are similar for all emissions scenarios but become distinctly different towards the end of this century. That is, in the longer term, the severity and rate of climate change will be strongly influenced by the level of greenhouse gases emitted from human activities from now onwards. More rapid and deep emissions reductions will limit the speed and magnitude of future changes to the climate system.

The rise in global average surface temperature for the period 2016-2035 relative to 1986-2005 will likely be in the range 0.3 to 0.7°C. Increases by 2081-2100 depend significantly on the amount of emissions (Figure 12). A very strong and rapid decarbonisation of the

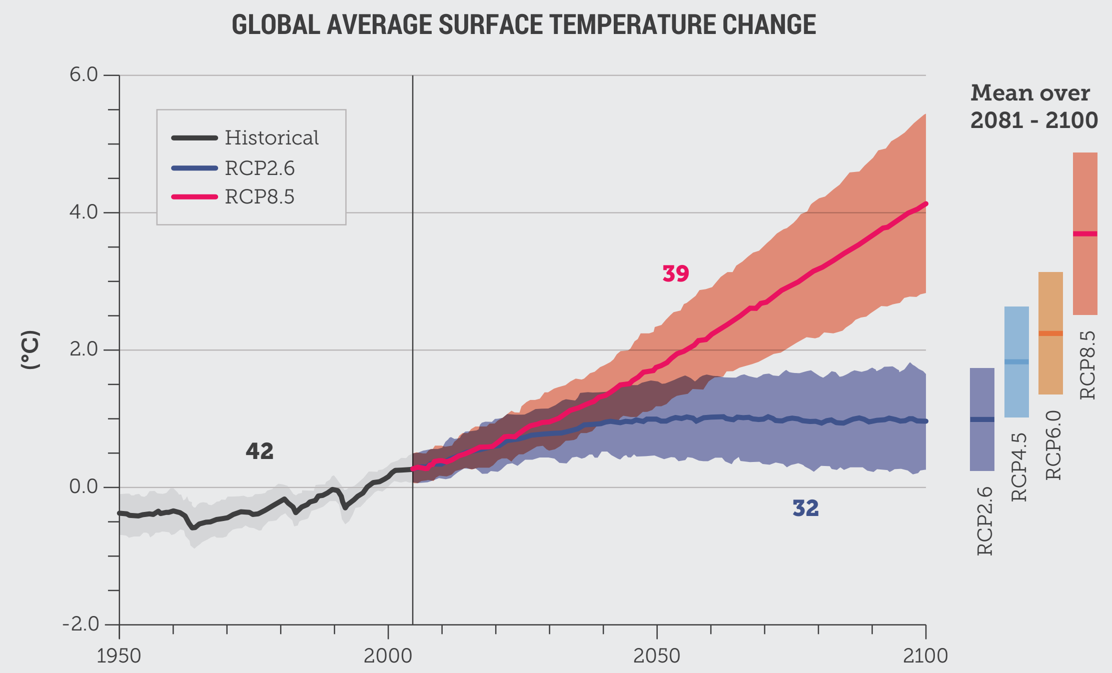

Figure 12: CMIP5 (Coupled Model Intercomparison Project) multi-model simulated time series from 1950 to 2100 for change in global annual mean surface temperature relative to 1986-2005. Time series of projections and a measure of uncertainty (shading) are shown for scenarios RCP2.6 (blue) and RCP8.5 (red). Black (grey shading) is the modelled historical evolution using historical reconstructed forcings. The mean and associated uncertainties averaged over 2081-2100 are given for all RCP scenarios as coloured vertical bars. The numbers of CMIP5 models used to calculate the multi-model mean is indicated. **Source:** IPCC 2013.

global economy, including net sequestration of carbon by 2100, could stabilise the climate system at a level between 0.3 and 1.7°C above the 1986-2005 average (0.9°C to 2.3°C above pre-industrial with a non-negligible chance of warming greater than 2°C above pre-industrial), while a business-as-usual (current trajectory) emission scenario could lead to additional temperature rises of 4°C or above by the end of the century and further rises beyond.

Most of the additional energy in the climate system will be stored in the world's oceans, which will continue to warm until an equilibrium is reached centuries after greenhouse gas emissions are reduced and then eliminated. Heat will continue to penetrate from the surface to the deeper levels and the ocean circulation will be modified by changes to the ocean's heat budget and salinity. Land areas will warm substantially more than the oceans, and somewhat more than the global average.

There is very high confidence in continued increases of average, daily minimum and daily maximum temperatures throughout this century for all regions of Australia (Figure 13). By 2030 Australian annual average temperature is projected to increase by 0.6 to 1.3°C above the 1986-2005 average (1.2 to 1.9°C above pre-industrial). By the end of the century, annual average temperature is projected to increase by 0.6 to 1.7°C (1.2°C to 2.3°C above pre-industrial) for a scenario with rapid and deep emission reductions, but by 2.8 to 5.1°C (3.4 to 5.7°C above pre-industrial) for a business-as-usual emissions scenario. Projected warming is expected to be greater than the average in inland Australia and less than the average in coastal areas. There is very high confidence that sea surface temperatures around Australia will continue to rise. Overall, temperature change across Australia and surrounding oceans is projected to be slightly more than the global average.

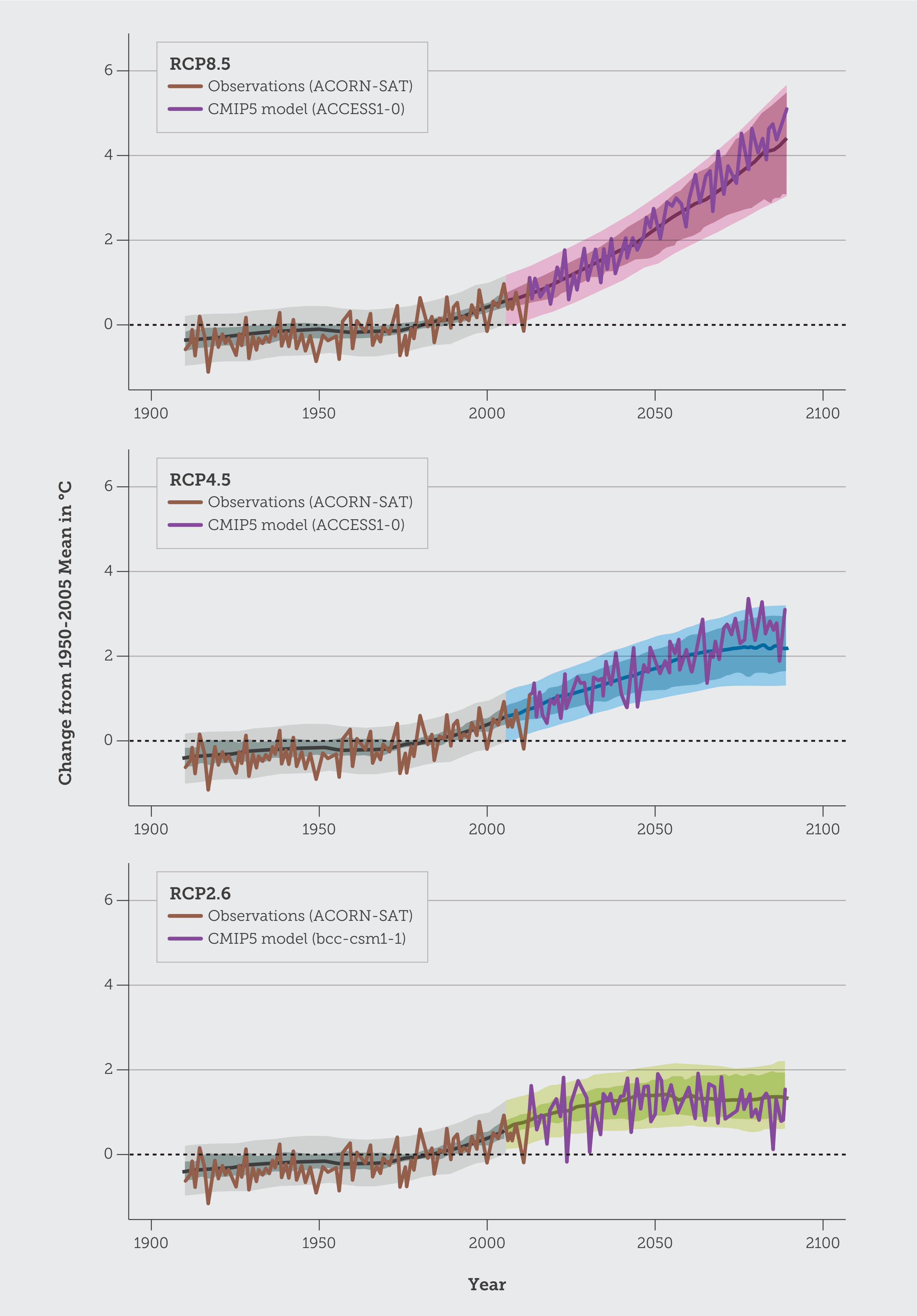

Figure 13: Time series for Australian average temperature for 1910-2090 as simulated in CMIP5 (Coupled Model Intercomparison Project), relative to the 1950-2005 mean. The central line is the median value, and the shading is the 10th and 90th percentile range of 20-year running means (inner) and single year values (outer). The grey shading indicates the period of historical simulation while three future emission scenarios are shown with colour-coded shading: RCP8.5 (purple), RCP4.5 (blue) and RCP2.6 (green). ACORN-SAT observations are shown in brown and simulations of future climate projections from Australia's national climate model (ACCESS) are shown in light purple. **Source:** CSIRO and BoM 2015.

Changes in the global water cycle over the 21st century will not be uniform across the globe. The contrast in precipitation between wet and dry regions and between wet and dry seasons will increase, although there may be regional exceptions. Another way of saying this is that dry areas will tend to become drier, and wet areas wetter.

In Australia there is high agreement amongst models that cool-season rainfall is likely to decline across the southern part of the continent, with winter decreases of as much as 50% for southwest Western Australia. The direction and magnitude of rainfall change in other seasons in southern Australia, and across the rest of the continent in all seasons, are uncertain. In particular, the outlook for northern Australia is very uncertain, in part because of the uncertainty in the response of ENSO (El Niño-Southern Oscillation) to climate change.

It is very likely that Arctic sea ice cover will continue to shrink and thin and that Northern Hemisphere spring snow cover will decrease during the 21st century. The amount of ice in the world's glaciers will decline further, contributing to the rise in sea level.

Global average sea level will continue to rise during the 21st century (Figure 14). Under all emission scenarios, the rate of sea-level rise will very likely exceed the rate observed during the 1971-2010 period due to increased ocean warming and increased mass loss from glaciers and ice sheets. The ranges given in Figure 14 are likely ranges, and by the end of the 21st century even larger rises are possible if marine-based sectors of the Antarctic ice sheet collapse. Sea-level rise will continue for centuries after 2100, and some potentially major contributions to sea-level rise, such as the loss of much of the Greenland ice sheet, are essentially irreversible on human timeframes.

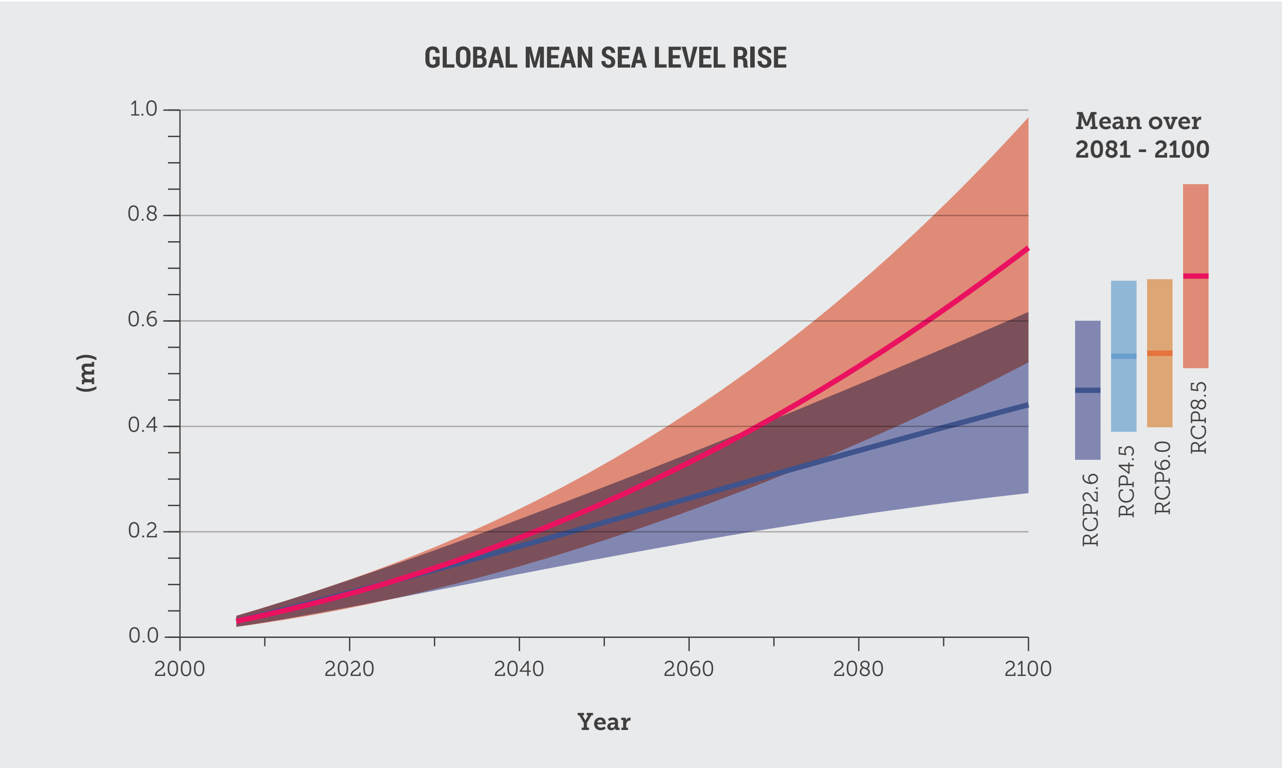

Figure 14: Projections of global mean sea-level rise over the 21st century relative to 1986-2005 from the combination of the CMIP5 ensemble with process-based models, for RCP2.6 and RCP8.5. The assessed likely range is shown as a shaded band. The assessed likely ranges for the mean over the period 2081-2100 for all RCP scenarios are given as coloured vertical bars, with the corresponding median values given as a horizontal line. **Source:** IPCC 2013.

