Climate change under enhanced greenhouse conditions in South Australia

An updated report on:

Assessment of climate change, impacts and risk management strategies relevant to South Australia

R. Suppiah, B. Preston, P.H. Whetton, K.L. McInnes,
R.N. Jones, I. Macadam, J. Bathols and D. Kirono

June 2006

Undertaken for the South Australian Government by the Climate Impacts and Risk Group, CSIRO Marine and Atmospheric Research

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EXECUTIVE SUMMARY

This report updates some of the chapters of a previous CSIRO report on climate change and impacts on South Australia (McInnes *et al*., 2003b) focussing on temperature and rainfall. It presents results of a project undertaken by CSIRO for the South Australian Government to assess observed and projected climate change in South Australia using a new set of climate change simulations conducted for the Fourth Assessment of the Intergovernmental Panel on Climate Change (IPCC), which will be published in 2007. It provides results for SA's eight Natural Resource Management (NRM) regions. This project does not update information about changes in extreme weather, nor does it update potential impacts.

Global climate change

The Third Assessment Report of the IPCC (2001) indicates:

- There has been a warming of the lower atmosphere and upper ocean.
- Global-average precipitation over land has increased by about 2% since the beginning of the 20th century, but there have been significant regional and seasonal increases and decreases.
- Most of the global warming observed over the last 50 years is attributable to human activities.
- By the year 2100, global average temperatures may rise 1.4 to 5.8°C and global sea level may rise 9 to 88 cm, relative to 1990, if there are no explicit policies to limit greenhouse gas emissions.
- Projected changes in climate extremes could have major consequences.

New evidence (Steffen, 2006) since the Third Assessment Report of the IPCC (2001) shows:

- Most of the IPCC conclusions have been confirmed or strengthened in recent years.
- The global average surface temperature has increased by about 0.7°C during the last century.
- Heatwaves and heavy rainfall have increased in many regions, while glaciers, ice-sheets and frosts have decreased.
- Oceans are becoming more acidic.
- The global average sea level has risen 1.7 mm per year since 1900.
- There have been shifts in plant and animal locations and seasonal behaviour consistent with global warming.
- The unusual nature of the warming of the past 50 years relative to the past 1000-2000 years, based on the so-called Hockey Stick graph, has been supported by many other independent studies.
- The influence of human activities has been detected in land-ocean temperature contrasts, the annual cycle of surface temperature over land, the hemispheric temperature contrast, regional (not just global) warming, the height of the tropopause (between the troposphere and stratosphere) and the heating of the oceans.
- New information about climate feedbacks indicates a greater likelihood of warming at the higher end of the uncertainty range.

Observed climate trends in Australia and South Australia

From 1910 to 2005, Australia's average temperature increased by 0.89ºC (0.09ºC per decade), with the minimum temperature increasing by 1.14ºC (0.12ºC per decade) and maximum temperature by 0.65ºC (0.07ºC per decade). The rate of increase has accelerated since 1950 - Australia's average temperature increased by 0.95ºC (0.17ºC per decade), while the minimum increased by 1.04ºC (0.18 per decade) and maximum increased by 0.86ºC (0.15ºC per decade).

From 1910 to 2005, South Australia's average temperature increased by 0.96ºC (0.10ºC per decade), with the minimum temperature increasing by 1.13 (0.12ºC per decade) and maximum temperature by 0.79ºC (0.08ºC per decade). Since 1950, South Australia's average maximum temperature has increased by 1.2ºC (0.21ºC per decade), the minimum by 1.01ºC (0.18ºC per decade) and the average temperature by 1.1ºC (0.20ºC per decade). Thus, compared to national trends, South Australian maximum temperature indicates a faster rate of increase, while minimum temperature shows a slower rate.

Sea surface temperatures in Spencer Gulf and the Bight have risen at about half the rate of the land-based temperatures (0.05ºC per decade from 1900 to 2005 and 0.11ºC per decade from 1950 to 2005).

Australian rainfall records from 1900 to 2005 show an increasing trend over many parts of the country, except for south-western Western Australia and some parts of coastal Queensland, Tasmania and southern South Australia. However, during the second half of the century, there is a stronger tendency for decreased rainfall in south-western Australia and eastern Australia and an increase over the northwest.

Trends in South Australian annual rainfall since 1900 are generally weaker than other parts of the continent. Much of the northern half of South Australia became wetter while southern coastal regions became drier. These tendencies were strengthened during last the 55 years.

Annual and seasonal rainfall shows fluctuations on multi-decadal time scales. In South Australia, the 1920s and 1960s were dry decades while the 1970s was a wet period. Decadal fluctuations in annual rainfall are dominated by summer and spring rainfall fluctuations. Winter rainfall shows no trend with weak year-to-year variability. Rainfall in autumn shows year-to-year variability which is greater in the second half of the century.

