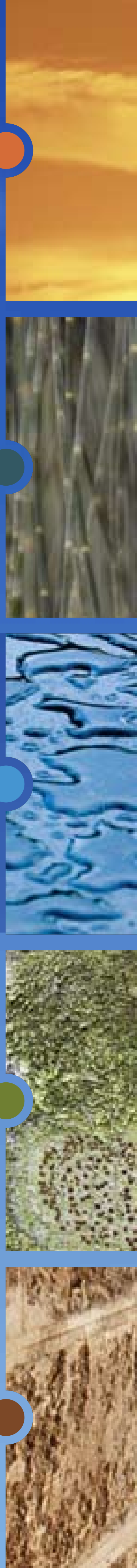
OFFICE OF climate change

Climate Change in Queensland

What the Science is Telling Us

2010



Toward Q2 Tomorrow's Queensland

Queensland Government

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Minister's foreword

A sound understanding of our climate and the impacts of climate change underpin the policies and initiatives that I have introduced to address climate change. Climate change poses very real risks to Queensland. The very climate that makes Queensland so attractive to residents and international tourists alike is changing with potentially major consequences.

The land-ocean temperature record indicates that 14 of the past 15 years have been the warmest since 1880. Last year was the fifth warmest year in the 160 years of global instrumental temperature records, with 1998 being the warmest.

Queensland is particularly vulnerable to climate change impacts such as sea level rise, more frequent heatwaves, more intense rainfall events in some regions and drought in others.

Without practical action informed by the latest science, priceless natural assets such as the Great Barrier Reef and the industries that rely on our natural environment such as agriculture, mining and tourism are at risk.

Climate science may be complex but a basic understanding of how the climate is changing and what the impacts mean will ultimately help each and every one of us to make more informed decisions about what we can do to deal with it. In 2008 the Queensland Government released the first edition of the *Climate Change in Queensland: What the science is telling us* report. It provided general information on climate change, the projected impacts across Queensland, and potential impacts on key sectors.

This 2010 edition offers a detailed review and update on the latest climate science and what it means for Queensland. It provides a more in-depth analysis drawing on a review of more than 200 peer-reviewed scientific papers published in the last three years. It highlights the fact that we now have multiple lines of evidence to show that Queensland's climate is changing.

This report presents the differences between weather and climate, the causes of climate change and the indicators which provide support for these changes. It highlights the latest developments in international, national and Queensland research and discusses the latest observations and projections on temperature, rainfall, sea level rise and extreme events. Importantly, it outlines how the climate is likely to alter in the future for regional Queensland.

By investing in our climate science capability, the Government is seeking to ensure that Queensland is well positioned to better understand and respond to the challenges posed by climate change. That is why the Queensland Government established the Queensland Climate Change Centre of Excellence, the only state-based climate science research centre in Australia. I commend the scientists for their expertise and commitment to world class climate change research.

Clearly, there is plenty of new data showing we have some serious issues ahead of us but there is simply no benefit in shying away from these 'inconvenient truths'. Climate literacy in our community will become increasingly important as regional and national governments around the world work towards global agreement on collective action to reduce our greenhouse gas emissions.

In reading this report, I am sure you will be left in no doubt that successful mitigation and adaptation actions will depend on effective communication of climate science. Preparing communities for the impacts of climate change on human health, water security, industries, our built environment, emergency services and ecosystems is uppermost in my mind.

A better understanding of the science of climate change will ensure that we can all engage in informed debate on the implications for Queensland communities. This report is another step along that path.

The Honourable Kate Jones MP
Minister for Climate Change and Sustainability

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Executive summary

This report updates the science in the previous report, *Climate Change in Queensland: What the science is telling us*, released in June 2008. It discusses the science on which the Queensland Government based its climate change mitigation and adaptation strategy, *ClimateQ: toward a greener Queensland*, released in August 2009, and additional scientific information released since then.

Key findings for Queensland

- The last decade (2000–2009) was the hottest on record with temperatures 0.58 °C higher than the 1961–1990 average.
- Queensland regions can expect increased temperatures of between 1.0 °C and 2.2 °C by 2050.
- Rainfall is expected to change, with a potential decrease by up to seven per cent in central Queensland by 2050.
- A three to five per cent decrease in rainfall in the south-east Queensland region is projected.
- More frequent hot days and warm nights.
- Less frequent cold days and cold nights.
- Sea levels are rising faster than expected and the 2007 Intergovernmental Panel on Climate Change estimate of a 0.26–0.79 metre rise by 2100 may be a significant underestimate.

As a result of climate change, Queensland is likely to experience impacts including:

- increased flooding, erosion and damage in coastal areas due to increased numbers of severe tropical cyclones and sea level rise
- cyclones occurring further south
- increased numbers of hot days and warm nights, placing increased stress on the population and infrastructure
- reduced rainfall across most of Queensland. Cape York, the Gulf Region and Far North Queensland are projected to be less affected than the rest of the state
- longer dryer periods interrupted by more intense rainfall events (especially in the Gulf and Cape York)
- difficulty in supplying water to meet urban and agricultural demand due to decreasing rainfall and runoff, and increasing temperature and evaporation

- changes to terrestrial biodiversity with a potential loss of half the existing high-altitude Wet Tropics rainforest from a 1 °C increase in temperature
- changes to marine biodiversity particularly in the Great Barrier Reef due to increased acidification of oceans
- annual bleaching of up to 97 per cent of the Great Barrier Reef and associated large-scale mortality, if the average sea-surface temperature increases by 2 °C
- changes to marine species distribution, with potential impact on the fishing industry, due to changes in currents
- reduced breeding habitat of seabirds and turtles due to sea level rise
- increased spread of disease due to changed conditions for vectors
- increased heat-related illnesses.

The impacts of climate change will affect society as well as the environment. Both mitigation and adaptation will be necessary across all sectors of society to help limit and reduce the extent of greenhouse gas emissions and to avoid and adapt to expected impacts.

Adaptation mechanisms could include:

- changing agricultural practices, including the use of different crops or stock that are more resilient to changed climatic conditions
- changing water management practices to more efficient use of scarcer water supplies
- increasing reservation of high-conservation areas to help retain at-risk species
- increasing planning and land allocation for habitat connectivity to allow species to move as climate zones change
- improving planning for, and management of, coastal impacts of sea level rise and storm surges.

ClimateQ: toward a greener Queensland contains policies and initiatives that aim to reduce greenhouse gas emissions and adapt to the impacts of climate change. Details of these initiatives can be found at ‹http://www.climatechange.qld.gov.au›.

Australian climate changes

A number of recent reports have consolidated climate science information to provide an overview of climate change and expected impacts on Australia.

Climate Change in Australia is a joint Commonwealth Scientific and Industrial Research Organisation (CSIRO) and Australian Bureau of Meteorology (BoM) publication, released in 2007 (CSIRO & BoM 2007). It builds on a large body of Australian climate research to provide a comprehensive assessment of Australia's climate. It outlines the latest information on observed and projected climate change over Australia and its likely causes.

The Garnaut Climate Change Review (2008) examined the impacts of climate change on Australia. It found that even at current emissions levels, the world is already committed to a level of warming that could lead to damaging climate change. The report noted that the business-as-usual approach to climate change increases the risk of serious and irreversible impacts. It found that the benefits of strong, early action on climate change would outweigh the costs.

Climate Change 2009 (Steffen 2009) reviewed the science of climate change since the publication of the Intergovernmental Panel on Climate Change's (IPCC) *Fourth Assessment Report, Climate Change 2007* (AR4) (IPCC 2007a–c). Steffen suggests that the AR4 was conservative in its range of projections and that many aspects of the climate system are changing at the upper level of the IPCC range of projections—towards more rapid and severe climate change with dangerous impacts.

The Science of Climate Change: Questions and Answers published in August 2010 by the Australian Academy of Sciences outlines changes in Australian climate including:

- an increase of about 0.7 °C in average surface temperature since 1960, with some areas having warmed faster and others showing little evidence of warming
- an increase in the frequency of extremely hot days
- a decrease in the frequency of cold days
- significant increase in rainfall over north-western Australia
- decrease in rainfall over south-eastern Australia
- sea level rise of about 1.2 millimetres per year since 1920.

Future impacts of climate change on Australia are likely to include:

- projected increases in average surface temperature of 0.6–1.5 °C by 2030 and 2.2–5.0 °C by 2070
- decreased average annual rainfall over much of Australia
- more intense rainfall on days with heavy rainfall over many areas
- an increase in the proportion of severe tropical cyclones, with a possible decrease in the total number of cyclones
- more frequent heatwaves
- more frequent droughts.

These findings (Australian Academy of Sciences 2010) indicate stronger than expected and sooner than expected climate changes.

Global climate changes

The IPCC has indicated that climate changes are linked to increased emissions of greenhouse gases caused by human activity.

Concentrations of atmospheric CO_2 are increasing rapidly, with the 2009 concentration level at 387 parts per million (ppm). Levels of atmospheric CO_2 are now at their highest concentration, much higher than the natural range over the last 800 000 years of 172–300 ppm. There is now 38 per cent more CO_2 in the atmosphere than at the start of the Industrial Revolution.

Recent research has indicated that the IPCC is likely to have been conservative in its projections and that the observed increase in the concentration of greenhouse gases has likely committed the world to an average warming of 2.4 °C (1.4–4.3 °C) above pre-industrial surface temperatures. The land–ocean temperature record indicates that 14 of the past 15 years are the warmest since 1880. Average global temperatures have increased by about 0.75 °C since 1900. Enhancement of the natural greenhouse effect due to the increased concentration of greenhouse gases is leading to global warming and long-term climate changes.

Over the past few decades, the Arctic has warmed at about twice the rate of the rest of the Earth. Arctic temperatures are currently higher than at any time in the last 2000 years, with the period 1999–2008 being the warmest.

At the current high levels of greenhouse gases in the atmosphere, warming of the climate will continue even if emissions are reduced. This is due to the long lifetimes of some greenhouse gases, especially CO_2. Even if emissions were to cease, slower heat loss from the ocean means that temperatures would not drop significantly for at least 1000 years.

Over the past 50 years the effectiveness of the Earth's carbon sinks has reduced. The fraction of total CO_2 emissions taken up by the land and oceans is decreasing, while the fraction that remains in the atmosphere has increased. The absorption of CO_2 into sea water is making the oceans increasingly acidic, with the potential to have negative impacts on marine organisms.

Data from tide gauges around the world shows that global sea level has risen by almost 0.2 metres since 1870. Since 1993, sea level has been more accurately measured by satellites. Both sets of measurements show that the rate of sea level rise has accelerated. Sea levels have been projected to rise by 0.8 metres, but indications are that the rise could be significantly greater.

Introduction

The 2008 publication *Climate Change in Queensland: What the science is telling us*, was principally based on the *IPCC Fourth Assessment Report* (AR4) (IPCC 2007a–c) and *Climate Change in Australia—Technical report 2007* (CSIRO & BoM 2007).

In August 2009, the Queensland Government released *ClimateQ: toward a greener Queensland*, which includes climate change mitigation and adaptation policies and programs informed by the IPCC AR4. The AR4 remains the authoritative reference for Queensland policy development.

However, considerable scientific research has been published since that time, contributing further to our knowledge of climate change and its potential impacts. For example, in May 2009 the Australian Government released the report, *Climate Change 2009: Faster change and more serious risks* (Steffen 2009), which reviewed and synthesised scientific papers published since the release of IPCC AR4. This was followed by a similar report released by the United Nations Environment Programme in September 2009 (McMullen & Jabbour 2009).

Climate change is a complex issue that will affect each of us in our everyday lives and we need to understand the issues better.

This document draws on a comprehensive list of peer-reviewed reports and articles published up to August 2010, to provide up-to-date climate science research and to indicate projected changes in climate.

The effects of climate change are being felt across the globe. This report provides an overview of basic climate science and information on expected global climate change. More importantly, it focuses on the outcomes and expected impacts on Queensland and its key sectors.

It describes the projected changes in temperature, rainfall and extreme events for Queensland's various regions. It also outlines the key issues relevant to Queensland and shows how climate change is affecting the key sectors including human settlements and infrastructure, primary industries, water supplies, health, emergency management, and marine and terrestrial biodiversity.

Finally, the report outlines the current and proposed research actions and priorities needed to fully determine the social, environmental and economic implications for Queensland.

Chapter 1: Climate and weather

The climate system is complex. The Earth's climate is controlled by the exchange and storage of heat through the ocean, land, atmosphere and snow/ice. It is influenced by interactions between the sun, ocean, atmosphere, aerosols, clouds, ice and land (Figure 1).

The climate system is also finely balanced. Small changes in any of these variables can lead to significant changes in global and regional climate. For example, Soden *et al*. (2002) found that aerosols from the eruption of the Mt Pinatubo volcano in 1991 caused lower than average global temperature for approximately 2–4 years.

In contrast to the weather, 'climate' is how the atmosphere behaves over long periods of time. Climate is about changes, trends and averages over years, decades and centuries.

'Weather' is the day-to-day changes in temperature, precipitation, cloudiness, humidity, air pressure and wind. Synoptic maps show global weather systems, particularly high- and low-pressure systems and tropical cyclones, over three-hour or six-hour time periods (as specified by the World Meteorological Organization).

The United Nations Framework Convention on Climate Change (UNFCCC) makes a distinction between 'climate change' attributable to human activities, and 'climate variability' due to natural causes. The UNFCCC defines climate change as 'a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods' (United Nations 1992).

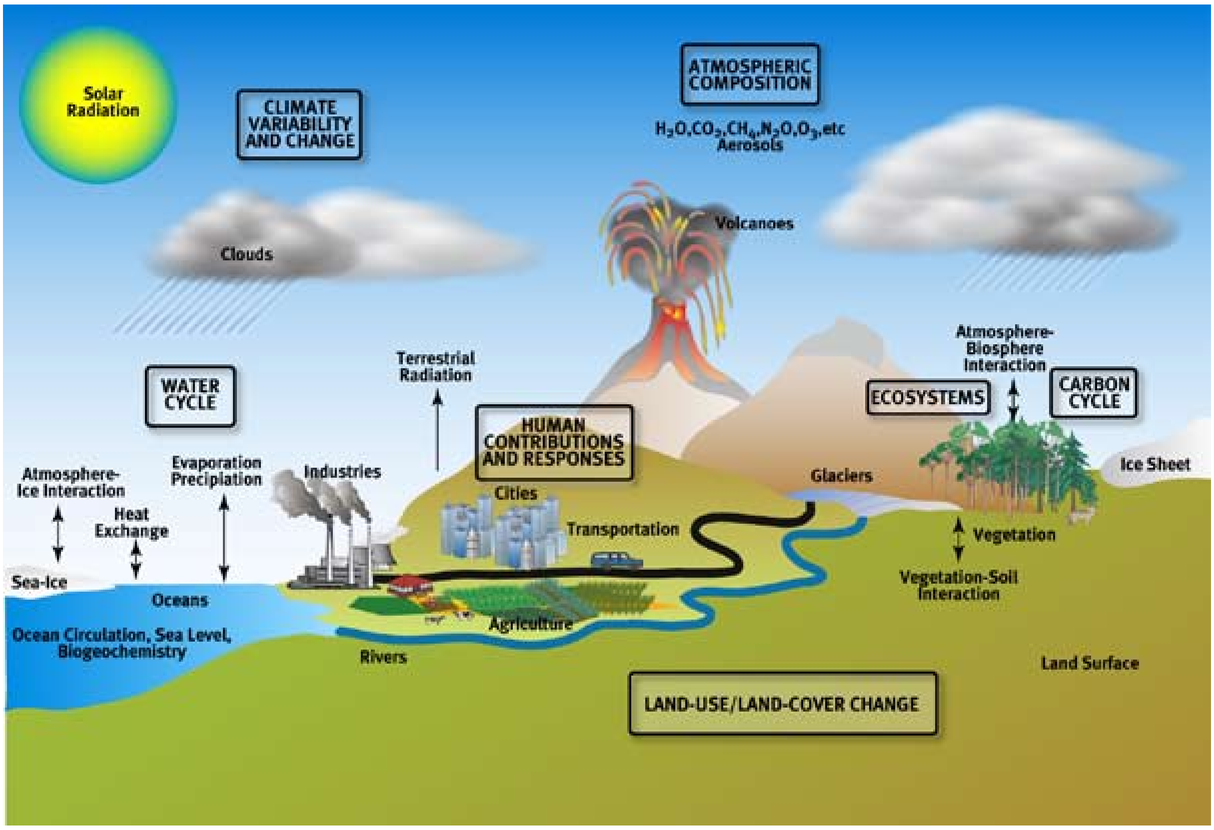


Figure 1: The climate system and climate change (Source: United States Global Change Research Program 2003; IAN 2010)

Two primary global atmospheric circulation patterns that have an impact on Australia's climate, in particular rainfall, are the Hadley cell and the Walker circulation.

The Hadley cell is a circulation pattern that transports excess heat from the equator towards lower temperate latitudes. It can be thought of as a conveyor belt, with warm moist air rising into the atmosphere in the tropics and moving southward (in the southern hemisphere) to the mid-latitudes where it cools and descends. The air is then returned to the tropics along the surface. The descending arm of the Hadley cell results in a band of high pressure known as the Sub-Tropical Ridge (STR). The Hadley cell also impacts on the easterly trade winds.

The Walker circulation is driven by the easterly trade winds (in the southern hemisphere) which carry warm moist air across the large ocean basins (Pacific, Indian and Atlantic) and is strongly linked to the El Niño Southern Oscillation (ENSO) in the Pacific Ocean. For example, during El Niño episodes the Walker circulation weakens, seas around Australia cool, and the trade winds feed less moisture into the Australian/Asian region.

Seasonal variations, for example the summer monsoon, affect synoptic weather patterns. Year-to-year fluctuations in the climate system and in particular the ENSO have a strong impact on the year-to-year fluctuations in Queensland's rainfall. There is also a multi-year cycle known as the Inter-decadal Pacific Oscillation (IPO) which contributes to extended dry or wet periods in Queensland. These fluctuations do not represent climate change but understanding these natural variations will improve our understanding of climate change impacts.

Australia's climate is among the most variable in the world. Figure 2 shows the main influences on Australian climate. Although there are many climatic features that affect Queensland's climate

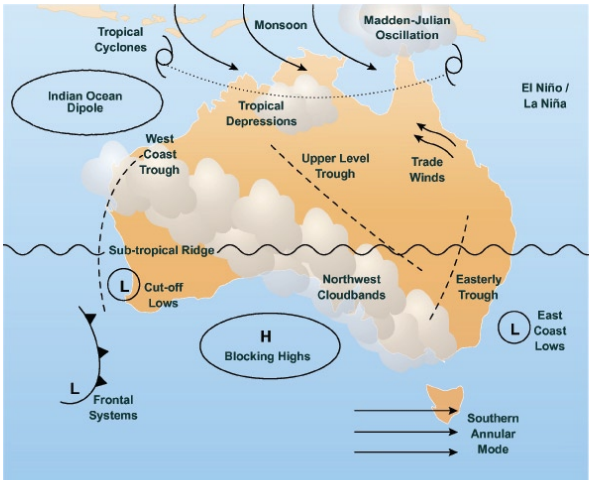


Figure 2: Climate signals which influence Australia's weather (Source: modified BoM 2010a)

the major climate drivers affecting the amount and pattern of rainfall across Queensland are the:

- El Niño Southern Oscillation (ENSO)
- Inter-decadal Pacific Oscillation (IPO)
- Madden-Julian Oscillation (MJO)
- Sub-Tropical Ridge (STR).

The ENSO has a significant effect on the annual fluctuations in seasonal conditions over eastern Australia. The ENSO is the oscillation between El Niño, La Niña and neutral conditions and is the result of variations in sea-surface temperatures and atmospheric patterns across the Pacific Ocean. The ENSO exerts a major influence on Queensland's climate, especially rainfall in northern and eastern Australia (Murphy & Ribbe 2004). Below-average seasonal rainfall in eastern Australia has long been linked to the El Niño phase of the ENSO and above-average seasonal rainfall with the La Niña phase (Murphy & Ribbe 2004).

There is also a link between major Queensland droughts and El Niño events, which occur when the sea-surface temperature rises in the eastern Pacific Ocean and cools in the west around Indonesia (DPI 2009).

El Niño and La Niña events typically last 9–12 months when equatorial sea-surface temperatures in the Pacific Ocean are well above (El Niño) or below (La Niña) average. The Southern Oscillation Index (SOI) is an indicator of ENSO conditions. It is calculated from the monthly or seasonal fluctuations in the air pressure difference between Tahiti and Darwin. SOI values are normally negative during an El Niño and positive during a La Niña.

Braganza *et al.* (2009) reconstructed the behaviour of ENSO from 1525 to 1982. They found that the variability of ENSO from the 16th to early 18th centuries was relatively low, but that high-frequency variability (at approximately 2–4 year intervals) has increased over the last 200 years (Braganza *et al.* 2009).

The IPO, like ENSO, is a change in the sea-surface temperatures in the Pacific Ocean. However, unlike ENSO, the IPO has an irregular interdecadal cycle. The positive phase of the IPO is characterised by warm sea-surface temperatures in the east, and central equatorial Pacific and cool sea-surface temperatures in the west Pacific. When the IPO is in this positive phase there is a weakening of the relationship between ENSO and Australian rainfall (Power *et al.* 1999).

The MJO is associated with a belt of low pressure that moves eastward across the equatorial Indian and Pacific Oceans. This 'pulse' of cloudiness has been observed to repeat roughly every 30–60 days. The passage of the MJO also influences the development of tropical cyclones. The MJO has its greatest effect on the tropical areas of Australia, increasing the intensity and duration of summer rainfall (Wheeler *et al.* 2009).

The STR is a large climatic feature that influences seasonal variations in weather across Australia. It is an area of high pressure to the south of Australia that moves north in winter, resulting in drier conditions over Queensland.

Recent warming appears to have increased the intensity of the STR (Timbal *et al.* 2010). The penetration of rain-bearing systems is impeded by the dry descending air of the STR which leads to a drier southern half of the Murray-Darling Basin. The influence of the STR was evident during the La Niña event in 2008, where storms and flooding affected Queensland and New South Wales, but had little impact on the Murray Valley or its headwater catchments (SEACI 2009).

Other climate drivers that affect rainfall include the East Coast Lows. These large-scale storm systems are one of a family of low-pressure systems which most often develop during the winter months along the east coast of Australia. East Coast Lows have the most impact on the New South Wales coast, with impacts off southern Queensland occurring occasionally. They are very intense and localised events which are difficult to predict. As with cyclones, they contribute to flooding and wind damage and beach erosion (BoM 2010a).

The Southern Annular Mode (SAM) also affects rainfall; however its impacts are felt primarily in southern Australia. The SAM is the north–south movement of the strong westerly winds that dominate the middle to higher latitudes of the Southern Hemisphere (BoM 2010a). Trends in SAM can account for 70 per cent of observed rainfall declines across southern Australia (Nicholls 2009). Although the relationship between the SAM and Australian rainfall is felt primarily in Southern Australia, the SAM is thought to have an impact on Queensland's rainfall through its effect on the STR (Williams & Stone 2009).

More research is needed to understand the relationship between rising global temperature and the STR intensification, and also the relationships among the various climate drivers, including the Hadley cell, ENSO and SAM.

The greenhouse effect

The natural greenhouse effect is a well-documented physical process which keeps the Earth at a stable temperature and makes it habitable. When energy from the sun (visible and ultraviolet radiation) reaches the Earth, it is either reflected back into space or absorbed by the land and oceans. The absorbed energy warms the Earth, which then emits heat (infra-red radiation). Some of this heat is captured by greenhouse gases, warming the atmosphere. Without the natural greenhouse effect, the average temperature on Earth would be about −19 °C, about 34 °C colder than it is today (Richardson *et al.* 2009).

Higher concentrations of greenhouse gases in the atmosphere increase the amount of outgoing heat absorbed, resulting in an 'enhanced' greenhouse effect. The increased level of greenhouse gases in the atmosphere, are contributing to changes in the climate.

The carbon cycle and carbon dioxide

Carbon dioxide or CO_2 is the major greenhouse gas responsible for human-induced (anthropogenic) climate change. Carbon in various forms circulates continuously between the atmosphere, oceans and land. Figure 3 shows the processes of release and storage of carbon, referred to as the carbon cycle. Carbon 'sources' (shown in Figure 3 as arrows) are activities such as burning fossil fuels, deforestation or fires that release CO_2 into the atmosphere. Carbon 'sinks' (shown in Figure 3 as asterisks) remove CO_2 from the atmosphere by sequestering (storing) it in the oceans, soil and vegetation. For example, the carbon from CO_2 absorbed by a tree may be stored as wood for hundreds of years. However, if the carbon becomes part of a leaf that dies and decomposes, the carbon is returned to the atmosphere relatively quickly.

It takes only a small change in the amount of CO_2 and other greenhouse gases in the atmosphere to upset the balance between the amount of carbon released and the amount sequestered.

Accelerated use of fossil fuels has increased emissions of greenhouse gases. Changes in land use also alter the amount of carbon in the atmosphere. For example it can increase through deforestation or be reduced through reforestation.

The continued and increasing release of CO_2 is altering the Earth's carbon cycle.

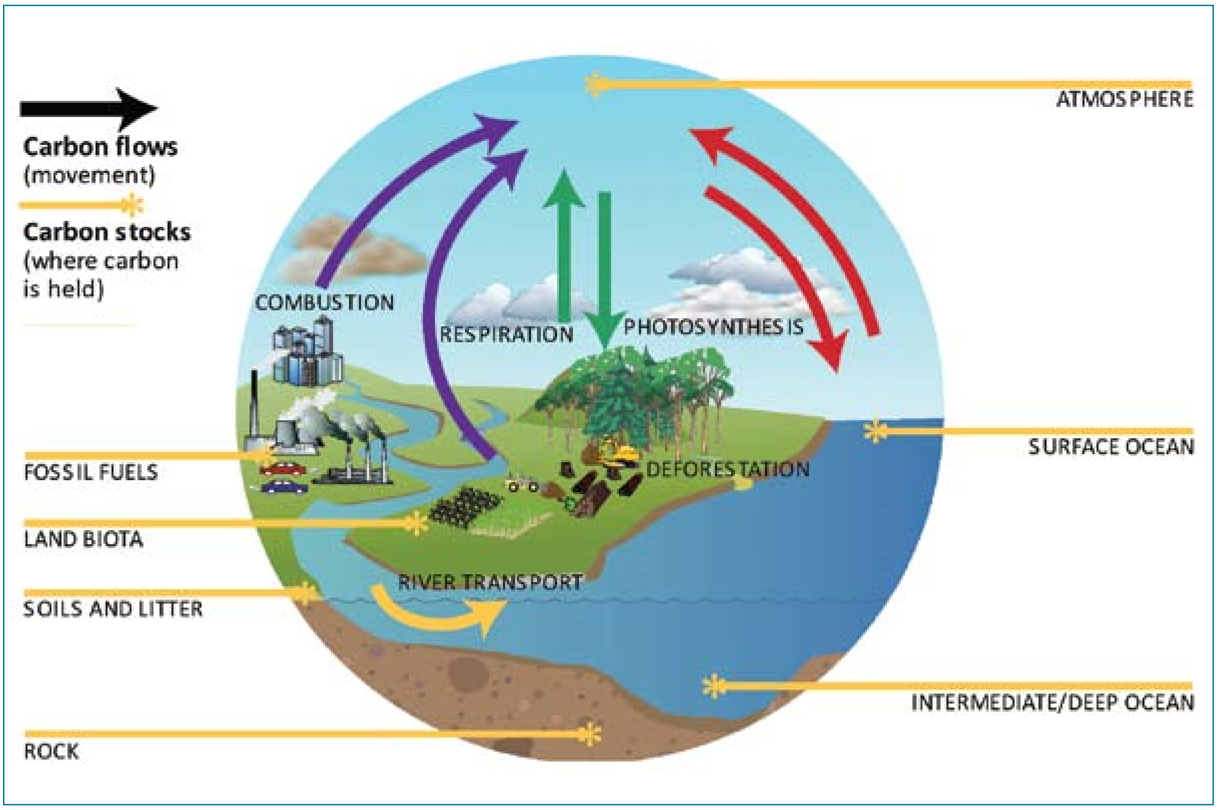


Figure 3: The carbon cycle (Source: DCC 2008; IAN 2010)

Contribution of human and natural factors to global warming

The term 'global warming' is often used with reference to climate change. Global warming describes the trend of increasing average global temperatures across the world, over decadal timeframes. It does not mean that every year is warmer than the previous year everywhere on Earth.

Both natural and human-caused (anthropogenic) climate forcings that can result in a changing climate include:

- greenhouse gases—carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) and halocarbons
- ozone (O_3)
- changing surface reflectivity (albedo)
- solar variability
- aerosols.

Radiative forcing

Radiative forcing is a measure of the change in the energy balance of the atmosphere and is used to compare the contribution of different factors to global warming or cooling.

The IPCC (2007a) explains radiative forcing as a measure of the influence that a climatic factor (e.g. ice, clouds or greenhouse gases) has in altering the balance of incoming and outgoing energy in the Earth–atmosphere system.

A positive radiative forcing increases the energy of the Earth–atmosphere system, thereby warming it. In contrast, a negative radiative forcing decreases the energy cooling the Earth–atmosphere system. There are both natural and human causes of positive and negative radiative forcing (Figure 4).

Increases in solar activity provide a natural positive forcing, whereas volcanic eruptions may result in a negative forcing. Negative forcings from volcanic eruptions can cause a drop in mean global surface temperature of about half a degree Celsius that can last for months or even years (IPCC 2007b).

Human activities that produce CO_2, such as the use of fossil fuel for energy generation and clearing land, cause positive forcing and significantly contribute to global warming.

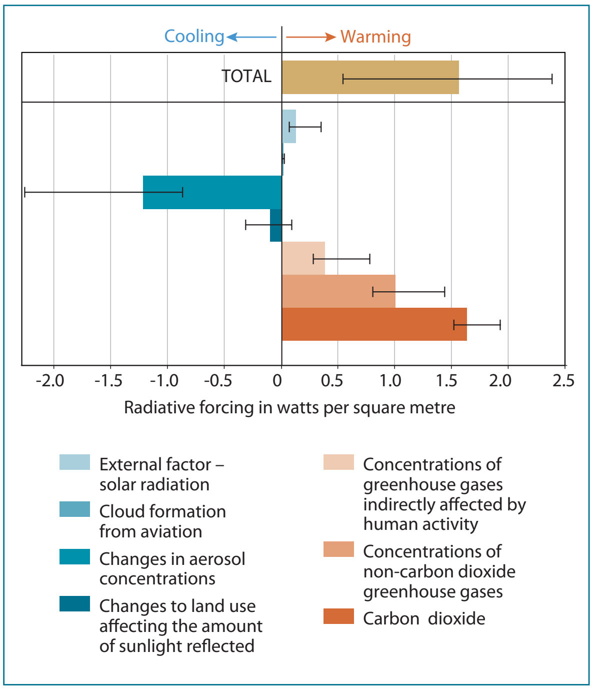


Figure 4: Contribution of human and natural factors to warming since 1750. The black error bars show the amount of uncertainty associated with each factor (Source: IPCC 2007a; updated Garnaut 2008)

The IPCC (2007a) compared the differences in natural variation and human activities between the present day and the start of the industrial era. It concluded that human activities caused a much greater difference in radiative forcing than natural variations (IPCC 2007a). Therefore, the radiative forcing from human activities has important implications for our current and future climate change.