The projections for sea-level rise for Australia are similar to the global projections. Australian sea levels are projected to continue to rise through the 21st century at a rate faster than that over the past four decades or over the 20th century as a whole, under any likely greenhouse gas emission scenario.

Globally, it is very likely that heatwaves will occur more frequently and last longer. Extreme precipitation events over most of the mid-latitude land masses and over wet tropical regions will likely become more intense and more frequent by the end of the century.

Projections for Australia indicate, with considerable confidence, that many extreme weather events will become worse through this century. More frequent and hotter hot days are expected as the century proceeds (very high confidence). Extreme rain events are projected to become more intense (high confidence). Time in drought is projected to increase in southern Australia (high confidence), with a greater frequency of severe droughts (medium confidence). Southern and eastern Australia are projected to experience harsher fire weather (high confidence). Tropical cyclones may occur less often but become more intense (medium confidence), and could reach further south (low confidence). Extreme sea-level events are very likely to increase (high confidence).

3. THE RISKS OF CLIMATE CHANGE FOR AUSTRALIA

The changes in the climate system described in the previous section pose serious risks across every sector of our society, with significant and costly impacts already being observed in virtually all regions of the country. These risks will continue to increase over the coming decades and beyond, with the level and severity of the risks in the second half of the century dependent on how successful we are in decarbonising the global economy in the next 20-30 years. Without effective climate policy and action, the projected impacts from the worst-case scenario towards the end of the 21st century is staggering, threatening the viability of our way of life.

In the sections below we outline the impacts that climate change is already having, and the risks that it poses in the future, for health, security, the economy, urban areas, regional Australia and natural ecosystems. We then present an analysis of the impacts and risks of climate change for Australia in a global context; this analysis underscores the compelling case for stabilising the climate system at a temperature rise of no more than 2°C above pre-industrial.

3.1. Climate Change and Health

We face significant risks to health, well-being and survival from climate change (Table 3). Although our health care system can protect us to some extent from these risks, the impacts of climate change are already being felt, and the risks will rise as the severity of climate change increases, with associated costs.

Table 3: Summary of health risks of climate change for Australians.

Event	Examples of health effects	People most affected (see section 4)
Higher temperatures	› Higher incidence of allergies caused by pollen. › Higher incidence of mosquito-borne diseases. › Higher incidence of food and water borne diseases.	- Those with existing illnesses - Those in hotter climates - Children
Heatwaves	› Higher incidence of heat-related illnesses, such as exhaustion, heatstroke and acute renal failure. › Exacerbation of existing health conditions, such as predisposition to heart attack and kidney disease. › Higher incidence of mental and behavioural disorders. › More premature deaths.	- Those with existing illnesses - City dwellers - Low-income households - Outdoor workers - Older Australians - Indigineous communities - Tourists - Obese and overweight people - Children
Bushfires	› More injuries burns and accidental death. › Higher incidence of respiratory illness, such as asthma attacks. › Higher incidence of mental health problems, including trauma and longer-term disruptions to social systems.	- Rural, urban-fringe and other fire-prone communities - Indigenous communities - Children - Older Australians
Long-term drought / decreased rainfall	› Higher incidence of mental health problems, including suicidal behaviour, from loss of income and moral and disruptions to social systems. › Reduced access to fresh healthy food from reduced food yield. › Higher incidence of illness from contamination of water supplies and reducd hygiene due to water shortage.	- Rural communities - Indigenous communities - Low-income households - Children
Flood / increased rainfall	› More injuries, drowning and other accidnetal deaths. › Higher incidence of infectious disease, such as from contamination of food and water supplies. › Increased risk of respiratory illness from mould.	- Rural communities - Children
Extreme weather events	› More injuries and death. › Higher incidence of mental health problems. › Exacerbation of existing illnesses from reduced access to health care. › Reduced access to fresh, healthy food and clean water.	- Emergency workers - Children - Rural communities - Older Australians - Tourists - Low-income households - Coastal communities

Source: Climate Commission 2011.

Increased incidence of extreme heat associated with the rise in average temperature has a clear impact on human health. Extreme heat has caused more deaths than any other natural hazard across Australia over the past 100 years (Coates 1996). Over the past four decades there has been a steady increase in the number of deaths in summer, compared to those in winter, in Australia, indicating that warming is already affecting mortality rates (PwC 2011; Bennett et al. 2013). For example, a severe heatwave in Melbourne in late January-early February 2009, during which maximum temperatures rose to the mid-40s for three consecutive days and night-time temperatures remained unusually high, led to an estimated 374 more deaths than would normally be expected at that time of year (DHS 2009; Figure 15).

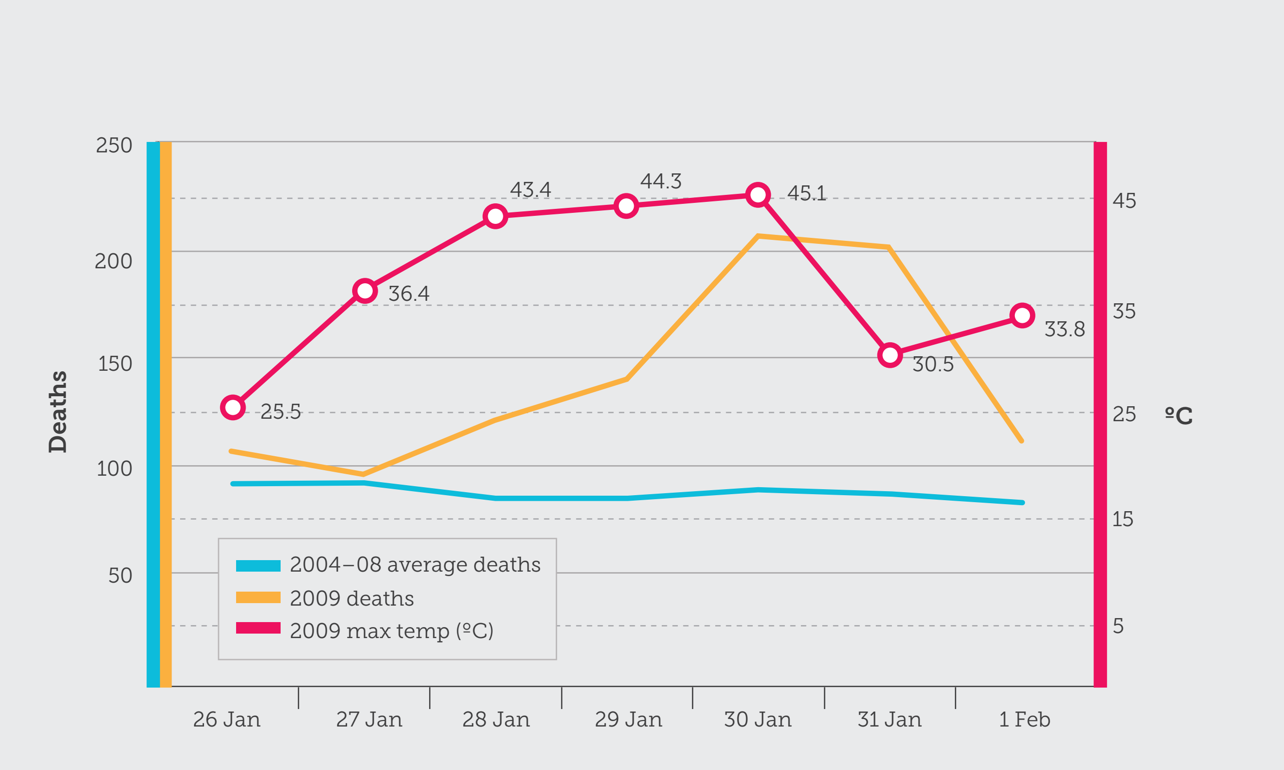

Figure 15: Mortality and temperature during the 2009 Melbourne heatwave. This graph shows the relationship between prolonged periods of higher temperature and death rates over the same period. **Source:** adapted from DHS 2009.

Increasing extreme heat is already affecting mortality rates.

Other capital cities have also suffered the impacts of extreme heat. Deaths in Brisbane increased by 23% during the 7-26 February 2004 heatwave (Tong et al. 2010). During the heatwave of January 1994, Sydney recorded 110 excess heat-related deaths (Gosling et al. 2007). Human heat exposures can escalate as urban infrastructure is also affected by the hot conditions, with power blackouts and extended waiting times arising from surges in ambulance call-outs (QUT 2010). Without adaptation, heatwaves may cause more than 6000 additional deaths (or more than 400 deaths annually) by 2050 in Victoria alone (Keating and Handmer 2013). Overall, deaths from heatwaves in Australian cities are projected to double over the next 40 years (PWC 2011).

Deaths from heatwaves in Australian cities are projected to double over the next 40 years.

The number of hot days when outdoor labour becomes dangerous is also projected to increase substantially by 2070, with considerable associated costs due to lost productivity and increased hospitalisations (Hanna et al. 2011; Maloney and Forbes 2011; AAS 2015). Only 41% of fully acclimatised Australian workers can operate at or near full capacity on days over 35°C, and nearly a third perform at less than 70% capacity (Hanna and Davis 2015). Further warming will amplify Australia's existing summertime productivity decline. Acclimatisation can offer some heat protection, but there are physiological limits to human capacity to thermoregulate (Hanna and Tait 2015). Increasingly hot summers will therefore risk more lives among those unable to secure cooled environments.

Beyond the direct effects on health, extreme heat also has important indirect effects, for example, by increasing the risk of severe bushfires. The Black Saturday bushfires in Victoria in 2009, which occurred during the Melbourne heatwave described above, resulted in 173 deaths and 414 injuries, ranking it as one of the world's ten most deadly bushfires in history (Teague et al. 2010; PoV 2010). Smoke from bushfires can also have significant health impacts. Cardiac arrests outside of hospitals have been reported to increase by 50% on bushfire smoke-affected days in Melbourne (Dennekamp et al. 2011). Asthma admissions in Sydney hospitals have been reported to rise by 12% on days of "smoke events" compared to non-smoke days (Martin et al. 2013). The trauma and stress of experiencing a bushfire can increase depression, anxiety and other mental health issues, both in the immediate aftermath of the fire and for months or years afterwards (McFarlane and Raphael 1984; Sim 2002; Whittaker et al. 2012).

Climate change increases the risk of severe bushfires, and consequent death and injury.

Other indirect impacts of extreme heat on health include: (i) power outages, which can lead to loss of air-conditioning and refrigeration, which in turn can lead to increase in harmful bacteria in food and to food poisoning; (ii) breakdowns in public transport, making it difficult for people to get to hospitals or cooler places; and (iii) increases in mental health problems in heat-stressed workers, such as aggression, confusion, psychological distress and behavioural change (Climate Council 2014b).

Serious health impacts can result from severe floods, a well-known consequence of extreme rainfall events that are occurring more often as a result of climate change. The massive floods in Queensland in 2010/2011, during which 78% of the state was declared a disaster zone, led to 33 deaths, widespread contamination of drinking water and food, and difficulties in accessing health services and treatments (QFCI 2012). Substantial increases in bacterial gastroenteritis are projected in the future; 205,000 to 335,000 new cases by 2050, and 239,000 to 870,000 cases by 2100, depending on the emission scenario (Bambrick et al. 2008; Harley et al. 2011).

The prospect of longer, hotter and drier droughts in the future has significant implications for mental health, especially in rural areas. Droughts are associated with increased incidence of suicide in rural populations, especially amongst male farmers (Page et al. 2002; Nicholls et al. 2006; Hanigan et al. 2012). Mental health impacts of drought are not confined to adults. Experience of drought is also associated with behavioural problems, stress, hyperactivity and difficulty in maintaining relationships in adolescents (Dean and Stain 2010).

Drought can also cause serious health impacts by reducing the availability and quality of water. For example, drought lowers water quantities in dams, thus increasing the concentration of pollutants and hotter temperatures can increase the growth of blue-green algae (Kjellstrom and Weaver 2009).

One of the most important indirect effects of climate change is its influence on the vectors that spread infectious diseases. Climate change affects the geographic distribution of mosquito-borne diseases such as malaria, dengue fever and tick-borne diseases (AAS 2015). Globally, the distributions of several diseases have changed in recent decades in association with changes in regional climate (IPCC 2014). In Australia, mosquito-borne diseases such as dengue fever are projected to extend their range and activity. A highly efficient disease vector that is capable of transmitting at least 22 different viruses, the Asian tiger mosquito (*Aedes albopictus*), is already widespread throughout the Torres

The number of Australians exposed to dengue fever could increase more than tenfold by 2100.

Strait islands and has been repeatedly detected at ports (Duncombe et al. 2013). Dengue is currently confined to northern Queensland, where outbreaks occur almost annually (Ritchie 2009; Russell et al. 2009). However, without effective action on climate change, the area suitable for dengue transmission will likely spread southwards, increasing the current number of Australians at risk of exposure from 430,000 today to between five and eight million by the end of the century (Bambrick et al. 2008; Åström et al. 2012), although changes in domestic water storage that can occur in response to urban water scarcity may have an even more important influence on disease incidence (Beebe et al. 2009; Kearney et al. 2009).

In summary, the impacts of climate change on health are already being felt, and are likely to get worse as time goes on (Figure 16). Without effective action on climate change, the risk of serious health impacts will increase sharply during the second half of the century.

Climate change action is crucial to protect Australians health in the long-term.