Among three South Australian stations, two coastal stations show a decreasing trend in pan evaporation, while an inland station shows an increasing trend.

Simulating South Australia's current climate

Twenty three global climate model (GCM) experiments, with the addition of the two regional climate models, were assessed for their ability to simulate observed average (1961-1990) patterns of mean sea level pressure, temperature and rainfall in the South Australian region. Thirteen models performed satisfactorily. Temperature and rainfall projections were made using the results from those 13 models.

Average regional temperature and rainfall projections

Annual and seasonal temperature projections were constructed using two types of greenhouse gas emission scenarios: (i) those from Special Report on Emission Scenarios (SRES, 2000) which exclude policies to reduce emissions, and (ii) emission reduction scenarios that stabilise CO_2 concentrations at 450 parts per million (ppm) by 2100 or 550 ppm by 2150. Temperature scenarios for 2030 and 2070 are given in Figure E.1. By 2030 under the SRES scenarios, areas within 200 km of the coast warm by 0.2 to 1.6ºC, the region 200 to 600 km from coast warms by 0.4 to 1.6ºC, and the region more than 600 km inland warms by 0.6 to 1.8ºC. By 2070, areas within 200 km of the coast warm by 0.5 to 4.7ºC, the region 200 and 600 km from coast warms by 1.0 to 5.5ºC and the region more than 600 km from coast warms by 1.2 to 5.5ºC. Spring and summer show greater warming than winter and autumn. If CO_2 concentrations are stabilised at 550 ppm by the year 2150, the upper limit of warming is reduced by 23% by 2030 and 38% by 2070. If CO_2 concentrations are stabilised at 450 ppm by the year 2100, the upper limit of warming is reduced by 25% by 2030 and 48% by 2070.

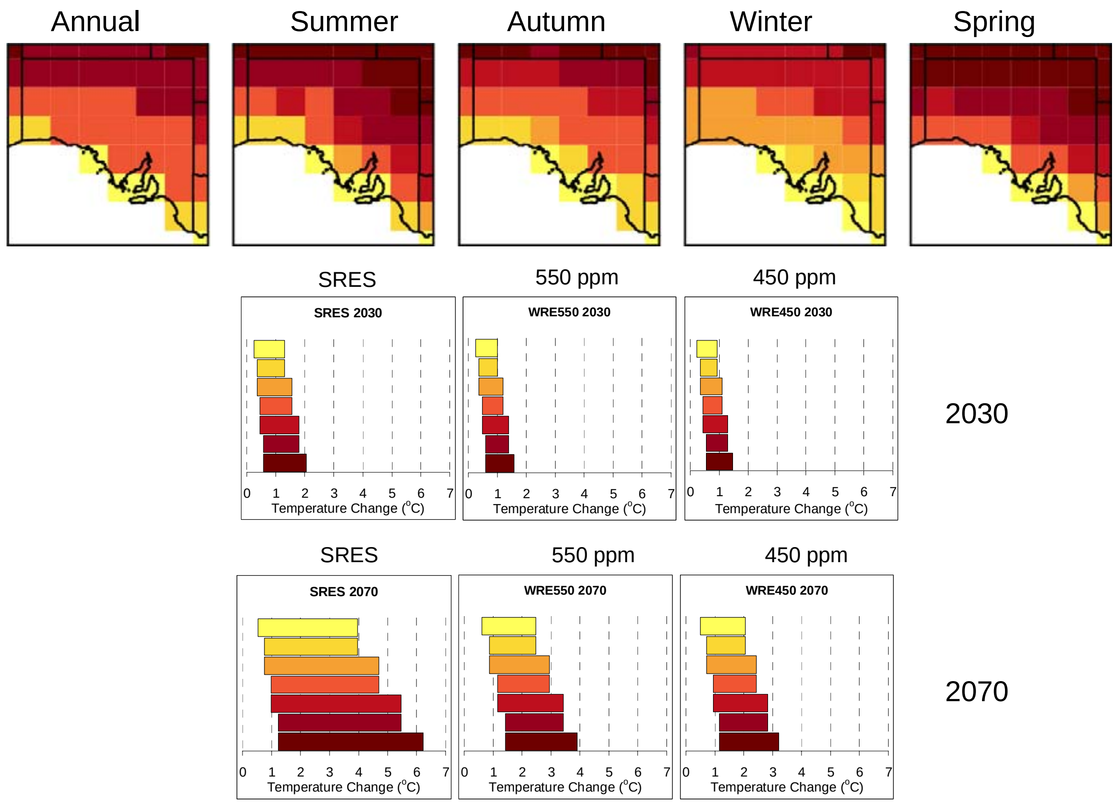

Figure E.1: *(a) Average seasonal and annual warming ranges (°C) for around 2030 and 2070 relative to 1990 for SRES scenarios, and CO_2 concentrations stabilised at 450 ppm by 2100 and 550 ppm by 2150. The coloured bars show ranges of change for areas with corresponding colours in the maps.*

Projected rainfall changes are more complex than the temperature projections, as rainfall projections show stronger spatial and temporal variations as well as large variations between models. A tendency for decreases is dominant (Figure E.2). Under the SRES scenarios for 2030, the region within 200 km of the coast shows annual rainfall changes between -15 and 0%, while regions further inland show changes between -15 and +7%. By 2070, the region within 200 km of the coast shows annual rainfall changes between -45 and 0%, while regions further inland show changes between -45 and +25%. There are significant differences in projected changes among the seasons. Summer and autumn show increases and decreases, but decreases dominate winter and spring. As for temperature, the magnitudes of projected rainfall changes are significantly smaller for the stabilisation scenarios.