Greenhouse gases

The four major human-generated greenhouse gases are carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) and halocarbons (better known as CFCs or chlorofluorocarbons). CFCs are chemicals used largely as refrigerants and cleaning agents.

Ozone (O_3) can also be either a warming gas or a cooling gas depending on where it is found in the atmosphere. Concentrations of O_3 have risen by around 30 per cent since the pre-industrial era and it is now considered to be the third most important greenhouse gas after CO_2 and methane (NOAA 2010).

Water vapour has the greatest influence on climate because of its abundance in the atmosphere. However, unlike CO_2, water vapour is not influenced by anthropogenic activities.

Not all greenhouse gases are alike, either in terms of their concentration, their 'warming potential' or the length of time they stay in the atmosphere. For example, each greenhouse gas has a different average lifetime and effectiveness at trapping infra-red radiation (heat). Methane lasts about five to twelve years. CO_2 is less powerful as a warming agent (molecule for molecule) than CH_4; however, it can last for hundreds of years in the atmosphere (IPCC 2007b).

In order to compare greenhouse gases against one another, a unit called carbon dioxide equivalent (CO_2-e) is used. CO_2 equivalency enables the comparison of global warming potential (GWP) over a specified time frame (generally 100 years). Methane has a GWP of 25 (i.e. it is 25 times stronger than CO_2 over 100 years) (IPCC 2007b).

Greenhouse gases in the atmosphere are measured either as emissions or concentrations. An emission is the amount of a substance released into the atmosphere from a specific source and in a specific time frame. It is expressed by the mass per time period, for example, million tonnes (Mt) per year. A concentration is the relative amount of a substance in the atmosphere and is usually expressed as parts per million (ppm).

Figure 5 shows the concentration of three greenhouse gases which have increased significantly over recent decades. This contributes to the enhanced greenhouse effect and thus impacts on anthropogenic climate change.

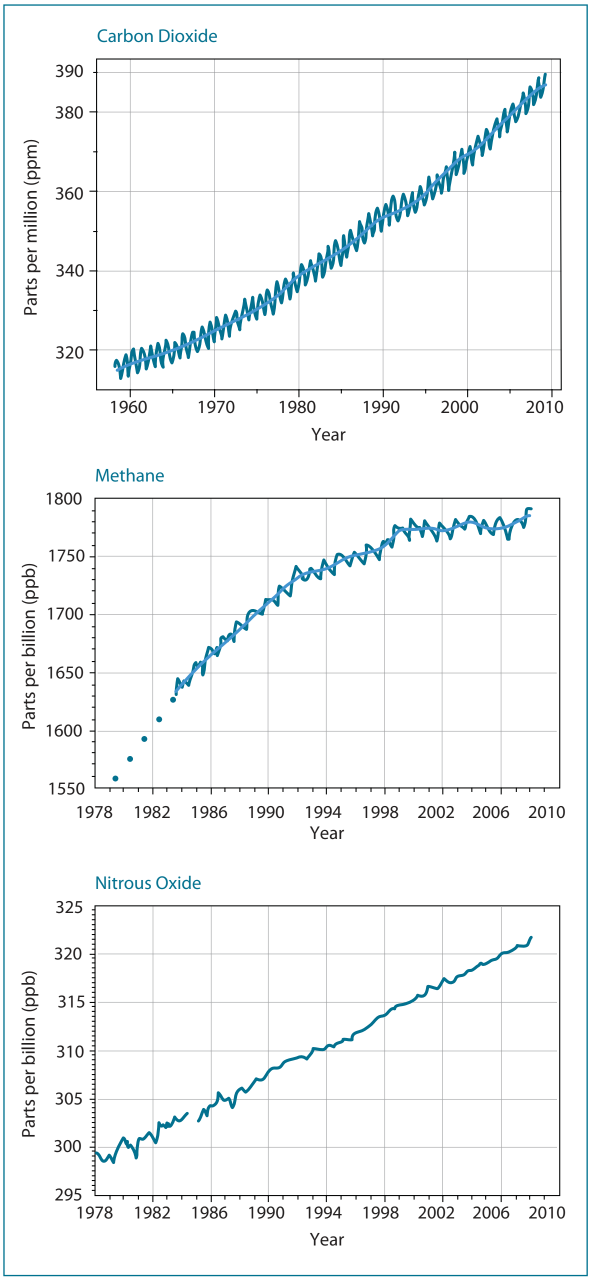


Figure 5: Atmospheric concentrations of carbon dioxide in ppm; methane in ppb (parts per billion); and nitrous oxide in ppb (Source: Richardson *et al.* 2009; Tans 2010; Hoffman 2009; Dlugokencky *et al.* 2005)

Since the start of the Industrial Revolution around 1750, the global CO_2 concentration has risen 38 per cent, CH_4 has risen 150 per cent and N_2O has risen 18 per cent (Le Quéré *et al*. 2009; IPCC 2007a).

The atmospheric CO_2 concentration in 2009 of 387 ppm (Tans 2010) is much higher than the natural range of 172–300 ppm that has existed over the last 800 000 years (Lüthi *et al*. 2008). The increase in CO_2 is due to the use of fossil fuels and land clearing. Increases in atmospheric concentrations of CH_4 and N_2O are primarily due to agricultural activities. Global carbon emissions from the combustion of fossil fuel and land-use change reached 10 billion tonnes in 2008, up from about two billion tonnes in 1950 (Le Quéré *et al*. 2009).

Denman and Brasseur (2007) report that over 60 per cent of atmospheric methane emissions are now related to human activities. Methane is responsible for almost a fifth of the enhanced greenhouse effect, second in importance only to CO_2 (IPCC 2007b).

Ozone

Ozone (O_3) absorbs long-wave infra-red radiation emitted from the Earth's surface, contributing to the greenhouse effect. Ozone makes a significant contribution to the radiative balance. Changes in the distribution of O_3 in the upper troposphere and lower stratosphere affect the radiative forcing of climate. During the 20th century, tropospheric ozone has been supplemented by anthropogenic ozone. Tropospheric ozone increases have contributed to warming, while stratospheric ozone decreases have contributed to cooling (IPCC 2007b).

Changing surface reflectivity (albedo)

Warming of the Earth is also affected by changing the fraction of solar radiation that is reflected (called 'albedo'). Albedo is affected by changes in cloud cover, atmospheric particles or land cover. About 30 per cent of the sunlight that reaches the top of the atmosphere is reflected back to space. Roughly two-thirds of this reflectivity is due to clouds and small particles in the atmosphere known as 'aerosols'. Light-coloured areas of Earth's surface (mainly snow, ice and deserts) account for the remaining one-third of the reflected sunlight. The energy that is not reflected back to space is absorbed by the Earth's surface and atmosphere (IPCC 2007b).

There is growing scientific evidence that the clearing of vegetation can have an impact on regional climate. Deo *et al*. (2009) found that the clearing of approximately 15 per cent of Australia for agriculture is likely to have contributed to a hotter and drier climate, and also exacerbated the El Niño effect by reducing evaporation and transpiration. Results for modified land-cover conditions show an increase in the number of dry and hot days, a decrease in wet-day rainfall (the amount of rain that falls on a wet day) and increases in the duration of droughts (Deo *et al*. 2009). These changes were statistically significant for all years and were especially pronounced during strong El Niño events. Therefore it appears that land-cover change has exacerbated climate extremes in eastern Australia, resulting in longer-lasting and more severe droughts (Deo *et al*. 2009).

Solar variability

Solar energy directly heats the climate system and can also affect the atmospheric abundance of some greenhouse gases such as stratospheric ozone. Solar output has increased gradually in the industrial era, causing a small positive radiative forcing. This is in addition to the changes in solar radiation that occur over the known 11-year cycle of solar activity (IPCC 2007b).

Aerosols

Aerosols (airborne particles) can also influence climate. Aerosols result both from natural sources and human activities. Natural sources include forest fires, sea spray, desert winds and volcanic eruptions. Human activities such as the burning of fossil fuels, deforestation and smoke from grass and bushfires also produce aerosols. Aerosols can cause both negative forcing (cooling) and positive forcing (warming) on the atmosphere (IPCC 2007b).

Aerosols, such as sulphates and nitrates, reflect visible solar radiation resulting in hazy skies and a cooling effect. Aerosols also cause an indirect negative radiative forcing through the changes they cause in cloud properties (IPCC 2007b). However, black carbon aerosols (soot) absorb visible solar radiation, warming the Earth (IPCC 2007b).

The direct radiative forcing summed over all aerosol types is negative. Currently the indirect effect of aerosols is not well quantified and the associated uncertainty is large (Figure 4).

Climate feedbacks

A change in a component of the climate, causing an impact which further changes the climate, is called a 'feedback'. A feedback can be either positive or negative.

A positive feedback increases the rate of global warming. For example, as the atmosphere heats up it has a greater capacity to hold water vapour, which will enhance the greenhouse effect leading to further warming. Another example of a positive feedback is when snow and ice melt to reveal darker land and water surfaces. These darker surfaces absorb more of the sun's heat, increasing the rate of warming, which causes more melting, and so on in a self-reinforcing cycle. This positive feedback loop is known as the 'ice-albedo feedback'.

A negative feedback slows the rate of global warming and has a cooling effect on the atmosphere. For example, as the ocean cools, its capacity to absorb CO_2 increases. The removal of CO_2 from the atmosphere dampens the greenhouse effect, resulting in further cooling.

Research into the Earth's climatic changes has focused on detecting, understanding and accurately quantifying climate feedbacks.

Climate modelling

Dynamical models and emissions or concentration scenarios are used to project changes in our climate and the relative impacts of these changes.

Climate models are numerical representations of various parts of the Earth's climate system. The models simulate the current climate system and use different emissions scenarios to project how the climate system might respond to natural and anthropogenic changes, such as increased greenhouse gas emissions or reduced land cover.

Models have a three-dimensional grid of points which extends horizontally and vertically on land, the sea and the atmosphere. Most global climate models use a grid spacing of approximately 200 kilometres. The latest UK Met Office Hadley Centre model, HadGEM1, uses a 135 kilometre horizontal grid.

Regional models operate at a finer resolution, for example using a 50 kilometre grid. Depending on the quality of the input data, these models can provide more detailed projections over a smaller area and take into account local effects.

The validity of a model is tested against the historical climate record. Once the ability of the model to accurately represent past climate has been established, the model can be refined to project future trends.

There is greater confidence in the model projections for temperature and pressure than there is for rainfall. Rainfall projections show stronger spatial and temporal variations which produce large variations between model outputs.

Simulation of large-scale climatic variability has improved, but local effects and small-scale extreme events are harder to simulate.

Queensland's climate change strategy, *ClimateQ: toward a greener Queensland*, released in August 2009, provides climate change projections for 13 Queensland regions. These indicate the projected changes (up to 2070) for temperature and rainfall. A summary of the climate projections and potential impacts for the 13 regions is presented in Chapter 3 and Table 1 (page 29).

Emissions scenarios

There is a distinction between climate change 'projections' and 'predictions'. Even with the best climate models, it is impossible to accurately predict the future climate. Climate change models take into account a range of climate variables on the physical environment and project the likely impact of greenhouse gases and other forcings on future climate.

There are various 'scenarios' developed by the IPCC (2007a) which reflect different assumptions about emissions of greenhouse gases, changes in population, rate of adoption of new technologies, economic growth and other factors.

These scenarios based on four 'storylines' (A1, A2, B1 and B2) are sets of assumptions about possible alternative futures. Each storyline yields a family of scenarios, 40 in total. The three IPCC scenarios most often used in climate modelling are:

- **B1 lower** emissions growth scenario—assumes a rapid shift to less fossil-fuel intensive industries and projects a global temperature increase relative to 1990 of 1.8 °C (1.1–2.9 °C) by 2100
- **A1B medium** emissions growth scenario—uses a diversity of energy sources and projects a global temperature increase of 2.8 °C (1.7–4.4 °C) by 2100
- **A1FI higher** emissions growth scenario—assumes a continued dependence on fossil fuels. The scenario projects a tripling of CO_2 concentrations (relative to pre-industrial levels) and a global temperature increase of 4.0 °C (2.4–6.4 °C) by 2100. Recent observations indicate that CO_2 emissions have been tracking above the A1FI level (Le Quéré *et al*. 2009).

The A2 emissions scenario is also used in climate modelling. The A2 scenario displays a continuously increasing population with a more fragmented and slower uptake of technology than the other storylines. Emissions for the A2 scenario are between those of the A1B and the A1FI scenarios for most of the century (from approximately 2030 to 2090) but by 2100, A2 emissions are greater than those of the A1FI scenario (IPCC 2007b).

The *IPCC Fourth Assessment Report* (AR4) also considers emissions reduction scenarios that would stabilise greenhouse gas concentrations at 445–490 ppm CO_2-e and global average temperature increases of 2.0–2.4 °C. The AR4 concluded that to stabilise greenhouse gas concentrations at this level, developed countries would need to reduce emissions by 25–40 per cent by 2020 relative to 1990 levels, and by 80–95 per cent by 2050 (IPCC 2007a).

A new area of climate science study—decadal projection—is emerging. This focuses on the links between seasonal forecasting and longer-term climate change projections. Decadal projections explore the evolution of regional climate conditions over the next 10 to 30 years. Projections on this timescale are very important to infrastructure planners, water resource managers and other land managers (McMullen & Jabbour 2009).

Improved modelling capability and increased knowledge of the climate system is enhancing the certainty of global climate change projections on a global scale. However, more local data and accurate regional modelling is needed for accurate projections of climate change on a regional scale.

Chapter 2: Global climate change

The Intergovernmental Panel on Climate Change (IPCC) is the authoritative international scientific body on climate change. The IPCC produces reports that assess climate change science which are based on published, peer-reviewed research. The most recent report, the *IPCC Fourth Assessment Report* (AR4) released in 2007, summarises the scientific research up to 2006 (IPCC 2007a).

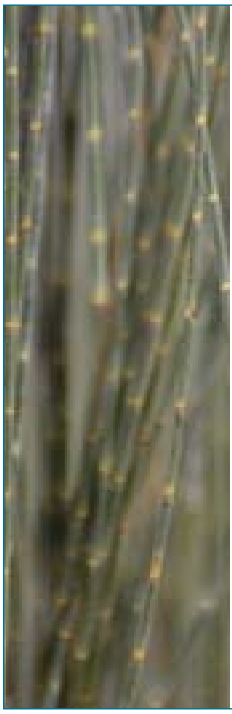
The AR4 concluded that warming of the climate system is unequivocal and that there is a more than 90 per cent probability that the warming is due to human activities, predominantly the burning of fossil fuels and clearing of natural vegetation.

The next report, the Fifth Assessment Report (AR5) is expected to be released in 2014.

Since 2006, a number of significant reports and papers have been published supporting the human influence on the climate and underlining the need for urgent action to mitigate the effects of climate change and to adapt to a changing climate.

In particular, the *2009 State of the Climate* report by the US National Oceanic and Atmospheric Administration (NOAA) released in July 2010 (Arndt *et al*. 2010) documents significant weather events from around the world that occurred in 2009, examines current climate anomalies, analyses 37 key climate indicators and provides a detailed review of 10 of these indicators. The 10 indicators were selected because of their clear and direct link with global temperatures. All 10 of these indicators were based on multiple global sets of observed data and all are consistent with a warming trend.

The Science of Climate Change: Questions and answers published in August 2010 by the Australian Academy of Sciences, unambiguously supports the conclusion that a continued reliance on fossil fuels would lead to a warmer world. The report addresses the current confusion about climate change created by contradictory information in the public domain and sets out to explain the current climate science, including areas of consensus or uncertainty.



Key messages

CO_2 emissions grew 3.4 per cent per year between 2000 and 2008, a growth more than triple that experienced during the 1990s. Increases in CO_2 in the atmosphere and oceans have resulted in:

- 14 of the past 15 years being the warmest since records began in 1880
- 2009 was the fifth warmest year (1998 was the warmest) in the 160 years of global instrumental temperature records
- global average temperature increasing by about 0.75 °C since 1900
- increased melting of permafrost releasing greenhouse gases into the atmosphere
- increased frequency of temperature extremes such as hot days and hot nights
- more frequent heatwaves
- extreme rainfall events with a greater number of severe tropical cyclones
- increased flooding associated with sea level rise and storm surges
- more severe droughts and bushfires
- increased ocean acidification disrupting marine ecosystems.

Observed climate change

Greenhouse gas emissions have increased rapidly over the last decade; if this continues it will result in increased impacts on human society and on ecosystems.

Observations of increasing global land and ocean temperatures, ocean heat content, rising sea levels and the retreat of glaciers and ice sheets all indicate the world is warming. Strengthening the certainty in this warming is the number of observations of each of these climate change indicators. There are four sets of global land and ocean temperature data, seven sets of global ocean heat content data and three sets of Arctic sea ice extent data. All of this data indicates that the world has warmed (Arndt *et al.* 2010). Increases in the number and severity of extreme weather events, which are expected in a warming world, are starting to be observed.

Greenhouse gases

Global emissions of CO_2 from fossil fuel combustion are currently at high levels. Le Quéré *et al.* (2009) found that CO_2 emissions grew 3.4 per cent per year between 2000 and 2008, more than triple the growth experienced during the 1990s. The concentration of CO_2 in the atmosphere is also increasing rapidly, rising to 387 ppm in 2009 (Tans 2010).

Figure 6 shows that observed emissions of CO_2 from fossil fuel combustion and cement production (a CO_2 intensive industry) align with the most carbon-intense emissions scenario (A1FI) of the IPCC.

The observed global CO_2 emissions up to 2006 are shown in Figure 6 from the US Department of Energy Carbon Dioxide Information Analysis Center, with 2007 and 2008 figures based on British Petroleum economic data.

The shaded area covers all the scenarios used by the IPCC to project climate change. Global CO_2 emissions in 2009 are expected to be approximately 3 per cent below 2008 levels, close to the level of emissions in 2007 (Le Quéré *et al.* 2009).

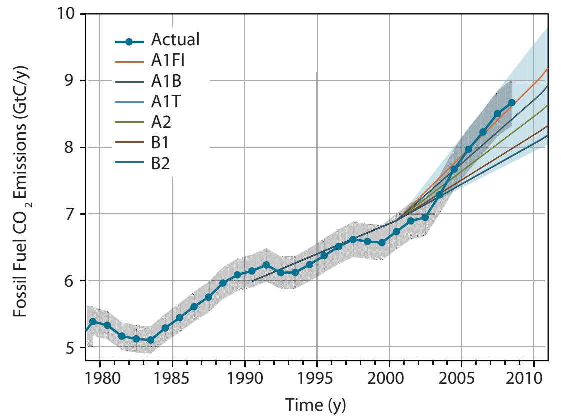


Figure 6: Observed global CO_2 emissions from fossil fuel burning and cement production compared with IPCC emissions scenarios between 1980 and 2010 (Source: Le Quéré *et al.* 2009)

Natural land and ocean carbon sinks absorb over half of all anthropogenic emissions. However, increased CO_2 emissions over the last 50 years have reduced the effectiveness of these sinks, increasing the amount of CO_2 retained in the atmosphere (Canadell *et al.* 2007).

Even if anthropogenic CO_2 emissions are reduced, the impacts will persist for centuries. Archer and Brovkin (2008) found that between 20 and 60 per cent of released CO_2 will remain in the atmosphere for a thousand years or longer (Archer & Brovkin 2008).

Temperature

The IPCC AR4 has increased our understanding of the causes of the recent century-scale warming and concluded that over 90 per cent of the observed warming is due to human factors (IPCC 2007a).

Lean and Rind (2008) compared the role of natural factors, such as solar variability and volcanoes, with human influences on temperatures since 1889. They found that over the last century, the sun contributed about 10 per cent of combined land- and sea-surface warming. Over the last 25 years, the sun's contribution to this warming was negligible (Lean & Rind 2008).

Ramanathan and Feng (2008) argue that the observed increases in the concentration of greenhouse gases has already committed the world to an average warming of 2.4 °C (1.4–4.3 °C) above pre-industrial surface temperatures.

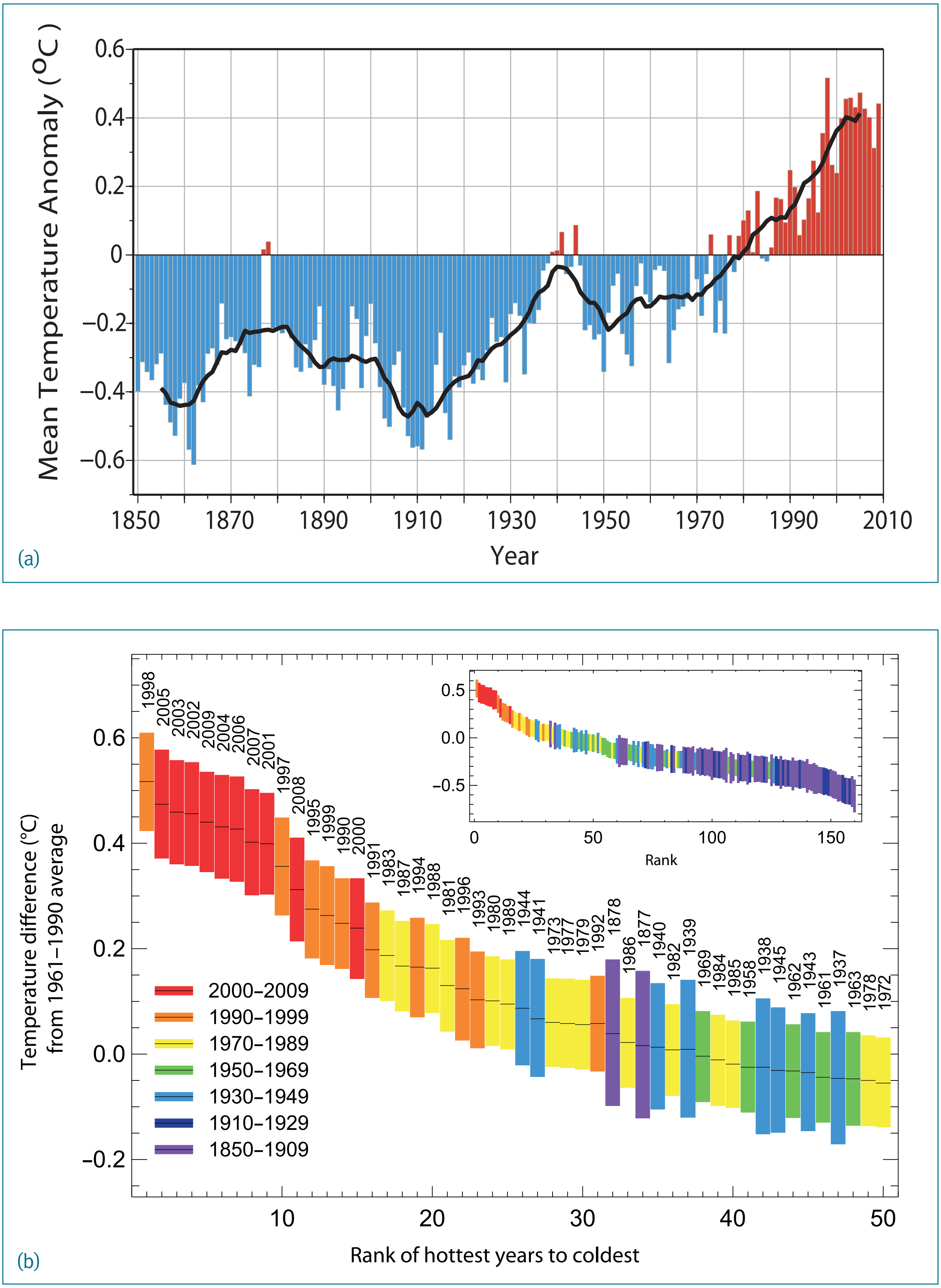


Figure 7: The global land–ocean temperature record from UK Met Office Hadley Centre (HadCRUT3) between 1850 and 2009 (temperature anomaly is relative to the average temperature from 1961 to 1990), (a) time series and (b) ranked by temperature (Source: Met Office 2010; Brohan *et al*. 2006)

Globally, the land–ocean temperature record indicates that 14 of the past 15 years are the warmest since records began in 1850 (Met Office 2010).

Figure 7(a) shows the strong warming trend in the global temperature record since the early 20th century. Figure 7(b) shows the individual years in the record ranked according to their average temperature, the year ranked as number one (1998) being the warmest year on record. This figure highlights the increasing trend in global temperatures, with recent decades dominating as the warmest years.

January 2000 to December 2009 was the warmest decade on record, with the last three decades displaying an upward trend. In total, average global temperatures have increased by about 0.75 °C since 1900 (Met Office 2010). The UK Met Office Hadley Centre (2010) data set shows that 2009 was the fifth warmest year in the almost 160 years of global instrumental temperature records.

There has also been a consistent and upward warming trend in ocean surface temperatures over the past 50 years. Satellite measurements of ocean surface temperature showed 2007 to be the warmest year ever recorded, despite the extremely strong El Niño event in 1997–98. Overall, ocean surface temperatures for 2009 were the second warmest on record (Allison *et al.* 2009; Met Office 2010).

Ocean heat content

Observations indicate that the world's oceans are warming. This is because they absorb most of the heat being added to the atmosphere by greenhouse gases. It is estimated that approximately 90 per cent of the heat added to the atmosphere from 1963 to 2003 was absorbed by the ocean (IPCC 2007b).

Arndt *et al.* (2010) and Palmer *et al.* (2010) summarise the recent observations of ocean heat content and compare eight separate studies examining the heat content of the upper 700 metres of the ocean. Although there are differences between the various datasets, they all show an increase in ocean heat content and a rapid increase over the last two decades. One of the most important consequences of increasing ocean heat content is sea level rise.

Sea level rise

Sea level rise is caused by increases in ocean thermal expansion and ocean mass due to increasing global temperatures. Water expands when it heats up, increasing the level of the ocean. Melting mountain glaciers, ice caps and the ice sheets of Greenland and Antarctica add new water to the ocean also increasing its level.

Domingues *et al.* (2008) found that the Earth's oceans have warmed 50 per cent more than previous estimates, which has direct implications for rising sea levels.

Data from tide gauges around the world shows that global sea level has risen by almost 0.2 metres since 1870 (Church & White 2006). Since 1993, satellites have been used to measure sea level more accurately. Both sets of measurements show that the rate of sea level rise has accelerated.

Coastal observations confirm that sea level rise has been occurring around Australia since at least 1920. Eastern Australia has experienced extreme sea level events three times as often in the last half of the 20th century compared with the first half (Church *et al.* 2006).

Figure 8 shows that the current rate of global average sea level rise is following the highest level (A1FI) of the IPCC projections. The sea level measurements using tide gauge data are indicated in red and satellite data is in blue. The shaded band shows the projections of the IPCC Third Assessment Report (IPCC 2001).

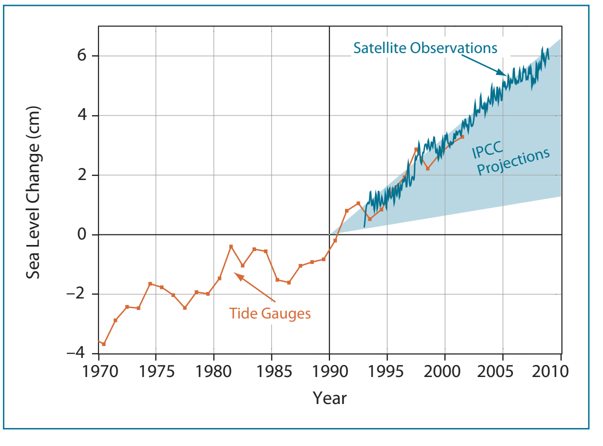


Figure 8: Sea level change compared with IPCC projections between 1970 and 2010 (Source: modified Allison *et al.* 2009)

Arctic sea ice

Over the past few decades, the Arctic has also warmed at twice the rate of the rest of the Earth. Kaufman *et al*. (2009) found that present Arctic temperatures are higher than at any time in the last 2000 years. The period from 1999 to 2008 was the warmest of the past 2000 years.

Since the early 1970s, Arctic sea ice extent at the end of the melt season in September has declined sharply and more rapidly than predicted by the IPCC AR4 (Stroeve *et al*. 2007).

Data from the National Snow and Ice Data Center (NSIDC) (Figure 9) indicates that at the end of the 2007 melt season, sea ice was 39 per cent below the long-term average and that 2005 to 2009 had the five lowest annual sea ice extents on record (NSIDC 2010). The observed September Arctic sea ice extent in millions of square kilometres is indicated by the orange line. The average sea ice extent from IPCC modelling is indicated by the solid blue line, while the dashed blue lines represent their range. The 2009 observed extent has been calculated at 5.1 million square kilometres, the third lowest year on record (NSIDC 2009).

A recent study by Wang and Overland (2009) found that by 2040, the Arctic Ocean could be nearly ice-free in the summer. Previous projections had this happening 60 years later—at the end of the century.

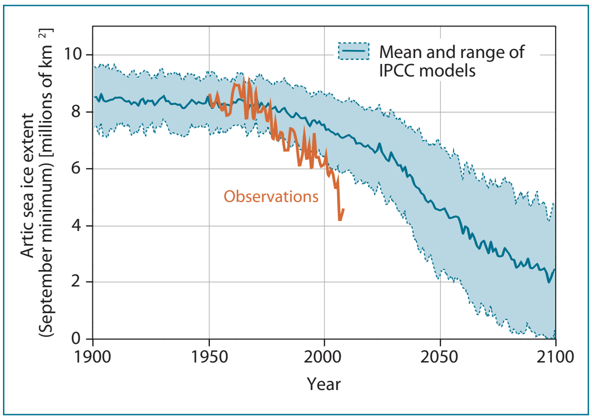
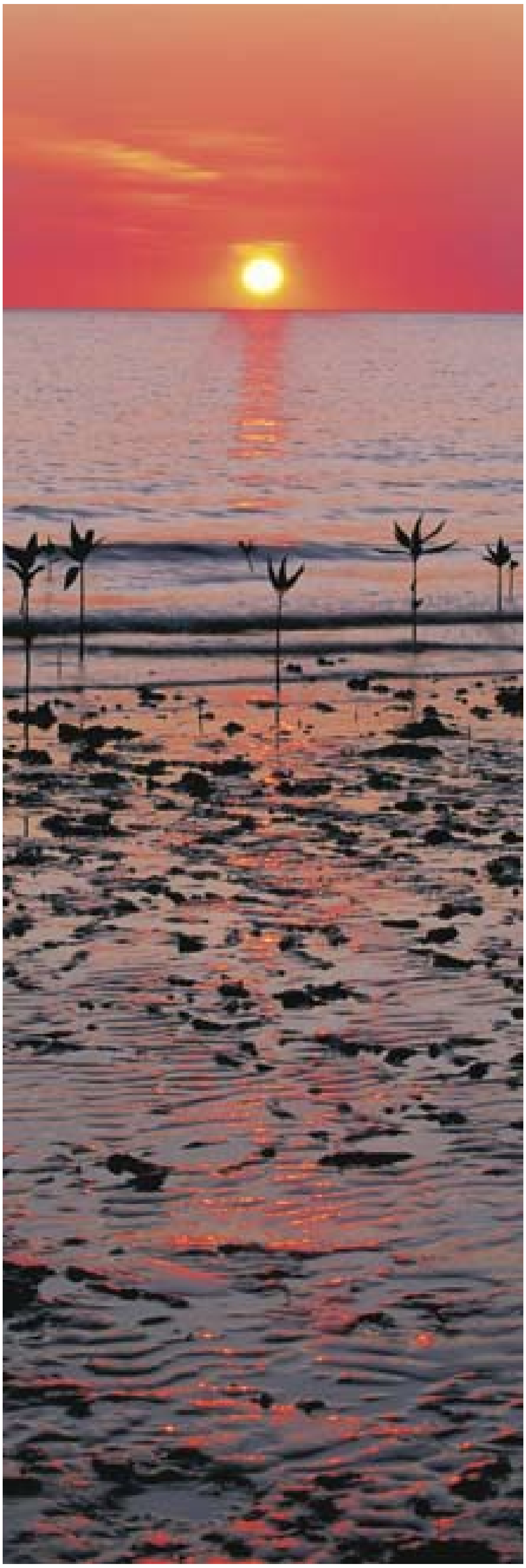


Figure 9: September minimum Arctic sea ice extent between 1953 and 2008 compared with IPCC AR4 projections between 1900 and 2100 (Source: Stroeve *et al*. 2007 updated; NSIDC 2009; Allison *et al*. 2009)



Ocean acidification

When CO_2 dissolves in sea water it forms carbonic acid, lowering the pH of the ocean and making the water more acidic. Hoegh-Guldberg *et al.* (2007) found that the increasing emissions of CO_2 have made the oceans more acidic than at any time in the last 420 000 years.