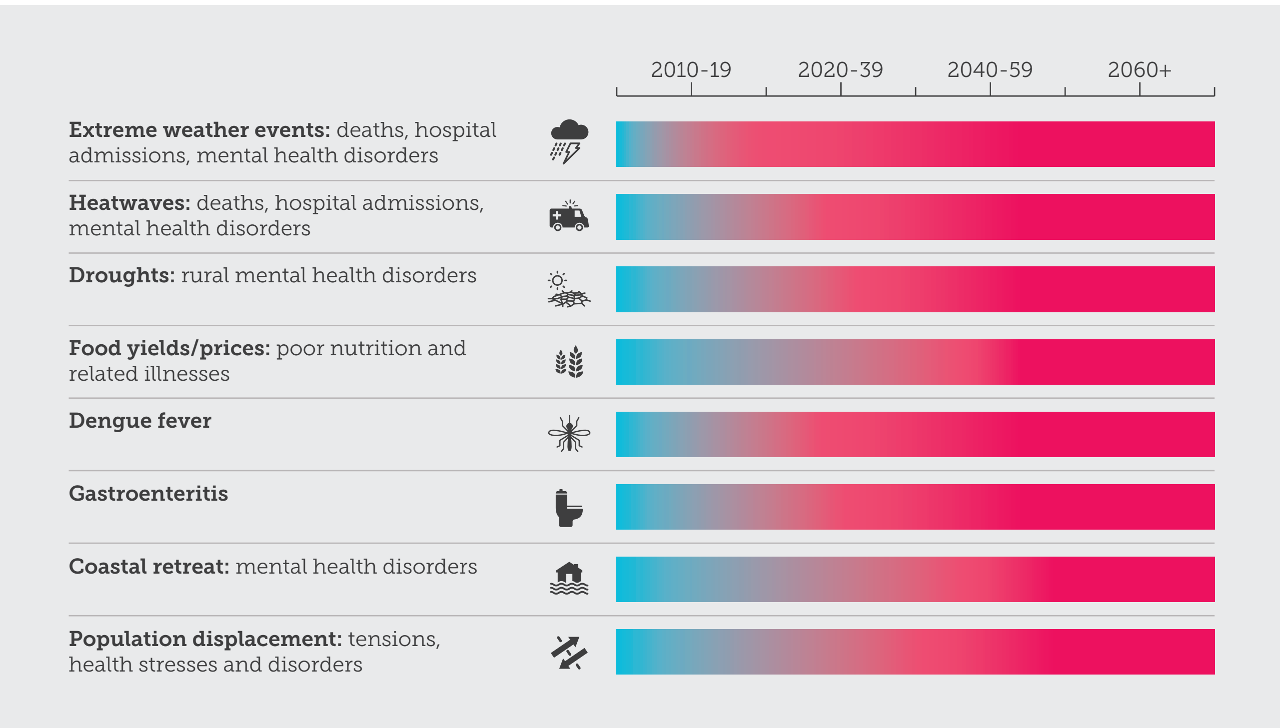

Figure 16: Possible timeline of some future adverse health impacts in Australia from climate change. **Source:** Climate Commission 2011; adopted from McMichael 2011 (unpublished).

3.2. Climate Change and Security

Human security is a condition that exists when human lives are protected, and when people have the freedom and capacity to live with dignity (Adger et al 2014). Climate change poses a threat to human security in a variety of ways including by undermining: health (Section 3.1), the economic conditions necessary for prosperity and poverty alleviation (Section 3.3), food and water systems, and critical infrastructure.

These impacts in turn amplify the risk of displacement, migration, and political tensions within and between countries (Adger et al. 2014). Climate change and its impacts will also have implications for the security sector, for example Defence forces are increasingly being called upon to assist with relief efforts following climate-related natural disasters (e.g. US Department of Defence 2014; Figure 17).

Figure 17: The US Army Assists with Pakistani Flood Recovery.

While the science of estimating the extent of future migration influenced by climate change cannot yet provide robust numbers (Barnett and O'Neill 2012), there is widespread agreement in the literature that increased displacement and migration as a result of future environmental changes and extreme climate events is likely (Adger et al. 2014).

For example, it is understood that some of the drivers of migration and displacement within and between states can be exacerbated by changes in climate and environmental conditions. Drought and land degradation, flooding, sea-level rise (Figure 18) and cyclones are all known factors in displacement and migration (e.g. Ballu et al. 2011; Dun 2011; Gila et al. 2011; McLeman 2013). Major extreme weather events have led to significant population displacement in the past, and projected future increases in the incidence of extreme events, such as extreme coastal flooding, are likely to amplify the risks of population displacement (Adger et al. 2014). A world that has warmed 4°C above pre-industrial levels (by 2100 or later), producing a 0.5–2 m sea-level rise, will expose between 1.2 and 2.2 million people from the Caribbean, Indian Ocean and Pacific Ocean to inundation (Nicholls et al. 2011).

In the Asia-Pacific region, increasing extreme weather puts people and communities at risk.

Figure 18: Coastal flooding on Saibai, Torres Strait Islands.

Figure 19: Cyclone Aila damage in Bangladesh.

In the Asia-Pacific region future changes in climate coupled with demographic and economic trends suggest that increased displacement and migration is likely. The region is one of the world's most disaster prone; in 2014 over half of the world's 226 natural disasters occurred here (UN 2014), and many of these were associated with episodes of population displacement. Over half of the urban population in Asia lives in low-lying coastal zones and flood plains that are highly exposed to the effects of climate change. Asia is also home to more than 90% of the global population that is exposed to tropical cyclones, with rising sea-levels magnifying the impact of storms (Hijioka et al. 2014). For example, in Bangladesh, rising sea-level increases saline intrusion, but also increases flooding associated with storms and cyclones. Cyclone Aila destroyed homes (Figure 19), infrastructure, land and livestock in 2009, forcing many Bangladeshi rural workers to migrate into urban areas following the destruction of their farms (Kartiki 2011).

The Pacific islands are also highly vulnerable to extreme weather events because many are low lying, remote and have limited disaster mitigation and adaptation capacity (Gero et al. 2013), although increasing extreme events in the region are much more likely to lead to internal (within country) crises rather than international migration. In the long term, the capacity of low-lying islands to sustain significant populations of people is at risk (Nurse et al. 2014).

Figure 20: A family crosses the flooded streets of Pakistan, 2010.

People displaced by violent conflict and/or extreme events are often highly vulnerable to further harm from climate change.

Displacement such as that driven by extreme weather events often undermines human security - migrants often have disrupted social networks, difficulty accessing work, social services, and natural resources, and tend to experience increased health problems (Barnett and O'Neill 2012; Adger et al. 2014). Thus people displaced by violent conflict and/or extreme events are often highly vulnerable to further harm from climate change (Barnett and Adger 2007) and under some circumstances migrants can increase the risk of violent conflict in places where they have sought refuge (Reuveny 2008).

Although there are many complex and interacting drivers of conflict that are not related to climate, there is "justifiable common concern" that climate change can increase the risk of armed conflict in certain circumstances (Adger et al. 2014), often acting as a "threat multiplier" that has the potential to make unstable conditions worse (e.g. MoD 2010; The White House 2015).

Climate change can increase the risk of armed conflict by exacerbating known risk factors such as poverty, economic shocks, and unstable state institutions (Adger et al. 2014). Importantly, poorly designed climate change mitigation and adaptation polices

Climate change is a 'threat multiplier'.

can also increase the risk of armed conflict through similar pathways. Furthermore, in recent years, extreme weather events such as heatwaves, droughts, floods and bushfires in major food producing countries have contributed to rising food prices (Garnaut 2011), affecting social and political stability (Barrett 2013). The 2008–2009 and 2010–2011 food price spikes may have also affected socio-political stability and contributed to food riots in the Middle East, and numerous African and Latin American countries. Research on climate change and armed conflict shows that a multitude of social factors, such as property rights institutions, mechanisms for conflict resolution, social protection, the availability of weapons, and the strength of civil society, all mediate between changing climatic conditions and violent outcomes, which in turn shows that both climate mitigation and adaptation are necessary to manage this risk (Adger et al. 2014).

Projected sea-level rise, coastline retreat and the eventual submergence of small low-lying islands may affect the maritime boundaries of nations and alter exclusive economic zones in which natural resources are located. This may intensify existing regional tensions and contribute to new disputes over access to natural resources (Houghton et al. 2010). Similarly, changing patterns of runoff in transboundary rivers may increase tensions between states (Adger et al. 2014). The availability of new resources may also have the potential to increase rivalry between nations. For example, since 1980, the Arctic has been warming at twice the global average, contributing to rapid sea ice decline. Melting sea ice makes Arctic waters easier to navigate, opening up new shipping routes, lengthening the shipping season and increasing access to significant oil and gas reserves (Adger et al. 2014). This could increase the risk of

Figure 21: The Australian Defence Force health facility provided primary health care to over 11,000 flood-affected people in Pakistan in 2010.

As extreme weather intensifies the Australian Defence Force will need to provide more humanitarian assistance at home and abroad.

potential disputes between nations over access to and exploitation of these reserves in the future (CNA 2014), although at present existing political institutions have succeeded in mediating these tensions (Ebinger and Zambetakis 2009).

In terms of climate-related natural disasters, Australian emergency services and the Australian Defence Force (ADF) are increasingly engaging in domestic and regional disaster assistance and humanitarian relief efforts. For example, Operation Pacific Assist was established in response to Tropical Cyclone Pam that devastated Vanuatu and the surrounding region in March 2015. More than 500 defence personnel were deployed to assist in the recovery (Australian Government 2015). In the wake of Typhoon Haiyan in the Philippines in 2013, the ADF evacuated over 3,500 internally displaced persons and moved thousands of tonnes of aid (Australia Government 2013). As the impact of extreme weather intensifies in the region, there will be increasing need for the ADF to coordinate with emergency services and provide more humanitarian assistance, both domestically and in Australia's neighbourhood. As the incidence of extreme weather events increases, the ADF may increasingly need to respond to multiple extreme weather events both in Australia and in the Asia-Pacific region simultaneously (Press et al. 2013; Figure 21 and 22).

Figure 22: Members of the Australian Defence Force in Malaysia, 2010.

3.3. Climate Change and the Economy

The impacts of climate change on the Australian economy have recently come into much sharper focus as the economic consequences of sea-level rise and coastal flooding, heat stress, prolonged drought and extreme weather events become better understood.

Most of our population lives in large cities on the coast, and much of our most critical infrastructure has been built on low-lying areas. More than $226 billion in commercial, industrial, road, rail and residential assets around the coast, mostly in urban areas, are potentially exposed to flooding and erosion hazards at a sea-level rise of 1.1 m (DCCEE 2011; Figure 23). Exposure is likely to increase as Australia's population grows to a projected 35 million people by mid-century.

Exposure to coastal flooding can be translated into projected economic damages as the sea level continues to rise. For example, in southeast Queensland, a current 1-in-100 year coastal flooding event risks damage to residential buildings of around $1.1 billion. With a 0.2 m rise in sea level, a similar flooding event would increase damages to around $2 billion, and a 0.5 m rise in sea level would raise projected damages to $3.9 billion (Wang et al. 2010).

The economic impacts of climate change are profound.

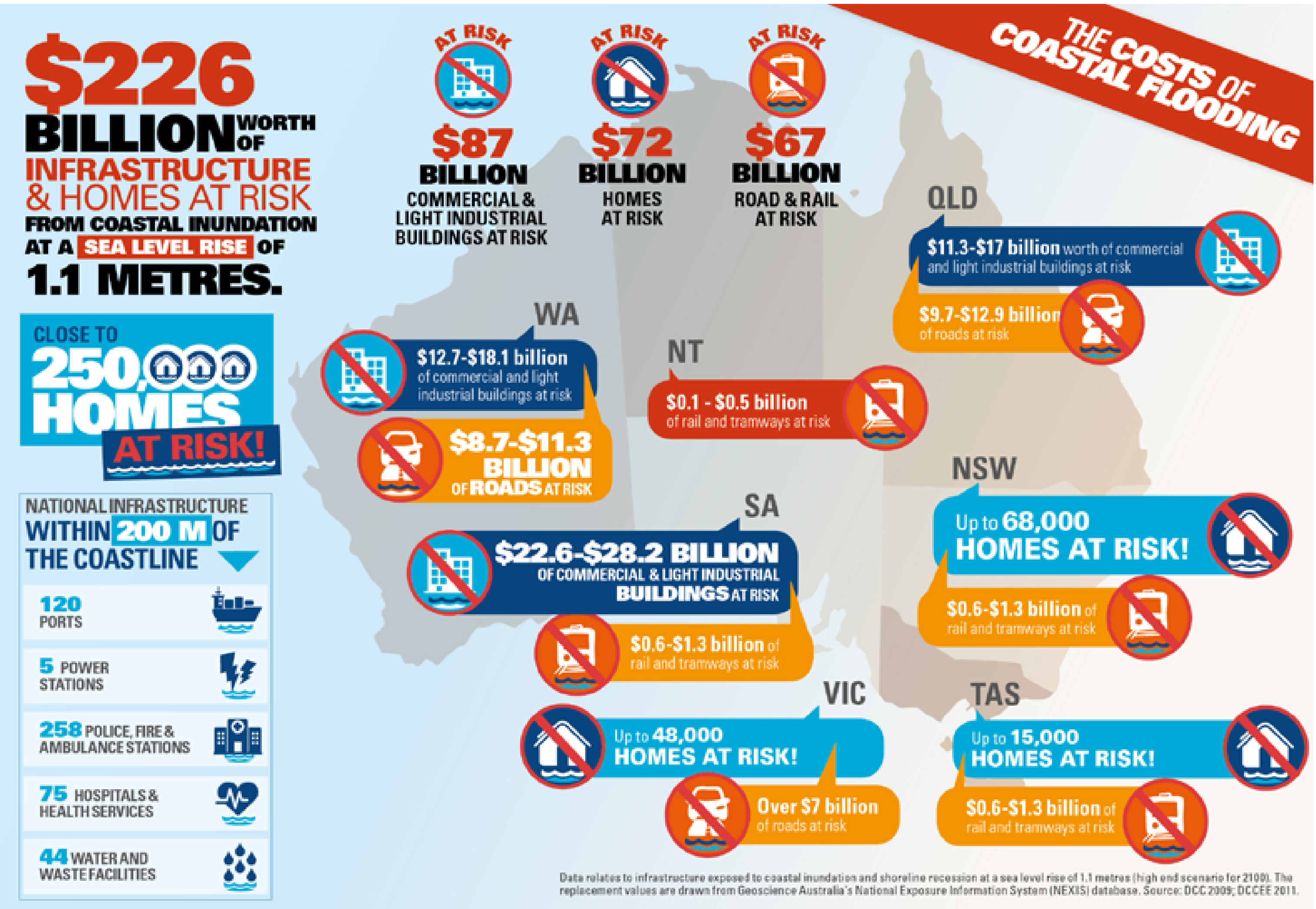

Figure 23: Counting the costs of coastal flooding in Australia. **Source:** Climate Council 2014a.

More than $226 billion of buildings and infrastructure are vulnerable to 1.1 m of sea-level rise.