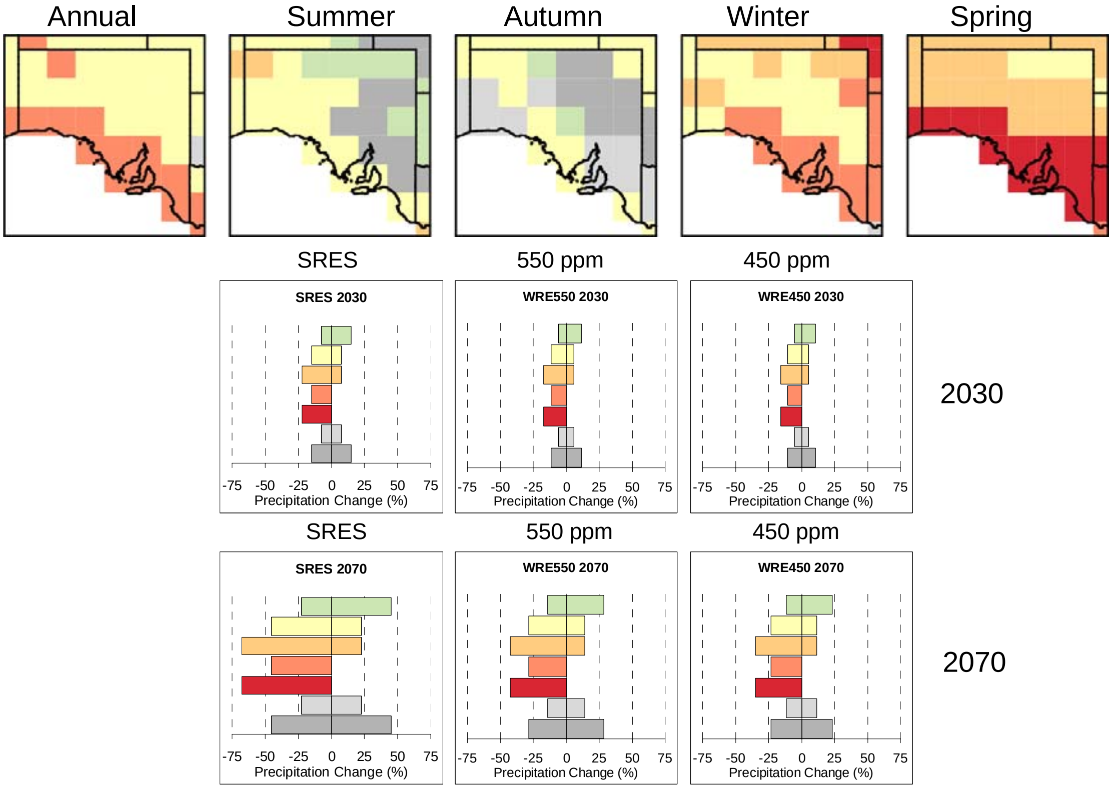

Figure E.2: *Average seasonal and annual rainfall change (%) for 2030 and 2070 relative to 1990 for SRES scenarios, and CO_2 concentrations stabilised at 450 ppm by 2100 and 550 ppm by 2150. The coloured bars show ranges of change for areas with corresponding colours in the maps.*

Projections for eight NRM regions

Inland or northern regions such as Alinytjara Wilurara and South Australian Arid Lands show annual warming between 0.5 and 1.5°C by 2030 and between 1.2 and 4.7°C by 2070, while coastal or southern regions (Adelaide and Mt. Lofty Ranges, Eyre Peninsula, Kangaroo Island, Northern and Yorke, SA Murray Darling Region and South East) show warming between 0.3 and 1.3°C by 2030 and between 0.6 and 3.8°C by 2070. Significantly reduced warming is projected for CO_2 stabilisation scenarios.

Rainfall changes show increases and decreases, but decreases dominate. Annual rainfall changes in Alinytjara Wilurara and South Australian Arid Lands are between -9 and +1% by 2030 and between -25 and +4% by 2070. In coastal or southern regions, annual rainfall changes are between -10 and 0% by 2030 and between -30 and -3% by 2070. Large decreases occur in spring with moderate decreases in other seasons. Significantly reduced warming and rainfall changes are projected for CO_2 stabilisation scenarios.