Ocean acidification affects all marine ecosystems in addition to reducing the capacity of oceans to store carbon. It is projected that once atmospheric CO_2 levels reach 450 ppm, large areas of the Southern Ocean and other polar oceans will have become so acidic that the shells and skeletons of key marine organisms will dissolve (Orr *et al.* 2009).

Figure 10 shows the changes that are projected to occur at different CO_2 concentrations. Changes in aragonite saturation are shown by the colour range, while the number at the top left of each panel is the atmospheric CO_2 concentration in ppm (Hoegh-Guldberg *et al.* 2007).

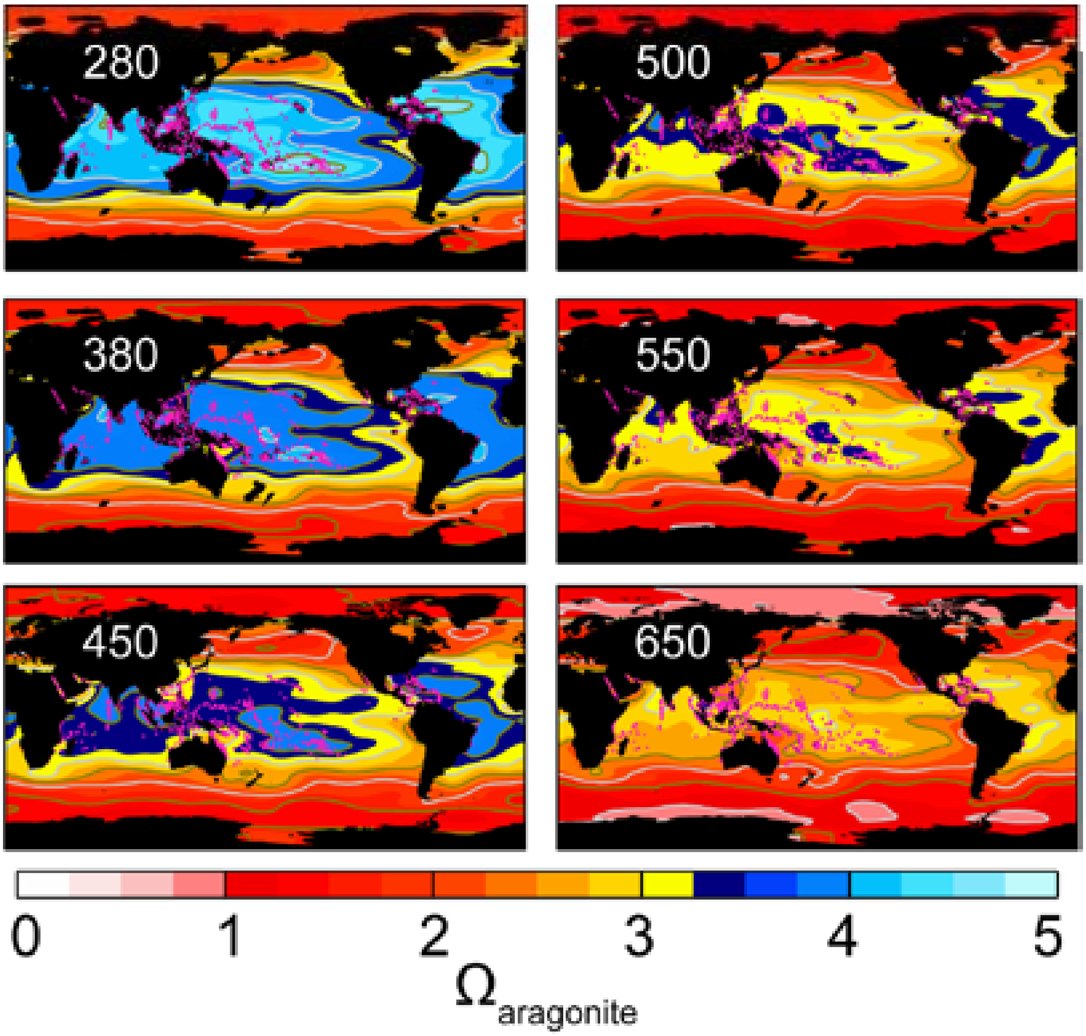


Figure 10: Changes in aragonite saturation as atmospheric CO_2 concentrations (ppm) increases (Source: Hoegh-Guldberg *et al.* 2007)

Aragonite is a mineral form of calcium carbonate used by organisms to form their shells and skeletons. If its concentration falls below about 3 ppm, marine organisms find it difficult to produce these shells and skeletons.

Increasing ocean acidification is likely to endanger many of the world's unique reef ecosystems including the Great Barrier Reef. Coral reefs now face a double threat of rising sea-surface temperature causing coral bleaching and acidification reducing some marine organisms' ability to grow (Hoegh-Guldberg *et al.* 2007). Moy *et al.* (2009) and De'ath *et al.* (2009) have already observed a decline in shell weights for several marine species since the Industrial Revolution.

Climate extremes

Extreme weather events occur within the climate's natural variability. However, recent observations show that an increasing number of extreme weather events can be attributed to human-induced changes in the climate system.

Steffen (2009) noted that during the last 50 years, hot days and hot nights have become more frequent, while cold days and cold nights are less frequent. He also found that over the same period, heatwaves have become more frequent and longer (Steffen 2009).

A comparison of satellite observations with model simulations of tropical rainfall events has also shown a clear link between temperature and rainfall extremes (Allan & Soden 2008). Allan and Soden (2008) found that heavy rain events increase during warm periods and decrease during cold periods.

Extreme weather events from climate change have the greatest potential impact on human and natural systems. Therefore accurate projections of such events are important for future climate change planning.

Future climate change

The long lifetimes of some greenhouse gases means that the climate will continue to warm into the future even if emissions are reduced. An analysis by Solomon *et al.* (2009) suggests that even if emissions were to stop completely, slower heat loss from the ocean would cause temperatures to remain high for at least 1000 years.

Sea level rise

For the high (A1FI) emissions scenario, the IPCC projected a sea level rise of 0.26–0.59 metres by 2100 (IPCC 2007a). A possible addition of 0.1–0.2 metres from melting ice sheets was also suggested but not included in the projections (IPCC 2007b). However, sea level has risen much faster than expected and current observations suggest that the projections of the IPCC AR4 may be significant underestimates (Rahmstorf *et al.* 2007; Vermeer & Rahmstorf 2009). The biggest uncertainty in current sea level rise projections is the response of the Greenland and Antarctic ice sheets to global warming.

Release of methane from permafrost

Permafrost (frozen soil) is found mostly in Siberia, Alaska, Canada and Scandinavia and acts as a large land-based carbon sink. An estimated 1670 billion tonnes of carbon is stored in permafrost—more than twice the amount of carbon in the atmosphere (Tarnocai *et al.* 2009).

Increasing land temperature could trigger rapid thawing of permafrost. As the soils defrost, the greenhouse gases (primarily CH_4) previously locked in the frozen soils are released into the atmosphere, further contributing to global warming (Lawrence *et al.* 2008).

Risk assessments estimate that if permafrost thawing continues, 0.5–1 billion tonnes of carbon per year would be released into the atmosphere, a figure similar in magnitude to current emissions from large-scale land-use change (Schuur *et al.* 2008).

Tipping points

Processes within the climate system appear to be unresponsive to change until a specific threshold is crossed. These thresholds or climatic 'tipping points' are regional-scale features that could result in abrupt or irreversible changes in the Earth's natural and climate systems (Lenton *et al.* 2008). Figure 11, shows some of the changes in systems which could trigger severe and long-term consequences for the climate system.

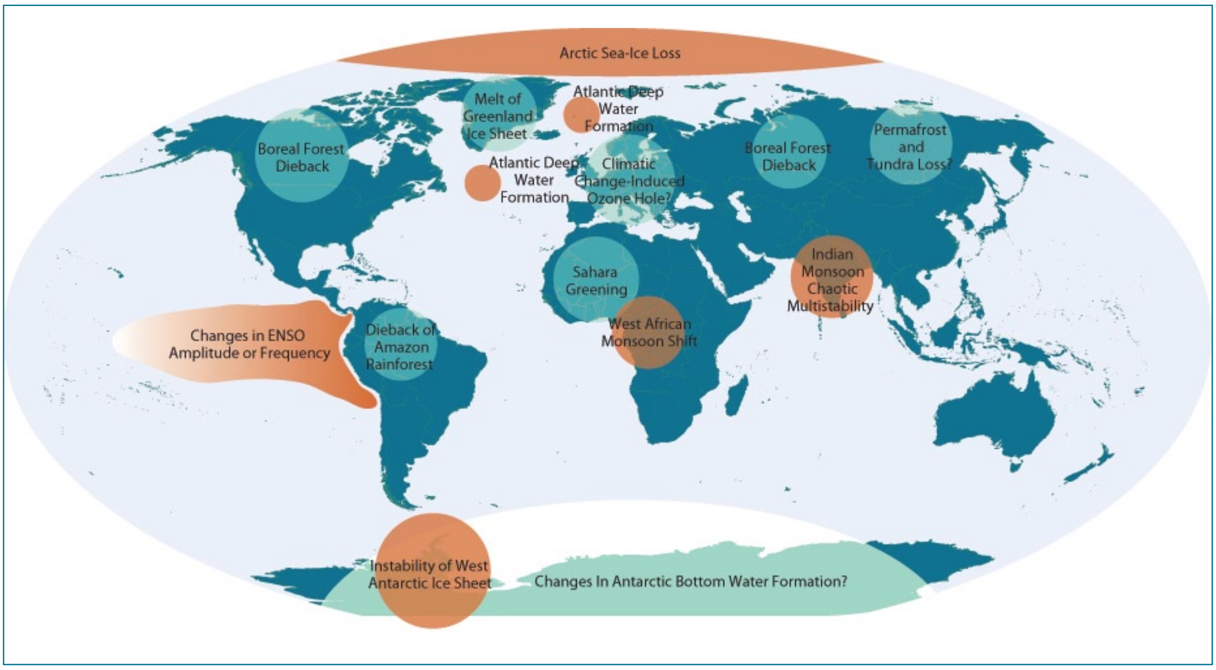


Figure 11: Map of some of the potential tipping points in the Earth's climate system (Source: Lenton *et al*. 2008; updated Richardson *et al*. 2009)

The question marks in Figure 11 indicate systems whose status as potential tipping points is particularly uncertain. Other potential thresholds include shallow-water coral reefs threatened in part by ocean acidification (Veron *et al*. 2009).

To minimise the risk of reaching these tipping points, Lenton *et al*. (2008) suggest that warming of the climate system must not exceed 2 °C above pre-industrial temperatures.

Meinshausen *et al*. (2009) showed that projected emissions from 2000 to 2050 are a good indicator of whether or not 21st century warming will exceed 2 °C. Limiting total 2000–2050 emissions to 1000 billion tonnes of CO_2 yields a 25 per cent chance of exceeding 2 °C. However, the likelihood of exceeding 2 °C of warming increases to 50 per cent if emissions total 1440 billion tonnes (Meinshausen *et al*. 2009).

While there is no global consensus on the definition of 'dangerous climate change', considerable support has developed for containing the rise in global temperature to a maximum of 2 °C above pre-industrial levels. However, research has shown that even with a temperature rise of less than 2 °C, impacts can be significant.

Beyond 2 °C, major societal and environmental disruptions may occur and the possibilities for adaptation of society and ecosystems may rapidly decline.

Many policy mechanisms focus on stabilising the level of greenhouse gas emissions at 450 ppm. This level reflects the need for continued economic growth and development, particularly in less developed countries. However stabilisation at 450 ppm will still result in significant impacts on society and the environment.

These impacts will require us to adapt to changes in how we live and work within our environment. Queensland's climate change strategy, *ClimateQ: toward a greener Queensland*, provides a range of mitigation and adaptation initiatives to help Queenslanders reduce emissions and adapt to a changing climate.

Chapter 3: Climate change in Queensland

Queensland has one of the highest per capita greenhouse gas emissions in the world and they have continued to grow over the last decade. Queensland is responsible for 30 per cent of Australia's carbon emissions despite having only 20 per cent of the national population (OCC 2009). Queensland's net greenhouse gas emissions are projected to rise from 175 million tonnes of CO_2-e in 2007, to nearly 250 million tonnes of CO_2-e by 2050 under a business-as-usual scenario (Nous Group & SKM 2008). Queensland is the Australian state that is most vulnerable to climate change.

All areas of Australia have experienced warming over the past 50 years. The geographic distribution of rainfall has also changed significantly over the same period.

Since 1960 the mean temperature in Australia has increased by about 0.7 °C. Some areas have experienced warming of up to 0.4 °C per decade resulting in total warming over the five decades of 1.5–2 °C. The number of days with record hot temperatures has also increased each decade over the past 50 years. While the total amount of rainfall has been relatively consistent, the distribution of rainfall over Australia has changed. Parts of northern and central Australia have experienced increasing rainfall while rainfall has decreased across much of southern and eastern Australia (CSIRO & BoM 2010).

The *State of the Climate* report (CSIRO & BoM 2010) indicates that in the future much of Australia will be drier; however, it is likely that the occurrence of intense rainfall events will increase in many areas. Australian average temperatures are projected to rise by 0.6–1.5 °C by 2030. If global greenhouse gas emissions continue to grow at rates consistent with past trends, warming is projected to be between 2.2 °C and 5.0 °C by 2070 (CSIRO & BoM 2010).

The effects of climate change will be superimposed on natural climate variability, leading to changes in the frequency and intensity of extreme weather events. For example, there is likely to be an increase in the proportion of severe tropical cyclones but a possible decrease in the total number of cyclones (CSIRO & BoM 2007). A strong increase in the frequency of hot days and warm nights is also projected (Garnaut 2008).

Key messages

The regional projections released in *ClimateQ*, Queensland's climate change strategy, indicate the key climatic changes expected in each of the 13 regions.

Regional changes in temperature, rainfall and evaporation are expected to impact on Queensland's biodiversity, infrastructure, water supplies, primary industries, human health and emergency management. To reflect projected changes in temperature and rainfall across Queensland, policy and planning should be based on:

- increased temperature, more hot days and warm nights
- increased frequency of heatwave events
- reduced rainfall across most of Queensland, with Cape York, the Gulf Region and Far North Queensland projected to be less affected than the rest of the state
- longer dry periods interrupted by more intense rainfall events, especially in the Gulf and Cape York
- rising sea levels of at least 0.8 metres by 2100
- increased number of severe tropical cyclones
- cyclones occurring further south
- increased hail days in south-east Queensland
- increased intensity of extreme rainfall events in some locations.

Observed climate changes

Observed global climate changes such as rising sea level and the retreat of Arctic ice have been examined in Chapter 2. Observed changes in Queensland climate, including trends in temperature, rainfall and evaporation are discussed below.

Temperature

Figure 12 shows the warming trend for Queensland, which is slightly stronger than the global trend (Figure 7a). The average surface temperature in Queensland has risen by almost 0.9 °C since early last century (Figure 12).

The warming trend over the whole of Queensland from 1950 to 2007 (Figure 13) shows that the greatest change in mean temperature occurs in southern Queensland, especially the south-western corner.

In the two decades to 2009, Queensland experienced just one year with an annual mean temperature below the 1961–1990 average (Figure 12). The decade 2000–2009 was the hottest on record for Queensland, 0.58 °C higher than the 1961–1990 average (BoM 2009a).

Throughout most of Queensland (especially central Queensland) the daily temperature range has decreased over the period 1950 to 2007. This is due to a greater increase in minimum temperatures than in maximum temperatures (Figure 13) (BoM 2009a).

Hennessy *et al.* 2008 define exceptionally hot years as those in which the annual mean temperature is in the highest 5 per cent of those on record. From 1968 to 2007, 11 per cent of Queensland experienced exceptionally hot years. This is more than twice the 20th century average of approximately 4.6 per cent (Hennessy *et al.* 2008).

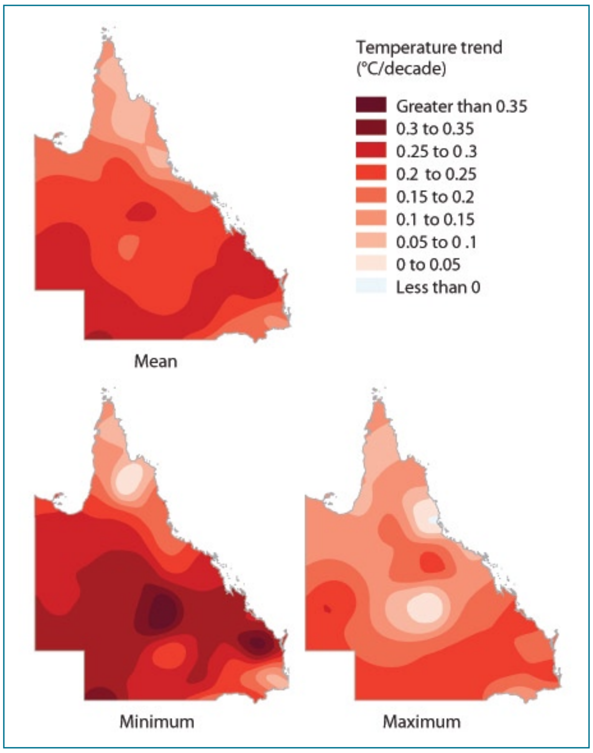


Figure 13: Trend in Queensland annual average temperature 1950–2007 (expressed as °C per 10 years) (Source: adapted by Department of Environment and Resource Management from BoM 2009a)

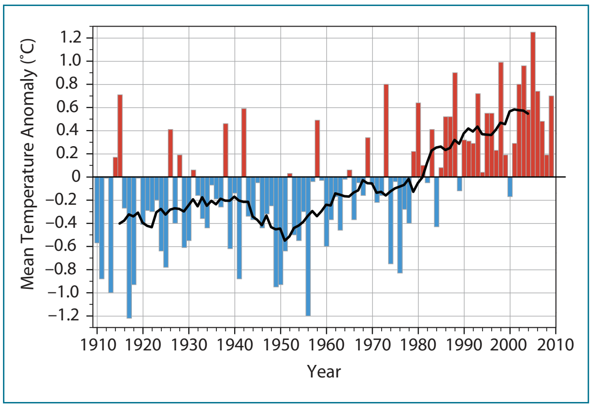


Figure 12: Time-series (1910–2009) of Queensland's annual mean surface temperature anomalies. The black line indicates the running 11-year average (Source: BoM 2009a)

Rainfall

Figure 14(a) shows the annual rainfall trend for the last century, with increased rainfall predominantly in north Australia. Since 1950 the western part of Australia, particularly north-west Australia, has experienced increases in total annual rainfall whereas eastern Australia; including Queensland (except Cape York), New South Wales, Victoria and Tasmania has experienced significantly reduced rainfall (Figure 14(b)).

The reduction in annual rainfall across eastern Australia since 1950 is reflected by decreases in the:

- total number of wet days per year (days with at least one millimetre rainfall) (BoM 2009a)
- number of very heavy precipitation days (at least 30 millimetres rainfall) (BoM 2009a)
- amount of precipitation falling on extremely wet days (those days with precipitation greater than 99 per cent of the days on record) (BoM 2009a; Gallant *et al.* 2007; Alexander *et al.* 2007).

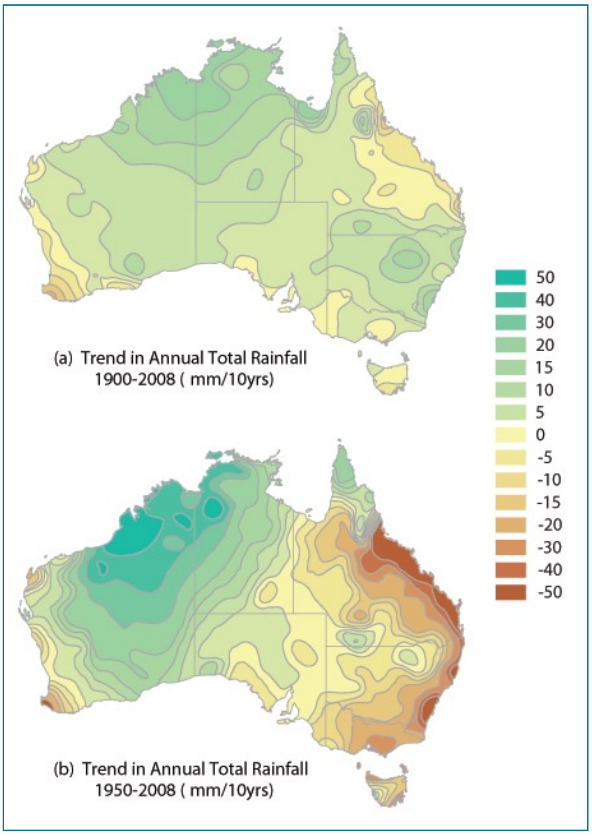


Figure 14: Trends in annual rainfall (expressed as millimetres per 10 years) for (a) 1900–2007 and (b) 1950–2007 (Source: adapted by Department of Environment and Resource Managment from BoM 2009a)

Queensland rainfall varies greatly from year to year. However, there has been a sustained decrease in rainfall along the east coast of Queensland since the 1950s (Figure 14).

This trend is partly due to natural variability in the global climate system. For example, changes in the Sub-Tropical Ridge and the Southern Annular Mode have been linked to recent reductions in south-east Australian rainfall. These changes may be linked to enhanced greenhouse gas concentrations; however, this needs to be clarified through further research (Murphy & Timbal 2008).

Drought

The recent drought in south-east Queensland (2001–2008) was the most severe on record. Previously the worst recorded drought was the Federation Drought from 1898 to 1903.

Figure 15 compares the cumulative rainfall deficiencies for south-east Queensland for the Federation and 2001–2008 droughts. The severe rainfall deficit and extended length of the recent drought (2001–2008) was magnified by higher temperatures and evaporation than had been experienced in previous decades (Nicholls 2004).

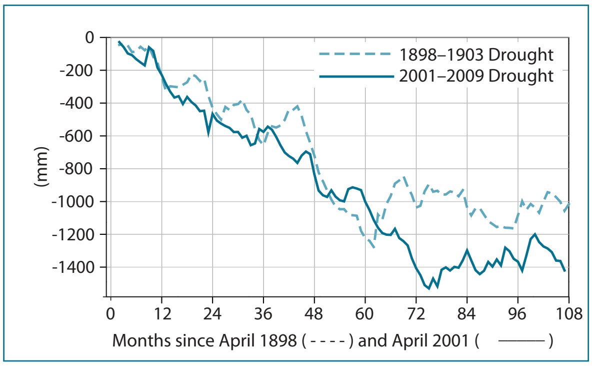


Figure 15: Comparison of the accumulated rainfall deficit in the catchment area west of Brisbane during the recent south-east Queensland drought (2001–2008) and the Federation Drought (1898–1903) (Source: DNRW 2007)

Tropical cyclones

Tropical cyclones are a common part of the Queensland climate and on average 4.7 tropical cyclones per year affect the Queensland area. However, not all of these cross the coast and cause damage (BoM 2010b). Those that make landfall can cause coastal erosion, property damage, flooding and inundation in coastal communities.

In January–February 2009, Category 1 tropical cyclones Charlotte and Ellie resulted in widespread flooding across north and west Queensland (BoM 2009b). The rainfall coincided with king tides along the Queensland coast, exacerbating flooding and inundation of coastal properties in Cairns, Townsville and Ingham.

Evaporation

Evaporation is measured as the amount of water that evaporates from an open pan called a 'Class A evaporation pan' (OCC 2009). Evaporation values range from 2–3 millimetres per day in south-east Queensland in winter, to over 10 millimetres per day in south-west Queensland in summer. While there is a strong link between evaporation and temperature, evaporation is also influenced by other factors such season, location, humidity, wind and cloud cover. Evaporation generally increases inland and is greatest in summer and spring.

Most of Queensland has experienced significant increases in evaporation. This has amplified the impacts of rainfall decreases, except in Cape York and the Gulf regions (BoM 2009a). Evaporation, unlike rainfall, is a constant process. Therefore during high evaporation conditions, small decreases in rainfall have a substantial impact on soil moisture and water storages. This affects water supplies available for people and agriculture.

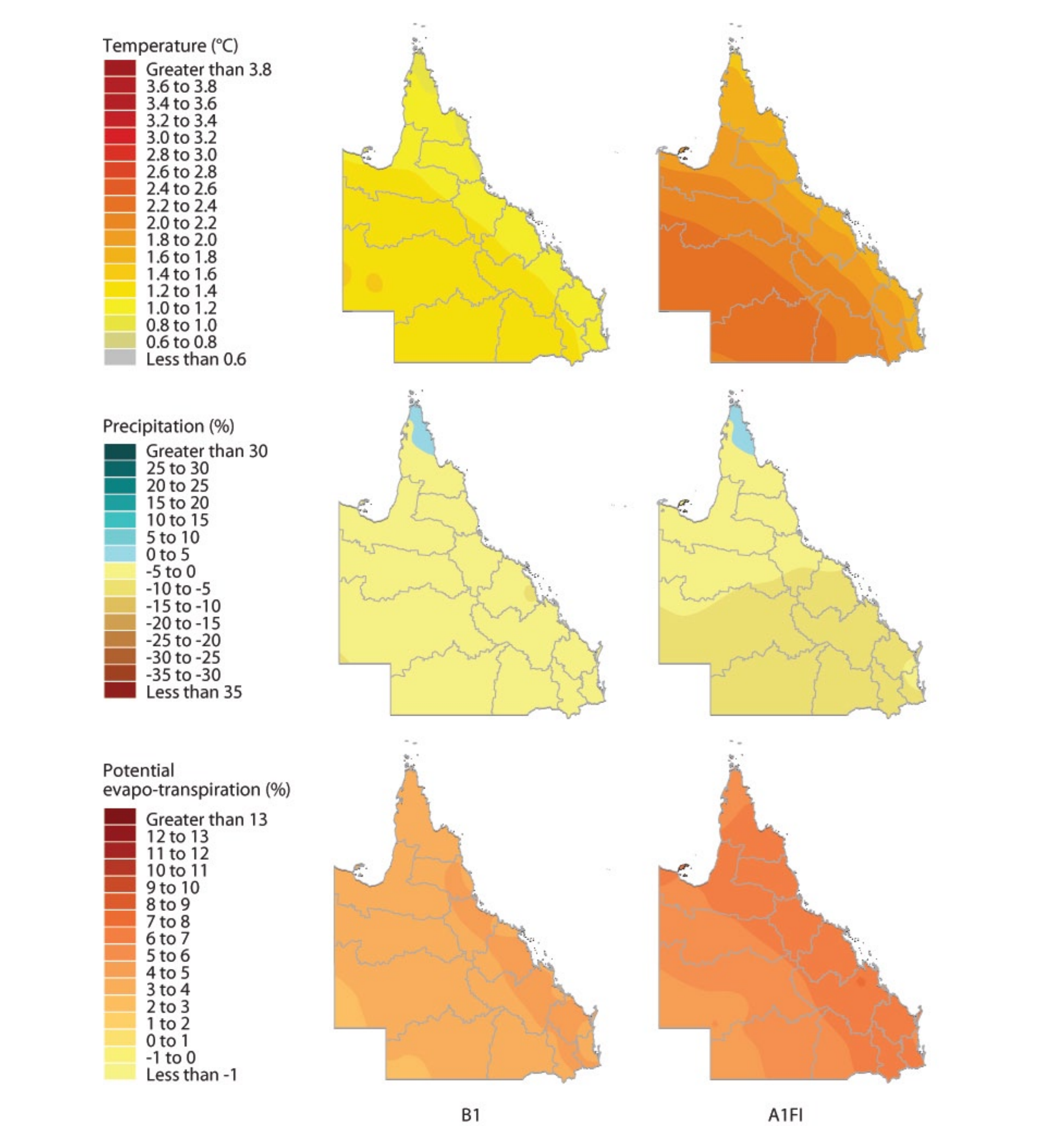


Figure 16: Best estimate (50th percentile) of projected change in annual temperature (°C), rainfall (%) and potential evapo-transpiration (%) by 2050 for low (B1) and high (A1FI) emissions scenarios (Source: OCC 2009, based on CSIRO data set)

Projected climate changes

ClimateQ contains detailed information on projected changes in temperature, rainfall and evaporation for each of the 13 regions of Queensland. These projections, based on climate modelling undertaken by the CSIRO for the Queensland Climate Change Centre of Excellence (QCCCE), are shown graphically in Figure 16 and summarised in Table 1. Figure 17 names the regions.

Figure 16 shows the expected changes in annual temperature, rainfall and potential evapo-transpiration (the amount of water that could evaporate and transpire from plants if sufficient water was available) for climate projections for Queensland in 2050 under low (B1) and high (A1FI) emissions scenarios. Temperature and evapo-transpiration are projected to increase across all of Queensland. Projections for rainfall are less clear.

The values in Figure 16 and Table 1 are the median (best estimate) projections resulting from 23 global climate models in the case of temperature and rainfall and 14 climate models for potential evapo-transpiration. Potential evapo-transpiration is calculated from projected values of surface air temperature, relative humidity and downward solar radiation (CSIRO & BoM 2007).

Table 1 lists the best estimates of the projected change in mean temperature (°C), rainfall (per cent) and evaporation (per cent) by 2050 under low (B1) and high (A1FI) greenhouse gas emissions scenarios for the 13 regions shown in Figure 17. A positive (+) figure indicates an increase in the variable. A negative(–) figure indicates a decrease in the variable. An historical (baseline) mean (1971–2000) is included for comparison.

Projections are the changes relative to the model base period of 1980–1999. The projections are expressed as changes in average climate for the 30-year period centred on 2050.