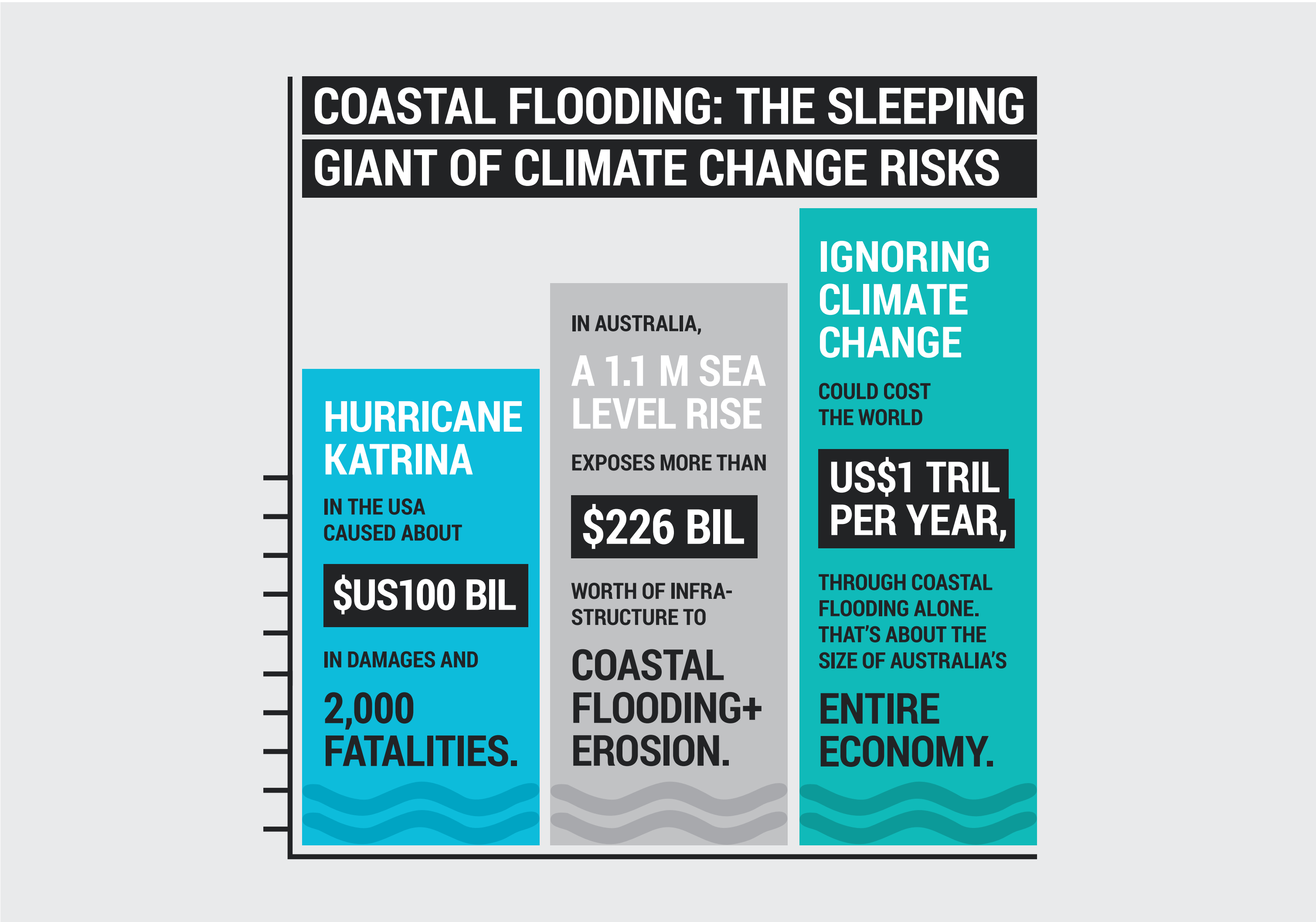

Figure 24: Coastal flooding: the sleeping giant of climate change risks. **Source:** Climate Council 2014a.

Climate change is expected to multiply the costs of coastal flooding.

The increasing incidence of coastal flooding as a result of rising sea level has been recognised as a sleeping giant in terms of its potential to wreak havoc on the global economy (Figure 24). By 2050 – without adaptation – the losses from coastal flooding globally are projected to rise to $US 1 trillion, about the current size of the entire Australian economy (Hallegatte et al. 2013). By 2100 the losses from coastal flooding are projected to be 0.3-9.3% of global GDP per year (Hinkel et al. 2014). The high-end projection is a scenario for global economic collapse.

Tropical cyclones and other storm systems, with their combination of high winds and heavy rainfall, can cause significant economic damages in addition to their direct impacts on health and well-being. Examples of the damages from specific extreme events over the past 15 years include:

- 2010-2011 Queensland floods and Cyclone Yasi: $6 billion (Queensland Government 2011; QFCI 2012; Figure 25)
- 2007 Pasha Bulker storm: $458 million (McDonald and Redford 2008; Verdon-Kidd 2010)
- 2006 Cyclone Larry: ca. $500 million (BoM 2014b)
- 2005 Cyclone Ingrid: $17 million (Queensland Government 2005; Northern Territory Government 2005; ABC 2005)
- 1999 Cyclone Vance: $108 million (2011 dollars) (AEM 2014).

Figure 25: A Queensland road damaged by the impacts of Cyclone Yasi.

One of the least known, but potentially most damaging, consequences of climate change for the economy is the impact of extreme heat on worker productivity through absenteeism and reductions in work performance. For example, the extreme heat of 2013/2014 in Australia drove an annual economic burden of nearly $8 billion in terms of productivity losses (Zander et al. 2015). Heat stress in northern Australia has already reduced labour capacity there by 10% over the past few decades, with a further 10% reduction projected during the hottest months by 2050 (Dunne et al. 2013). The loss of worker productivity globally due to heat stress is projected to be as much as US$1 trillion by 2030 (Kjellstrom and McMichael 2013).

In addition to their devastating impacts on health, bushfires can also result in very large economic losses (Table 4). During the period 1 July 1966 to 30 June 2013, insured losses due to bushfires totalled $5.6 billion (in 2011/12 dollars), or an annual loss of $120 million. In the decade up to 30 June 2013, the insured losses from bushfires were $1.6 billion, an average of $160 million per year (ICA 2013). These estimates do not take into account indirect costs, such as loss of life, social disruption, opportunity costs for volunteer fire fighters, impacts on health, costs of rebuilding and compensation (King et al. 2013b).

Extreme heat in 2013/2014 drove an annual economic burden of nearly $8 billion in terms of productivity losses.

Bushfires have been estimated to cost the Victorian agricultural industry about $42 million per year in direct damages and about $92 million per year when disruption to business is included (Keating and Handmer 2013). The costs of the Black Saturday fires in 2009 have been estimated to be about $4.4 billion (PoV 2010).

From 1966 to 2013 insured losses due to bushfires totalled $5.6 billion (in 2011/12 dollars), or an annual loss of $120 million.

Table 4: Recorded losses from major bushfire events in Australia since 1939.

Fire Event	Losses (direct deaths due to fire)[1]	Losses (including residential property, stock)	Significant Insured Losses (normalised to 2011 values)[2]
Black Friday, January 1939, Victoria	71 (AIC 2004; Reuters 2009)	1000+ homes (ABS 2004; AIC 2004)	N/A
Hobart, February 1967, Tasmania	62 (Reuters 2009; TBI 2013)	1300-1400 homes (McAneney et al., 2009; TBI 2013) 62,000 stock (TBI 2013)	$610 million (ICA 2013)
Ash Wednesday, February 1983, Victoria and South Australia	75 (AIC 2004; Reuters 2009; Stephenson et al., 2013)	> 2,300 homes (Ramsey et al., 1996; AIC 2004; McAneney et al., 2009; Stephenson et al., 2013) > 200,000 stock (Ramsey et al., 1996; AIC 2004; CFA 2012; Stephenson et al., 2013)	$1.796 billion (ICA 2013)
Sydney, NSW, January 1994	4 (Reuters et al., 1996; ABS 2001; NSW Ministry for Police & Emergency Services 2007)	> 200 homes (Ramsey et al., 1996; NSW Ministry for Police & Emergency Services 2007)	$215 million (ICA 2013)
Canberra & alpine fires, 2003	4 in Canberra (McLeod 2003); 4 in alpine (Stephenson et al., 2013) Major injuries: 52; Minor injuries: 338 (Stephenson et al., 2013)	> 500 homes (McLeod 2003; McAneney et al., 2009) including the Mt Stromblo Observatory (Pitman et al., 2007) > 17,000 stock (Stephenson et al., 2013)	$660 million (ICA 2013)
Black Saturday, February 2009, Victoria	173 (Teague et al., 2010, Stephenson et al., 2013) Major injuries: 130; Minor injuries: 670 (Stephenson et al., 2013)	> 2000 homes (CFA 2012; Stephenson et al., 2013) 8000-11,800 stock (Teague et al., 2010; Stephenson et al., 2013)	$1.266 billion (ICA 2013)
Tasmania, January 2013	0	203 homes (TBI 2013) 10,000 stock (TBI 2013)	$89 million in 2013 values (ICA 2013)
Blue Mountains, October 2013	0	208 properties (Whyte 2013)	$183 million as of 19.11.13 in 2013 values (ICA 2013)

[1] Only deaths attributed directly to fires are included, but it should be noted that other deaths associated indirectly with fires have occurred (e.g. deaths indirectly associated with NSW Blue Mountains fires in **2013** include one due to heart attack, and another due to a plane crash).

[2] Insured losses shown have been normalised to **2011** values (taking inflation, and wealth changes into account) except for **2013** fires (Tasmania and NSW).

Source: Climate Council 2013.

The economic impacts of drought are also extremely significant at the national level. Between 2002 and 2003, for example, decreases in agricultural production due to drought (e.g. Figure 26) resulted in a 1% fall in Australia's Gross Domestic Product (GDP), which is equivalent to half of Australia's decline in annual GDP following the global financial crisis in 2009 (World Bank 2015).

This decrease in production represented a 28% fall in the gross value added for the agricultural industry compared to the preceding year (ABS 2004). Between 2006 and 2009 the Millennium Drought (Figure 24) reduced national GDP by about 0.75% (IPCC 2014); aggregated over the 2002-2009 period the drop in GDP was 2.4 to 2.9% (van Dijk et al. 2013). The 1982-83 drought resulted in a loss of about $3 billion in agricultural production (ABARES 2012b), about a 1% fall in GDP (ABS 2004). From 2020, the predicted increase in drought frequency is estimated to cost $7.3 billion annually, reducing GDP by 1% per annum (Carroll et al. 2007).

Drought assistance also entails large economic consequences for Australian taxpayers. From 2002-2008 the government provided $1 billion in drought assistance to farmers (Productivity Commission 2009). From 1991 to mid-2010 the government had paid a total of $4.4 billion in drought assistance (ABARES 2012b).

Figure 26: South Australia in drought in 2008.

3.4. Climate Change and Urban Areas

Australia is one of the most urbanised countries in the world, with 89% of our population living in urban areas in 2014, with this proportion projected to grow to 92% by 2050 (UN 2014). Cities are obviously important for the reduction of greenhouse gas emissions, summarised by the oft-quoted statement that the challenge of climate change will be won or lost in the world's cities. The vulnerability of urban dwellers to the risks of climate change is already apparent, as shown by the impacts of heatwaves on health (Section 3.1).

Many of Australia's coastal cities are highly vulnerable to coastal flooding during storms, especially in terms of economic damages (Section 3.3). By the end of this century, with a business-as-usual greenhouse gas emissions scenario, the projected increases in coastal flooding frequency are startling (see Table 5; Figure 27). For example, in Sydney, Darwin and Hobart, a current 1-in-100 year flooding event would happen every day or so, in Melbourne it would happen more than every month, and in Adelaide it would happen every year or so. The implications for coastal infrastructure are enormous.

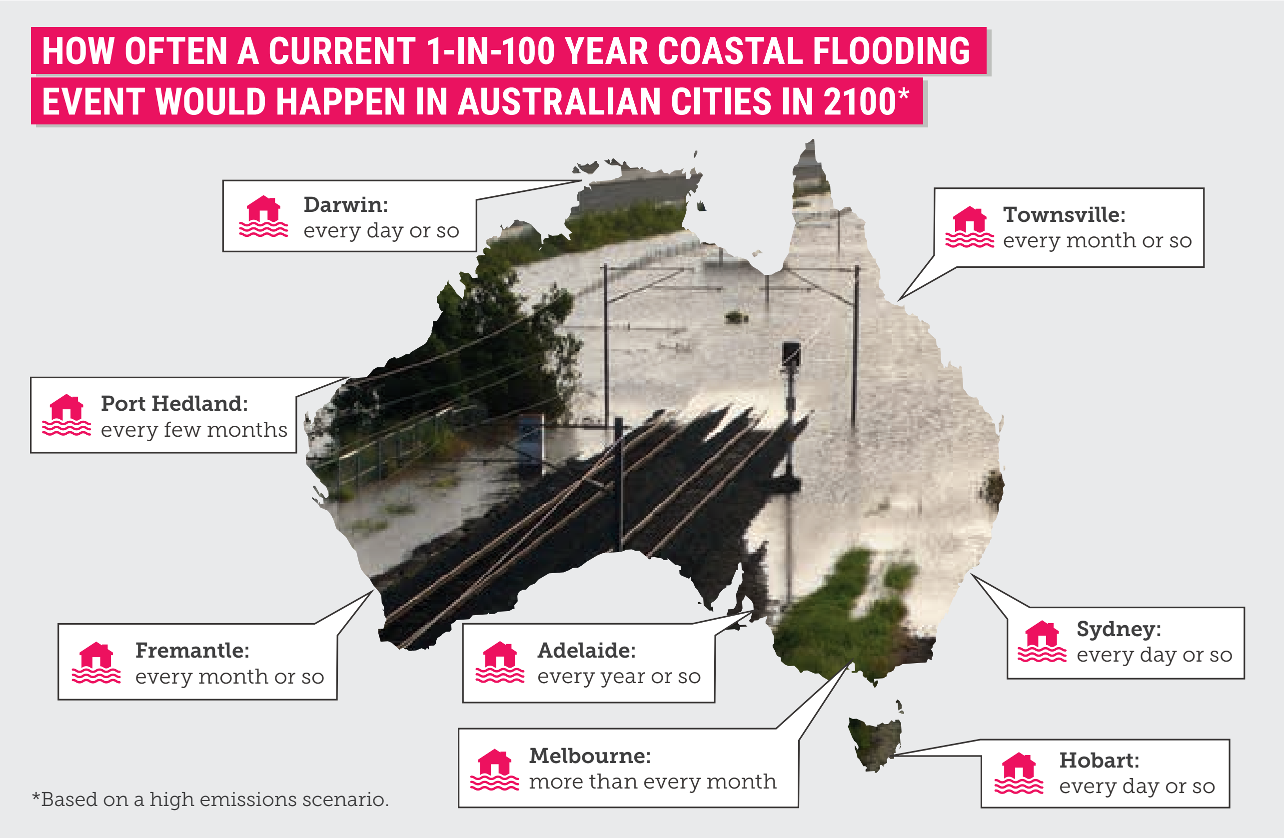

Figure 27: Australian cities are becoming more vulnerable to coastal flooding.