The enhanced greenhouse signal in temperature emerges from the natural variability around the year 2000 and simulations show it becomes stronger in the second-half of the 21st century. For rainfall, large natural variability and differences between model simulations indicates that it will be difficult to detect an enhanced greenhouse signal in annual rainfall before 2050 in South Australia. However, an enhanced greenhouse signal appears to emerge from natural variability around 2000 for Kangaroo Island and the Eyre Peninsula. More rigorous attribution studies are needed to separate the natural and anthropogenic trends.

Downscaling

There is a strong demand for appropriate downscaling methods to obtain fine resolution climate information from coarse resolution climate model simulations. This is critical where topography and extreme weather phenomena are important, such as southern part of South Australia. Fine resolution climate change information can be derived through statistical and dynamical downscaling methods. However, as this addresses only one of a range of uncertainties associated with projecting regional climate change, the expense involved in this approach needs to be considered. Fine resolution climatic information for use in impact assessment can also be prepared using simple interpolation simulated changes to a fine-resolution observed climate database. This can be done using CSIRO's OzClim scenario generator. However, not all risk assessment and management practices require fine resolution information.

Risk management

Strategies for addressing climate change and its potential consequences are increasingly being viewed by both public and private institutions in a risk management context. Risk-based tools have been applied to better understand different magnitudes of impacts on agriculture, water resources, and coastal infrastructure. There is a growing interest in using such information in current planning decisions.

Despite public concern about climate change, effective communication of climate change science, impacts and adaptation remains challenging. Novel tools for fostering discussions about climate change with different audiences are emerging at an ever-growing rate, but they must compete for the public's attention with a range of other priority issues.

Scientists and public and private institutions must work collectively to build upon recent advances in assessing and communicating climate risk. Access to resources – human, financial, and technical – for risk assessment and adaptation remains limited, particularly for local governments, which are likely to be the focal points for climate change impacts and adaptive responses.

Recommendations for further research and planning

A significant degree of climate change across South Australia now seems inevitable, and is likely to become increasingly apparent during the second half the 21st century as carbon dioxide concentrations in the atmosphere exceed twice the pre-industrial level. Changes are to be expected in both the average values and in the magnitude and frequency of extremes. This means that long-term planning should not be predicated on the assumption that future climate statistics and resources will be as they were over the last century. Significant adaptation to a changing climate will be necessary.

Climate change will have significant impacts on water supply, floods, sea level and storm surges. This has strong implications for coastal ecosystems and sustainable development of planned infrastructure including coastal development, ports, bridges and urban centres.

Higher temperatures and lower rainfall would lead to an increase in drought and fire that could have increasing impacts on biodiversity, agriculture and forestry. Significant changes in management may be required to minimise costs, maximise benefits and ensure environmental sustainability.

Decadal scale climate change is expected to affect the present functional capacity of ecosystems in South Australia. Some animal and plant species are likely to come under increasing stress, causing long-term change in species composition.

Coastal ecosystems will also be affected by sea level rise and changes in runoff. Globally sea level is expected to rise faster in the future due to thermal expansion of the oceans and melting of mid and low-latitude glaciers. An increase in temperature in the Antarctic region would initially lead to an increased accumulation of ice, but to increased meltwater contributing to sea level rise beyond the twenty-first century.

Significant uncertainties remain in relation to the estimation of future climate. These can be reduced by:

- Developing climate change scenarios based on improved and much finer resolution GCMs and regional climate model simulations.
- Improving the ability of GCMs to simulate climatic processes that influence South Australia as well as the whole of Australia.
- Improving climate change scenarios using new statistical and dynamical down scaling methods.

Climate impact and adaptation assessment should be done through a range of approaches including:

- Risk assessment using a bottom up approach, i.e. participation of key stakeholders in project design, workshops and communication.
- Development of versatile climate impact models and methodologies for a number of key sectors and activities. These models should be developed and tested as soon as possible. Priorities should be on the basis of potential sensitivity, impact model availability and stakeholder interest, and should include a wide range of sectors, such as agriculture, forestry, fisheries, water resources, coastal impacts, health, indigenous communities, biodiversity, transport, land planning, energy sector, urban infrastructure, emergency services and tourism.
- The impact assessment work will need to be done through close collaboration between scientists and stakeholders. Where appropriate integrated impact and adaptation assessment should be carried out.