Table 1 also indicates the climate change impacts that can be expected in each of the 13 regions. In general, Queensland can expect to experience: increases in heat-related illnesses, difficulty in supplying urban and agricultural water needs due to decreasing rainfall; and increasing temperature and evaporation. Greater numbers of severe tropical cyclones, combined with storm surges, will increase erosion and coastal flooding and cause more damage.

Temperature

Projected temperature increases for Queensland regions by 2050 are in the range 1–1.4 °C for the low emissions scenario and 1.7–2.2 °C for the high emissions scenario (Table 1). Inland regions that already experience high temperatures will have the greatest increases.

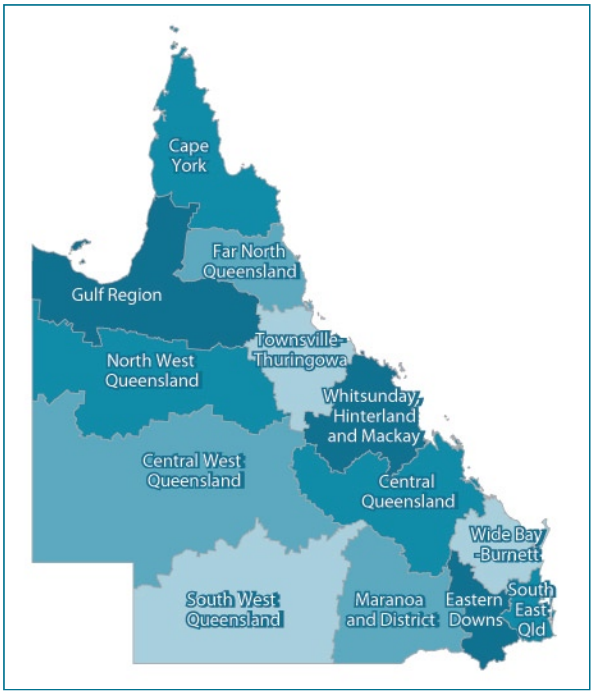


Figure 17: Queensland regions—land-use planning regions as at October 2007 (Source: OCC 2009)

Rainfall

Although the confidence in projections for Queensland's rainfall is lower than that for temperature, the best estimates (of both low and high emissions scenarios for 2050) are for decreasing or stable rainfall across each of the regions.

The low emissions scenario projections range from no change to a decline of four per cent in rainfall across Queensland. The high emissions scenario projects a decline of one to seven per cent. Cape York, the Gulf Region and Far North Queensland are projected to experience smaller declines in rainfall than the rest of the state.

Daily rainfall intensity is the average amount of rainfall occurring on 'wet days', that is, for days when daily rainfall exceeds one millimetre. Increases in rainfall intensity are projected for large areas of Queensland, especially in Cape York and the Gulf Region (CSIRO & BoM 2007).

These changes in rainfall intensity are due to an increase in rainfall on 'wet days', which may be accompanied by a reduction in the annual number of 'wet days'. In the areas where rainfall intensity increases, it could be expected that within the year there will be longer dry periods interrupted by more intense rainfall (CSIRO & BoM 2007).

Evaporation

Potential evaporation is strongly linked to temperature. By 2050 evaporation is projected to increase in Queensland regions by two to four per cent under the low emissions scenario and by five to seven per cent under the high emissions scenario (Table 1).

Sea level rise

Regional sea level rise will be influenced by localised effects. Modelling using the A1B (medium) emissions scenario shows a localised sea level rise along the east coast of Queensland and the Gulf Region of up to 0.05 metres by 2070, due to the strengthening of the East Australian Current. This is in addition to the IPCC's projected global sea level rise of up to 0.79 metres (CSIRO & BoM 2007), giving a total of 0.84 metres. For planning purposes, Queensland is currently using 0.8 metres as the projected sea level rise by 2100 (DERM 2009).

Future sea level rise will have dramatic consequences for many coastal communities. Relatively moderate levels of sea level rise are projected to cause large increases in the frequency of extreme sea level events. For example, an event that currently occurs once every 100 years could occur two or three times per year with a 0.5 metre sea level rise (Steffen 2009).

This multiplying effect of sea level rise is likely to impact on major population centres and have the greatest effect on eastern Australia (ACE CRC 2008).

Figure 18 shows the effect of a 0.5 metre sea level rise on high sea level events. The size of the circles shows the estimated multiplying factor for the increase in frequency of occurrence of high sea level events. For example, if the sea level was to rise 0.5 metres, high sea level events in Cairns could be a thousand times more frequent.

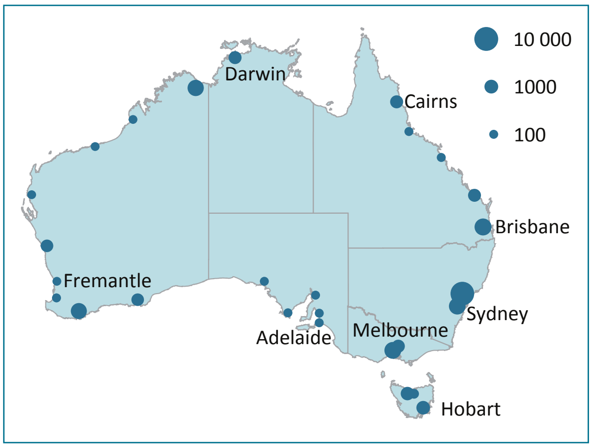


Figure 18: The multiplying effect of sea level rise on high sea level events in Australia (Source: ACE CRC 2008)

Extreme weather events

Extreme weather events can be classified as infrequent events at the high or low end of the range of values of a particular variable. For example, the number of hot days (those with a maximum temperature greater than 35 °C) is a measure of the high end of temperature values. Extreme weather events can also be classified by their impacts on the community, the economy and the environment. In this way any weather event that has a severe impact would be labelled an extreme event (Nicholls 2008). Potential changes in some extreme weather events are considered below.

Drought

Temperature, rainfall and soil moisture contribute to drought conditions. An 'exceptional' year is defined by Hennessy *et al.* (2008) as one in which a variable, such as mean temperature, rainfall or soil moisture, falls in the highest or lowest five per cent of years for that variable. Projections of changes in the number of exceptional years provide an indication of future drought conditions.

Projections for Queensland indicate a significant increase in the number of 'exceptionally hot' years. These are also projected to increase in frequency from an average of approximately one every 22 years to an average of one every 1.7 years by the period 2010–2040. Historically, 4.6 per cent of Queensland has been affected by these exceptionally hot years. Hennessy *et al.* (2008) have estimated that this will increase to 62.2 per cent over the period 2010–2040.

There is expected to be little change in the frequency and extent of exceptionally low rainfall years. However, slight increases in the frequency of exceptionally low soil moisture years, from an average of one every 16.5 years (1900–2007) to an average of one every 12.6 years (2010–2040), are projected.

The extent of Queensland affected by these exceptionally low soil moisture years is also expected to increase from 6.5 per cent in 1900–2007 to 7.4 per cent from 2010 to 2040. Hennessy *et al.* (2008) calculated these projections for soil moisture from a rainfall-runoff model using projected values of rainfall and potential evaporation.

Hot days

Figure 19 shows the average number of hot days (days with a maximum temperature greater than 35 °C) projected to 2050 for a selection of Queensland locations. The current number of hot days is calculated using a base period of 1971–2000 and the values in brackets are an indication of the range of projections from the different climate models (10th and 90th percentiles). Not surprisingly, inland sites are expected to have the greatest number of hot days.

The IPCC (2007b) states that, in the future, warmer and more frequent hot days over most land areas are virtually certain and that more frequent warm spells/heatwaves over most land areas are very likely. The projections for Queensland show increases in the number of hot days across the entire state (Figure 19).

Station Name	Number of days per year over 35°C			
	Current	2030 Mid	2050 Low	2050 High
Barcaldine	87	110 (100-121)	115 (103-129)	134 (116-156)
Birdsville	125	141 (135-149)	144 (137-154)	158 (145-173)
Brisbane Aero	1	2 (1-2)	2 (2-3)	3 (2-5)
Cairns	4	6 (5-8)	7 (5-11)	13 (8-26)
Camooweal	156	180 (168-190)	183 (171-195)	204 (185-224)
Longreach	112	133 (126-144)	138 (129-152)	156 (140-179)
Mackay	1	1 (1-2)	1 (1-3)	3 (2-8)
Rockhampton	16	26 (22-33)	29 (24-36)	40 (31-58)
Townsville	4	7 (6-9)	8 (6-13)	16 (9-31)
Weipa	55	82 (74-92)	86 (76-105)	118 (91-162)

Figure 19: Number of projected days per year above 35 °C for a range of emissions scenarios in regional centres (Source: OCC 2009, using CSIRO high-quality data set 2009)

Warm nights

Warm nights, defined as those with a minimum temperature higher than that of the temperature of 90 per cent of the nights between 1961 and 1990, are projected to increase across all of Queensland (and Australia). Northern Queensland is projected to experience up to a 50 per cent increase in warm nights by 2080–2099 under a medium emissions (A1B) scenario (CSIRO & BoM 2007).

Throughout most of Queensland, minimum temperatures are projected to increase more than mean temperatures (except for the tip of Cape York). This suggests that minimum temperatures will continue to increase more rapidly than maximum temperatures, as has occurred over the period 1950–2007 (Figure 13).

Extreme rainfall

Extreme rainfall is defined as the amount of rain falling in the top one per cent of rainfall days. Projections based on 15 climate models and a medium emissions (A1B) scenario indicated that Cape York can expect up to a four per cent increase in extreme rainfall across all seasons, and that western Queensland and the Gulf Region can expect up to a four per cent increase in summer and autumn (CSIRO & BoM 2007).

Climate change is also likely to affect extreme rainfall in south-east Queensland (Abbs *et al*. 2007). Projections indicate an increase in two-hour, 24-hour and 72-hour extreme rainfall events for large areas of south-east Queensland, especially in the McPherson and Great Dividing ranges, west of Brisbane and the Gold Coast. For example, Abbs *et al*. (2007) found that under the A2 emissions scenario, extreme rainfall intensity averaged over the Gold Coast sub-region is projected to increase by 48 per cent for a two-hour event, 16 per cent for a 24-hour event and 14 per cent for a 72-hour event by 2070. Therefore despite a projected decrease in rainfall across most of Queensland, the projected increase in rainfall intensity could result in more flooding events.

Fire danger

The Forest Fire Danger Index provides a measure of the bushfire risk. The index is based on the amount of moisture in the air, temperature, wind speed and the drought factor—a measure of the influence of recent rainfall and temperatures on fuel availability.

The most dangerous fire conditions occur with low relative humidity and high temperature and wind speed after periods of low rainfall (which raises the drought factor). The Forest Fire Danger Index is commonly lower for Queensland, with fewer high-risk days than in other states, due to higher levels of relative humidity.

By 2070 under a high emissions scenario, projections indicate up to a two per cent decrease in relative humidity across the majority of Queensland (except for a band along the east coast and the tip of Cape York where no change is projected) (CSIRO & BoM 2007).

Decreases in relative humidity, combined with projections of increased temperature, an increase in the number of hot days and less frequent rainfall events, are likely to increase the number of high Forest Fire Danger Index days.

Tropical cyclones

As reliable satellite observations of tropical cyclones only began in 1969, there is limited data on the long-term variations of tropical cyclones (Donnelly & Woodruff 2007; Nyberg *et al*. 2007). Therefore it is very difficult to distinguish between natural variability and human-induced climate change as the cause of changes in cyclone behaviour (Hunt & Watterson 2009).

Abbs *et al*. (2006) projected a nine per cent decrease in tropical cyclone frequency off the east coast of Australia by 2070, but an increase in the number of long-lived and severe (Category 3–5) tropical cyclones.

Two different studies have projected that the number of severe tropical cyclones will increase by 56 per cent by 2050 (Walsh *et al*. 2004) and 22 per cent by 2050 (Leslie *et al*. 2007). The variation in these projections is due to a lack of good observational data and the limited ability of global climate models to represent cyclone behaviour (Hunt & Watterson 2009). Leslie *et al*. (2007) projected an approximately 200 kilometre southward shift in cyclone source areas.

Severe thunderstorms

For a thunderstorm to be classified as severe by the Bureau of Meteorology, it needs to produce any of the following:

- hailstones with a diameter of two centimetres or more at the ground
- wind gusts of 90 kilometres per hour or greater at 10 metres above the ground
- flash flooding
- a tornado.

Current climate models do not have fine enough resolution to project small-scale events such as thunderstorms. Therefore it is difficult to attribute changes in thunderstorm frequency, intensity and location to human-induced factors. The likelihood of a thunderstorm event is determined on the basis of more widespread meteorological conditions. Projections obtained in this way demonstrate an increase in hail risk (hail days per year) associated with thunderstorms of up to four hail days per year by 2070 in south-east Queensland (CSIRO & BoM 2007).

Table 1: Summary of climate projections for 2050 and key impacts for 13 Queensland regions (Source: CSIRO & BoM 2007).

Region	Temperature			Rainfall			Evaporation			Impacts
	Baseline mean (°C)	2050 Low (°C)	2050 High (°C)	Baseline mean (mm)	2050 Low (%)	2050 High (%)	Baseline mean (mm)	2050 Low (%)	2050 High (%)	Examples of climate change impacts for the given region
Cape York	26.5	+1.0	+1.7	1431	0	-1	2216	+3	+6	• flooding, erosion and damage to infrastructure associated with sea level rise/increased storm surge • increased spread of disease (e.g. malaria, dengue) due to more favourable conditions for vectors • ecosystem changes and extinctions in the Wet Tropics rainforests • increased heat-related illness • increase in amount of rain falling on extremely wet days is likely to increase the severity of flooding
Central Queensland	21.6	+1.2	+2.0	692	-4	-7	1997	+4	+7	• more regular bleaching and mortality of corals of the Great Barrier Reef due to increased temperature • increased acidification of sea water and resultant decrease in coral growth and coral reef maintenance • increased spread of disease (e.g. malaria, dengue) due to more favourable conditions for vectors • increased pressure on water supplies • increased heat-related illness • increased risk and intensity of bushfires
Central West Queensland	23.6	+1.4	+2.2	362	-4	-6	2914	+3	+5	• declining pasture quality and quantity due to increased evaporation and decreased rainfall • increased pressure on water supplies • increased heat-related illness • increase in amount of rain falling on extremely wet days is likely to increase the severity of flooding • increased risk and intensity of bushfires • increased pressure on water supplies

Region	Temperature			Rainfall			Evaporation			Impacts
	Baseline mean (°C)	2050 Low (°C)	2050 High (°C)	Baseline mean (mm)	2050 Low (%)	2050 High (%)	Baseline mean (mm)	2050 Low (%)	2050 High (%)	Examples of climate change impacts for the given region
Eastern Downs	18.3	+1.2	+2.0	694	-3	-6	1737	+3	+7	• increased pressure on water supplies • reduction in grain quality due to increased temperature, evaporation and decreased rainfall • increased heat-related illness • increased risk and intensity of bushfires
Far North Queensland	24.4	+1.1	+1.8	1250	-1	-2	1999	+3	+6	• more regular bleaching and mortality of corals of the Great Barrier Reef due to increased temperature • increased acidification of sea water and resultant decrease in coral growth and coral reef maintenance • ecosystem changes and extinctions in the Wet Tropics rainforests • increased spread of disease (e.g. malaria, dengue) due to more favourable conditions for vectors • flooding, erosion and damage to infrastructure associated with sea level rise/increased storm surge • increased heat-related illness
Gulf	26.6	+1.2	+2.0	855	-1	-1	2549	+3	+6	• flooding and erosion associated with sea level rise/increased storm surge • increased spread of disease (e.g. malaria, dengue) due to more favourable conditions for vectors • increase in amount of rain falling on extremely wet days is likely to increase the severity of flooding
Maranoa and Districts	20.2	+1.3	2.2	582	-4	-6	1985	+3	+6	• reduction in grain quality due to increased temperature, evaporation and decreased rainfall • increased pressure on water supplies • increased risk of heat-related illness • increased risk and intensity of bushfires

Region	Temperature			Rainfall			Evaporation			Impacts
	Baseline mean (°C)	2050		Baseline mean (mm)	2050		Baseline mean (mm)	2050		Examples of climate change impacts for the given region
		Low (°C)	High (°C)		Low (%)	High (%)		Low (%)	High (%)	
North West Queensland	25.2	+1.3	+2.1	534	-2	-3	2775	+3	+6	• increased pressure on water supplies • increased risk of heat-related illness • increase in amount of rain falling on extremely wet days is likely to increase the severity of flooding • increased risk and intensity of bushfires
South East Queensland	19.4	+1.1	+1.8	1135	-3	-5	1553	+3	+6	• declining pasture quality and quantity due to increased evaporation and decreased rainfall • increased pressure on water supplies • conditions may become more favourable for plant diseases, weeds and pests • flooding, erosion and damage to infrastructure associated with sea level rise/increased storm surge • increased risk of heat-related illness • increased risk of tropical cyclone impact due to southward shift in genesis region
South West Queensland	21.6	+1.4	+2.2	383	-4	-6	2588	+2	+5	• declining pasture quality and quantity due to increased evaporation and decreased rainfall • increased pressure on water supplies • increased risk of heat-related illness • increase in amount of rain falling on extremely wet days is likely to increase the severity of flooding (especially in summer and autumn) • increased risk and intensity of bushfires

Region	Temperature			Rainfall			Evaporation			Impacts
	Baseline mean (°C)	2050		Baseline mean (mm)	2050		Baseline mean (mm)	2050		Examples of climate change impacts for the given region
		Low (°C)	High (°C)		Low (%)	High (%)		Low (%)	High (%)	
Townsville Thuringowa	23.3	+1.1	+1.9	813	-3	-5	2025	+4	+7	• more regular bleaching and mortality of corals of the Great Barrier Reef due to increased temperature • increased acidification of sea water and resultant decrease in coral growth and coral reef maintenance • flooding, erosion and damage to infrastructure associated with sea level rise/increased storm surge • increased spread of disease (e.g. malaria, dengue) due to more favourable conditions for vectors • declining pasture quality from increased temperatures • ecosystem changes and extinctions in the Wet Tropics rainforests • increased risk of heat-related illness • increased risk and intensity of bushfires
Whitsunday Hinterland and Mackay	22.7	+1.1	+1.9	837	-4	-7	1964	+4	+7	• more regular bleaching and mortality of corals of the Great Barrier Reef due to increased temperature • increased acidification of sea water and resultant decrease in coral growth and coral reef maintenance • flooding, erosion and damage to infrastructure associated with sea level rise/increased storm surge • increased risk of tropical cyclone impact due to possible southward shift in genesis region • increased risk of heat-related illness • Increased spread of disease (e.g. malaria, dengue) due to more favourable conditions for vectors • increased risk and intensity of bushfires

Region	Temperature			Rainfall			Evaporation			Impacts
	Baseline mean (°C)	2050		Baseline mean (mm)	2050		Baseline mean (mm)	2050		Examples of climate change impacts for the given region
		Low (°C)	High (°C)		Low (%)	High (%)		Low (%)	High (%)	
Wide Bay Burnett	20.5	+1.1	+1.8	862	-4	-6	1715	+4	+7	• increased pressure on water supplies • flooding, erosion and damage to infrastructure associated with sea level rise/increased storm surge • variable and declining rainfall, combined with rising temperatures and increased evaporation could have a significant impact on primary production • increased risk of tropical cyclone impact due to possible southward shift in genesis region • increased risk of heat-related illness • increased risk and intensity of bushfires

Storm surge

Storm surge is a local rise in sea level caused by the combined action of severe surface winds and decreased atmospheric pressure (Hardy *et al.* 2004). When storm surge is combined with normal astronomical tide variations and wave setup this is referred to as storm tide. It is the storm-tide level which must be accurately predicted to determine the likely extent of inundation from a storm event (Hardy *et al.* 2004).

The height of storm surge on the Queensland east coast is expected to increase with rising sea level and changes in tropical cyclone behaviour. The most recent Queensland study by Hardy *et al.* (2004) assesses the risk to coastal communities of changes in storm surge and wind speed from tropical cyclones. Figures 20 and 21 summarise the key results.

Figure 20 shows the height of the one-in-100-year storm surge added to the expected highest tide at some key Queensland coastal locations. The dark blue line indicates current conditions while the light blue line represents projected conditions to 2050.

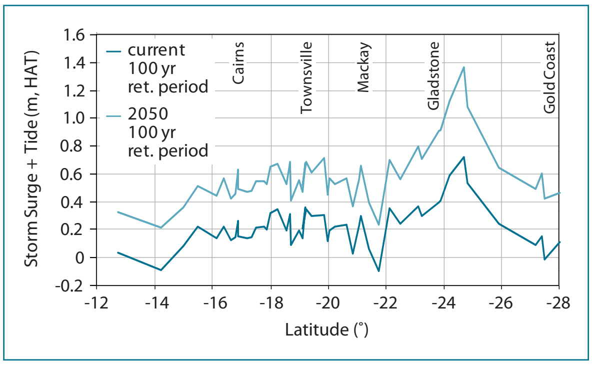


Figure 20: Height above highest astronomical tide (HAT) of storm surge plus tide for current and 2050 100-year return periods (Source: Hardy *et al.* 2004)

In assessing the risk to coastal communities Hardy *et al.* 2004 used the following values:

- a 0.3 metre mean sea level rise (IPCC 2001)
- a 10 per cent increase in the frequency of cyclone occurrence (Harper 2001)
- the combined effects of a:
  - » 10 per cent increase in maximum intensity
  - » southward shift of tropical cyclone tracks of approximately 120 kilometres (Henderson-Sellers *et al.* 1998; Walsh & Katzfey 2000).

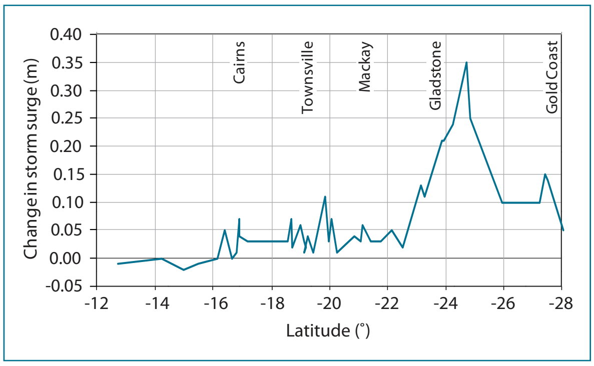


Figure 21: Changes in storm surge between 2050 and current 100-year return period events, not including the contribution from sea level rise (Source: Hardy *et al*. 2004)

Figure 21 shows the projected change in storm surge to 2050 after the 0.3 metre sea level rise is removed. It represents changes in storm surge associated with increases in frequency and intensity, as well as a southward shift in tropical cyclones (as for Figure 20). It shows significant rises in storm surge independent of the mean sea level rise, especially for the south-east Queensland coast.

The storm surge shown in Figures 20 and 21 is not a true indication of the actual potential level of inundation (storm tide) as it does not include wave setup.

Most of the south-east Queensland coastline is projected to experience an increase of over 0.1 metres in storm surge from changes in tropical cyclone behaviour alone (Hardy *et al*. 2004). The complexity of the coastline and the proximity of the Great Barrier Reef create various responses to storm surge along the Queensland coast. Storm surge is magnified in open coast locations, where a wide continental shelf creates a 'pile up' of water; as well as in embayments, where the water is funnelled into a concentrated area.

Chapter 4: Impacts of climate change on key sectors

Projected changes to temperature, rainfall, evaporation and extreme events, such as cyclones and sea level rise have been discussed in Chapter 3. This chapter provides information on the impacts of these changes on key sectors of the Queensland economy and indicates some adaptation options.

Human settlements and infrastructure

Human settlements refer to cities and towns right down to much smaller communities. Infrastructure is the essential physical structures that exist to support these settlements, including transport and service facilities such as water, sewerage and power.

As Queensland's population and settlement densities continue to grow, so do the potential impacts of climate change on Queensland settlements and infrastructure.

Greater urbanisation in vulnerable areas increases risks from climate change to both existing and future infrastructure.

Key messages

In Queensland the major risks to communities and their supporting infrastructure are cyclones and flooding. In addition, poor building design will place an increasing load on mechanical cooling to manage the effects of higher temperatures, increasing the need for fossil-fuelled electricity generation and thereby increasing greenhouse gas emissions.

Climate change will affect settlements through direct and indirect impacts resulting in damage to buildings and other infrastructure. These climate changes include:

- increased intensity of rainfall events
- increased temperatures
- more frequent extreme weather events
- increased extent and frequency of coastal flooding due to sea level rise and storm surges.

There will be a need for:

- changes to building codes to strengthen buildings in areas that may be at greater risk of cyclones due to the projected southward shift of cyclone source areas
- planning decisions and building standards reflective of the life span of the built environment, which can be up to 200 years
- design and loading codes to be based on a risk assessment process to ensure that the potential impacts of climate change are considered and factored into design of buildings and infrastructure
- consideration of the impact of changes in land use driven by climate change on supporting infrastructure services including transport.

The current accuracy of topographic data constrains planning for the impacts of sea level rise, storm surge and flooding. Digital elevation modelling being undertaken by the Queensland Government will provide more accurate topographic information to inform planning and emergency management decisions.

Policy and legislative mechanisms will help to reduce the impacts of climate change and the level of adaptation required. However, these will need to be regularly reviewed and revised to reflect the changing science.

Climate risks

Climate projections for Queensland point to higher temperatures, rising sea levels and an increased intensity of extreme events. The resilience of building and infrastructure to climate change will depend on building stock characteristics such as design, structure, size, age and condition.

Extreme heat events and higher temperatures, particularly in inland regions, will generate greater demand for well-designed new buildings and retrofitting of existing buildings.

Climate change may increase the risk of structural damage to buildings, especially damage resulting from strong winds associated with more intense tropical cyclones or damage resulting from more intense storms and associated flooding. Cracking may also occur as soils dry out from higher temperatures and reduced rainfall. Residential buildings are likely to be more vulnerable to such damage than commercial buildings, with older buildings more vulnerable than newer ones.

The structures that support our energy, telecommunication and transportation requirements (e.g. transmission lines, roads, railways, ports and bridges) have been identified in a number of studies as vulnerable to climate change impacts (IPCC 2007c; PMSEIC 2007; ATSE 2008).

Poorly designed buildings with increased reliance on mechanical air-conditioning to manage effects of higher temperatures will place additional loads on supporting energy infrastructure, with associated increases in greenhouse gas emissions. Through more frequent extreme daily rainfall events there is also a risk of exceeding the capacity of stormwater, drainage and sewerage infrastructure (NCCARF 2009).

Climate change impacts

Variations in temperature and rainfall across Queensland will produce a wide range of climatic impacts which will affect the planning and management of infrastructure requirements. These are discussed below.

Cyclones

Tropical cyclones are the main hazard for low-lying lands along the Queensland coast due to very high winds, heavy rain and storm surges (DCC 2009a). For example, Tropical Cyclone Larry crossed the far north Queensland coast on 20 March 2006 near Innisfail, with wind gusts of up to 240 kilometres per hour. This resulted in more than $1 billion damage to coastal townships, infrastructure and crops, as well as flooding coastal rivers (DCC 2009a).

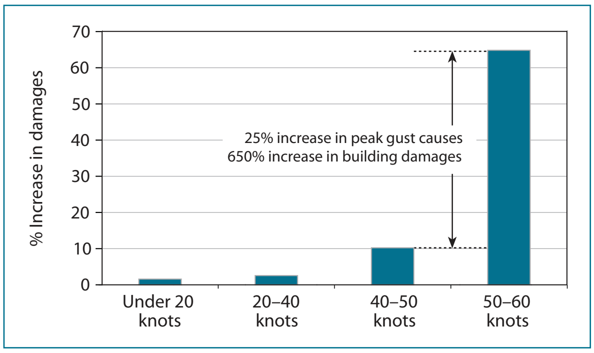


Figure 22: Increase in building damage due to wind gust speed (Source: Coleman 2002, in DCC 2009a)

The impacts of cyclones on the built environment are from winds, heavy rainfall, flooding and storm-tide events. Damage to buildings includes weakening of structural loadings of buildings, uplifting of roofs, collapse of buildings, impacts from flying debris, and internal damage from rain and moisture penetration. Extreme rainfall events are expected to affect the stormwater and sewerage infrastructure, while roads and bridges are vulnerable to changes in moisture content.

Vulnerability of buildings and infrastructure varies widely and depends on the location, topography, construction materials, age, features and standards applicable at the time of construction and subsequent levels of maintenance.

Coastal areas are subject to greater impacts from extreme wind events than inland areas, and climate change could increase the intensity of wind gusts.

The Australian Government's report on risks to Australia's coasts (DCC 2009a) suggests that this could lead to a significant increase in damage to buildings. Figure 22 shows that a 25 per cent increase in wind gust speed could generate a 650 per cent increase in building damage.

A preliminary study by Wang and Wang (2009) of the risk to buildings in Australia from extreme wind gust speeds found that the building standard specifications for Brisbane may not be adequate when the combined hazard of cyclonic and non-cyclonic winds is considered.

Models are being developed to help understand what makes residential buildings vulnerable. These consider how buildings resist and transmit wind loading forces and include the impact of windborne debris. This engineering modelling approach has been applied to north Queensland structures to help define the range of damage for a given wind gust speed (Henderson & Harper 2003).

Ensuring good quality construction of wind-resistant buildings, the securing of elements that can blow away (e.g. metal sheeting, roofing, fences and signs) and engineering to withstand wind forces and water damage can help reduce impacts.

A quantitative assessment of the impacts of climate change on Australia's physical infrastructure by the Australian Academy of Technological Sciences and Engineering (ATSE 2008) identified that comprehensive risk assessment techniques should be applied to support the design of critical infrastructure. This would require the review of existing design codes, particularly loading codes.

Options for better building performance with respect to cyclones, winds and intense storms include the development of:

- impact-resistant building materials, especially external claddings and glazing
- enhanced external finishes and claddings that prevent water access
- better window designs (e.g. increased thickness of glazing or reduced panel sizes to reduce wind forces)
- improved 'fixing' systems (roof to walls, walls to floors)
- aerodynamic building designs
- better foundation design
- better planning guidance to avoid a 'wind tunnel' effect.

Sea level rise, coastal and inland flooding

Flooding occurs most commonly from heavy rainfall when natural watercourses do not have the capacity to convey excess water. La Niña years experience more floods on average than El Niño years.

Riverine flooding occurs in relatively low-lying areas adjacent to streams and rivers in the extensive flat inland regions. Such floods may spread over thousands of square kilometres and last several weeks. Flash floods can occur when there is a relatively short intense burst of rainfall such as during a thunderstorm and where the drainage system has insufficient capacity or time to cope with the downpour.

However, floods are not always caused by heavy rainfall. In coastal areas inundation can be caused by a storm surge associated with a tropical cyclone. East coast lows (intense, short-lived low-pressure systems) can also bring widespread rain, gale force winds, rough seas and prolonged heavy swells over coastal and ocean waters in south-east Queensland, resulting in damage to the coastline, buildings and infrastructure.

The IPCC AR4 (IPCC 2007b) projected an increase in the severity of storms and coastal flooding by 2050. Sea level rise will also have an impact on extensive coastal housing and tourism development. Low-lying coastal areas such as the Gold Coast and the Torres Strait islands will potentially be adversely affected by rising sea levels.