By 2100 in Sydney, Darwin and Hobart, a current 1-in-100 year flooding event would happen every day or so.

Table 5: Showing expected multiplying factors for coastal flooding for Australian cities in 2100 based on a high emissions pathway.

City	Multiplying factor	Impact
Sydney	>10000	1-in-100-year event would happen every day or so
Bundaberg	>10000	1-in-100-year event would happen every day or so
Townsville	1500	1-in-100-year event would happen every month or so
Darwin	>10000	1-in-100-year event would happen every day or so
Port Hedland	580	1-in-100-year event would happen every few months
Fremantle	820	1-in-100-year event would happen every month or so
Adelaide	120	1-in-100-year event would happen every year or so
Hobart	>10000	1-in-100-year event would happen every day or so
Melbourne	2100	1-in-100-year event would happen more than every month

Source: Climate Council 2014a.

Urban infrastructure is vulnerable to other types of climate impacts. The 2009 heatwave in Victoria caused widespread disruption of electricity supplies and transport in Melbourne (Figure 28). On the evening of 30 January, an estimated 500,000 residents were without power due to blackouts. Railways in the Melbourne area were also damaged, with 29 cases of rail tracks buckling, electrical faults that caused breakdowns in signalling, and failure of air-conditioning units in over 50% of the trains. Table 6 shows how heatwaves in Australia's major cities are already changing and how they are projected to change into the future.

Urban infrastructure is particularly vulnerable to heatwaves.

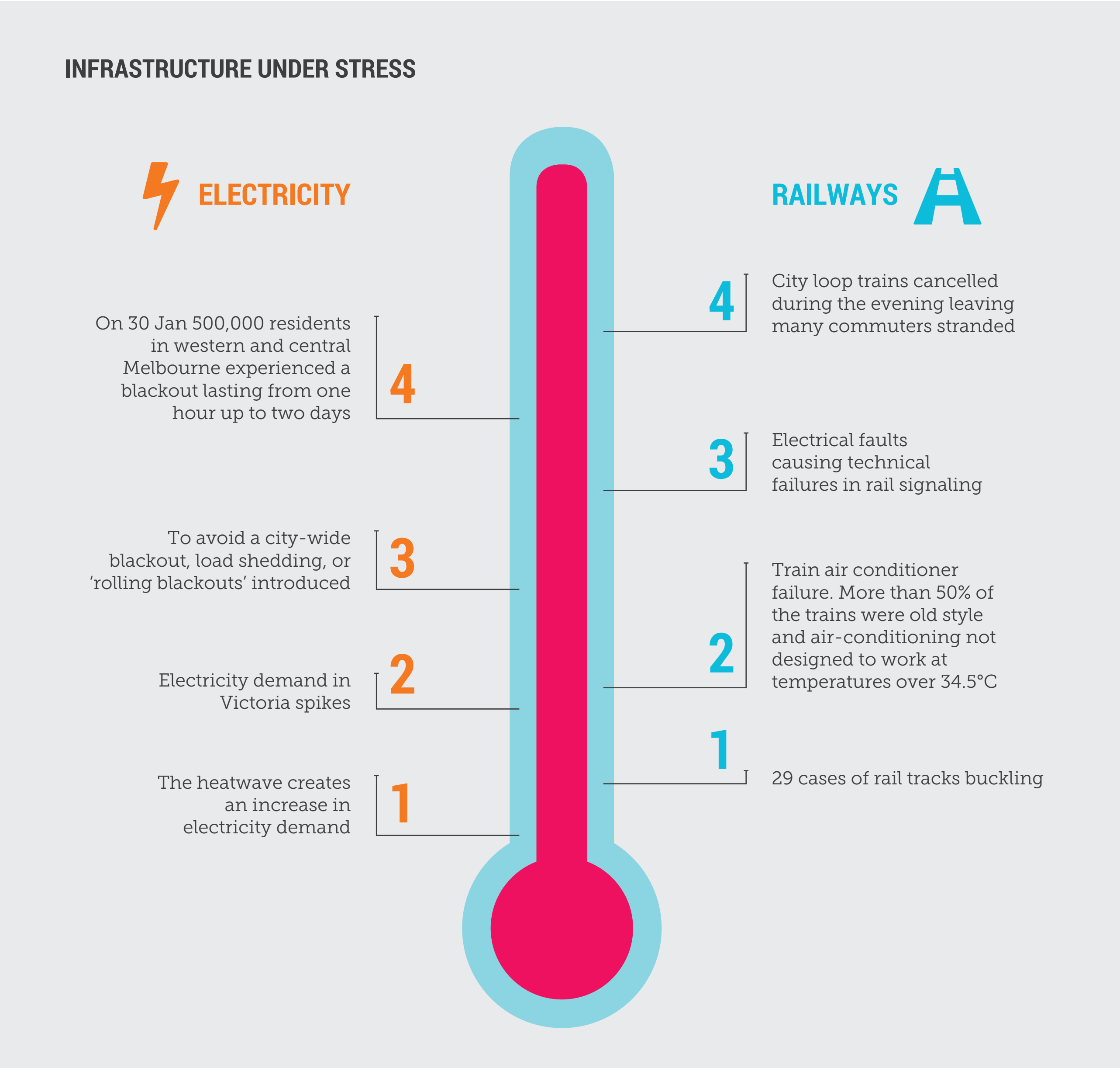

Figure 28: Anatomy of a heatwave: Infrastructure breakdown during the Melbourne 2009 heatwave. **Source:** Climate Council 2014b.

Table 6: Heatwaves in Australia's capital cities.

City	Number of heatwave days		Number of heatwave (events)		Length of longest event		Changes in average intensity of the heatwave (°C)	Changes in average intensity of the peak day (°C)	Changes in timing of first event (days)
	1950-1980	1981-2011	1950-1980	1981-2011	1950-1980	1981-2011			
Sydney	6	9	1-2	2-3	4	5	1.5	1.5	-19
Melbourne	5	6	1-2	1-2	4	4	1.5	2	-17
Brisbane	10	10	2-3	2-3	6	6	1	1.5	-8
Perth	6	9	1-2	2-3	4	5	1.5	1.5	+3
Adelaide	5	9	1-2	1-2	4	6	2.5	4.3	-2
Hobart	4	5	1	1-2	4	4	-1.5	1.7	-12
Darwin	3	7	1	1-2	4	5	0	1	-7
Canberra	6	13	1-2	2-3	5	7	0	1.5	-3

Notes: The average number of heatwave days, number of events, length of the longest event, average heatwave intensity, average intensity of the peak heatwave day, and change in the timing of the first summer heatwave for Australia's capital cities (Perkins and Alexander 2013). Statistics were calculated from the high-quality ACORN-SAT temperature dataset for the period 1951-2011 (Trewin 2012), using the Excess Heat Factor heatwave definition (Nairn and Fawcett 2013; Perkins and Alexander 2013). All statistics are rounded to the nearest integer. The first column for each characteristic is for the 1950–1980 period and the second is for the 1981–2011 period. Changes in average intensity and peak intensity are calculated by subtracting the respective average from 1950–1980 and 1981–2011. Changes in timing are calculated by subtracting the average start date during 1981–2011 from that of 1950–1980. **Source:** Climate Council 2014b.

Floods can also be extremely damaging to infrastructure. The 2010/2011 floods in the greater Brisbane area caused major damage; much of the electrical infrastructure in the Lockyer Valley was destroyed, and 300,000 homes in Brisbane and Ipswich lost power at some stage during the event (QFCI 2012).

Although droughts are often associated with impacts on agriculture and rural communities, they also directly threaten urban areas through their impact on urban water supplies. The rainfall decline in southwest Western Australia of 15% since the mid-1970s has reduced the annual average stream flow into Perth's dams by nearly 80% (Figures 29 and 30). Reduced rainfall creates drier soils and vegetation that, in turn, retain more water when rain does fall and thus typically reduces stream flow disproportionately more than the reduction in rainfall. In Melbourne, stage 3 water restrictions were implemented from 2007 to 2010, and by 2009 the city's water storage levels fell to a record minimum of 25.6% (Melbourne Water 2013, 2014).

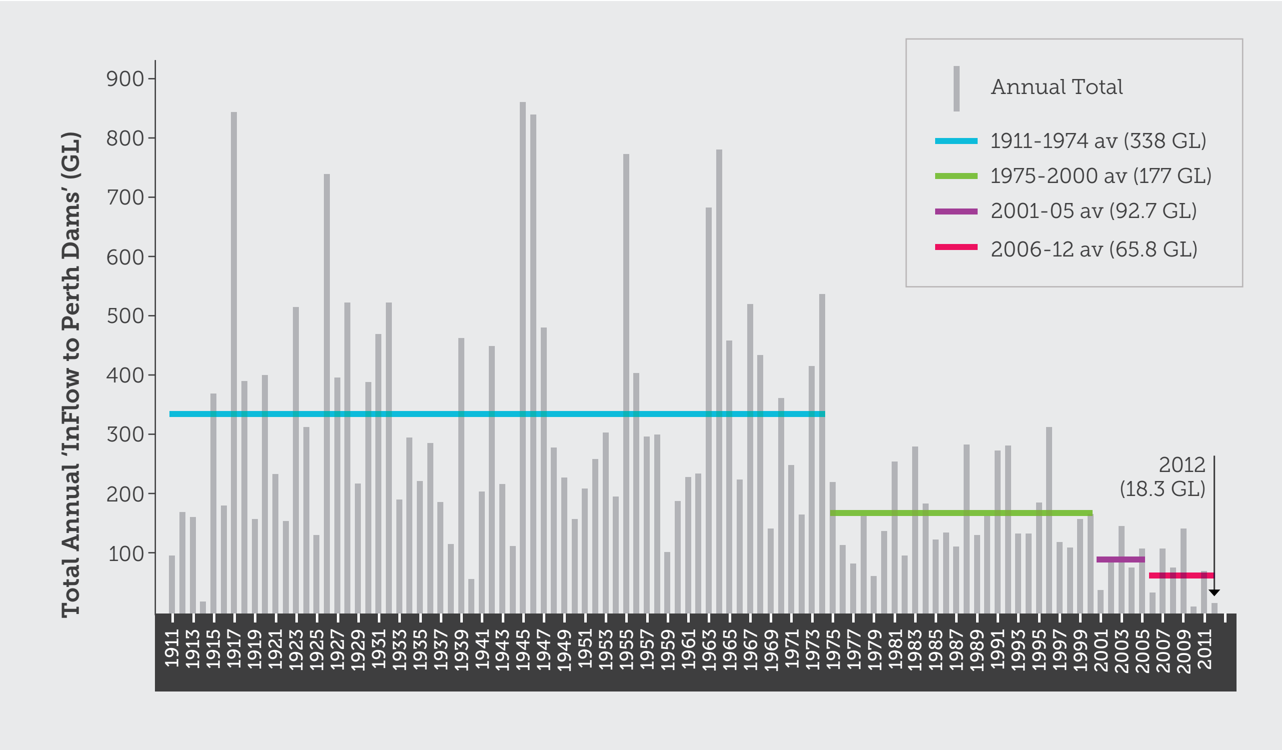

Figure 29: Trend in total annual stream flow into Perth dams 1911–2012. **Source:** Climate Commission 2013.

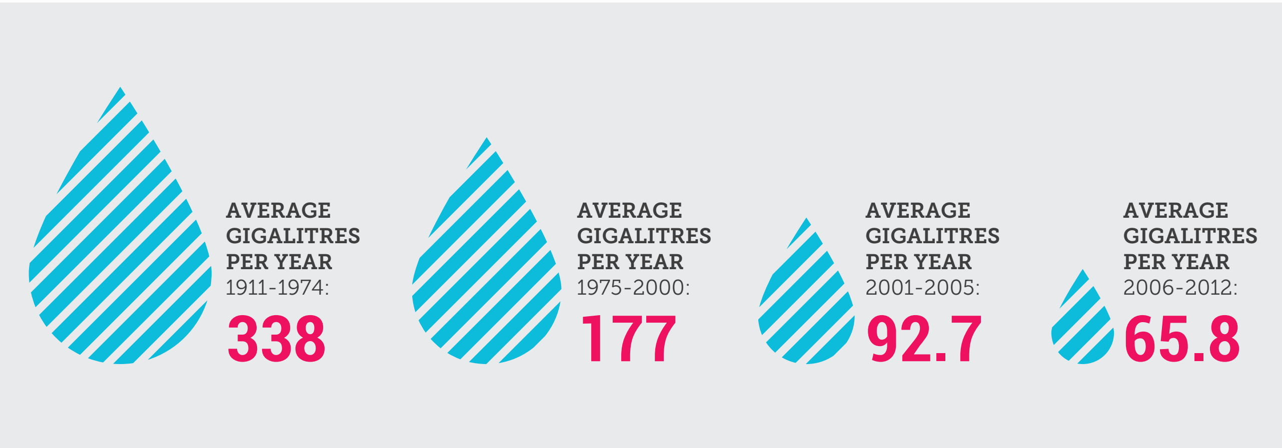

Figure 30: Changes in water inflow into Perth dams. **Source:** Climate Commission 2013.

Urban water supplies can also be diminished and damaged by bushfires. Following the 2003 Canberra fires, there was severe disruption to drinking water supplies due to increased erosion and runoff from denuded soils, increasing sediment and nutrient concentrations in the reservoirs (White et al. 2006). In the longer term, water supplies can be affected by the vigorous regrowth of forests, which have been reported to use twice as much water as mature forests (Buckley et al. 2012). The cost to Melbourne of recovering from the damage to the water supply system from the Black Saturday bushfires was estimated to be over $2 billion (WRF 2013).