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1. INTRODUCTION

In recent years, the evidence for past climate change has become stronger and the challenges posed by future climate change have grown. Steffen (2006) states:

"*According to data from the reinsurance industry, the number of climate-related disasters has increased since about 1970. Impacts of a warming world on the Earth's biological diversity are becoming evident, especially in alpine ecosystems and in the northern high latitudes. The number of bleaching events on the world's coral reefs has increased strongly over the last two decades, and the combination of increasing acidity in the ocean and higher sea surface temperatures, both highly likely to increase further over the next half-century at least, will put more pressure on reefs. Although there is no evidence for an increase in the number of tropical cyclones, some studies show an increase in the destructiveness of tropical cyclones, again related to the increase in sea surface temperature.*

The instrumental record showing a warming Earth is supported by satellite measurements of tropospheric warming and by observations in the cryosphere and biosphere. The heat content of the upper layers of the ocean is increasing. A growing number of reconstructions of surface temperature over the past 1000 to 2000 years shows that the sharp temperature rise over the past century is now beyond the bounds of natural variability.

The imprint of greenhouse gases as the primary cause of the observed warming has also become clearer. The pattern of heat uptake in the world's ocean basins agrees well with that simulated by climate models for greenhouse gas forcing. The observed moistening of the upper troposphere accords with expectations for greenhouse gas-driven changes in atmospheric water vapour content.

Model-based estimates of the degree of global waming by the end of this century lie between 1.4 and 5.8^{o}C. In part, the spread in the range of estimates is due to the uncertainty about the nature and strength of processes that could dampen or amplify the initial greenhouse gas forcing. Most of the emphasis up to now has been on feedbacks associated with water vapour and clouds. Over the past few years, however, research has yielded a better understanding of three additional effects. The first of these effects is based on the radiative properties of aerosols, small particles suspended in the atmosphere that generally scatter incoming solar radiation and thus cool the Earth's surface, acting in opposition to greenhouse gases. Estimates of the magnitude of the aerosol cooling effect have now been made, and the estimates are moving towards a higher value than earlier thought. This implies enhanced warming later this century as greenhouse gas concentrations increase and aerosol loadings are reduced. A second effect is associated with a decrease in albedo – the reflectivity of the Earth's surface – caused by the melting of snow and ice. The most dramatic example of this effect will likely occur in the Arctic Ocean, which is now projected to become almost totally ice-free in summer late this century. Retreating ice and snow expose darker underlying land and ocean surfaces, leading to enhanced absorption of sunlight and further warming. Thirdly, terrestrial carbon cycle dynamics are expected to change significantly through this century, with strong amplifying feedbacks to climate change.

Although much uncertainty still surrounds the timing, rate and magnitude of these effects, they all operate to amplify the initial greenhouse warming. Thus, there is now perceived to be a greater risk that the upper end of the well known IPCC estimate of a 1.4 to 5.8°C temperature rise will be reached or exceeded by 2100".

In 2005, the South Australian government released “Tackling Climate Change: South Australia’s draft greenhouse strategy” (SA Government, 2005). South Australia’s Strategic Plan, 2003, adopted the target for greenhouse gas emissions set by the Kyoto Protocol for the first commitment period of 2008-12 (108% of 1990 levels). In 2006, Premier Rann announced that South Australia would reduce emissions by at least 60 per cent of 1990 levels by 2050. The 2005 draft greenhouse strategy also states that CSIRO's assessment of the implications of climate change within the State will underpin development of strategies for adapting to climate change. Moreover, a recent report for the CSIRO’s Water for a Healthy Country Flagship (Van Dijk et al., 2006) placed climate change as the first among six threats to the water resources of the Murray Darling Basin.

This report updates chapters 2, 3, 4 and 7 of the previous CSIRO report (McInnes et al., 2003b) dealing with observed global and regional climate, simulating current regional climate, projecting future climate for South Australia and assessing current and future risk. These chapters are updated with additional observed data, results from a new set of GCMs and a new literature review on risk assessment. Chapters 5 and 6 of the previous report focused on climatic extremes, coastal impacts and storm tracks, but these are not updated here.

In this report, Chapter 2 updates observed global, national and South Australian climate change over the past century. Chapter 3 provides an assessment of the performance of global climate models in simulating South Australia’s current climate. Chapter 4 gives detailed temperature and rainfall scenarios for high, mid and low global warming scenarios for the whole of South Australia and for eight NRM regions by 2030 and 2070. Chapter 5 provides an overview of risk management and adaptation strategies. Chapter 6 describes future directions for the development of regional climate change scenarios. Conclusions and recommendations are given in chapter 7.

2. OBSERVED GLOBAL, NATIONAL AND SOUTH AUSTRALIAN CLIMATIC TRENDS

2.1 Global climate change

Since 1900, the average global temperature has risen by 0.7°C (Jones and Moberg, 2003). Temperatures have risen in the lowest 8 km of the atmosphere (Vinnikov *et al.*, 2006). The upper ocean has warmed and become more acidic (IPCC, 2001). Global-average sea-level has risen 1.7 mm per year since 1900 (Church and White, 2006). Global-average precipitation over land has increased by about 2% since the beginning of the 20th century, but there have been significant regional and seasonal increases and decreases (IPCC, 2001). Heatwaves and heavy rainfall have increased in many regions (Alexander et al., 2006), while glaciers, ice-sheets and frosts have decreased. There have been shifts in plant and animal locations and seasonal behaviour consistent with global warming. the unusual nature of the warming of the past 50 years relative to the past 1000-2000 years, based on the so-called Hockey Stick graph, has been supported by many other independent studies. The influence of human activities has been detected in land-ocean temperature contrasts, the annual cycle of surface temperature over land, the hemispheric temperature contrast, regional (not just global) warming, the height of the tropopause (between the troposphere and stratosphere) and the heating of the oceans. (Steffen, 2006).