Floods are the most expensive natural disaster in Australia (BTE 2001), estimated to contribute 29 per cent of the average annual natural hazard damage in Australia and costing around $314 million each year. Some of the largest floods in Australia have been caused by decaying tropical cyclones; for example, the 1974 Brisbane flood was caused by the decaying Tropical Cyclone Wanda. This flood resulted in 16 deaths, 300 injuries and made 9000 people homeless (EMA 2006).

The decay of cyclone systems can bring significant rain which can affect areas that are some distance from the coast. Under such circumstances, the risk of localised flooding is high in urban or rural areas where drainage is poor. For example, while having little direct effect on the inland Eastern Downs region, tropical cyclone systems have been associated with flooding in the region through the weakening of such systems into significant rain-bearing depressions.

In 2006, peak flood levels were recorded in the Leichhardt River after Tropical Cyclone Larry travelled almost 450 kilometres inland to around Croydon before being downgraded to a rain depression. The anticipated greater intensity of rainfall in certain regions of Queensland will also have implications for flooding risks.

Crompton and McAneney (2008) reviewed the insurance losses from the ten major events in Australia since 1973. Wang *et al.* (2010) provided estimates of flood damage in Queensland. Table 2 shows a number of weather-related events resulting in significant financial losses. For example, the 1974 Brisbane flood resulting from Tropical Cyclone Wanda resulted in losses of $2090 million at current prices.

Event	Year	Location	State	Current Loss as at 2006 (AUD$ million)
Earthquake	1989	Newcastle	NSW	4300
Tropical Cyclone Tracy	1974	Darwin	NT	3650
Hailstorm	1999	Sydney	NSW	3300
Flood (Tropical Cyclone Wanda)	1974	Brisbane	QLD	2090
Hailstorm	1985	Brisbane	QLD	1710
Ash Wednesday Bushfires	1983	Multiple	VIC/SA	1630
Hailstorm	1990	Sydney	NSW	1470
Tropical Cyclone Madge	1973	Multiple	QLD/NT/WA	1150
Hailstorm	1976	Sydney	NSW	730
Hailstorm	1986	Sydney	NSW	710
Flood	2008	Mackay	QLD	342
Flood	1981	Dalby	QLD	200
Flood	1998	Townsville	QLD	154
Flood	2008	Emerald	QLD	104

Table 2: Normalised losses from insured events (Source: Wang *et al.* 2010; Crompton & McAneney 2008)

Coastal and inland floods cause direct damage by inundation, erosion or 'washing away' of facilities. Damage to infrastructure can include damage or disruption to power and communication services, sewerage, water supply and transportation links. Bridges and many major airports are vulnerable to sea level rise and storm surge.

An Australian Government Department of Transport and Regional Services report (Amitrano *et al.* 2007) found that there is a greater chance of flooding events in areas with the potential for increased rainfall and storm events, including Cairns, Brisbane and the Gold Coast.

Building code requirements for flooding are generally limited, with most residential buildings not specifically designed to cope with flooding. Flood modelling to determine the likelihood of flooding for a given area is undertaken by estimating flood potential or probable flood flows (hydrologic analysis), and evaluating the flow of water through the specific area (hydraulic analysis) (Amitrano *et al.* 2007).

The accuracy of the topographic data is often the greatest constraint for flood risk modelling. While many factors contribute to flood damage of buildings, knowledge of the depth of flooding is a key data requirement. The velocity and duration of inundation is also required for a more rigorous analysis of flood risk.

Engineers Australia is currently revising the Australian rainfall and runoff guideline for assessment of rainfall, runoff, water resources and flooding to include issues related to climate change (NCCARF 2009). The Australian Bureau of Meteorology in conjunction with CSIRO has embarked on a major program to collect, manage and interpret Australia's water information (BoM 2009c).

Severe storms, including cyclones, can cause damaging storm tides. The resultant storm tide (a combination of storm surge, normal tidal variations and wave setup) can cause severe coastal flooding. This can undermine, erode or destroy structural foundations; material durability can be affected by salt spray; and building contents can be damaged from water, sewage and mud (Amitrano *et al.* 2007).

An Australian Government report assessing the risks of climate change to the coast found that the delivery of essential services such as electricity generation and wastewater management will be increasingly impacted by climate change (DCC 2009a). The report suggests that under a worst case sea level rise scenario of 1.1 metres, between 157 000 and 247 600 existing residential buildings are at risk of inundation, with a replacement cost of approximately $63 billion (DCC 2009a). Figure 23 shows the distribution of these properties in Australia and indicates that Queensland has the second-highest susceptibility to inundation from sea level rise.

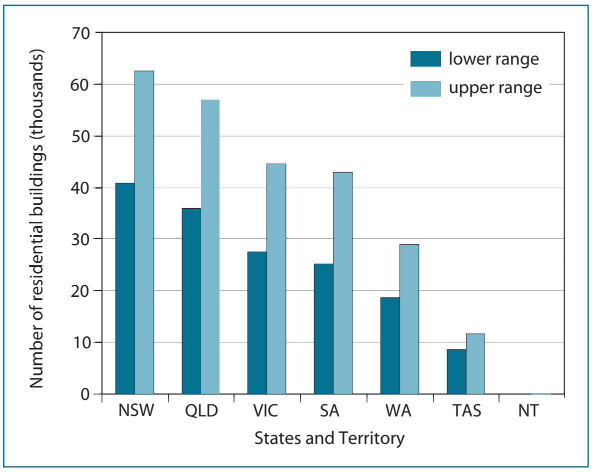


Figure 23: Estimated numbers of residential buildings at risk from sea level rise of 1.1 metre by 2100 (Source: DCC 2009a)

Wang *et al*. (2010) assessed the effects to infrastructure in south-east Queensland of a 1-in-100-year inundation event under different adaptation scenarios in 2030 and 2070. The study found that although about 227 000 people are at risk, this could increase with rising sea levels to 245 100 by 2030 and 273 000 by 2070. This is based on current population alone and does not consider the potential increase in population in south-east Queensland from the current 2.69 million to a projected 4.4 million by 2030.

Options for better building performance with respect to flooding include:

- more sophisticated rainwater collection and re-use technology
- water-resistant building materials
- roofing materials and design to cope with increased drainage loads, including drainage systems, gutters and downpipes
- better land-use management and site analysis
- better foundation design to cope with subsidence, cracking and heave.

Better planning and development guidance is most important if Queensland is to build resilience against coastal flooding. The *Draft Queensland Coastal Plan* requires that redevelopment in built-up urban areas and in high hazard and medium hazard zones consider the inundation impacts associated with a one-in-100-year defined storm-tide event with a sea level rise of 0.8 metres above 1990 levels by 2100. High hazard areas are those subject to inundation levels greater than one metre, while medium hazard areas are subject to inundation levels less than one metre. New permanent structures will be required to mitigate hazard impacts for example, by ensuring that habitable rooms remain above the anticipated storm-tide inundation levels (DERM 2009).

Adaptation

Buildings and other infrastructure can have a life expectancy of 30–200 years; therefore planning and construction decisions made now can have long-term consequences (Hallegatte 2009). Adaptation to climate change through the planning process and building standards is therefore crucial to ensure that these effects are managed.

The Queensland Government requires all state government investment in buildings and infrastructure to conduct a climate change impact assessment to identify the impacts on the project and mitigation and adaptation actions to be taken (OCC 2009).

A number of common approaches lead to good adaptation. Avoiding and reducing future risk is the most cost-effective adaptation response in most cases (DCC 2009a). Upgrading of building and engineering codes and standards for building, plumbing and construction could ensure that future buildings and infrastructure are adapted to climate change impacts.

Land-use plans and development codes need to identify where climate change risks can be accommodated, where protection is required, how planned retreat could be undertaken and the costs and benefits of early or delayed action.

In addition, many opportunities exist for new technologies and construction techniques to assist buildings to cope with inland or coastal flooding. Most of these relate either to keeping water out or the capture and use of the water.

Improving planning and building regulations is likely to considerably reduce the future costs of managing climate change impacts. CSIRO has developed a preliminary estimate of the costs and benefits of the uptake of strengthened planning and building regulation on inundation of residential buildings for a 1-in-100-year storm surge event in south-east Queensland (DCC 2009a). Table 3 shows the expected number of people and buildings impacted by climate change in 2030 under varying adaptation options and the cost of those options in today's dollars (DCC 2009a).

Adaptation Option	People affected 2030	Buildings affected 2030	Total costs 2030
Business as usual (same planning and building regulation as today)	616 000	124 800	$4 billion
Planning regulations tightened to allow no further risky development, building stock under same regulation	378 000	83 200	$2.6 billion
In addition to planning regulation tightened as above, retrofit/reclaim to maintain existing level of risk	270 000	47 900	$1.5 billion

Table 3: Estimated costs and benefits of residential adaptation in south-east Queensland for 2030 (Source: DCC 2009a).

Accurate modelling of storm tides and other sources of flooding will lead to a better understanding of the impacts of sea level rise, storm surge and coastal erosion along Queensland's coastline.

The Queensland Government is investing $8 million to develop a digital elevation model that will allow more accurate modelling and subsequent planning decisions. Improved planning taking into account regional variations (e.g. risk-based vulnerability zoning such as coastal zone and hazard mapping) and restrictions on development will also help increase resilience to the impacts of climate change.

Water supplies

On average, 40 per cent of Australia's total stream discharge or approximately 160 million megalitres (ML) per year occurs in Queensland (DEEDI 2009). About 94 per cent of the water in Queensland's river systems drains to the coast, with only six per cent draining inland (Cox 2008).

Inland regional communities obtain more water from groundwater and/or overland flow storages than coastal areas. Thirty-six per cent of all water used in Queensland, about 1.4 million megalitres per year, comes from underground water, principally the Great Artesian Basin and associated sub-artesian water. This is significantly higher than the national average of approximately 20 per cent and it is thought that underground water is being extracted faster than it is being replenished in some systems (Cox 2008; DEEDI 2009).

Queensland relies heavily on surface water storages with almost 200 major reservoirs providing approximately 64 per cent of the state's total water supply (Cox 2008).

Annual water usage in Queensland varies from 4–5 million megalitres, with agriculture accounting for approximately 70 per cent (DEEDI 2009). The amount of irrigation water used by Australia's 40 000 irrigating agricultural businesses increased 3 per cent to 6501 gigalitres in 2008–09. Queensland continued to be the largest irrigating state, using 2058 gigalitres of water for irrigation, an increase of 12 per cent from 2008–09 (ABS 2010).

In 2007–08 the south-east Queensland residential and business sectors together used 80 per cent of available water supplies. Of this 80 per cent, households used 71 per cent and businesses used 29 per cent (QWC 2009).

The Millennium Drought (2001–08) was the worst drought in the history of south-east Queensland. In 2008, the combined levels of south-east Queensland's major dams (Wivenhoe, North Pine and Somerset) fell to 16.7 per cent (QWC 2009). Although dam levels have since risen substantially and south-east Queensland is no longer officially in drought, securing water supplies is still a concern given Queensland's highly variable rainfall.

Key messages

Water security is a key factor in the development of Queensland communities and industries. Climate change is projected to have impact on rainfall, evaporation and runoff and hence on the amount of water that is available for use as well as the frequency and intensity of rainfall events. In particular:

- the amount of rainfall will change depending on the region of Queensland
- Queensland is more likely to experience reduced rainfall across most regions
- the number of severe tropical cyclones is projected to increase
- projected increases in temperature and evaporation and reduction in rainfall are expected to significantly impact water availability and security
- groundwater is being extracted faster than it can be recharged in some important systems
- higher temperatures, increased evaporation and lower rainfall associated with climate change are expected to adversely affect water runoff
- 75 per cent of Queensland's rain falls in the less populous north of the state
- demand for water is increasing and long-term average inflows into rivers and dams as well as end-of-system flows are expected to decrease
- without additional supplies, the gap between supply and demand of water in south-east Queensland would be between 97 000 and 308 000 megalitres per year by 2056, depending on population growth, water savings achieved and the impacts of climate change.

Policy makers and planners must therefore take into account these changing rainfall regimes and diversify water supply mechanisms to optimise the capture and use of rainfall.

The Queensland Government is focusing on developing regional water supply strategies as a means of managing water supply changes expected as a result of climate change impacts.

These strategies provide information and guidance for the management of water supply issues to meet predicted changes and meet urban, industrial, agricultural and environmental water demands.

Climate risks

Climate change has emerged as an important issue in water resource management. Rainfall in Queensland is seasonal, falling mostly during summer, with 75 per cent of all Queensland rain falling in the less developed and sparsely populated northern catchments that drain into the Gulf of Carpentaria and the Coral Sea (Cox 2008).

Projected increases in temperature and evaporation, reductions in rainfall and a higher variability in weather conditions and extreme events are expected to significantly impact water availability and security.

Challenges for managing water resources in Queensland are compounded by the fact that Queensland's rivers are characterised by alternating severe droughts and major floods and that Australian stream flow is more variable than anywhere else in the world (CSIRO 2007).

Climate change impacts

The impacts associated with climate change are also related to changes in climate variability. Although Queensland's landscape has adapted to a variable climate, changes in both the magnitude and frequency of rainfall may have unknown impacts on the water cycle. Seasonal shifts in rainfall, temperature changes and evaporation can affect agricultural and residential water demand and put pressure on major industrial water users such as power stations. In addition, coastal communities may be faced with saline intrusion or sea level rise, which will put additional pressure on water infrastructure and supply.

Rainfall, temperature and evaporation

Future climate trends in Queensland include changes to the frequency and magnitude of rainfall and increases in minimum and maximum temperatures leading to increased evaporation. Coastal zones are particularly at risk due to increasing population placing pressure on water supplies.

While mean temperature is projected to increase across Queensland regions by 1.7–2.4 °C by 2050 under the high emissions scenario, there is greater uncertainty regarding rainfall projections. By 2050, the increase in annual average evaporation (defined as potential evapo-transpiration) is projected to be 5–7 per cent for the high emissions scenario across Queensland regions (Table 1).

Factors are applied to values of evaporation to estimate potential evaporation over various surfaces; for example rivers, dams and crops. An Urban Water Security Research Alliance study (UWSRA 2009) estimated that the loss of water through natural evaporation from dams, rivers and other water storages in south-east Queensland could be 300 000 megalitres per year, while losses through degraded or damaged infrastructure could be as high as 40 000 megalitres per year.

Runoff

Runoff is the amount of rainfall that is not evaporated, stored as soil moisture or filtered down to groundwater and which therefore runs into streams and rivers and other surface water storages.

While runoff generally tracks rainfall, increases and decreases in precipitation do not necessarily lead to equal increases and decreases in runoff. Droughts cause soil moisture reductions that can reduce expected runoff until soil moisture is replenished. Conversely, water-saturated soils can generate floods with only moderate additional rain (Karl *et al*. 2009).

Higher temperatures, increased evaporation and lower rainfall associated with climate change are expected to adversely affect water runoff. Rural landscapes may need 50–100 millimetres of rain before runoff can occur and they usually produce runoff only a few times each year (DNRW 2008a). Estimating short- and long-term future runoff patterns is important for managing potential climate change impacts on water supply sources.

Rainfall–runoff modelling that includes climate change projections from global climate models (GCMs) is progressively being done for all major catchments in Queensland as part of the Regional Water Supply Strategies' development and implementation. Results indicate that future runoff is more likely to decrease than increase in most catchments (Preston & Jones 2006).

Groundwater

Groundwater accounts for over 30 per cent of Australia's total water consumption (NWC 2009a). Groundwater is the water that has seeped from the surface into porous sands, silts and fractured rocks, to be stored in underground aquifers.

Surface water in many rivers, dams, lakes and wetlands is connected to aquifers. Groundwater is a finite resource and is only replenished when surface water seeps into and recharges aquifers. Changes in rainfall may have positive or negative impacts on the recharge of groundwater.

Queensland has extensive underground water resources. The Great Artesian Basin is the largest known artesian basin in the world, underlying 20 per cent of continental Australia, including most of Queensland (Cox 2008).

Groundwater in the south-east Queensland region is considered to be almost fully utilised (QWC 2008). Historically south-east Queensland has relied on rainfall over dam catchments and the recharging of groundwater aquifers to meet urban and rural water needs. A key challenge facing south-east Queensland includes planning for the impact of climate variability and climate change on the region's surface and groundwater supplies.

How climate change will affect groundwater is not well known. Increased water demands of regional communities already reliant on groundwater may further stress this resource, which can often be drawn down faster than it can be recharged (IPCC 2007c).

Reduced precipitation or increased evaporation and runoff would reduce the amount of water available for recharge. Changes in vegetation and soils that occur due to temperature changes, fire or pest outbreaks are also likely to affect recharge by altering evaporation and infiltration rates (Bates *et al*. 2008).

Groundwater has become a national research priority. An $82 million National Groundwater Action Plan is investing in projects to improve our knowledge and understanding of groundwater (NWC 2009b). The National Water Commission is also assisting the states and territories to improve knowledge of the expected effects of climate change on these resources.

Climate change impacts on regional water flow systems

Climate change will impact on the quantity, distribution and flow of water in Queensland's regions through changes to rainfall frequency and intensity, and through higher temperatures leading to increased evaporation. Potential impacts of climate change on system flows for a number of Queensland regions are discussed below.

South-east Queensland

By 2050 under a high emissions scenario annual rainfall in south-east Queensland is projected to decrease by five per cent (about 55 millimetres) combined with a six per cent (about 90 millimetres) increase in potential evaporation (Table 1).

The Urban Water Security Research Alliance is conducting a climate and water project which aims to increase the accuracy of climate modelling and provide the best projections on south-east Queensland rainfall and inflow to storage reservoirs.

The Burdekin catchment

In the 129 500 km^2 Burdekin River catchment, the channel floodplain configuration combines with rapid runoff to create very fast flood-wave speeds (Alexander *et al*. 1999). Current climate change predictions indicate that the region is increasingly likely to be subject to more extreme flooding due to more severe cyclones, higher summer rainfall intensity and increased flooding of low-lying coastal areas by rising sea levels (DIP 2008; OCC 2009).

Central Queensland and the Fitzroy catchment

Current average annual rainfall varies from 500 to 1700 millimetres and evaporation averages 2000 millimetres. The stream flow is highly variable with an average annual discharge from the Fitzroy catchment of around 5 million megalitres. The minimum recorded discharge was 96 000 megalitres in 1969. Over the period 2000–2005, the annual discharge ranged from 581 000 to 2 450 000 megalitres (DNRW 2008b).

It is likely that changes to rainfall, temperature and evaporation in the region will translate into reductions to inflows and water storage in coming decades.

Wide Bay–Burnett

Higher temperatures, lower rainfall and increased evaporation are expected under a changing climate. By 2050 the region can expect decreases in supply from existing storages and decreased end-of-system flows. In the same time period, an increase in urban and rural water demand is expected, largely due to a growing population (OESR 2010).

Cape York Peninsula and the Gulf

Strongly seasonal rainfall in north Queensland causes extremely variable water discharge. Tropical cyclones commonly produce high-magnitude, short-duration floods resulting in increased runoff. Possible increases in rainfall in the Gulf and Cape York catchments may contribute to stronger recharge of the Great Artesian Basin.

Condamine–Balonne

The Condamine–Balonne region of the Murray–Darling Basin (MDB) represents 12.8 per cent of the total area of the MDB (CSIRO 2008). Increasing temperatures and evaporation and more prolonged drought, combined with periodic extreme flow events, are projected to be the main climate change impacts (OCC 2009).

Rainfall–runoff modelling with climate change projections from global climate models indicate that future runoff in the region is more likely to decrease than increase, with a nine per cent reduction by 2030. The extreme estimates (which come from a high global warming scenario) range from a 20 per cent reduction to a 26 per cent increase in average annual runoff (CSIRO 2008).

Adaptation

It is estimated that in 2056, without additional supplies, the gap between supply and demand of water in south-east Queensland would be between 97 000 and 308 000 megalitres per year, depending on population growth and water savings achieved and the impacts of climate change (QWC 2008). The $9 billion South East Queensland Water Grid, has been designed to optimise water storage and supply infrastructure to maintain water supplies for an increasing population. It includes dams, recycled water and desalination water facilities.

Filling the supply gap is an important challenge that the Queensland Government is addressing through regional water supply strategies (RWSS). Under the RWSS, the available water supplies and projected demands are examined to determine the water balance for any given strategy area. Water resource plans and resource operations plans provide a structure for the allocation of water, while also maintaining environmental flows.

Better management of artesian bores and dams through leakage reduction and implementing best-practice systems will help reduce water loss. The development of new technologies and farm management techniques is an important challenge for the rural sector.

Terrestrial biodiversity

Australia supports such a rich diversity of life that it has been named one of 17 'mega-diverse' countries—a group of countries that are home to more than 70 per cent of the Earth's species (Steffen *et al*. 2009).

Queensland also has a wide range of unique and diverse terrestrial ecosystems, from the well-known Wet Tropics and Fraser Island World Heritage rainforests, to the desert floodplains of the Channel Country.

Queensland is Australia's most naturally diverse state. Around 1350 ecosystems support 70 per cent of Australia's mammals, 80 per cent of its native birds and more than 50 per cent of its native reptiles, frogs and plant species. Queensland's plants are unique, with 45 per cent of all plant species found nowhere else on earth (EPA 2008).

Despite the intrinsic and environmental value of this diversity of animals and plants, the world is currently losing species at the rate of about one per day and more mammals are threatened with extinction in Australia than anywhere else in the world. Of Queensland's diverse ecosystems, some 222 are currently listed as endangered and 561 as vulnerable (DERM 2010).

Key messages

Significant and adverse effects on terrestrial ecosystems are projected if global mean surface temperatures rise more than 2 °C above pre-industrial levels including:

- declining native biodiversity
- increase in weeds and pests
- loss of high-altitude species due to lack of suitable habitat
- potential loss of half the existing high-altitude Wet Tropics rainforest from a 1 °C increase in temperature
- landscape-level tree mortality due to climate-induced water stress contributing to greenhouse gas emissions and reducing carbon sequestration
- reduced extent and diversity of ecosystems having potentially adverse impacts on tourism income and regional economies
- loss of the benefits of ecosystem services which contribute directly and indirectly to Queensland's economy and lifestyles.

The consequences of a business-as-usual scenario for Australia's biodiversity are severe. Without rapid and effective mitigation of climate change, there is a high risk of an accelerating wave of extinctions throughout the 21st century and beyond (Steffen *et al*. 2009).

Climate risks

The Millennium Ecosystem Assessment (MEA 2005), a four-year study involving more than 1300 scientists worldwide, found that by the end of this century climate change and its impacts may be the dominant direct drivers of biodiversity loss and changes in ecosystem services globally.

The study found that earlier predictions of climate change impacts are too conservative and that future climate conditions can be expected to be hotter and drier than predicted. Also sea levels may rise faster than projected. This suggests that impacts on ecosystems, supporting biodiversity, ecosystem services and dependent human systems, could be even more severe than first predicted.

Figure 24 shows that the current trends of several non-climate factors on terrestrial ecosystems are now being exacerbated by the increasing impact of climate change on ecosystem and species loss.

We benefit from a multitude of resources and processes that are supplied by natural ecosystems and collectively these benefits are known as ecosystem services. The MEA (2005) identified four broad categories of services:

- provisioning—the production of food and water
- regulating—the control of climate and disease
- supporting—nutrient cycles and crop pollination
- cultural—spiritual and recreational benefits.

MEA (2005) found that the degradation of ecosystem services could increase during the first half of this century as climate change impacts intensify. There may be a significant and harmful impact on ecosystem services worldwide if global mean surface temperature increases more than 2 °C above pre-industrial levels.

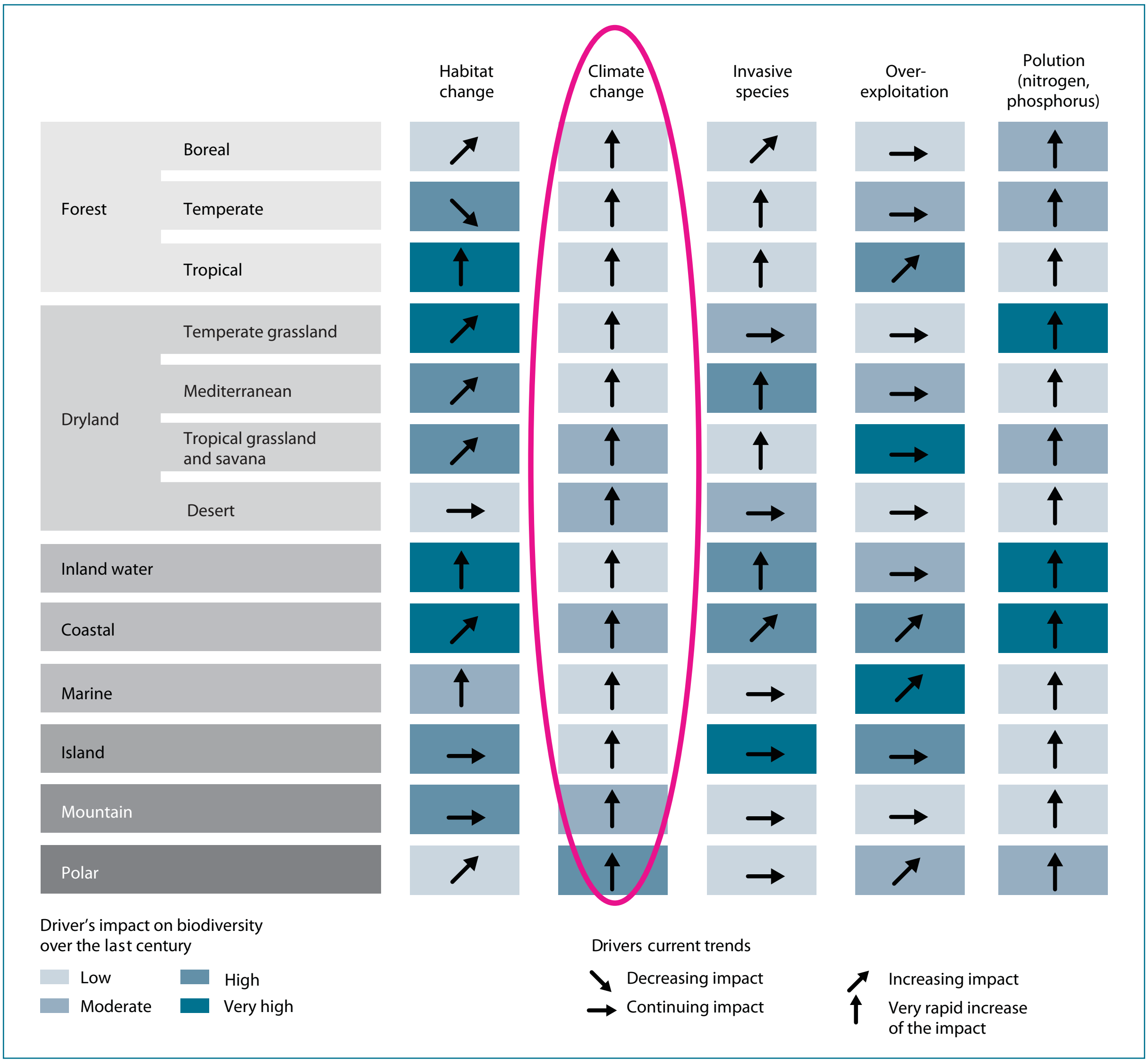


Figure 24: Impact of climate change on biodiversity (Source: MEA 2005 updated; Richardson *et al*. 2009)

Changes in temperature, precipitation patterns and levels of atmospheric carbon dioxide all impact on biodiversity. In biological terms, the contemporary rate of climate change is unprecedented since the last mass species extinction event that took place 60 million years ago (Steffen *et al*. 2009).

Many of Queensland's ecosystems and native wildlife are also threatened by a range of non-climate factors. Clearing for agriculture and urban development, construction of water supply infrastructure, poor land management and invasive species all contribute to ecosystem degradation (EPA 2008).

Managing these non-climate threats is critical to building the resilience of ecosystems to withstand future climate change impacts. Climate change is likely to exacerbate these existing stressors through declining water availability, changed fire regimes and more frequent heatwaves and extreme heat events.

The *Australia's biodiversity and climate change* report (Steffen *et al*. 2009) identifies the key climate change impacts as:

- increases in temperature
- sea level rise
- altered rainfall and runoff patterns
- changed frequency of weather events.

Secondary impacts associated with these key impacts include:

- changes in species distribution
- changes in ecosystem and community composition
- changes in the ranges of invasive species
- a reduced capacity to recover from fires
- a reduced capacity to recover from other extreme events.

The currently high rates of species extinction are also likely to increase as the global average temperature rises by just 1.0 or 1.5 °C above pre-industrial levels, and are likely to accelerate sharply as temperature rises beyond 2 °C (Steffen *et al*. 2009).

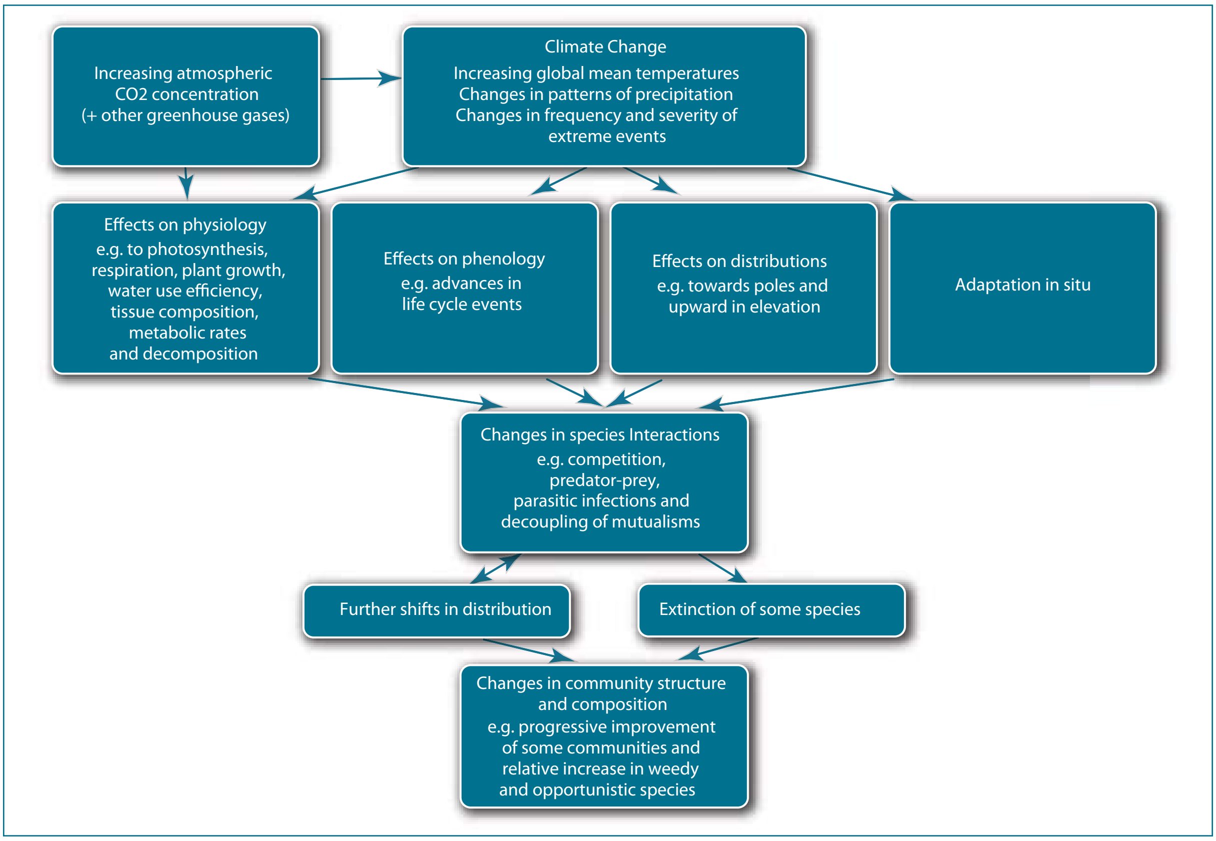


Figure 25: Impacts and pathways of changes due to climate change (Source: Hughes 2000)

Thomas *et al*. (2004) found that for a mid-range climate change scenario, 15–37 per cent of known plant and animal species become 'committed to extinction' by 2050.