3.5. Regional Australia

Rural communities already face many challenges, such as international currency and market fluctuations and other global forces; population drift to urban areas; lack of employment opportunities; relatively poor access to education and health infrastructure and services; competition for water and declining water quality; and the ongoing degradation of fragile landscapes, from soil erosion, salinity and pests.

Climate change is presenting rural and regional Australia with an additional set of challenges that are interacting with, and potentially exacerbating, traditional challenges – climate change can be thought of as a *threat multiplier* – exacerbating existing stresses on rural communities. Current agricultural practices across much of the continent are becoming increasingly threatened, mainly due to increased risks of extreme heat and water scarcity. The long-term sustainability, health, livability and productivity of Australia's rural and regional country towns will require a strong commitment to climate adaptation by individuals, families, communities, and all levels of government. But moving to a new, low carbon economy, also presents exciting opportunities.

Vulnerability to the impacts of climate change vary a great deal, depending on location, environment, remoteness, and sources of income. The key changes in rural communities include: changing local environments and the decline of resources, including soil, biodiversity, and major river systems; impacts of extreme weather events; and changes in agricultural productivity. Direct impacts of the changing climate on factors such as crop productivity are relatively easy to quantify. Other more indirect impacts, such as changes to the distribution and incidence of pests and diseases, are more complex. Even more difficult to measure are losses due to such factors as reduced confidence in investments and adoption of new technologies, and changes to the social fabric of farming communities (Garnaut 2008; Hayman et al. 2012).

Impacts of climate change, both direct and indirect, also interact with changing international and national markets, as well as technological, social, institutional and demographic changes. Some experts consider that many country towns are unlikely to survive until 2050 even in the absence of climate change (Beer et al. 2013), with some of the most at-risk communities being indigenous communities in remote areas, especially in the Northern Territory. This assessment found that the level of vulnerability was high throughout NSW, but particularly in the remote western and northern regions, and in Western Australia's agricultural areas. One of the most significant findings of this study was that, at both the national and state levels, country towns already at risk because of demographic change and economic restructuring are also the most at risk from climate change.

Climate not only affects virtually every aspect of food production and farm profitability, it also has significant impacts on food affordability, accessibility, quality and safety, factors that collectively affect food security. The risks posed by climate change for Australia's food production systems and our food security are complex and inter-connected and include: risks posed by ongoing degradation of Australia's natural resource base; direct risks of changes in temperature, rainfall and other climatic impacts on agricultural production; direct impacts of extreme events on food supply, safety and distribution; economic risks posed by energy costs and policies, including those designed to reduce greenhouse gas emissions; and changes to Australia's competitiveness due to climatic changes in other countries. One study by Gunasekera et al. (2007), assuming no planned adaptation and a relatively high emissions scenario, estimated potential declines of Australia's major export commodities (wheat, beef, dairy and sugar) of 9-10% by 2030 and 13-19% by 2050, and overall declines of agricultural exports by 11–63% by 2030 and 15–79% by 2050.

The impacts of climate change on the Australian agricultural sector are already clearly evident and well documented. For example, the Millennium Drought of 1996-2010 resulted in dramatic drops in production; irrigated rice and cotton production in the Murray-Darling Basin fell by 99% and 84% between 2002 and 2009, respectively (ABS 2011) and wheat production suffered a 12% reduction in yield during that period (van Dijk et al. 2013). Future declines in freshwater resources have been identified as a key risk for Australian food production in the Fifth Assessment Report of the IPCC, should the projections of ongoing drying in southern Australia, especially in the Murray Darling Basin and the wheat belt in southwest Western Australia, be realised (Reisinger et al. 2014).

The 2009 heatwave in southeast Australia caused crop losses in many vineyards, with 2008-09 wine production about 7% lower than the previous year (Gunning-Trant 2010). The extremely dry growing conditions in 2010 in southwest Western Australia, embedded in a long-term drying trend in the region, caused a reduction of 43% in production of wheat and other winter crops compared to the previous season (ABARES 2011). By 2050, rising temperatures and further decreases in rainfall could result in yield losses of more than 30% compared to 1999 (van Gool 2009).

Tropical cyclones can cause extensive damage to livelihoods in rural areas along Australia's northern coasts. For example, tropical cyclone Larry destroyed many banana plantations in Queensland in 2006, causing a sharp reduction in banana production at the national level for several years. While tropical cyclones may not occur more often in future, it is projected that their intensity could increase, with commensurate increases in damage caused (see Tables 1 and 2).

Figure 31: Cattle in fields near Wagga Wagga NSW during the Millennium Drought.

The livestock industry is also vulnerable to the impacts of climate change: extreme heat causes loss of appetite, productivity, reproductive vigour and sometimes death (Lefcourt and Adams 1996). Dairy cattle are particularly susceptible to heat stress, which can reduce appetite, milk production and milk quality (QFF 2008; DEEDI 2010).

Some rural communities, especially those located in forest areas in southeast Australia, are vulnerable to bushfires. Loss of property, especially homes, is one of the most important risks of bushfires, with a major factor in the level of risk being the proximity of homes and other built infrastructure to bushland (Chen and McAneney 2010). Infrastructure such as powerlines and roads can also be damaged in bushfires. For example, in the 2003 alpine fires in Victoria, about 4500 km of roads were damaged and local businesses reported a 50-100% economic downturn in the aftermath of the fire (Stephenson 2010). Bushfires also cause high incidence of trauma and long-term disruptions to social systems.

Livestock losses were estimated at 13,000 in the 2003 alpine fires in Victoria, 65,000 in the 2005-06 Grampians fire, and more than 11,000 in the Black Saturday fires of 2009 (Stephenson 2010; Teague et al. 2010). Stock that survive often face starvation or attacks from predators due to loss of fencing; over 8000 km of fences were lost in the Black Saturday fires (Stephenson 2010).

The impacts of climate change on agriculture often result in serious consequences for health and societal well-being in rural Australia. During the Millennium Drought (Figure 31) many rural communities suffered losses of employment, household income, local businesses, services, recreational opportunities and social cohesion (van Dijk et al. 2013). For example, it is estimated that employment was reduced by 3% in the Murray River region and from 2006 to 2009 about 6000 jobs were lost (Horridge et al. 2005; Wittwer and Griffith 2011).

As noted in the health section, the direct impacts of climate change on livelihoods and the indirect effects on social services and cohesion in rural communities can have profound effects on the mental health of those struggling to cope with the impacts. A study in New South Wales found that during drought the relative risk of suicide can increase by up to 15% for rural males aged 30-49 as the severity of drought increases (Hanigan et al. 2012).

3.6. Climate Change and Natural Ecosystems

Australia is one of the most biologically diverse countries in the world. Our ecosystems are already subject to considerable stresses, including habitat loss and degradation, pests and weeds, over-allocation of river flows, over-harvesting of commercial species, and pollution. Climate change is interacting with, and in many cases exacerbating, these existing threats (Steffen et al. 2009; Reisinger et al. 2014). Even relatively modest future warming (~1°C) has the potential for negative effects on many Australian species and ecosystems (Hughes 2011; VanDerWal et al. 2012).

Many species are proving to be highly sensitive to the climatic changes of the past few decades. Observed effects include changes in the timing of bird migrations (Chambers et al. 2013; Beaumont et al. 2015) and the emergence of butterflies (Kearney et al. 2010), shifts in the balance between warm-adapted and cold-adapted species (Chessman 2009), and changes in population sizes and geographic distributions within ecological communities (Last et al. 2011). As warming and other climatic changes continue, we also expect to see ongoing changes to traditional partnerships and interactions between species, causing changes in the structure and composition of ecological communities and the services these communities provide (Steffen et al. 2009).

In terrestrial and freshwater environments, negative impacts of extreme heat, drying, and changes in bushfire patterns are already evident. While the impacts of extreme heat on human health have attracted much attention (Section 3.1), heatwaves can also have profound effects on plants and animals. The January 2009 heatwave in Western Australia, when air temperatures reached over 45°C on several consecutive days, caused the deaths of thousands of birds, mostly zebra finches and budgerigars (McKechnie et al. 2012). An extreme heat event in January 2010, when temperatures rose to 48°C, caused the deaths of over 200 of the endangered Carnaby's Black Cockatoo near Hopetoun, WA (Saunders et al. 2011). Since 1994, more than 100,000 flying foxes are estimated to have died in heatwaves along the east coast of Australia. On 12 January 2002, for example, over 3,500 flying foxes were killed in nine colonies along the NSW coast when temperatures exceeded 42°C (Welbergen et al. 2008; Figure 32). Heatwaves, combined with extended droughts, have been observed to cause mass mortality in koalas (Gordon et al. 1998). Other tree-dwelling marsupials are also vulnerable. The green ringtail possum, for example, (Figure 33), which is restricted to rainforests above 300 m in Queensland's Wet Tropics, is unable to control its body temperature if subjected to air temperatures greater than 30°C for five hours per day over four-six days (Krockenberger et al. 2012).

The timing of bird migration, emergence of butterflies and flowering is changing.

Figure 32 (left): Flying foxes suffer high mortality rates during heatwaves. **Figure 33 (right):** The green ringtail possum is unable to control its body temperature when exposed to temperatures above 30°C for long periods of time, making it at risk during extended periods of hot weather.

Changes in fire regimes – the intensity, timing and frequency of fires – can cause major shifts in ecosystems from one state to another. For example, in the mountainous areas of the southeast, dense forests could be converted to open woodlands if the interval between severe fires is reduced due to a hotter and drier climate (Williams et al. 2009), as appears likely. For example, after successive fires in 2003 and 2006/7 in Victoria, Acacia shrublands replaced some mountain and alpine ash forests because there was insufficient time between fires for the ash trees to become reproductively mature (Lindenmayer et al. 2011; Bowman et al. 2013b). In the Northern Territory, changes in fire regimes are associated with the expansion of monsoon rainforest into eucalypt savanna and grasslands (Bowman et al. 2010).

Drought can also have severe impacts on terrestrial and freshwater ecosystems. Observed drought-related impacts over the past decade include mortality of amphibians in southeast Australia (Mac Nally et al. 2009), savanna trees in northeast Australia (Fensham et al. 2009; Allen et al. 2010) and eucalypts in sub-alpine regions in Tasmania (Calder and Kirkpatrick 2008). During the Millennium Drought, flows into the Murray-Darling system upstream of the Coorong were the lowest on record (CSIRO 2010), causing extreme levels of salinity that threatened the viability of many plants and animals in the wetlands (Leblanc et al. 2012).

While climate change is affecting all Australian ecosystems, our alpine species and communities are amongst the most vulnerable. Alpine habitat only occupies about 0.15% of the Australian land surface, but is home to many species found nowhere else (Hughes 2011). The Australian Alps have been warming by about 0.2°C per decade over the past 35 years (Hennessy et al. 2003), and snow cover has declined by about a third since the 1950s (Nicholls 2005). Many endemic alpine species, already considered rare and threatened, face an uncertain future, not just from the loss of snow cover, but also from increased frequency of bushfires, invasion of low elevation species - both native and exotic - to higher altitudes, expansion of woody vegetation into herbfields, drying of alpine fens and bogs, and changes to ecological interactions such as those between predators and their prey (Pickering et al. 2004; Hughes 2011).

Australia's marine ecosystems, considered hotspots of global marine biodiversity with many rare, endemic, and commercially important species, are also undergoing considerable change. The waters around the Australian coast are warming rapidly (Section 2.1) especially in the southeast where the East Australian Current has shifted hundreds of kilometres southwards over the past few decades (Kelly et al. 2015). Oceans globally are also becoming more acidic from the dissolution of atmospheric CO_2 into seawater (Howard et al. 2012; Figure 32). Recent analyses have concluded that under the current rate of emissions, most marine organisms will have a very high risk of serious impacts from warming and increasing acidity this century, and many are threatened even under the lowest emissions scenario (Gattuso et al. 2015).

There is probably no better-known Australian marine ecosystem than the Great Barrier Reef (GBR). The reef is not faring well. Over the past 30 years the GBR has lost 50% of its coral cover due to multiple climate and non-climate related stresses – death by a thousand cuts (De'ath et al. 2012). Some of these stresses are directly related to climate change. Bleaching events (Figure 36) have occurred repeatedly on the GBR since the late 1970s, while none were observed before this time. This problem is also appearing on coral reefs elsewhere; the 2011 marine heatwave in Western Australia caused the first-ever reported bleaching of Ningaloo reef (Wernberg et al. 2013; Figure 35). Coral reefs are also at risk from the increasing acidity of ocean waters which reduces calcification rates of corals and many other marine organisms, making it more difficult for them to recover from other stresses (Cooper et al. 2008; De'ath et al. 2009; Figure 34). Other threats to reefs include the projected increase in intense tropical cyclone activity. In 2011, Cyclone Yasi, one of the most intense tropical storms ever recorded in Queensland (Callaghan and Power 2011), caused extensive damage, with impacts over an area of nearly 90,000 km^2 of the Great Barrier Reef Marine Park. An estimated 15% of the total reef area suffered damage, with 6% severely affected (GBRMPA 2011). Sea level rise, which favours fast-growing over slower-growing species, poses another threat to some reefs (Hoegh-Guldberg 2011; Woodroffe and Webster 2014) and new diseases of corals are emerging, associated with warming waters, including white syndrome (since 1998) and black band disease (since 1993 – 1994) (Bruno et al. 2007; Sato et al. 2009; Dalton et al. 2010).