2.2 National and regional temperature trends

In Australia, the average temperature has risen by 0.9°C from 1910 to 2004 (Nicholls and Collins, 2006). Minimum temperature has increased by 1.14ºC (0.12ºC per decade) and the maximum has increased by 0.65ºC (0.07ºC per decade).

The regional warming over the second half of the century has been stronger. For the period 1950 to 2005, Australian average surface temperature shows an increase of 0.95ºC (0.17ºC per decade). Maximum temperatures have increased by 0.86ºC (0.15 per decade) and minimum temperatures have increased by 1.04ºC (0.18 per decade) (BoM, 2006a).

Greater warming has been observed over southern and eastern Australia while slower warming (and some cooling) has been observed over the northwest and southwest in maximum temperature (Figure 1a). The spatial pattern of minimum temperature trends is very similar to the maximum temperature trends, but the magnitude of the trend in minimum temperature is larger over southern and eastern Australia (see Figures 1 b and 1c). The warmest year on record for Australia was 2005, when the annual mean temperature was 1.06°C above the 1961-1990 average, the maximum temperature was 1.21°C and the minimum was 0.91°C above average (BoM 2006b).

In general, the frequency of extremely warm days and nights has increased while that of extremely cool days and nights has decreased. From 1957 to 2004, the Australian-average shows an increase in hot days (35^{o}C or more) of 0.10 days/year, an increase in hot nights (20^{o}C or more) of 0.18 nights/year, a decrease in cold days (15^{o}C or less) of 0.14 days/year and a decrease in cold nights (5^{o}C or less) of 0.15 nights/year (Nicholls and Collins, 2006).

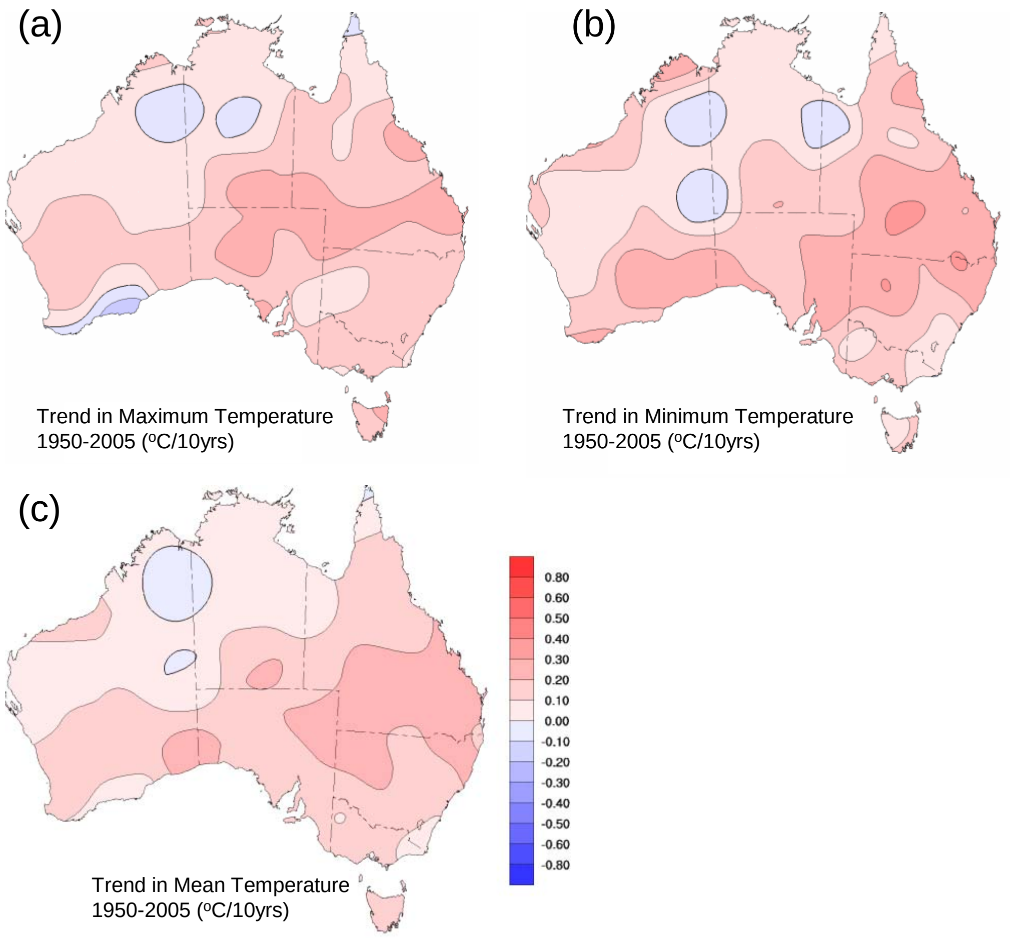

Figure 1: Spatial patterns of trends in (a) maximum, (b) minimum and (c) mean temperatures in Australia from 1950 to 2005. Source: Australian Bureau of Meteorology.