The unique responses of different species to climate change mean that many ecosystems and communities might change in ways that we currently cannot predict.

Climate change is expected to cause local extinctions in some areas and the establishment of new species from other areas thereby changing community composition and species distribution. Figure 25 shows the process of climate change impacts on biodiversity.

For the majority of biological systems, climate change may affect:

- individual organisms (physiology)
- timing of life cycles (phenology)
- population processes (birth and death rates)
- shifts and changes in distribution (dispersal and shifts in geographic range)
- potential for adaptation (rapid evolutionary change).

These effects on individual organisms and populations cascade into changes in interactions among species due to the interconnection of ecosystems, especially rainforest ecosystems. Changes in interactions further heighten extinction rates and shifts in geographic range, reducing biodiversity and favouring pest species at the expense of native species.

Many plant and animal species depend on the wide dispersal of individuals for both demographic processes and interchange of genes to avoid inbreeding effects.

Over large areas and long periods, many species have already responded to climate change by moving their geographic range. However, some species now lack a suitable habitat into which to move, have limited or impeded mobility or do not possess the necessary genetic diversity to adapt. The geographic ranges for these species are expected to contract, increasing the risk of extinction.

High-altitude ecosystems

Queensland's high-altitude species are especially vulnerable to climate change. These species are already at their range limits and lack any suitable, higher-altitude habitat. The potential for their extinction is therefore high, even under moderate levels of warming.

Wet Tropics rainforest

The Wet Tropics rainforests and vertebrates of northern Queensland are also likely to face high levels of extinction.

Montane rainforest's endemic vertebrates are projected to decrease by 50 per cent with only a 1 °C rise in average temperatures (Williams & Hilbert 2006). These animal species are found only in the high-altitude rainforests of the Queensland Wet Tropics.

An Australian Centre for Biodiversity study (2008) found that an average temperature rise of 2 °C would eventually force all endemic Australian tropical rainforest vertebrates to extinction.

An assessment by Meynecke (2004) of the potential changes in the distribution of 12 endemic Wet Tropics rainforest vertebrates in response to global warming suggested that even species with currently wide climatic ranges may become vulnerable.

Figure 26 shows the distribution of habitat in the Wet Tropics with mean annual temperature less than 22 °C, which is approximately the upper temperature limit for many Wet Tropics leaf-eating species. A 2 °C rise would reduce the range of this Wet Tropics habitat to small areas of Mt Windsor, Mt Lewis, Mt Bartle Frere and the Atherton Tablelands (Figure 26).

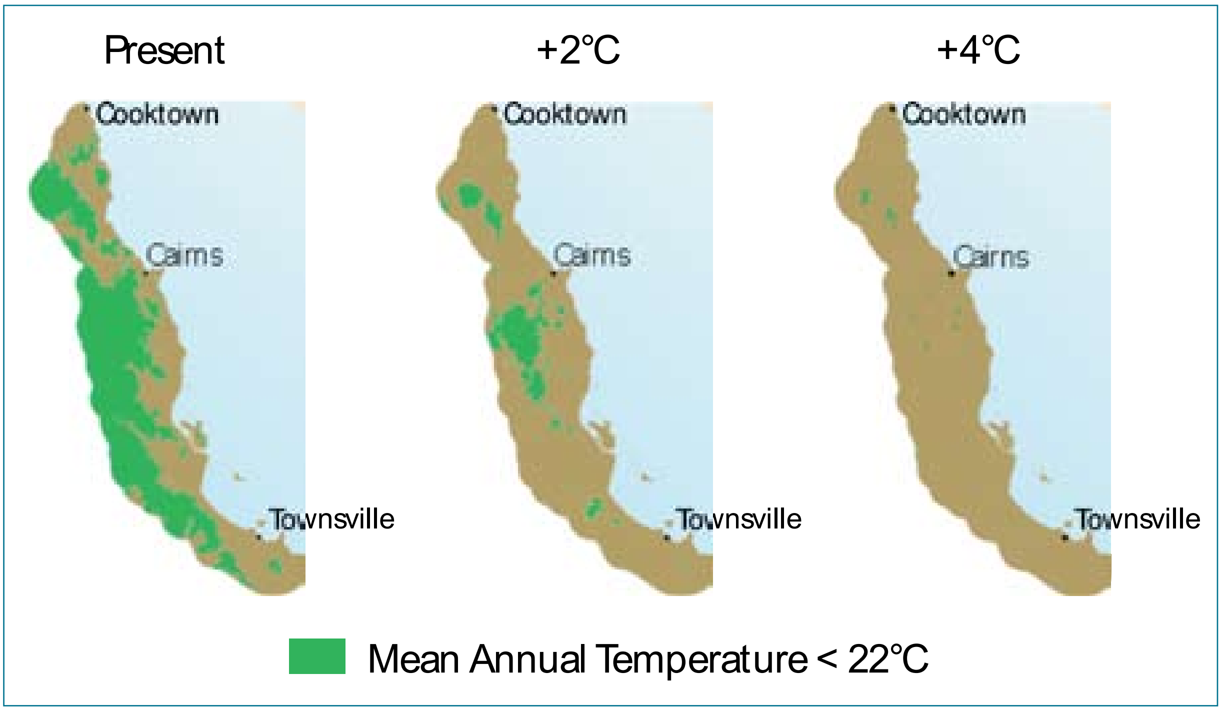


Figure 26: Projected changes to Wet Tropics habitat with increased warming (Source: VanDerWal & Williams 2010)

It has been estimated that by 2050 large areas of the Wet Tropics rainforest habitat could be lost (Garnaut 2008; IPCC 2007b). Hilbert *et al.* (2001) estimated that a 1 °C rise in temperature could result in a 50 per cent decrease in the area of the cool–wet rainforest environment occurring at the highest elevations. As well as loss of biodiversity, reductions in rainforest area also have implications for the tourism industry and for regional economic development.

Tropical savannas, grasslands and dry eucalypt forests

These ecosystems are home to a wide diversity of wildlife in Queensland. They also contain a great deal of Australia's stored terrestrial carbon and are some of our most fire-prone ecosystems.

Fires in these ecosystems contribute significantly to Australia's greenhouse gas emissions and strongly influence the rate of carbon sequestration. Appropriate restoration of these lands to support carbon sequestration may help protect biodiversity and build ecosystem resilience.

Climate-induced water stress over extended periods can force plants to shut down photosynthesis to conserve water, triggering landscape-level tree death (Allen & Breshears 2007). Even larger-scale events can occur when combined with other stressors such as insect outbreaks (Kurz *et al.* 2008). Beckage *et al.* (2008) found that these changes are expected to be most rapid and prominent at the boundaries of ecosystem types.

Adaptation

Australia's Biodiversity and Climate Change (Steffen *et al.* 2009) suggests the following potential adaptation mechanisms to maintain biodiversity:

- reducing existing threats to species
- including information on climate change in biodiversity management tools
- maintaining well-functioning ecosystems
- improving management of areas of high conservation value
- building appropriate types of landscape connectivity to give space for nature to self adapt
- eco-engineering to allow ecological systems to self organise for anticipated climatic conditions
- preservation of genetic stocks, for example in zoos and seed banks
- increased monitoring and research into the impacts of climate change and adaptation options for threatened species and ecosystems.

The Queensland Government has recognised the value of maintaining and enhancing biodiversity. *ClimateQ* includes an initiative to create biodiversity corridors that link parcels of remnant habitat across the landscape, increasing the capacity of species to adapt to climate change impacts.

Several potential corridor projects have already been identified in Queensland, such as the Great Eastern Ranges Corridor project. It aims to link and protect ecosystems along the Great Dividing Range from the Victorian Highlands to the Atherton Tableland in Queensland, and the Coastal Ranges and Great Artesian Basin corridors.

Steffen *et al.* (2009) proposed the following integrated actions to provide effective policy and management responses to the threat of biodiversity from climate change:

- reform management of biodiversity—adapt the way we manage biodiversity to meet existing and new threats and develop new approaches to enhance the resilience of our ecosystems
- strengthen the national commitment to conserve Australia's biodiversity—develop a new national vision for Australia's biodiversity
- invest in our life-support system—create public and private investment in this capital
- build innovative and flexible governance systems—build agile and innovative structures and approaches
- meet the mitigation challenge—establish strong emissions mitigation actions.

Marine biodiversity

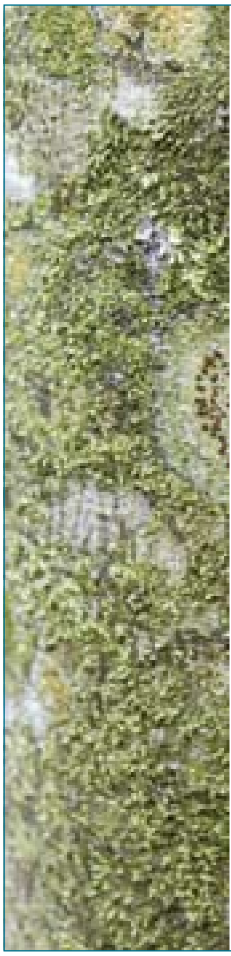
Queensland's mainland coastline encompasses a variety of habitat types including beaches, dunes, rocky reefs, mangroves, seagrass, sand flats and islands. These coastal habitats support a wide range of organisms and are important for tourism, fisheries (i.e. commercial, recreational and Indigenous), aquaculture and maintaining high ecological diversity. Substantial sections of the coastline are also heavily urbanised and industrialised, although large sections in the north and far north remain free from dense development.

Two key marine parks in Queensland are the Great Barrier Reef Marine Park and Moreton Bay Marine Park.

The Great Barrier Reef (GBR) extends for over 2100 kilometres along the Queensland coastline, with an area of 348 000 km^2.

The GBR comprises more than 2900 coral reefs and a diverse range of marine life. It includes about 1500 species of fish, 350 species of hard coral, more than 4000 species of mollusc, 500 species of algae, 24 species of seabird, more than 30 species of whale and dolphin, the dugong and six of the world's seven species of marine turtle (GBRMPA 2009a).

Moreton Bay in south-east Queensland is one of the largest estuarine bays in Australia, covering 3400 km^2 between Caloundra and the Gold Coast. Now a marine park, it contains a wide variety of habitats including coral reefs, sandy beaches, mangroves, rocky shores, mudflats, sandbanks and seagrass beds. It is home to more than 1000 species of fish, six of the world's seven marine turtle species, and threatened species including dugong and grey nurse sharks. Migratory whales and birds add to the bay's biodiversity.



Key messages

The impacts of climate change on marine ecosystems and biodiversity are expected to be considerable, affecting organisms at all life stages as well as their habitat. In particular:

- sea level rise will adversely impact on the nesting grounds of turtles and seabirds, reducing the available breeding habitat of many species
- continued ocean acidification will negatively affect calcification and early development in many important reef species, such as corals and crustose coralline algae (reef cementers)
- the expected increase in the strength of the East Australian Current will influence larval dispersal patterns and durations, and nutrient supply, and may extend the southward distribution of tropical species
- changes in breeding cycles and productivity of fisheries could lead to a range of positive and negative impacts on commercial, recreational and Indigenous fisheries
- an increase in average sea-surface temperature of 2 °C is predicted to lead to annual bleaching of up to 97 per cent of the Great Barrier Reef and associated large-scale mortality, shifts in species' distribution and abundance, changes in the timing and success of reproductive events, and changes to food availability, resulting in serious changes to many marine ecosystems. All these will in turn have a negative impact on tourism and the regional economy.

Some species may be able to adapt better than others but more research is required to model and predict the impacts of climate change and to understand species interactions.

Climate risks

The GBR is vitally important for Australia's tourism and fisheries industries. In 2009, the GBR's contribution to the economy was estimated to be $6 billion. As a World Heritage Area, it attracts two million tourists each year (Access Economics 2008).

The GBR also acts as a natural barrier protecting coastal communities, which has an additional economic value in terms of avoided loss of productive land and infrastructure. While it is difficult to put a value on this coastal protection function, Oxford Economics (2009) estimated that the cost of constructing and maintaining coastal defences equivalent to the length of the GBR could be at least $10 billion in present value terms.

Key environmental variables that affect marine ecosystems include water temperature, circulation patterns, water chemistry (e.g. pH, salinity, nutrient supply), sea level, tropical cyclones and sources of climatic anomalies such as ENSO events (Munday *et al*. 2009). All of these variables are likely to be affected by climate change, potentially resulting in changes to:

- the distribution of organisms—due to shifts in species' ranges or changes in larval dispersal and habitat availability
- phenology—shifts in the timing of reproduction (spawning and nesting) and migrations
- population biology—due to changes in survival rates or physiological effects on biological processes such as metabolism, growth and reproductive output
- breeding cycles and productivity of fisheries—leading to a range of positive and negative impacts on commercial, recreational and Indigenous fisheries
- community structure and species interactions—due to uneven sensitivities of species to climate change impacts, which may result in changes to species interactions and community dynamics.

A recent Great Barrier Reef Marine Park Authority (GBRMPA) report (GBRMPA 2009b) identified climate change as the greatest threat facing the GBR, with almost all species and habitats affected. Figure 27 shows that when CO_2 levels are above 450 ppm corals, seabirds and reef habitats are severely affected. Changes in sea temperature, pH and sea level are indicative only and provide the range of likely values.

Temperature

Increased sea water temperatures are likely to have a dramatic impact on marine ecosystems because temperature influences many biological processes including growth, metabolism, development and calcification (shell and skeleton formation). As well, many marine species can only tolerate a limited temperature range. Species may have some capacity to acclimatise to increased sea water temperatures or shift their range southwards. However, a southwards shift can only occur if a species has a means of getting there (through larval dispersal or mobile adults), if there is suitable habitat available and if they can compete with residents. Species that cannot move or acclimatise will decline in abundance.

As most corals live close to the upper limit of their temperature tolerance, prolonged high temperatures (1–2 °C above the average summer maximum temperature) can cause corals to bleach. If temperatures return to their previous level quickly, corals can recover but may still experience lower rates of growth and reproduction Fabricius *et al*. (2007).

Climate-related warming of sea-surface temperatures (SST) is projected to increase the frequency and severity of coral bleaching episodes, reducing the time available for recovery between episodes and resulting in higher rates of coral death. Annual SST on the GBR could rise by 1–3 °C from the present average temperature by 2100 (GBRMPA 2009b). An average SST increase of 2 °C is predicted to lead to annual bleaching of up to 97 per cent of reefs and coral death on a large scale (GBRMPA 2009a). Reefs that experience large-scale coral mortality from bleaching are at risk of being overgrown by fast-growing algae, making coral recovery difficult. Algal growth increases with nutrient runoff and predicted increases in rainfall intensity and subsequent increases in runoff could further compound the problems faced by inshore reefs (Fabricius *et al*. 2007).

Recent research found that high nutrient levels (particularly dissolved inorganic nitrogen) in the sea water surrounding reefs can potentially lower the temperature threshold at which corals bleach by 1.0–1.5 °C and by as much as 2.0–2.5 °C in the most nutrient-enriched locations (Wooldridge & Done 2009). Management strategies that reduce nutrient levels in terrestrial runoff could help to maximize the coral's resistance to heat stress and subsequent bleaching.

In the event of a total and permanent bleaching of the GBR, Oxford Economics (2009) estimated that there would be a 50 per cent reduction in reef visitors and a total monetary cost (in present value terms) to tourism and fishing (in present value terms) of about $37.7 billion, with an estimated cost of $16.3 billion to the Cairns area alone.

Impacts on coral populations will have extensive implications for thousands of other species (including fish, invertebrates and reptiles that use corals for food and/or shelter) and for biodiversity in general.

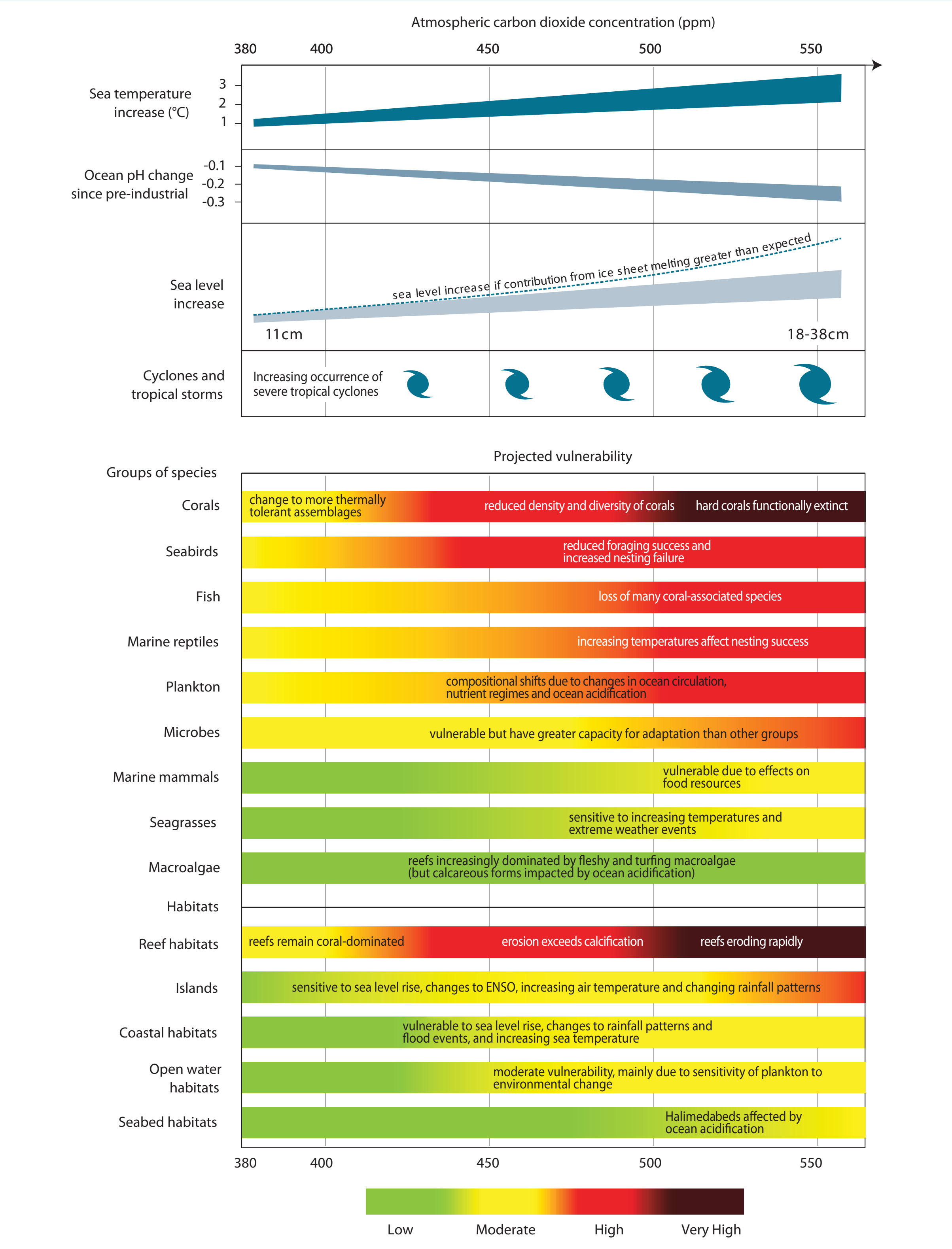


Figure 27: Projected vulnerabilities of GBR ecosystem components across a range of atmospheric CO_2 concentrations (Source: GBRMPA 2009b)

Elevated temperatures also have significant impacts on the breeding success of seabirds and turtles (GBRMPA 2009b). Seabirds have suffered complete nesting failures in very hot years due to the parents' inability to find sufficient fish to feed their chicks. Turtle gender is dependent on the temperature experienced by the eggs, with higher temperatures increasing the proportion of females.

Sea level rise

Low-lying islands such as Heron Island and Lady Musgrave Island are important nesting sites for seabirds and turtles. A sea level rise of only 0.38 metres will flood important turtle nesting beaches (GBRMPA 2009a). Saltwater intrusion into freshwater wetlands on the Queensland coast could reduce breeding habitat for many bird species. Coastal erosion is likely to be exacerbated by increased sea level combined with larger storm-tide events.

An additional sea level rise of up to 0.05 metres by 2070 is projected for the east coast of Australia due to the strengthening of the East Australian Current (CSIRO & BoM 2007). Sea level rise influences the inundation and establishment of coastal habitats and ecosystems (Brierley & Kingsford 2009) and could negatively affect intertidal organisms living on rocky shores. Such rocky shore inhabitants are often confined to distinct vertical zones and may simply run out of habitat as sea level rises. Rocky shores are common on Queensland's mainland coastline and islands.

Rainfall and floods

Projections for the far north of Queensland include more intense rainfall events particularly in summer, with possibly fewer but more intense tropical cyclones (OCC 2009).

Increased intensity of rainfall events will increase runoff, with elevated levels of sediments and nutrients reducing water quality and exacerbating other stressors for nearshore reefs and coastal habitats (Fabricius *et al*. 2007).

Cyclones and storm surge

Higher mean sea level combined with more intense weather systems could increase inundation of coastal areas, potentially impacting mangrove nursery areas and damaging aquaculture facilities, coastal developments and tourism infrastructure.

Strong winds, increased wave intensity and storm surge generated during cyclonic conditions can also disrupt bird and turtle nesting and damage corals. This damage reduces invertebrate and fish habitat and results in greater fragmentation of coral reefs and their communities.

Acidification

Ocean acidification is the term given to the ongoing process whereby increasing amounts of atmospheric CO_2 dissolve in sea water, lowering sea water pH (increasing acidity) and decreasing concentrations of carbonate ions. This makes it more difficult for calcifying organisms such as shellfish and corals, to form their shells and skeletons.

Corals may also be weakened and become more susceptible to storm damage if calcification rates are reduced due to ocean acidification (GBRMPA 2009b).

Global surface ocean pH has already decreased by 0.1 units since pre-industrial times and is projected to decrease a further 0.3–0.4 units by 2100 (Caldeira & Wickett 2003). In addition to this, McMullen & Jabbour (2009) found a 25 per cent reduction in the saturation states of calcite and aragonite, the key mineral forms of calcium carbonate used by organisms to form their shells and skeletons.

Under doubled CO_2 conditions, calcification rates of reef-building corals could decline by 9–60 per cent depending on the species (Guinotte & Fabry 2008). Analysis of cores taken from massive (i.e. non-branching) *Porites* coral on the GBR indicated that calcification had declined by

21 per cent over a 16-year period in two regions (Cooper *et al.* 2008), and 328 sites on 69 reefs showed a 14.2 per cent decline in *Porites* calcification since 1990 (De'ath *et al.* 2009).

An experimental study by Anthony *et al.* (2008) indicated that branching corals may be more sensitive to the effects of sea water warming and acidification than massive corals. This difference in species' susceptibility to climate change could change the community structure of future coral reefs, reducing structural complexity and habitat availability for fish and invertebrates.

Also at high risk are crustose coralline algae (CCA), with acidification significantly reduces their survival, growth, productivity and calcification and increasing the bleaching response (Anthony *et al.* 2008; Kuffner *et al.* 2008; Martin & Gattuso 2009). CCA are an important component of coral reef ecosystems, making a significant contribution to reef building and cementation.

Studies by Gazeau *et al.* (2007), Fabry *et al.* (2008), Kurihara *et al.* (2009) and Parker *et al.* (2009) found that ocean acidification impacts a wide range of other calcifying organisms. These include sea urchins and aquaculture species such as oysters, mussels and clams. Laboratory-scale studies have found that early life history stages are often susceptible to acidification, with negative impacts on fertilisation rates, development rates and the formation of larval skeletons in echinoderms and crustaceans (Fabry *et al.* 2008).

Fish may be less impacted by acidification than invertebrates because they are more efficient at regulating chemicals within their bodies to compensate for changes in water composition. However, Munday *et al.* (2009) found that acidification could affect the ability of larvae to locate suitable habitat. Indirect effects are also likely, with potential changes to ocean productivity affecting food supply.

Ocean currents

Climate change could alter the strength and pattern of ocean currents with wide-ranging consequences. The projected continued increase in the strength of the East Australian Current may extend warmer waters further south with possible impacts on marine ecosystems, species distribution and larval dispersal (Steffen *et al.* 2009).

Modelling of the dispersion of passive particles around Lizard Island (14° S) on the northern GBR in response to a two-degree southerly shift in the position of the South Equatorial Current resulted in modelled particles being transported to the north-west, rather than to the south (Munday *et al.* 2009). Such pronounced changes in dispersal patterns could have negative consequences, by moving larvae to unsuitable temperature regimes and habitats.

Ocean upwelling

Climate change could also reduce the intensity and duration of vertical circulation patterns (upwelling) that bring deep, often nutrient-rich, water to the surface. Such changes could result in reduced ocean productivity and biodiversity.

Adaptation

A species can adjust to environmental changes through physiological changes at the cellular level, behavioural changes at the level of individuals (termed acclimatisation) or genetic changes that occur over many generations (adaptation). Adaptation usually occurs over long geologic timeframes and, given the rapid rate of climate change, it is unknown whether organisms will be able to adapt quickly enough to their new environmental conditions.

Most marine larvae disperse away from the reef where they were born and join distant populations.

The best way to build the resilience of marine ecosystems to climate change impacts is by protecting source populations enhancing connectivity (physical connection) between populations and reducing other stressors such as pollution, nutrient runoff and overfishing. This ensures the continued supply of larvae and adults for recolonising populations depleted by storms, bleaching or runoff.

Steps have been taken to reduce non-climate stressors in the marine environment. The *Reef Water Quality Protection Plan* released in 2003 aims to manage diffuse sources of pollution from agricultural land.

To strengthen this protection, in 2009 the Queensland Government introduced regulations to improve land management and restrict the use of chemicals in the reef catchment. The aim was to achieve a 50 per cent reduction in the discharge of dangerous pesticides and fertilisers over four years.

In south-east Queensland a comprehensive ecosystem health monitoring project has been implemented to evaluate water quality condition and trends. This project includes ongoing community education.

Tourism industry leaders and GBRMPA, working together as the Tourism Climate Change Action Group, have developed the *Great Barrier Reef Marine Tourism Climate Change Action Strategy 2009–2012*. The strategy is intended to guide action to be taken by industry to improve reef health and the viability of the marine tourism industry.

A major challenge for scientists and policy makers is identifying thresholds at which major ecosystem changes might occur. It is predicted that ecological responses of ecosystems to climate change are likely to occur in a series of abrupt steps separated by intervals of relatively minor change (GBRMPA 2009b). More ecosystem-based research and management approaches, combined with adaptive management strategies, will help to identify and manage ecological thresholds.

Key research to fully understand the impacts of climate change on marine ecosystems and determine appropriate management strategies should address:

- how climate change will alter ocean currents and circulation patterns, habitat availability, and the physiology and development of larvae and reproductive adults. This research will inform management strategies to enhance population connectivity
- the implications of ocean acidification through long-term measurements of ocean chemistry and studies on a wider range of species, using experimental conditions that more adequately mimic the natural environment
- species' tolerances to projected climate change and their capacity for acclimatisation or genetic adaptation
- the identification of thresholds at which major ecosystem changes might occur. This will be addressed through both experimental studies and community dynamics modelling for each ecosystem type (e.g. coral reefs, seagrasses, rocky shores).

Primary industries

The Queensland primary industries sector is a key contributor to the Queensland economy, society, culture and environment, especially in regional areas. In 2006–07, primary industries contributed around six per cent of the Queensland economy with the gross value of production in the sector forecast to be more than $13 billion in 2008–09 (DPI&F 2008).

In Queensland, the beef and sugar industries comprise a large part of the primary industries sector, with fruit, vegetables and nuts also making up a significant proportion (Figure 28).

The grain industry is an important input to the beef industry, while the coastally located sugar industry generates $1 billion per annum for Queensland (DPI&F 2008).

Horticulture contributes $3 billion to the Queensland economy every year and is very climate sensitive in terms of crop type and cultivars (DPI&F 2008).

Of Queensland's total net greenhouse gas emissions in 2008 (160.3 Mt CO_2-e) 26.6 Mt (17 per cent) came from agriculture, with the majority being methane emissions from livestock (DCCEE 2010).

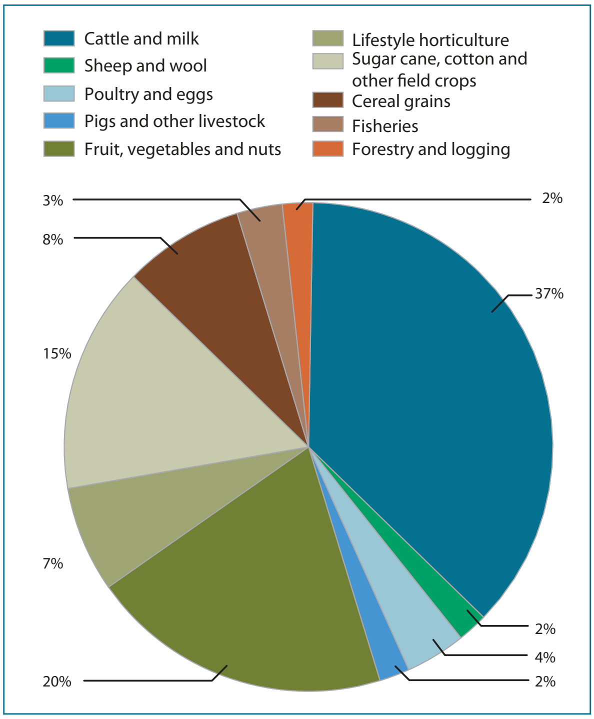


Figure 28: Queensland's major primary industries 2008–09 (Source: DPI&F, 2008)

Key messages

The effects of declining rainfall and runoff into streams are already being felt by primary producers and the effects of temperature changes are likely to be felt within the next decade. Key impacts on the primary industries sector are likely to include:

- warmer and drier weather in future decades over much of Queensland
- more frequent droughts and drier conditions
- increased frequency of severe weather events including flooding, which could also reduce primary and agricultural production through reduction in crop yields and through stock losses
- changes in average rainfall and temperatures, in seasonal distribution of rainfall and in rainfall variability, which directly affect crop production.

Land clearing is a significant factor in Australia's recent droughts and changing climate. The intensity and duration of droughts may have increased as a result of large-scale clearing of native vegetation, amplifying the effects of El Niño-related droughts. Maintaining adequate land cover could help reduce the impacts of climate change.

Climate risks

Recently there has also been increased recognition of the ecosystem services that biodiversity provides. Industries such as forestry, agriculture and other primary industries that rely directly on ecosystem services are most exposed to impacts of climate change on these services.