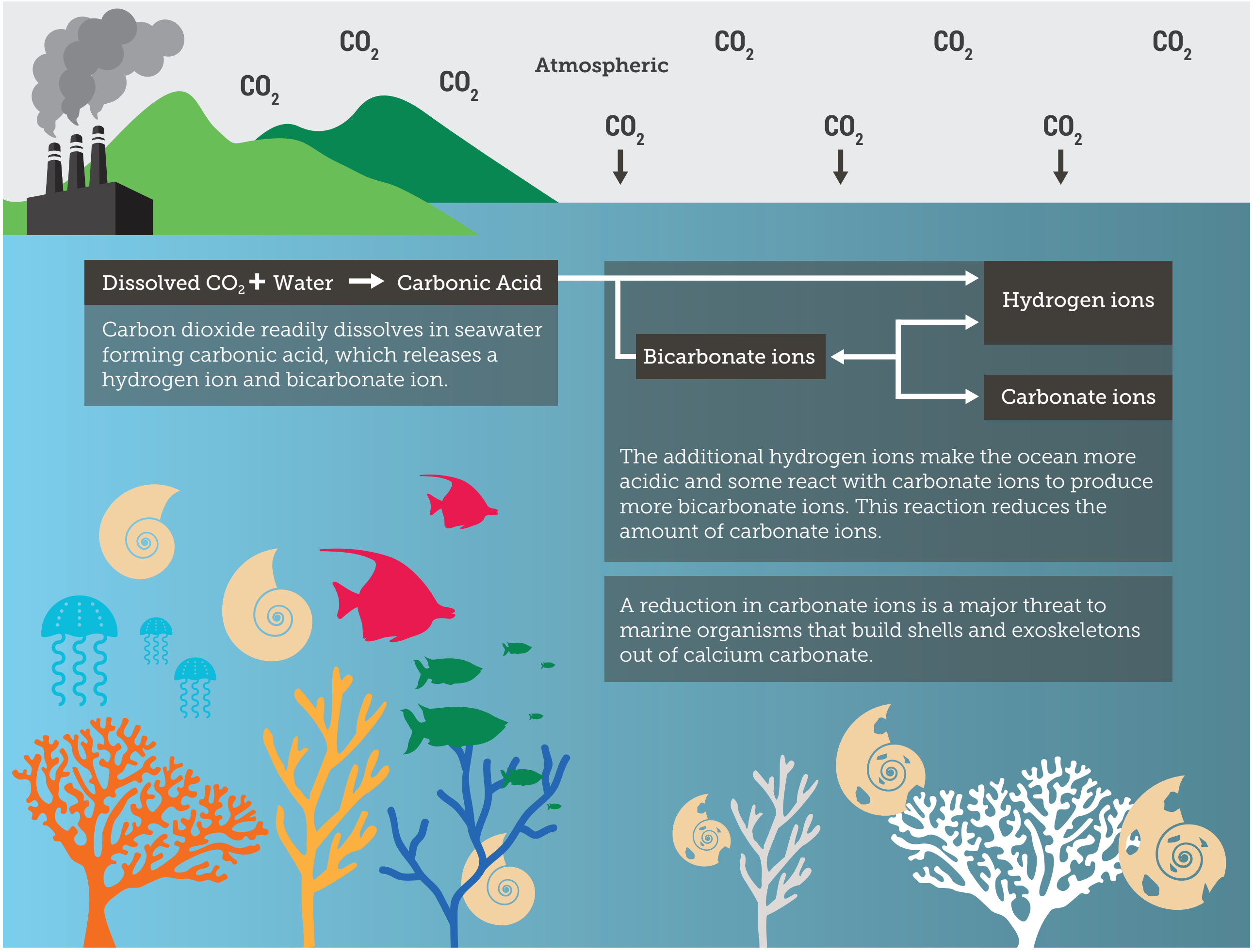

Figure 34: The chemistry of ocean acidification. **Source:** The Climate Commission 2013.

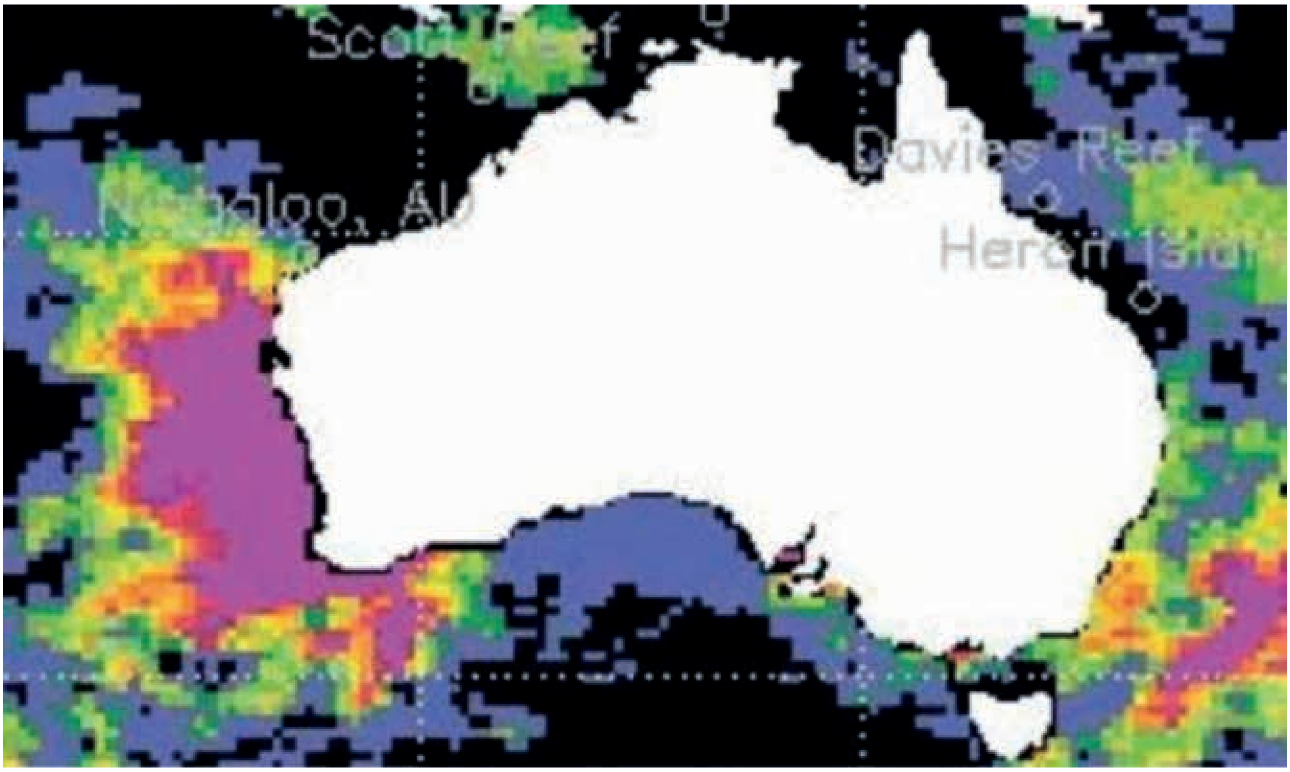

Figure 35: Satellite image of an underwater heatwave, 2011. The hottest areas are shown in pink. **Source:** NOAA; Climate Commission 2013.

Figure 36: Coral reefs are very vulnerable to bleaching as the oceans warms.

Climate change is affecting marine organisms in many other ways. Many fish species, as well as invertebrates and plants such as kelp, are now being observed at more southerly sites, shifting their distributions as the oceans warm (Pitt et al. 2010; Last et al. 2011). The long-spined sea urchin *Centrostephanus rodgersii*, formerly only known from the NSW coast, has established in Tasmania, where it is having major negative impacts on marine communities and the lobster fishery because it is denuding kelp habitats (Ling et al. 2008).

Marine turtles are threatened by rising sea levels that can inundate nesting sites, and by warming which can affect the development of hatchlings (e.g. Fuentes et al. 2010). Extreme heat events also expose plants and animals in shallow waters and intertidal systems to stress, causing mortality and reducing reproduction (Cardoso et al. 2008; Garrabou et al. 2009). Coastal habitats, such as seagrass, saltmarsh and mangroves, also face increasing stress. Changes to coastal rainfall patterns affect the flows of nutrients and sediments to these habitats, while sea-level rise combined with urban and agricultural development is "squeezing" the area available and reducing the capacity of these communities to adapt. Degradation and reduction of these habits has important implications for the important ecosystem services they provide, including coastal protection, carbon storage and nursery grounds for fish (Reisinger et al 2014).

Finally, of most concern, climate change is likely to greatly increase the rate of species extinction, both in Australia and globally. The most comprehensive study to date has estimated that a global average warming of 2°C (compared to pre-industrial levels) could risk the loss of about 5% of the world's species. If global temperatures reach 3°C above pre-industrial levels, 8.5% of species are estimated to be at risk, and under a "business as usual" (high emissions) scenario, leading to global warming of 4°C, a staggering 16% (1 in 6) of species could be lost (Urban 2015).

Climate change is likely to greatly increase the rate of species extinction.

4. THE MORE WE KNOW ABOUT CLIMATE CHANGE, THE RISKIER IT LOOKS

The research described in the sections above is part of an enormous body of evidence that climate change is already having negative impacts on almost every aspect of human society, as well as the environment that supports us (IPCC 2014).

Research such as this is crucial to inform the magnitude of the effort required to stabilise the climate system at a global average temperature that keeps these risks to a tolerable level. Based on this research, 195 countries, including Australia, have agreed to limit the human-driven increase in global average temperature to no more than 2°C above the pre-industrial level (UNFCCC 2010), although a limit of 1.5°C is more consistent with our current understanding.

The Intergovernmental Panel on Climate Change (IPCC) has developed the "reasons for concern" approach (Smith et al. 2001) to synthesise and communicate the observed and projected impacts of climate change at various levels of temperature rise. This approach, often illustrated by a graphic called the "burning embers diagram", is based on a small number of broad areas where climate change is either already driving observable impacts or is projected to pose major risks for human well-being (Figure 37).

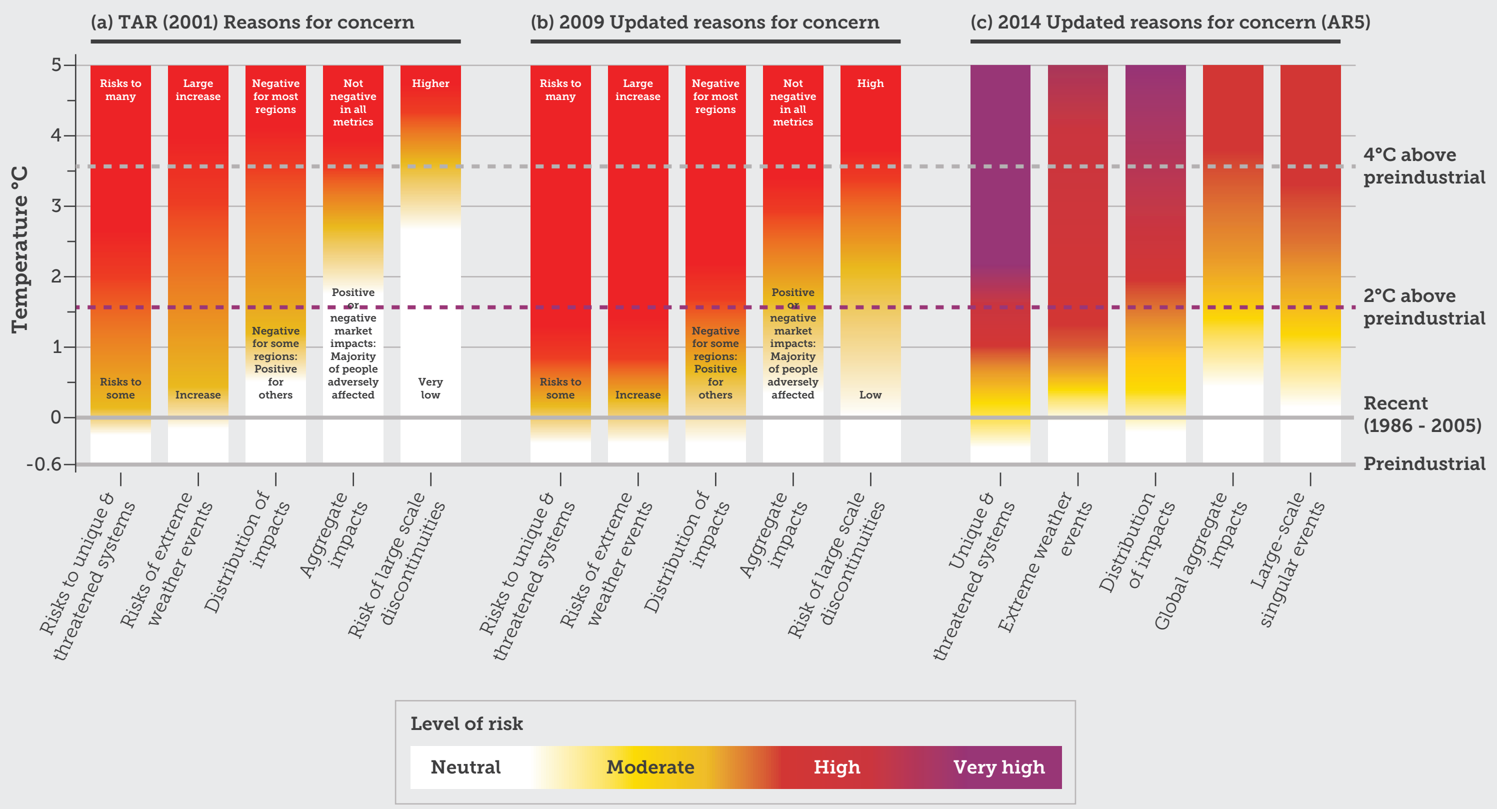

Figure 37: Risks from climate change by reason for concern (RFC) for 2001 compared with the updated data for 2009 and for 2014. Climate change consequences are plotted against increases in global mean temperature (GMT) (°C) after 1990. Each column corresponds to a specific RFC and represents additional outcomes associated with increasing global mean temperature. The colour scheme represents progressively increasing levels of risk. The historic period 1900 to 2000 warmed by about 0.6°C, which led to some impacts. (A) RFCs adapted from the IPCC Third Assessment Report as described in Smith et al. (2001); (B) Updated RFCs adapted from IPCC Fourth Assessment Report as discussed in Smith et al. (2009); (C) Updated RFCs adapted from the IPCC Fifth Assessment Report (IPCC 2014). **Source:** Climate Council 2015a.