Temperature anomalies for South Australia from 1910 to 2005 are shown in Figures 2 and 3, based on an average of ten stations across the state. The maximum temperature increased by 0.79ºC (0.08ºC per decade), the minimum temperature increased by 1.13ºC (0.11ºC per decade) and the average rose by 0.96ºC (0.10ºC per decade).

Since 1950, South Australia's average maximum temperature has increased by 1.2ºC (0.21ºC per decade), the minimum by 1.01ºC (0.18ºC per decade) and the average by 1.10ºC (0.20ºC per decade). Thus, compared to national trends, South Australian temperatures are rising at a faster rate. The rise since 1950 is larger than the rise since 1910 since temperatures in the 1950s were cooler than those at the beginning of the century. Similar to All-Australian records, 2005 was the warmest on record in South Australia. The annual mean temperature was 1.05°C above the 1961-1990 average, the maximum temperature was 1.40°C above average and the minimum was 0.69°C above average (BoM 2006b).

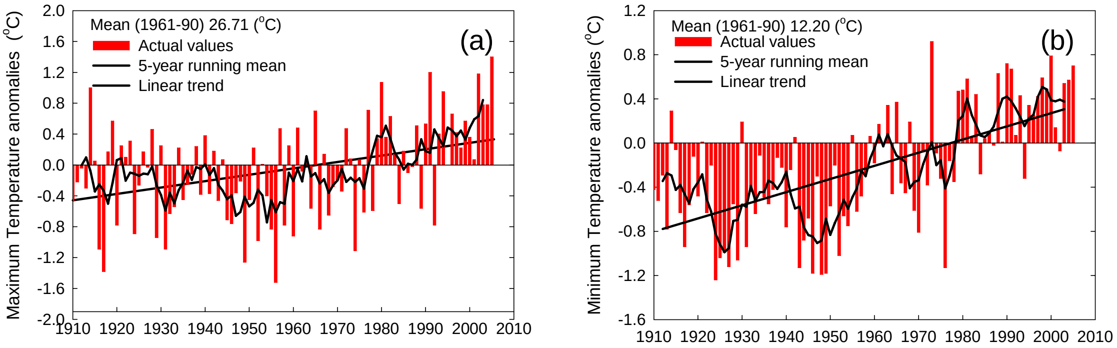

Figure 2: Trends and fluctuations in (a) maximum and (b) minimum temperatures in South Australia. Source: Australian Bureau of Meteorology.