Climate change threatens to undermine Queensland and Australia's food security. Production from primary industries is projected to decline by 2030 over much of eastern Australia due to increased drought, reduced water resources and higher temperatures.

Queensland is projected to be warmer and drier in future decades. An assessment of the impact of climate change on extreme weather events found that events once considered exceptional may become more common in the future. For example, there may be an increase in the number of exceptionally hot years, with associated lower soil moisture and changes to evaporation and rainfall (Hennessy *et al*. 2008).

Climate change is also projected to have a significant adverse impact on Australia's agricultural production and exports (Stern 2006; Garnaut 2008).

Crop production is likely to be affected directly by changes in average rainfall and temperatures, in seasonal distribution of rainfall and in rainfall variability.

Australian production of beef, sheep meat and wool could decline by five to eleven per cent by 2030 under a business-as-usual case (Heyhoe *et al*. 2008). In northern Australia, the decline in beef production is expected to be 3.5 per cent by 2030 with significant impacts on the entire grazing industry (Heyhoe *et al*. 2008).

However, the agricultural sector's relatively good ability to adapt to changing climate conditions is also likely to mitigate some of the adverse impacts.

Not all impacts of a warming climate are negative for primary industries: some agricultural impacts are likely to be positive. For example, increases in CO_2 concentration will increase the rate of photosynthesis in some plants provided there is adequate moisture (Steffen & Canadell 2005).

However, this positive impact of carbon fertilisation is likely to be restricted by higher temperatures and lower rainfall, which are both expected to become more prevalent through the 21st century. Howden *et al*. (1999) and Crimp *et al*. (2002) found that a 10 per cent reduction in rainfall would be likely to remove the CO_2 fertilisation benefit.

Land clearing over the past 200 years is a significant factor in Australia's recent droughts and changing climate. Research by Deo *et al*. (2009) indicates that the intensity and duration of droughts has increased as a result of large-scale clearing of native vegetation, amplifying the effects of El Niño-related droughts and increasing the annual number of days with over 35 °C temperatures.

Adaptation

Understanding the implications of climate change would help the primary industries sector to adapt and develop new ways of functioning within a changing climate.

The Queensland Government is committed to working with rural communities to ensure that resources and skills are available to prepare for greater climate variability.

Queensland Government financial incentives in exceptional drought events provide support to primary producers.

The development of climate forecasting techniques and management tools that integrate climate information into producers' operations also helps prepare for changes in climate.

The Queensland Climate Change Centre of Excellence has developed a climate risk management matrix to assess climate change impact, risk and adaptation potential for the Queensland grazing industry (Table 4) (Cobon *et al*. 2009)

The cells in the matrix give information on likely impacts in relation to specific elements of climate change. For example, with higher minimum temperatures, a moderate increase in pasture growth is projected (and researchers are highly confident that climate change will bring higher minimum temperatures).

For some cells in the matrix, interactions are complex. These cells are completed using complex modelling tools. Other cells are filled subjectively, based on knowledge of climate change science along with local and industry knowledge.

Adaptation to the changing climate needs to address:

- capacity building to adapt to climate change
- awareness raising about the effects of climate change and the advantages of early action

- analysis of climate-related financial risks and opportunities
- development of industry sector plans and communication with commodity producers, businesses and decision makers on what climate change means for their businesses and industry
- communication with customers on industry actions to address climate change.

The Queensland Government, through its *ClimateQ* strategy, is investing $3.2 million to provide information and tools to help primary producers in Queensland manage climate change risks and take advantage of emerging opportunities. This initiative will support research on the impacts of climate change on primary industries (including fisheries and forestry); assess the flow-on impacts to farm business, local communities and the Queensland economy, and develop adaptation options to manage the risks.

The key to Table 4 is shown below. The blue shading indicates a level of positive impact and brown shading indicates a negative impact of climate change on the grazing industry.

	LEVEL OF NEGATIVE IMPACT					LEVEL OF POSITIVE IMPACT				
	Negative consequences					**Positive consequences**				
Likelihood	Minor	Moderate	Major	Severe	Catastrophic	Minor	Moderate	Major	Extreme	Phenomenal
Rare	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low
Unlikely	Low	Low	Medium	Medium	Medium	Low	Low	Medium	Medium	Medium
Possible	Low	Medium	Medium	High	High	Low	Medium	Medium	High	High
Likely	Low	Medium	High	High	Extreme	Low	Medium	High	High	Extreme
Almost certain	Low	Medium	High	Extreme	Extreme	Low	Medium	High	Extreme	Extreme

Feature	Pasture Growth	Surface Cover	Plant Available Water Capacity	Wind Erosion	Rural Human Health and Wellbeing	Biodiversity
Elevated CO_2	Moderate increase in pasture growth due to Co_2 fertilisation	Minor increase in surface cover	Moderate increase in plant available water capacity due to increased surface cover and transpiration rates	Moderate reduction in wind erosion due to higher surface cover	No direct effect	Changes in species composition and structure for plant species
Increased evaporation	Decrease in pasture growth	Decrease in surface cover	Reduced plant available water capacity due to lower water availability/surface cover	Increased wind erosion due to lower surface cover	Decrease in human health and welfare related issues	Changes in species composition and structure for plant and freshwater dependent species
Higher minimum temperature	Moderate increase in pasture growth	Increased surface cover	Reduced plant available water capacity depending on extent of increase in surface cover	Reduced wind erosion due to higher surface cover	Small decrease in rural human health	Changes in insect and plant species composition
Less frost	Increase in pasture growth during winter	Increased surface cover	Increase in plant available water capacity due to higher surface cover	Reduced wind erosion due to higher surface cover	No direct effect or not measurable	Changes in insect and plant species composition
Higher maximum temperature °C	Decreases in pasture growth	Decrease in surface cover	Reduced plant available water capacity due to a reduction in water availability/surface cover	Increased wind erosion due to lower surface cover	Decrease in rural human health and capacity to cope at current rate of functioning	Changes in amphibian, insect and plant species composition

Feature	Pasture Growth	Surface Cover	Plant Available Water Capacity	Wind Erosion	Rural Human Health and Wellbeing	Biodiversity
More days over 35 °C	Decrease in pasture growth	Decrease in surface cover	Reduced plant available water capacity due to a reduction in water availability/surface cover	Increased wind erosion due to lower surface cover	Large decrease in rural human health and capacity to cope at current rate of functioning	Changes in plant structure and species composition
More droughts	Severe reduction in pasture growth	Severe reduction in surface cover	Severe reduction in plant available water capacity due to reduction in water availability/ surface cover	Increased wind erosion due to lower surface cover	Large decrease in human health, potential for stress related incidence	Major changes in plant and animal species composition
Increased storm intensity - same total rainfall	Decrease in pasture growth	Decrease in surface cover	Decrease in plant available water capacity	Increased wind erosion due to lower surface cover	No change	Changes in insect and plant species composition, siltation of waterholes
Decrease in winter rainfall	Minor decrease in pasture growth	Minor decrease in surface cover	Minor reduction in plant available water capacity due to lower water availability/surface cover	Minor increase in wind erosion due to lower surface cover	Minor decrease in rural human health	Major changes in plant and animal species composition
Decrease in summer rainfall	Severe reduction in pasture growth	Severe reduction in surface cover	Reduced plant available water capacity due to lower water availability/surface cover	Severe increase in wind erosion due to lower surface cover	Large decrease in human health, hardship and welfare, potential for stress related incidence	Changes in plant and animal species composition
More wildfires	Increase in pasture growth	Decrease in surface cover	Decrease in plant available water capacity due to lower surface cover	Increased wind erosion due to lower surface cover	Decrease in human health and welfare related issues	Changes in plant structure and species composition
Higher peak wind speeds	Decrease in pasture growth due to higher evaporation and erosion of topsoil especially in arid and semi-arid regions	Decreased surface cover due to higher evaporation, erosion of topsoil	Decrease in plant available water capacity due to lower surface cover (reduced infiltration into soil)	Increased wind erosion due to higher peak wind speeds	Decrease in human health and increase in welfare related issues	Damage to some tree and animal species
Overall estimate for the risk averse	Reduction in pasture growth	Decrease in surface cover	Decrease in plant available water capacity	Increased wind erosion	Decrease in human health and increase in welfare related issues	General negative long-term effects on ecosystem function

Table: 4: Climate change risk management matrix for the Queensland grazing industry (Source: Cobon *et al.* 2009).

Health and wellbeing

Climate change will have an impact on the social, health and lifestyle needs of all Queenslanders. This section provides an overview of some of the key impacts to human health under changes to climate in Queensland.

Existing literature on the impacts of climate change on human health is mostly descriptive rather than quantitative. It makes inferences about broad climate-related health risks (McMichael *et al*. 2009). Direct links between climate change and changes in many diseases or illnesses are difficult to establish but in general terms climate change can negatively affect the environment and a poor environment can negatively impact human health.

Key messages

The potential impacts of climate change on people's health and wellbeing are likely to include:

- increased intestinal illness as changing rainfall will affect water availability, quality and access
- increased illnesses caused by viruses carried by mosquitoes (e.g. Ross River fever) as changing temperatures and rainfall will affect mosquito breeding patterns
- increase in respiratory and allergic diseases as changing temperatures and weather patterns will affect airborne pollution
- increased heat-related illnesses as a result of increasing heatwaves and temperatures, including heat stress and illnesses affecting the vascular and respiratory systems
- trauma from extreme weather events and more mental illness in areas affected by long-term drought and other natural disasters
- increased pressure on health infrastructure and services across Queensland.

Climate risks

Climate change, particularly raised temperatures and variations in rainfall, are likely to result in health and wellbeing impacts across Queensland society.

Temperature increases can bring prolonged periods of hot days and warm nights, increasing the mortality rate, especially in the elderly.

Longer and more frequent droughts in regional Queensland can increase personal stress and mental illness.

Gradual sea level rise, coupled with stronger storm surges, will tend to bring more frequent and more severe coastal flooding, increasing environmental and social pressures and potentially requiring the relocation of communities, especially from low-lying islands (IPCC 2007c).

Projected increases in the frequency and severity of flooding and storms could result in the destruction of homes and essential services including health services. People living in marginal conditions are likely to be more at risk.

Figure 29 portrays the pathways linking climate change and health.

The World Health Organization estimates that in 2004 more than 140 000 deaths worldwide were attributable to climate change. Climate change was estimated to be responsible for 3 per cent of diarrhoea, 3 per cent of malaria and 3.8 per cent of dengue fever deaths worldwide in 2004 (WHO 2009). These impacts are likely to increase in the future.

Horton and McMichael (2008) predict that by 2020 it is likely that Australian doctors and hospitals will be treating patients with a range of climate change-related illnesses, including:

- heat stress
- other heat-related illness (affecting the heart, blood vessels and lungs)
- trauma from extreme weather events
- mental illness in areas affected by long-term drought and other natural disasters
- respiratory problems from airborne pollutants
- infectious diseases such as gastroenteritis
- dengue fever and Ross River virus due to changes in the distribution of disease-carrying mosquitoes.

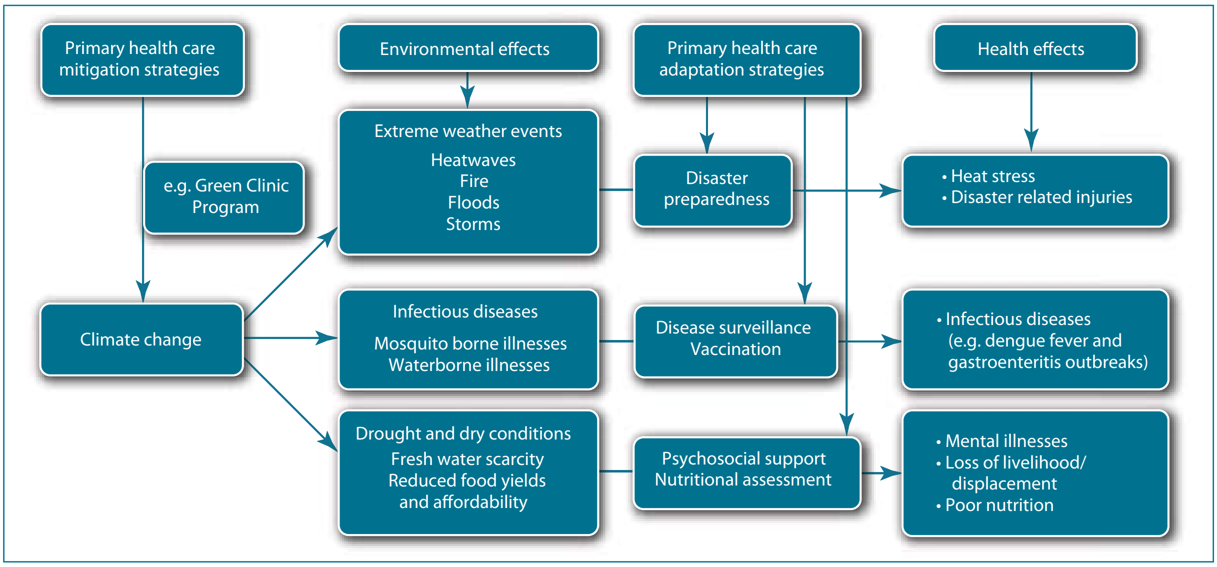


Figure 29: Pathways by which climate change can impact on health and potential primary health-care adaptive strategies (Source: Blashki *et al.* 2007)

Heatwaves

Heatwaves are viewed as a 'passive' hazard in contrast to the more widely studied catastrophic hazards such as tropical cyclones and earthquakes. According to Coates (1996), heatwaves kill more people than any other natural hazard experienced in Australia.

The most vulnerable groups are the sick, the young, the elderly and the poor. Heatwaves significantly increase human mortality and hospital admissions, especially for people with cardiovascular diseases (Queensland Health 2004). A Canadian study found the risk of mortality increased by 1–3 per cent per 1 °C change at high temperatures (Hajat & Kosatsky 2009).

Australia has an aging population. In 2007, people aged 65 years and over made up 13 per cent of the population (ABS 2008a). This proportion is projected to increase to 23–25 per cent in 2056 and to 25–28 per cent in 2101 (ABS 2008b).

The elderly (over 65 years) are particularly vulnerable to heatwaves, with limited mobility being an important mortality risk factor (Bambrick *et al.* 2008; Van Iersel & Bi 2009).

An investigation of all causes of death in Brisbane found a high correlation between higher temperatures and deaths in the elderly (Bi *et al.* 2008).

Taking into consideration changes in population and age demographics, McMichael *et al.* (2003) found that a temperature increase of 1.6 °C above 1990 levels could increase heat-related deaths in Brisbane from the current estimated 134 deaths per year to over 1000 deaths per year by 2050.

The number of annual temperature-related deaths in Queensland, in a scenario without climate change mitigation, is expected to rise to over 5800 deaths by 2100 (Garnaut 2008).

The January–February 2009 heatwave in Victoria provides an example of the potential effects of such events. The heatwave was of unprecedented intensity and duration with maximum temperatures 12–15 °C above normal for much of Victoria, while Melbourne endured three consecutive days of temperatures above 43 °C (BoM 2009d).

The heatwave caused major power disruptions in Melbourne leaving over half a million people without power. Ambulance Victoria (2009) reported a 70 per cent increase in emergency calls. Data for the week of the heatwave (26 January–1 February 2009) compared to the same period in previous years showed that there was a 62 per cent increase in total all-cause mortality, with 374 excess deaths (DHS 2009).

The total number of deaths was 980, compared to a mean of 606 for the previous five years. The greatest number of deaths occurred in those 75 years or older, representing a 64 per cent increase (DHS 2009).

The January 2000 heatwave in south-east Queensland resulted in 22 reported deaths and 350 injuries. The Queensland Audit Office (2005) estimated the cost at $2 million.

Preliminary data on the February 2004 heatwave in Brisbane indicated that it resulted in 12 recorded deaths and 221 heat-related hospitalisations (Queensland Health 2004). The highest temperature recorded in the 2004 heatwave was 42 °C. The highest recorded temperature was 34 °C during the same months of 2001–03 (Tong *et al.* 2009).

The impact of heatwaves will potentially be exacerbated by disruption to energy services, either through storm damage or as a result of increased demand. In the United States, the 2003 summer heatwave caused the electricity grid to fail, resulting in 50 million people being without power for several days (Miller *et al.* 2008).

Other extreme weather events

Other extreme weather events impacting on Queensland include cyclones, storms, floods, bushfires and drought. Future changes in extreme weather events are difficult to assess and model at regional scales.

Most of the deaths directly related to storms are a result of drowning (Sellman & Hamilton 2007). Direct health impacts from extreme weather events include traumatic injuries and post-traumatic stress syndrome.

Table 5 lists major disasters in Queensland from 1975 to December 2002, as identified by Emergency Management Australia. Each of these caused at least 12 fatalities or 50 injuries or resulted in at least $200 million in total estimated costs.

Date	Disaster Category	Location	Fatalities	Injured	Estimated Cost $ millions (1997 value)
Dec 1976	Cyclone Ted	Queensland	..	2	220
Jan 1985	Severe storm (including Tornado)	Brisbane	..	20	390
Jan 1986	Cyclone Winifred	Cairns-Ingham	3	12	325
Apr 1989	Cyclone Aivu (including storm surge)	Ayr, Home Hill, Wunjunga	2	13	200
Jan 1991	Flood (Cyclone Joy)	Central Coast	6	35	385
Jan 1994	Heatwave	northern including Townsville	5	150	8
Mar 1997	Cyclone Justine	Cairns-Innisfail	7	50	190
Jan 1998	Flash Floods	Townsville-Cairns	2	40	210
Jan 2000	Heatwave	south-east region	22	350	2

Table: 5: The cost to Queensland from natural and non-natural disasters (Source: adapted from Queensland Audit Office 2005)

Disasters do not generate 'new' diseases. According to Smith (1999), disasters may increase transmission of diseases that already exist in a region by:

- altering the environment through disruption and damage to power supplies, water and sewerage infrastructure, waste disposal facilities and services
- reducing access to clean food and water
- encouraging disease-carrying animals to thrive.

Unmitigated climate change could result in global sea level rise of one metre or more by 2100 and more intense storms. Under such conditions, heavy rain has been implicated as a source of infection (McMichael *et al*. 2009).

Climate change is expected to create a substantial increase in fire weather risk in much of south-eastern Australia (McMichael *et al*. 2009). The Victorian heatwave in January and February 2009 resulted in 374 excess deaths and generated extreme fire conditions. Resulting bushfires claimed 173 lives (Victoria Police 2009).

Mosquito-, water- and foodborne diseases

Climate change is projected to increase risks relating to vector- and waterborne and infectious diseases as well as impacting on food safety. Lower income groups are particularly at risk.

Mosquito-borne diseases

The IPCC predicts that by 2050, 0.6–1.4 million more people in the Oceanic region will be exposed to dengue fever (IPCC 2007c). The current distribution of dengue fever is at an historical low, even though cases have been reported in New South Wales and the dengue mosquito has been found throughout Queensland and in Victoria and Western Australia (Russell *et al*. 2009). Queensland's largest recorded dengue fever epidemic in at least 50 years began in November 2008 and was exacerbated by the early 2009 flooding. A total of 931 people in northern Queensland were confirmed as having the virus (Queensland Health 2009).

Queensland currently has the highest number of Ross River fever cases each year in Australia. Longer dry periods followed by intense rainfall and flooding are expected to bring added periods of mosquito activity followed by rapid outbreaks of disease. Poor maintenance of rainwater tanks can also cause mosquito proliferation and increase the spread of the disease (Woodruff & Bambrick 2008; McMichael *et al*. 2009).

Flooding across central Queensland in early 2008 may have been the cause of a substantial increase in notifications of Ross River fever. In Queensland, there were 1246 notifications compared with 535 notifications for the same period in 2007, when no major flooding occurred (McMichael *et al*. 2009).

A systematic literature review by Tong *et al.* (2004) between climate factors and Ross River virus transmission found that rainfall and temperature were major determinants of the spread of the disease.

Waterborne diseases

The European Centre for Disease Prevention and Control noted in a report on climate change and waterborne disease that climate change will alter the water cycle by increasing the frequency of extreme events such as excessive rainfall, storm surges, floods and droughts (ECDPC 2004). These events can affect water availability, quality or access, posing a health threat.

Waterborne pathogens often act through two major exposure pathways: drinking water and recreational water use (ECDPC 2009). Hot weather may increase the prevalence of these pathogens, resulting in widespread contamination of surface water supplies (McMichael *et al.* 2009).

Climate change is likely to increase health risk from two environmental pathogens associated with wet weather—leptospirosis and melioidosis (McMichael *et al.* 2009).

The potentially fatal disease melioidosis, which can cause external and internal abscesses or ulcers and blood poisoning, is endemic to northern Australia (Cheng *et al.* 2006) and can be spread by contact with contaminated soil or water.

There are typically 150–300 cases of leptospirosis per year, mostly from Queensland, with increases in cases associated with severe weather events (Inglis *et al.* 2004; Currie *et al.* 2009).

Sudden heavy rainfall and associated flooding can overload some sewer and stormwater systems, potentially leading to faecal contamination of stormwater released into the environment. Heavy rainfall events will also tend to flush out pathogens from upstream water catchments, especially in farm runoff. As a result, *Cryptosporidium, Giardia* and other pathogens may enter surface water supplies (McMichael *et al.* 2009).

Rodents act as reservoirs and carriers for various diseases, and increase in numbers in temperate regions following mild wet winters. Rodent-borne diseases associated with flooding include leptospirosis, tularaemia and viral haemorrhagic diseases (WHO 2010). Infections with these diseases occur through eating or drinking of contaminated food or water.

Many diarrhoeal diseases vary seasonally, suggesting sensitivity to climate. In the tropics diarrhoeal diseases typically peak during the rainy season. Both floods and droughts increase the risk of diarrhoeal diseases (WHO 2010).

Reduced rainfall increases the risk of toxic algal blooms and can increase the salinity of drinking water (IPCC 2007c; McMichael *et al.* 2009) while rising water temperature may promote earlier and longer lasting algal blooms (Moore *et al.* 2008). Hunter (2003) found that increases in the nutrient content and water temperature of dams, caused by heavy precipitation, can also lead to blooms of toxic algae.

Foodborne disease

Heatwaves may cause failure of electricity supplies which could result in food spoilage, increasing the likelihood of infection (Cretikos *et al.* 2007; McMichael *et al.* 2009). *Salmonella* is a bacterium that causes salmonellosis—one of the most common intestinal infections. *Campylobacter* is another common cause of bacterial foodborne illness. There are strong seasonal patterns for *Salmonella* and *Campylobacter* infection in Australia: warmer weather increases infections and cooler weather reduces infections (Hall *et al.* 2002).

Climate change, combined with changes in production, distribution and management of food, has the potential to affect foodborne disease (Hall *et al.* 2002). D'Souza *et al.* (2004) conducted a study in five Australian cities, including Brisbane, which showed a long-term increase in salmonellosis notifications between 1991 and 2001. Seasonal patterns in salmonellosis notifications were fully explained by changes in temperature. A later study found that rainfall and temperature in Brisbane and Townsville correlated positively with the number of cases of salmonellosis (Zhang *et al.* 2009).

Air quality

Air quality is also affected by climate change (IPCC 2007c). Air pollution, including ozone (O_3) and other contaminants (such as smoke, dust and moulds) can cause respiratory and cardiovascular problems (such as asthma attacks and bronchitis) and premature death among the elderly and young (Galbally *et al.* 2007; Jalaludin *et al.* 2009). Horton and McMichael (2008) found that increased temperatures may interact with air pollution to compound such illnesses. Premature deaths due to air pollution-related illnesses are estimated to be in the thousands annually across Australia (Potterton 2005).

Ozone

Most O_3 is found in the upper atmosphere, where it acts to screen out much of the harmful radiation from the sun. Upper-level O_3 is an important part of the Earth's life support system.

Lower-level O_3 is created when sunlight hits hydrocarbons and nitrogen oxides are released into the lower atmosphere by industrial and vehicle emissions and natural processes.

Higher temperatures hasten the chemical reactions that lead to the formation of certain pollutants such as ground-level O_3, the primary constituent of urban smog.

Ground-level O_3 is likely to increase with increasing temperature and this could increase the incidence of asthma (Wilson & King 2003). Researchers (Shea *et al.* 2007; Blashki *et al.* 2007) have concluded that climate change may cause increased respiratory illnesses from temperature-enhanced pollution.

Contaminants

Air contaminants such as smoke from bushfires, dust from dust storms, airborne pollens and moulds may increase as a result of climate change. Potterton (2005) found that smoke, agricultural sprays and windblown dust from mining and agriculture are health issues in rural and regional Australia.

Climate change will result in much of Australia becoming warmer and drier (CSIRO & BoM 2007). Drought and long-term drying conditions will increase the risks of exposure to dust and smoke (Horton & McMichael 2008). Chen *et al.* (2006) and McMichael *et al.* (2009) found correlations between increased smoke and windblown dust from bushfires and a rise in hospital admissions for respiratory complaints.

Dust events may be associated with changes in asthma severity in Brisbane, particularly if the level of fine particulates increases (Rutherford *et al.* 1999).

UV exposure

Now that stratospheric ozone depletion is under control by the Montreal Protocol, interest has turned to the effects of climate change on the ozone layer.

As the Earth warms, the overturning circulation of the upper atmosphere is projected to speed up. Model simulations suggest that this will increase the movement of O_3 from the stratosphere to the troposphere and alter surface levels of ultraviolet radiation (Stevenson 2009).

A study by Hegglin and Shepherd (2009) showed that under the IPCC A1B emissions scenario, global stratosphere-to-troposphere O_3 flux would increase by 23 per cent between 1965 and 2095 as a result of climate change.

Changes to the distribution of O_3 in the atmosphere may increase exposure to photochemical atmospheric pollution. Stratospheric O_3 depletion, together with more sun exposure in warmer weather could accelerate the existing rise in the incidence of skin cancer and increase the risk of cataracts (Bentham 1992).

Climate change will also influence surface UV radiation through changes in clouds and in the ability of the Earth's surface to reflect light (WMO 2007).

Mental health

Impacts of climate change such as increases in extreme weather events and disruption to communities have implications for mental health. Fritze *et al.* (2008) found that the aftermath of extreme events can include stress-related problems such as depression, anxiety disorders, drug and alcohol abuse and increased suicide attempts.

Drought and prolonged dry periods are projected to become more common in the future for much of Australia (Hennessy *et al.* 2008). Various studies have been carried out on the impacts of drought on the mental health of Australians. McMichael *et al.* (2003) concluded that drought-related stress increased suicide rates, while several authors report a higher proportion of young men being affected (Page & Fragar 2002; Berry *et al.* 2008; McMichael *et al.* 2009).

The connection between an increase in mental health problems and the financial hardship that drought brings for many rural Australian families is well established (Nicholls *et al*. 2006; Berry *et al*. 2008; McMichael *et al*. 2009). A New South Wales study by Nicholls *et al*. (2006) found that a decrease in rainfall of about 300 millimetres was associated with an 8 per cent increase in the long-term mean suicide rate. These problems would be exacerbated if climate change brought prolonged and more frequent droughts, as is expected to be the case.

Berry *et al*. (2008) found that high humidity has been associated with poorer concentration and increased fatigue. In addition increasing temperatures (especially lengthy spells of hot weather) has been associated with higher rates of criminal and aggressive behaviour, suicides and hospital admissions.

Remote communities and Indigenous health

Sea level rise, storm surges and saltwater intrusion on low-lying islands will impact on the long-term viability of remote and Indigenous communities in the far north of Queensland and the Torres Strait (CSIRO 2007; Green 2008).

It is anticipated that at least 8000 people in the Torres Strait Islands could be displaced if sea levels rise by one metre (HREOC 2008). Forced relocation resulting in loss of traditional connection with land could cause serious distress and mental illness (Green 2008).

The climate change impacts of higher temperatures, increased flooding and bushfires could also result in increased mosquito-borne diseases, heat stress, respiratory problems and diarrhoeal diseases (HREOC 2008; McMichael *et al*. 2009; Green *et al*. 2009).

Storms and floods can facilitate the spread of infectious intestinal diseases that cause diarrhoea in young children. Indigenous people living in remote communities are at increased risk with the number of Aboriginal children being admitted to hospital with diarrhoea likely to increase by 10 per cent by 2050 (DCC 2009b).

Health-care services

Health-care services, including their supporting infrastructure, would be subject to increased demands if the frequency and intensity of extreme events increased, assuming that such services are not damaged or isolated by the event (Carthey *et al*. 2008).

Bell (2009) considered that education and training of rural and remote practitioners is needed to help deal with climate change health impacts.

Similarly the increased demands placed on health-care services as a result of increased extreme weather events require strategies to plan, design, deliver and operate health-care infrastructure to maintain an appropriate standard of health service.

An Australian Research Council linkage project is currently assessing the potential vulnerability of hospital facilities and their ability to adapt to climate-related extreme weather events.

Adaptation

Adaptation to climate change refers to adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects (IPCC 2007c). Blashki *et al*. (2007) identified a range of primary health-care adaptation strategies including:

- public education and awareness
- early alert systems to warn of impending weather extremes or infectious disease outbreaks
- disaster preparedness, including increasing the health system's 'surge' capacity to respond to emergencies
- enhanced infectious disease control programs
- food safety programs, vaccine programs, vector control, case detection and treatment
- improved surveillance of risk indicators (e.g. mosquito numbers, allergen concentration) and health outcomes (e.g. infectious disease outbreaks, rural suicides, seasonal asthma peaks)
- appropriate health workforce training (e.g. updated understanding of climate influences on health, training in public health).

Some of these strategies are associated with specific climate change impacts on human health; for example, disaster preparedness is associated with extreme weather events and enhanced infectious disease control programs are associated with the impacts of climate change on infectious disease risk.

An example of disaster preparedness in the case of heatwaves is the *Queensland Heatwave Response Plan (2004)* which aims to coordinate agencies, raise public awareness and minimise the impact of heat on service providers (Queensland Health 2004).

To further increase community awareness, the Bureau of Meteorology is developing a heatwave warning system (McMichael *et al*. 2009). Other strategies, such as public education and awareness and health workforce training, work across many different climate change impacts.

Emergency management

Queensland's natural risk hazard cost profile is dominated by flood, storm surge and tropical cyclones, severe storm and bushfire (Figure 30). Other hazards experienced include landslip, earthquake, tsunami and heatwaves (COAG 2007). While flooding accounts for the greatest share of the costs of natural disasters to Queensland, the other natural hazards also represent a risk to communities, especially coastal communities.

Climate variability due to climate change is expected to affect the behaviour of natural hazards in different ways. For example, some areas of the Queensland coast can expect intense rainfall and more intense and southerly moving cyclonic events. Many of the climate projections summarised in Chapter 3 will impact on the emergency management sector in the long term.

Climate change represents another risk that must be incorporated within a broad-based disaster risk reduction framework.

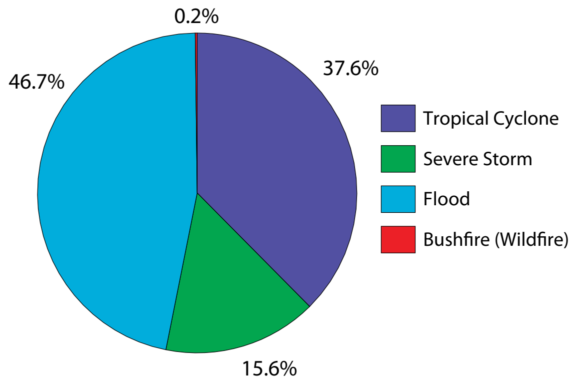


Figure 30: Costs by type of disaster in Queensland 1967-1999 (Source: BTE 2001).