The reasons for concern include (i) extreme weather events, where the influence of climate change is already apparent (IPCC 2012, 2013), (ii) the risks to unique and threatened ecosystems, (iii) the local and regional distribution of impacts (e.g., showing relatively larger impacts on disadvantaged communities and countries), (iv) the aggregation of impacts to the scale of the global economy and Earth's biodiversity, and (v) the risk of crossing thresholds or tipping points in large-scale features of the climate system, called "large-scale discontinuities" in the figure. The figure is coloured from white through yellow to red, where increasing red tones denote increasing risk of damaging impacts. The three panels of the figure represent assessment of impacts or risk at three different times – 2001 (IPCC Third Assessment Report; Smith et al. 2001), 2007 (IPCC Fourth Assessment Report; Smith et al. 2009) and 2014 (IPCC Fifth Assessment Report 2014). The 2°C policy target is shown as a horizontal line, referenced to the pre-industrial estimate of global average temperature.

The figure clearly shows that as the science improves, our assessment of risk changes. The enhanced knowledge base includes observations of actual impacts at the current temperature rise of about 0.85°C above pre-industrial, as well as improved modelling capability to project future impacts. For example, in 2001 the expected risk of increasing extreme weather with a rise of between 1 and 2°C in global temperature was considered moderate. Today the risk is considered high. Risks to unique and threatened ecosystems, like coral reefs, at 1 to 2°C of warming were considered moderate in 2001. Today the risk is high. Globally aggregated impacts were estimated at the low end of the risk scale in 2001 whereas they are now assessed as the moderate risk level. In 2001 the risk of crossing tipping points was considered negligible up to a temperature rise of 3°C and a high risk did not appear until above 4°C. The 2014 assessment suggests that a moderate risk of crossing large-scale tipping points exists in the 1.5-2°C range and a very high risk in the 3-4°C range. In summary, Figure 37 shows that the scientific underpinning for the 2°C policy target as a "safe" level of climate change is now weaker than it was a decade ago, and the scientific case for the 1.5°C limit is more consistent with our current level of understanding.

As noted above, at a 2°C temperature rise above pre-industrial we are now closer to the risk of crossing thresholds or tipping points, which are large features of the climate system prone to abrupt and/or irreversible change when a critical threshold level of temperature rise is reached. Examples include loss of the Greenland ice sheet, the partial conversion of the Amazon rainforest to a savanna or grassland, and the large-scale emission of carbon dioxide (CO_2) and methane from thawing permafrost. Each of these examples would cause very significant disruptions to the climate system, with knock-on effects for human societies.

The melting of the Greenland ice sheet would eventually raise sea level by approximately 7 metres (Church et al. 2013), committing humanity to continuously rising sea levels for centuries or millennia, devastating major coastal cities worldwide as their limits to adapt to coastal flooding were exceeded. The tipping point for the Greenland ice sheet is estimated to lie within a temperature rise of 1°C and 4°C above pre-industrial (Church et al. 2013). At the current rise in global average temperature of 0.85°C above pre-industrial levels, there are already early warning signs that a tipping point could be crossed this century. The average rate of ice loss from Greenland has accelerated over the past few decades, rising from 34 Gt per year in the 1992-2001 period to 215 Gt per year in the 2002-2011 period (Stocker et al. 2013; Figure 9).

There is no consensus yet on where the tipping point might lie for large-scale release of carbon from permafrost in the northern high latitudes (e.g., Siberia, Alaska), but the potential for such releases to accelerate climate change have recently been estimated. The potential emissions of CO_2 and methane from melting permafrost are assessed to be in the range of 50 to 250 billion tonnes of carbon over the 21st century under the highest emissions scenario (Ciais et al. 2013). By comparison, current human emissions of carbon averaged about 10 billion tonnes per year over the most recent decade (Le Quéré et al. 2014), so the high-end estimate of possible carbon emissions from thawing permafrost is equivalent to 25 years of human emissions at current rates.

In summary, the more we know about climate change, the riskier it looks. This conclusion (i) underscores the urgency in stabilising the climate system as soon as possible to minimise the high-end risks; and (ii) emphasises the need to dramatically reduce CO_2 emissions from fossil fuel combustion.

5. NOW IS THE TIME FOR STRONG ACTION ON CLIMATE CHANGE

The science of climate change is more strongly grounded than ever. There is no doubt that the climate is changing rapidly and that human emissions of greenhouse gases, primarily from the burning of fossil fuels, are the main cause. As research progresses and strengthens, the risks of climate change for our well-being now look more serious at lower levels of climate change.

We face a clear, urgent choice. The climate our children and grandchildren will experience through their lives depends on how much and how fast we reduce greenhouse gas emissions now, and in the coming years and decades. The two possible futures resulting from low and high emissions scenarios are vastly different, as shown in Figures 12, 13 and 14, described in Section 3, and summarised in Figure 37. The low emissions future is one where climate change, though significant, is slowed and then stabilised in the second half of the century. The high emissions future is one of escalating risks, increasingly damaging impacts, and a climate system that is changing even more rapidly through the rest of the century and beyond, perhaps out of human control. The longer we delay action, the more difficult it becomes to implement the low emissions scenario.

The task we face in meeting the 2°C policy target is most clearly laid out in the carbon budget approach (cf. Climate Council 2015a). The carbon budget is defined as the maximum amount of CO_2 from human sources that can be released into the atmosphere to limit warming to no more than 2°C above pre-industrial levels. That is, the carbon budget is the amount of CO_2 that humanity can "spend". Once the carbon budget is spent, global emissions of CO_2 must be zero; the global economy must be completely decarbonised. Table 7 shows the remaining carbon budget for three probabilities of meeting the 2°C policy target. The higher the probability we want of preventing a global temperature rise of 2°C, the more stringent the budget.

A recent economic analysis (McGlade and Ekins 2015), under the most generous assumptions for fossil fuel usage (which give only a 50:50 chance of meeting the 2°C target), estimates that 38%, at most, of the world's reserves can be burned ("reserves" are the subset of resources that are defined to be recoverable under current economic conditions and have a specific probability of being produced). The amount of fossil fuel reserves that can be burned is reduced if we want a better-than-even chance of limiting the rise in global temperature to no more than 2°C. For a 75% chance of meeting this target, this allowance reduces substantially to only 23% of reserves. That is, 77% of the world's fossil fuel reserves cannot be burned. The conclusion is clear: under any set of assumptions, effectively tackling climate change requires that most of the world's fossil fuels be left in the ground, unburned.

Table 7: The carbon budget for three probabilities of meeting the 2°C warming limit. **Sources:** IPCC (2013) and Meinshausen et al. (2009).

Probability of meeting 2°C policy target	Budget from 2000 Gt CO_2	Budget from 2012 Gt CO_2
50%	1440	1112
66%	1338	1010
75%	1000	672

The current reserves of the main types of fossil fuels – oil, gas and coal – compared to the range of carbon budgets are shown in Figure 38 (McGlade and Ekins 2015). Based on the results of a sophisticated integrated assessment model that minimises whole-energy system costs for an assumed carbon budget (Anandarajah et al. 2011), coal is the fossil fuel with the greatest proportion that cannot be used; 88% of global reserves are unburnable. Oil is the fossil fuel with the least proportion that cannot be used, with 35% of reserves unburnable. Just over half – about 52% - of the known reserves of gas are unburnable.

Effectively tackling climate change requires that most of the world's fossil fuels be left in the ground, unburned.

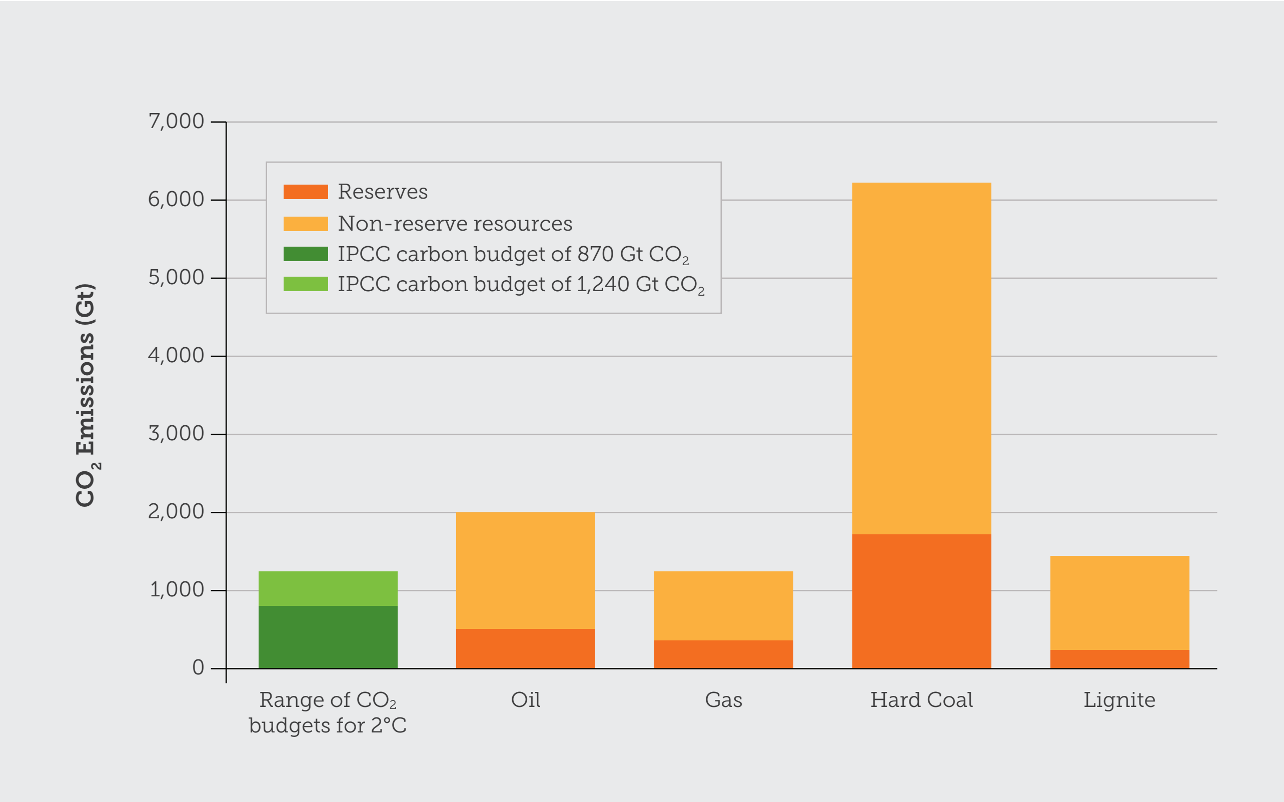

Figure 38: The combustion CO_2 emissions for oil, gas and coal (hard coal and lignite) resources and reserves. The range of carbon budgets between 2011 and 2050 that are approximately commensurate with limiting temperature rise to 2°C (870-1240 Gt CO_2) is also shown. **Source:** Adapted from McGlade and Ekins (2015).

	Consistent with 2°C?	Annual rate of emissions reductions	Per capita emissions (t CO_2e)	Emissions intensity (t CO_2e/ GDP PPP)	Change on base year		
		Post-2020	2030	2030	2005	2000	1990
Australia (26% by 2030)	NO	-1.6%	16	198	-26%	-19%	-20%
Canada	NO	-1.6%	14	190	-30%	-18%	+6%
EU	POSSIBLE	-2.6%	6	104	-34%	-33%	-40%
Germany	NA	-2.6%	7	89	-45%	-46%	-55%
Japan	NO	-2.4%	8	134	-25%	-25%	-19%
New Zealand**	NO	-0.5%	11	175	-30%	-23%	-10%
Norway	POSSIBLE	-1.5%	4	41	-18%	-20%	-40%
Excluding LULUCF		-1.5%	5	51	-44%	-44%	-40%
Switzerland	POSSIBLE	-4.1%	3	32	-51%	-51%	-50%
UK	NA	-5.1%	5	74	-49%	-51%	-64%
USA	POSSIBLE	-2.3%	11	113	-39%	-40%	-29%
Average (excluding Australia)		-2.5%	8	116	-36%	-36%	-35%

Not consistent with 2°C (orange)
Green is credible pathways to 2°C exist*
Worst among developed countries (red)
Australia in worst three (pink)
Blue is best among developed countries

Notes: NA - Not applicable as country is part of the EU and independent assessments of their contribution to the 2°C goal have not been undertaken. * Consistent on some assessments - credible pathways to 2°C exist, high probability of avoiding 2°C requires an acceleration of effort to 2050. ** Excluding LULUCF

Figure 39: Comparison of the emission reduction targets that various countries will take into the Paris COP meeting later this year. **Source:** The Climate Institute 2015.

The carbon budget has important implications for Australia's fossil fuel industry. The McGlade and Ekins (2015) analysis estimates that under any set of assumptions, including the use of Carbon Capture and Storage (CCS) technology, over 90% of Australian coal reserves cannot be burned. Furthermore, meeting the 2°C policy target implies that it is highly unlikely that any of Australia's potential coal resources beyond the reserves already being exploited could ever be developed.

Halfway through the Critical Decade, 2015 is a pivotal year for global action: the international community will converge in Paris at the end of the year to negotiate a new agreement aiming to limit the increase in global average temperature to no more than 2°C above pre-industrial levels. The window for having a realistic chance of meeting this policy target is closing rapidly.

In the lead up to the United Nations conference in Paris, countries are submitting their emissions reduction targets, known as Intended Nationally Determined Contributions (INDCs). Emissions reduction targets are important because they signal the commitment of individual countries to tackle climate change. Further, by combining all of the countries' emissions reduction targets, a more complete picture can be developed of how the world is (or is not) tracking towards limiting global warming to 2°C (cf. Climate Council 2015b).

Figure 39 shows how Australia's INDC stacks up against those of other countries, and how all of the countries' pledges rate in terms of the 2°C policy target. It is clear that Australia is lagging well behind the rest of the developed world in climate action; in any indicator used to measure level of effort, Australia is at the bottom or within the bottom three countries in the developed world. Our target of a 26% emission reduction by 2030 on a 2005 base year is much lower than comparable targets of 41% for the USA, 46% for Germany, 48% for the UK and 34% for the EU as a whole. Our target is not even close to what is required for Australia to do our fair share in meeting the 2°C policy target. In fact, if the entire world made an effort similar to Australia's, we would be heading for a warming of 3-4°C above pre-industrial (The Climate Institute 2015).

It is in Australia's national interest to play a strong role in this agreement because we are on the front line of climate change impacts and are one of the world's largest emitters of greenhouse gases. Our response to meeting the challenge of Paris is disappointingly weak; it is out of step with the science and out of step with most countries in the developed world. Now is the time to lift our game. We need much stronger action and we should be helping to lead the way.

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