Key messages

Queensland's natural hazard risk profile is dominated (in priority order) by flood, storm surge and tropical cyclones, severe storm and bushfire. The potential impacts of climatic changes on the emergency management sector include:

- an increase in the number of severe tropical cyclones which could increase the risk to communities located in regions with a history of cyclones
- a southward shift in the region in which cyclones develop, exposing additional communities to risk, including south-east Queensland
- temperature rises throughout Queensland with the potential to increase the intensity of future heatwaves, increasing the demand for emergency services
- projected increased intensity of rainfall events in some locations, potentially resulting in increased flooding which is one of the most costly natural hazards in Queensland.

The National Climate Change Adaptation Research Facility (NCCARF) climate change adaptation research plan highlights the infancy of planning for climate change risks in Australia's emergency management sectors.

Climate risks

Natural disasters and extreme events result in significant cost to life as well as damage to property and the natural environment. In the period 1967–1999, 265 natural disasters, with each event costing over $10 million, cost the Australian community a total of around $37.8 billion (in 1999 prices) or $85 per person per year (BTE 2001).

The Council of Australian Governments found that natural disasters cause an average of $1.14 billion damage each year to homes, businesses and infrastructure (COAG 2002). The vast majority of major Australian insurance events are weather-related. New South Wales and Queensland account for 66 per cent of total disaster costs and 53 per cent of the total number of disasters (BTE 2001).

Table 5 indicates the relative financial costs of natural disasters in Queensland. It shows that these costs are historically dominated by climatic events.

Under climate change conditions there is a greater chance that multiple extreme events will occur at the same time (or one will occur while the effects of another are still being felt), limiting resources available to be reallocated from different regions for aid in response and recovery efforts (Pearce *et al*. 2009).

As extreme weather events become more common under a climate change scenario, greater stress will be placed on governments and communities. This will be felt especially during times of high storm, rainfall and bushfire activity.

Floods

In terms of economic costs, flooding is Australia's and Queensland's most damaging natural hazard. On average, flooding cost Australia $420 million per annum over the period 1967–1999 (BTE 2001). Across Australia there are around 170 000 residential properties in the areas considered susceptible to a flood recurring every 100 years on average (Attorney-General's Department 2009).

Figure 31 shows the flood potential across Australia associated with coastal and inland rivers. In inland Australia, floodwater can spread thousands of kilometres and persist for weeks, whereas flooding in the coastal regions is generally faster flowing, localised and over a shorter period. All population centres on the Queensland east coast are exposed to short-duration, rapid-onset floods (COAG 2007).

Floods represent Queensland's most significant natural hazard risk, accounting for the greatest share of claims made under the Natural Disaster Relief and Recovery Arrangements (NDRRA) and for mitigation projects funded under the Natural Disaster Mitigation Program. For example, Queensland's January and February 2008 floods are estimated to have caused $1.85 billion in overall economic losses (Munich Re 2009).

During times of probable maximum flood, the total value of the assets at risk is estimated at over $100 billion (Attorney-General's Department 2009). Projections for increases in intense rainfall events and hence flooding, especially in the more densely populated regions of northern and south-eastern Queensland, are therefore likely to have great economic consequences.

Tropical cyclones

Cyclones also represent a significant natural hazard risk for Queensland. Damage from tropical cyclones results from severe wind, heavy rain and/or storm surge. In 2006, Cyclone Larry caused US$1300 million in economic losses across north Queensland (Munich Re 2007).

Although the exact change in behaviour of tropical cyclones under climate change is uncertain, projections indicate an increase in the number of severe tropical cyclones as well as a southward shift in the cyclone genesis region (Walsh *et al*. 2004; Leslie *et al*. 2007). For much of Queensland's east coast, storm tide heights are projected to increase beyond the contribution from rising sea levels.

An increase in the number of severe tropical cyclones could increase the risk to communities located in regions with a history of cyclones. However, a southward shift in the cyclone genesis region exposes additional communities to risk, including densely populated south-east Queensland.

According to the international reinsurance agency Munich Re, south-east Queensland 'has Australia's highest exposed values in terms of the tropical cyclone peril' and in the event of a major cyclone 'would suffer the highest accumulated losses'. It estimates that a Category 3 cyclone hitting south-east Queensland could cause up to US$200 billion in damage (Munich Re 2007).

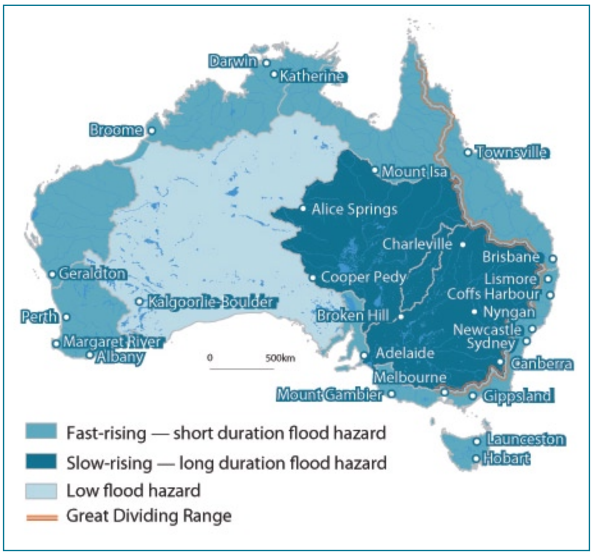


Figure 31: Flood potential in Australia for coastal and inland river systems (Source: Geoscience Australia, in COAG 2007)

Severe storms

Severe storms are Australia's most frequent major natural hazard and the resultant hail, strong winds and lightning pose a significant risk in Queensland. As such, the costs associated with severe storms make up a significant component of the cost of natural disasters in Queensland (Figure 30).

An example of the devastating effect of severe storms is the Sydney hailstorm in April 1999. This storm cost $1.7 billion, more than the estimated cost for Tropical Cyclone Larry (COAG 2007). In Queensland, severe storms in Brisbane and the south-east on Sunday 16 November 2008 particularly affected the suburbs of The Gap, Keperra, Ferny Hills and Arana Downs. Mt Tamborine, the Gold Coast hinterland and Beaudesert also experienced hailstorms. The storms were the first in a series that hit south-east Queensland from 16–22 November 2008 and impacted over 8000 properties (DCS 2008).

Bushfires

Bushfires made up just 0.2 per cent of the total damage cost from natural hazards in Queensland (1967–1999) compared to almost 35 per cent in Victoria (BTE 2001). This is mainly due to the higher moisture content in the atmosphere over Queensland during summer which reduces the fire risk.

The fire season in Queensland normally commences in the Gulf and Cape York Peninsula during August and progresses southwards through spring and summer. However, these timeframes can vary significantly each year, as they are largely dependent on the fuel loads as well as long-term climate and short-term weather conditions in each area.

Northern Australia's pastoral lands and savannahs are affected by grassfires. Although these fires can account for the majority of area burnt by bushfires they have comparatively little economic impact on life and property. However, they may have a significant impact on pastoral economies and may also result in long-term environmental impacts. As such, the risk posed by the projected increase in high fire danger days could be significant.

Heatwave

The number of hot days (days with maximum temperature over 35 °C) is projected to increase across Queensland under all emissions scenarios. High temperature conditions already have a significant effect in Queensland. For example, the January 2000 heatwave in south-east Queensland resulted in 22 recorded deaths and 350 injuries costing an estimated $2 million (Queensland Health 2004).

The projected temperature rises throughout Queensland have the potential to increase the intensity of future heatwaves and thus their impacts, increasing the demand for emergency services. It is estimated that heatwaves killed 4500 people in Australia between 1803 and 1999 compared with 2500 for floods and 2200 for tropical cyclones (BTE 2001).

Landslide

The Geoscience Australia Landslide Database indicates that there have been 201 landslides recorded in Queensland since 1848 (Geoscience Australia 2010). Historically landslides have not contributed significantly to the economic costs of natural hazards in Queensland. However, they do pose a threat to people and property. For example, the Currumbin Hill landslides in 2005 on the Gold Coast caused structural damage to nine properties (Golder Associates Pty Ltd 2006).

The combination of longer dry periods interrupted by more intense rainfall events, as projected for Queensland, is expected to increase the likelihood of landslides (COAG 2002).

Adaptation and emergency management practice

The emergency management approach to climate change risk involves applying existing tools and practices. The current goal of emergency management is to establish resilience in the community, making communities better prepared for possible emergencies (COAG 2007; Yates & Bergin 2009).

Community resilience also involves partnering among a number of stakeholders; including Australian, Queensland and local governments and local communities, not-for-profit organisations and volunteers, businesses, families and individuals.

Climate projections can aid in planning to increase community resilience; therefore, projections of extreme weather events are of interest in the emergency management sector.

The COAG 2002 report, *Natural Disasters in Australia*, established a national disaster mitigation grants program and modernised relief and recovery arrangements. The 2009 *National Disaster Resilience Strategy* reiterates well known principles used by the sector to improve national coordination of disaster resilience across government.

Emergency managers take a 'comprehensive approach' to managing disasters, treating prevention, preparedness, response and recovery as a continuum. Along with an 'all hazards approach', this increases efficiency by using the same systems in response to natural and human-induced hazards.

In Queensland, emergency and disaster response is managed principally through the *Disaster Management Act 2003* and the *Fire and Rescue Service Act 1990*. Prevention, preparedness and recovery are managed through a range of national, state and local government policies, procedures and governance arrangements. These include:

- *planning measures*—regional and urban planning, land-use planning, development planning, building codes and associated engineering standards
- *policy interventions*—individual education and health initiatives as well as regional economic development
- *the market*—raising community awareness of risk through price signals e.g. cost of insurance as well as provision of relief and recovery
- *government grants*—funding of resilience-building and community awareness-raising activities
- *emergency response*—residual natural hazard risk is managed by governments through emergency and disaster response planning, early warning, response arrangements, hazard-specific response plans (e.g. *Queensland Heatwave Response Plan*), maintaining volunteer capacity, communications networks, evacuation planning and community recovery. The *ClimateQ* strategy acknowledges the following initiatives as climate change aspects to Queensland disaster management plans:
  - » incorporating climate change considerations into local disaster management plans
  - » implementing Queensland's heatwave response plan to minimise mortality and morbidity from heatwaves
  - » developing storm-tide maps for the Queensland coastline (OCC 2009)

- *empowered communities and individuals*. It is not possible to mitigate all of the impacts of natural disasters. A significant source of resilience is a community's own efforts to prepare for, respond to, and recover from natural disasters and associated climate change impacts. Community resilience to natural disasters can be boosted through activities such as:
  - » community awareness of local natural hazard risks
  - » business continuity planning
  - » risk management
  - » early warning
  - » well-known evacuation routes and assembly points
  - » emergency stores and caches
  - » coordinated recovery efforts by local providers
  - » partnerships between local government and small businesses.

The emergency management sector is also very dependent on volunteers. NCCARF's *Emergency Management and Climate Change National Adaptation Research Plan* estimates that there are approximately 500 000 emergency services volunteers nationwide, 350 000 of whom are involved in response and recovery activities (i.e. those activities required after the event has occurred).

To improve emergency management planning and response, the research plan (Pearce *et al*. 2009) identifies the following priority research areas:

- understanding the nature and location of risk posed by climate change—there is considerable uncertainty associated with climate change projections (especially those for extreme events) which limits understanding of the risk. For this reason effectively communicating the uncertainty associated with climate change risk is essential
- enhancing community and organisational resilience to climate change risks—the effects of climate change on community resilience and how community resilience is best promoted are the main research objectives identified
- developing and implementing adaptive strategies—this would involve research into how climate change will affect the emergency management sector's ability to support preparedness, response and recovery and the private sector's role in supporting disaster response.

Chapter 5: Climate change science and research priorities

For Queensland to respond to challenges posed by global climate change and a naturally highly variable climate, scientific research that (i) continues to enhance and refine our knowledge of the climate system, (ii) delivers reliable climate change projections, and (iii) strengthens the application of science to key sectors affected by climate risks is crucial.

National climate change science research

The Australian Government is supporting a broad range of climate change science research activities through its $31 million Australian Climate Change Science Program (ACCSP). The ACCSP is the focus of national efforts to improve our understanding of the causes, nature, timing and consequences of climate change in Australia. The program is administered by the Department of Climate Change and Energy Efficiency and conducted in partnership with the Commonwealth Scientific and Research Organization (CSIRO), the Bureau of Meteorology (BoM) and leading universities. The research is helping us to better understand global and regional climate change and its potential impact on Australia's natural and managed systems.

The program covers six themes:

- understanding the key drivers of climate change in Australia
- improved climate modelling system
- climate change, climate variability and extreme events
- regional climate change projections
- international research collaboration
- communications.

In December 2009, the Australian Government released *Australian Climate Change Science: A national framework* (DCC 2009c). The framework identifies the national climate change science priorities and proposes approaches to direct and coordinate climate change research. The framework links climate system science with adaptation responses, mitigation science and technology, and policy development. The framework contains four elements:

- challenges—key areas of climate science research addressing projected changes in greenhouse gas emissions, rainfall, evaporation, sea level rise, ocean acidification and extreme events
- capabilities—areas that must be maintained or developed to meet the climate change challenges
- people and infrastructure—investment in skilled workers or improved infrastructure to undertake modelling and research
- implementation through coordination of activities and investment.

The Australian Government is also investing $387 million in marine and climate science research through the Marine and Climate Super Science Initiative. It is funding high-performance computing and new observing systems and replacing key facilities.

Key Australian research-based organisations making significant scientific contributions on climate science include the CSIRO, BoM, the Antarctic Climate and Ecosystems Cooperative Research Centre and the National Climate Change Adaptation Research Facility (NCCARF). Many Australian universities are also advancing understanding of climate change risks and impacts.

A number of collaborative research projects are already addressing climate change in specific Australian regions. For example the South Eastern Australian Climate Initiative (SEACI) is a research program of around 40 projects addressing the impact of climate change on water availability, temperature, bushfires and other climate-related features in south-eastern Australia. Launched in

2006, SEACI is a partnership involving government and industry and includes the CSIRO and the BoM as research partners.

The Indian Ocean Climate Initiative (IOCI) which commenced in 1998 is a research partnership between the Western Australian State Government, CSIRO and the BoM. IOCI is investigating the causes of the changing climate in Western Australia and is developing projections of the state's future climate.

Queensland climate change science research

A key element of evidence-based policy development is that decisions are underpinned by the best available science. The Queensland Government is taking a leading role in contributing to climate science research through the Queensland Climate Change Centre of Excellence (QCCCE).

The QCCCE is an integral part of the Office of Climate Change within the Queensland Department of Environment and Resource Management and is undertaking research on climate change, climate variability and extreme weather events in Queensland to inform planning and policy decisions.

The QCCCE has established collaborations with leading international climate science research centres; including The Walker Institute for Climate System Research at the University of Reading, the UK Met Office Hadley Centre for Climate Change and the Ministry of Science and Technology, China. These collaborations encourage the sharing of data and models, information exchange and cooperative research programs.

The QCCCE also maintains and provides a range of climate analysis, coastal and land management monitoring and impact tools and information which assist with assessing the impacts of climate change. SILO is the QCCCE's climate database of temperature, rainfall and radiation. AussieGRASS is an Environmental Calculator, used to assess current and future impacts of climate variability on natural resource systems throughout Australia. Seasonal climate outlooks produced by the Centre allow primary producers to plan their planting and grazing regimes.

In addition, the QCCCE's coastal expertise provides information on wave heights and tidal conditions to support coastal planning and regional and local emergency management planning.

Current research programs address climate forecasting and modelling, climate change scenarios, climate variability, extreme weather events and adaptation.

Climate forecasting and modelling

To accurately project climate into the future we need to understand what has happened in the past, including the key drivers affecting Queensland's climate. The QCCCE is one of a number of climate centres around the world involved in the Atmospheric Circulation Reconstructions over the Earth's surface (ACRE) project.

The aim of ACRE is to provide a record of global climate back to the mid-1800s. These climate reconstructions are valuable because they support the outputs from climate models (historical and future analyses). They provide important insights into climate cycles that affect Queensland, such as ENSO.

Like ACRE, the Climate of the 20th Century project is also improving our knowledge of past climate. The QCCCE along with climate research centres around the world is contributing to investigating the ability of global climate models to reproduce major climatic events such as droughts and floods. This work provides important insights into the climate drivers that influence Queensland's climate, and will also allow for more accurate seasonal climate forecasts.

Predicting changes in rainfall is highly complex. To develop an improved understanding of the key processes that influence rainfall over a range of timescales, the QCCCE is working with the University of Reading's Walker Institute to investigate decadal-scale climate processes. The outputs of such collaborations are critical for deriving more robust climate projections, especially for rainfall and extreme events, such as flooding, droughts and cyclones.

The development of the *IPCC Fifth Assessment Report* to be released in 2014 involves the contribution of modelling results from around the globe. The QCCCE and CSIRO are working together to provide a set of climate models simulating the past, present and future climate for use in the assessment.

Climate change scenarios for Queensland

Queensland's size, diverse climatic conditions, broad range of settlement patterns and potential for extreme events generates complexities for adaptation responses.

Regional climate change data is therefore important to support sector-based planning for the impacts of climate change.

In collaboration with the CSIRO, global climate change projections are being tailored to increase the robustness of Queensland climate change projections at the regional scale. Thirteen comprehensive regional climate change assessments have been developed for use in climate risk vulnerability projections, policy development and planning (see Chapter 3).

Improved forecasting of severe storms, sea level rise, cyclones and flooding remains an important area for further research. The QCCCE's coastal impacts team monitors waves and tides and prepares storm-tide and wave networks for each cyclone season, including updating storm-tide inundation assessment maps for Emergency Management Queensland.

To improve our understanding and management of the impacts of sea level rise, storm surge and erosion along Queensland's coastline, the Queensland Government is investing $8 million to deliver a high resolution digital elevation model. It will underpin more accurate modelling of sea level rise and flooding in Queensland and will inform planning and emergency management decisions.

The QCCCE is also researching an approach to managing inland flood risks that takes account of the latest climate change science to help plan for and manage existing flood risk, as well as residual risks resulting from the impacts of climate change.

The modelling of future climate change scenarios is a dynamic and a continually evolving exercise. Over the coming years, there will be further gains made by the QCCCE in conjunction with the CSIRO and the BoM in downscaling global climate models to provide improved climate forecasting at the regional scale.

Adaptation and mitigation initiatives

The Queensland Government committed $3 million towards establishment of the NCCARF to support the development of climate change adaptation research plans across a range of sectors; including water, biodiversity, agriculture, infrastructure, health and emergency management.

The Office of Climate Change has developed a Climate Change Impact Statements assessment tool, which will assist planners and developers of major projects to take the impacts of climate change into consideration. This tool assesses the potential greenhouse gas emissions as well as the potential risks to major building and infrastructure projects from climate change.

At the sectoral level, the QCCCE is working with Queensland Health, the Department of Community Safety and Queensland University of Technology to evaluate the impacts of heatwaves on community health in south-east Queensland.

The QCCCE is collaborating with the University of Queensland and the CSIRO on a three-year project to analyse climate model projections in order to determine the effect of land cover on climate and to investigate how reafforestation may be used to reduce the impact of extreme events.

The QCCCE has developed a climate risk matrix which promotes a risk management approach to climate change adaptation. Developed specifically for the grazing industry in western Queensland, the matrix can be tailored for use by any industry or sector.

The regional projections developed by the QCCCE are being used by a number of research institutions, for example the Marine and Tropical Sciences Research Facility, to support studies of climate change impacts on ecosystems such as the Wet Tropics rainforest and the Great Barrier Reef.

With industry and government support, considerable research is also being undertaken in Queensland academic institutions with industry and government support on mitigation of greenhouse gas emissions through sequestration and carbon capture and storage.

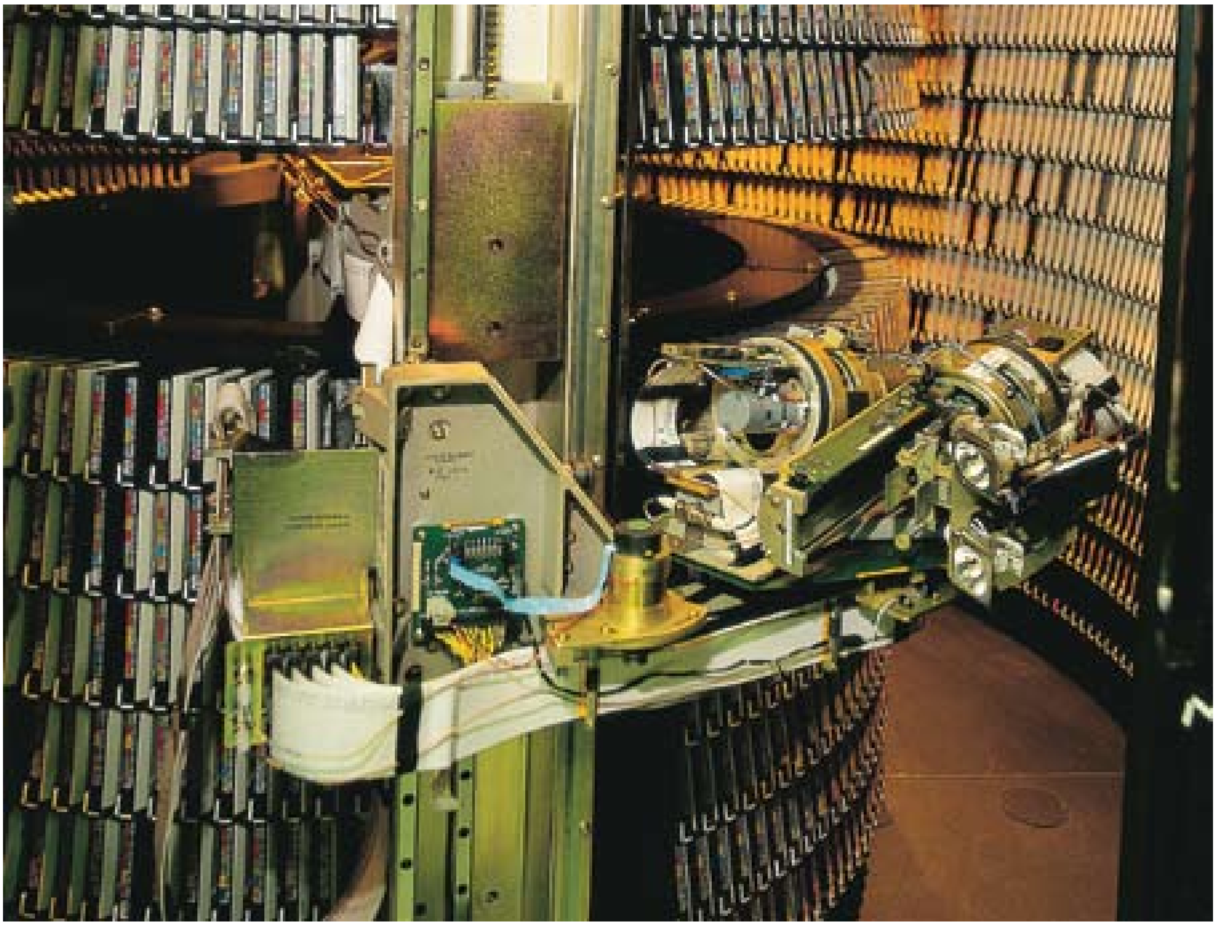
Research challenges

Forecasting the impacts of climate change on the generation of cyclones, on rainfall patterns and on changes in storm frequency and intensity requires extensive, ongoing research. Regional and localised climate information is also a priority for land-use planning and disaster preparedness.

Specific areas of research that are required to provide improved predictions of climate and its impacts on Queensland include:

- tropical cyclone generation and intensity
- frequency and magnitude of extreme events
- influence of ENSO, movement of the Hadley cell, and other ocean–atmosphere interactions
- impact of aerosols on atmospheric circulation and rainfall
- sea level rise and the role of the oceans
- magnitude and statistical significance of trends
- understanding natural climate variations and the impacts of climate change on natural climate variability
- improved regional climate projections
- regional and sector-based risk/vulnerability assessments to identify adaptation options.

For policy makers, the need for ongoing research means that policies will need to be regularly reviewed and revised to reflect the latest scientific knowledge and data.



Glossary

Adaptation – Adjustment in natural or human systems in response to actual or expected climatic changes or their effect, which moderates harm or exploits beneficial opportunities.

Aerosols – Small particles or droplets in the atmosphere which are both natural and anthropogenic. Their net effect is a direct cooling influence on climate by reflecting sunlight back into space. The increase of aerosols in the atmosphere is thought to be masking the upward trend in global temperatures. They also have an indirect effect by acting as condensation nuclei to increase cloud formation.

Anthropogenic – Resulting from or produced by human activities, in particular, factors that affect the atmosphere due to burning of fossil fuels, deforestation and other land-use change.

Carbon cycle – Description of the movement of carbon in various forms (for example, as carbon dioxide or methane) through the atmosphere, ocean, plants, animals and soils.

Carbon dioxide equivalency (CO_2–e) – A measure that allows comparison of different greenhouse gases to carbon dioxide in terms of their global warming potential. Methane has a global warming potential 25 times that of CO_2.

Climate –The atmospheric conditions over a long time interval, generally referring to the average state of the weather for a particular area.

Climate change – A change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability over comparable time periods.

Coral bleaching – A process that occurs when the coral host expels its symbiotic zooxanthellae (microscopic algae that live in the coral's tissues and provide energy to the coral) in response to stress. Most commonly resulting from prolonged high water temperatures, but also from high light levels, sedimentation, pollutants and changes in salinity. The pigments of the zooxanthellae give corals much of their colour and when the zooxanthellae are expelled, the coral's white skeleton is visible through the transparent tissues of the coral, hence the term 'bleaching'.

CSIRO – The Commonwealth Scientific and Industrial Research Organisation, Australia's national science agency.

El Niño Southern Oscillation (ENSO) – Year-to-year oscillations in atmospheric pressure, ocean temperatures and rainfall associated with El Niño (the warming of the oceans in the equatorial eastern and central Pacific) and its opposite, La Niña. Over much of Australia La Niña tends to bring above average rain, and El Niño tends to bring below average rainfall. A common measure of ENSO is the Southern Oscillation Index (SOI) which is normalised mean sea level pressure difference between Tahiti and Darwin. The SOI is positive during La Niña events and negative during El Niño events.

Emission – Amount of substance (e.g. CO_2) released into the atmosphere from a specific source and in a specific time frame. Emissions are generally expressed by the mass per time period (e.g. millions of tonnes (Mt) per year).

Emissions scenario – A plausible future pathway of human-made emissions (e.g. greenhouse gases and other pollutants) that can affect climate, based on a consistent set of assumptions about factors such as demographic and socioeconomic development, technology change and their key relationships.

Enhanced greenhouse effect – The addition of anthropogenic greenhouse gases that bolster the natural greenhouse effect increasing the surface temperature of the Earth.

Extreme weather event – An infrequent event, here specifically related to weather, at the high and low end of the range of values of a particular variable.

Global warming – An increase in global average surface temperatures due to natural or anthropogenic climate change.

Global warming potential (GWP) – The index used to translate the level of emissions of greenhouse gases into a common measure in order to compare the relative radiative forcing of different gases without directly calculating the changes in atmospheric concentrations.

Greenhouse effect – An effect created by greenhouse gases in the Earth's atmosphere. These gases allow short-wavelength (visible) solar radiation to pass through to the surface and absorb the long-wavelength radiation that is reflected back, leading to a warming of the surface and lower atmosphere.

Greenhouse gases – Natural and anthropogenic gases in the atmosphere that absorb and emit infra-red or heat radiation, causing the greenhouse effect. The main greenhouse gases are water vapour, carbon dioxide, nitrous oxide and methane.

Hadley cell – The process by which an air mass undergoes convergence at the tropics and divergence at 30 °C N or 30 °C S latitude in one large convection cell.

Hot days – Days with maximum temperature over 35 °C.

Indian Ocean Dipole (IOD) – The difference between sea-surface temperature in the western and eastern tropical Indian Oceans. A positive IOD occurs when the western basin is warmer than average and the eastern basin is cool.

Inter-decadal Pacific Oscillation (IPO) – An irregular inter-decadal cycle of rising and falling sea-surface temperatures in the Pacific Ocean which modulates the strength of the ENSO.

Madden-Julian Oscillation (MJO) – A tropical atmospheric phenomenon, with a timescale ranging from 30 to 60 days which develops over the Indian Ocean and travels eastward through the tropics.

Mitigation – A lessening in force or intensity; specifically used to describe a reduction in the source of greenhouse gases or enhancement of greenhouse gas sinks.

Ocean acidification – Increase in acidity of sea water forms carbonic acid due to the increased uptake of CO_2 emissions by the Earth's oceans. Increased acidity lowers the pH of the ocean and causes acidification.

Radiative (climate) forcing – Radiative forcing is a measure of the change in the energy balance of the atmosphere. It is also used as an index of the influence a factor has as a potential climate change mechanism. A positive radiative forcing increases the energy of the Earth–atmosphere system, leading to a warming of the system. In contrast, a negative radiative forcing decreases the energy, leading to a cooling of the system.

Sequestration – Removal of carbon from the atmosphere by, and storage in, terrestrial or marine reservoirs.

Southern Annular Mode (SAM) – Refers to the north–south movement of the band of westerly winds south of Australia. SAM is positive when there is a poleward shift of the westerly wind belt and is associated with enhanced spring and summer rainfall in New South Wales and Queensland.

Storm surge – A temporary increase, at a particular location, in the height of the sea, due to extreme meteorological conditions (low atmospheric pressure and/or strong winds). The excess above the level expected from the tidal variation alone at that time and place.

Storm tide – The absolute combined mean water level reached when storm surge is combined with the normal astronomical tide variation and the wave contribution at the coast. It is the storm tide level which must be accurately predicted to determine the extent of coastal inundation.

Stratosphere – The region the atmosphere above the troposphere. The stratosphere is characterised by the presence of ozone and by temperatures which rise slightly with altitude, due to the absorption of ultraviolet radiation.

Sub-Tropical Ridge (STR) – A ridge of high pressure which moves north and south of Australia depending on the time of year. During the southern hemispheric summer (November to April), the ridge is located south of the Australian continent. During autumn it moves north and remains over the Australian continent for most of the colder half of the year (May to October).

Tipping point – A specific threshold point or unstable state where the response of a climate effect or perturbation can be sudden, severe and have long-term consequences for the climate system.

Thermal expansion – The increase in volume (and decrease in density) that results from expansion of warming water. A warming of the ocean leads to an expansion of the ocean volume and hence to sea level rise.

Troposphere – The lowest region of the atmosphere within which nearly all cloud formations occur and weather conditions manifest themselves. In the troposphere, temperatures decrease with increasing altitude.

Walker circulation – The east–west movement of trade winds across the tropical Pacific Ocean, bringing moist surface air to the west with dry air returning along the surface to the east.

Weather – The state of the atmosphere at a particular place, at a particular time.

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