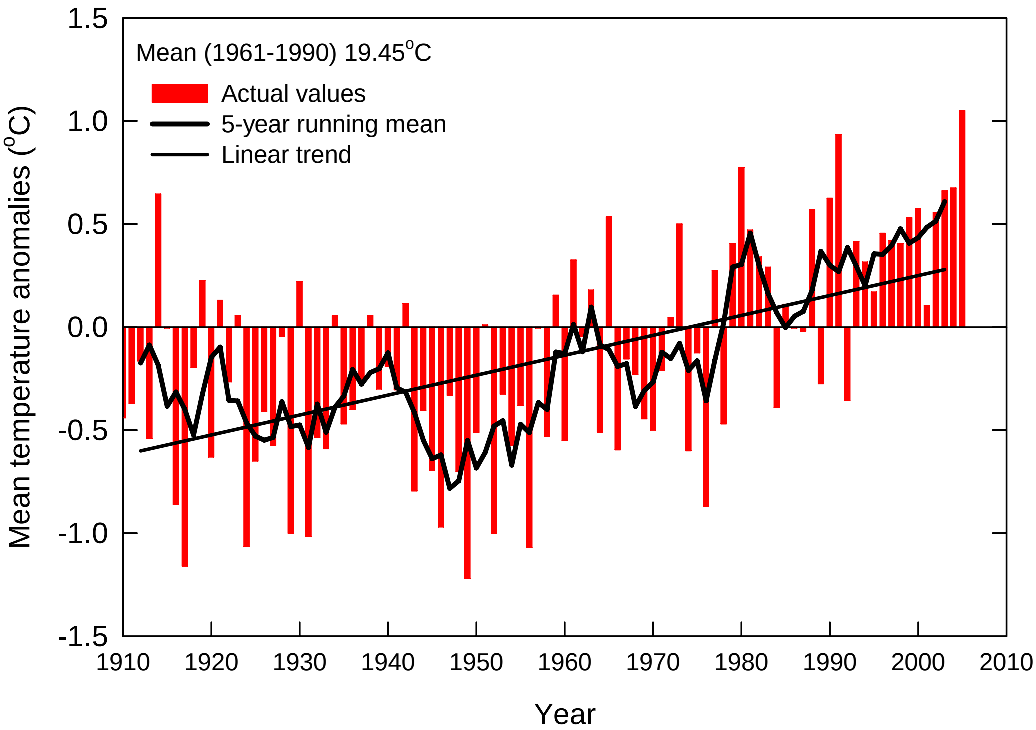

Figure 3: Trends and fluctuations in mean annual temperature for South Australia. Source: Australian Bureau of Meteorology.

Figure 4 shows changes in sea surface temperature (SST) anomalies over the period between 1900 to 2005 for two locations: (i) on the continental shelf at the mouth of Spencer Gulf (35.5°S, 136°E) and (ii) in the deeper and cooler water further south in the Bight (38°S, 136°E). The data were obtained from the improved and extended SST reconstruction (1854-2002) of Smith and Reynolds (2004). SST anomalies in the Spencer Gulf increased by 0.56ºC (0.05ºC per decade) from 1900 to 2005. Since 1950, faster warming has been recorded, i.e. an increase of 0.61ºC (0.11ºC per decade). SST anomalies in the Bight increased by 0.76ºC (0.7ºC per decade) between 1900 and 2005 and by 0.64ºC (0.12 per decade) since 1950. Overall, SST increases are smaller than those over the land, and about half of those seen at the aggregate of land-based stations in South Australia since 1950.

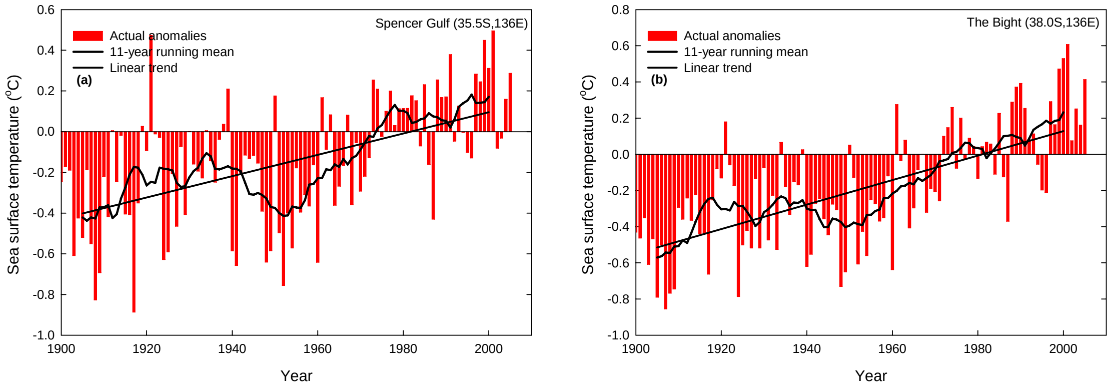

Figure 4: Fluctuations and trends in sea surface temperature (SST) at (a) south of Spencer Gulf and (b) The Great Australian Bight. The SST anomalies are from a 30-year period (1961-1990). Source: US National Climatic Data Center.

2.3 Rainfall trends

Australian rainfall records from 1900 to 2005 show an increasing trend over many parts of the country, except for south-western Australia and some parts of coastal Queensland, Tasmania and southern South Australia (Figure 5a). However, during the second half of the century, there is a stronger tendency for decreased rainfall in south-western and eastern Australia and increased rainfall over north-western and central Australia (Figure 5b). Due to the high natural variability of rainfall on decadal and longer time scales, it is difficult to distinguish any statistically significant long-term trends from this natural variability. In the 1970s, many regions were wet, while the 1990s were dry in many regions.

Figure 6 shows rainfall trends in South Australia from 1900 to 2005 and from 1950 to 2005. Much of the northern half of South Australia has experienced an increase in rainfall while southern coastal regions around the Eyre Peninsula and the far south-east of the state have experienced drying trends.

Figures 7 and 8 show fluctuations in annual and seasonal rainfall in South Australia from 1900 to 2005. There is no clear trend during the past century, but there are fluctuations on multi-decadal time scales. In particular, the 1920s and 1960s were dry decades and the 1970s was a wet period. Decadal fluctuations in annual rainfall are dominated by summer and spring rainfall variations. Rainfall in winter shows no clear trend with less variability compared to other seasons. Rainfall in autumn shows greater variability in the second half of the period, with a relatively dry period since 1990 after record autumn rainfall in 1989. In autumn, most of the years since 1990 have experienced rainfall below their median values.

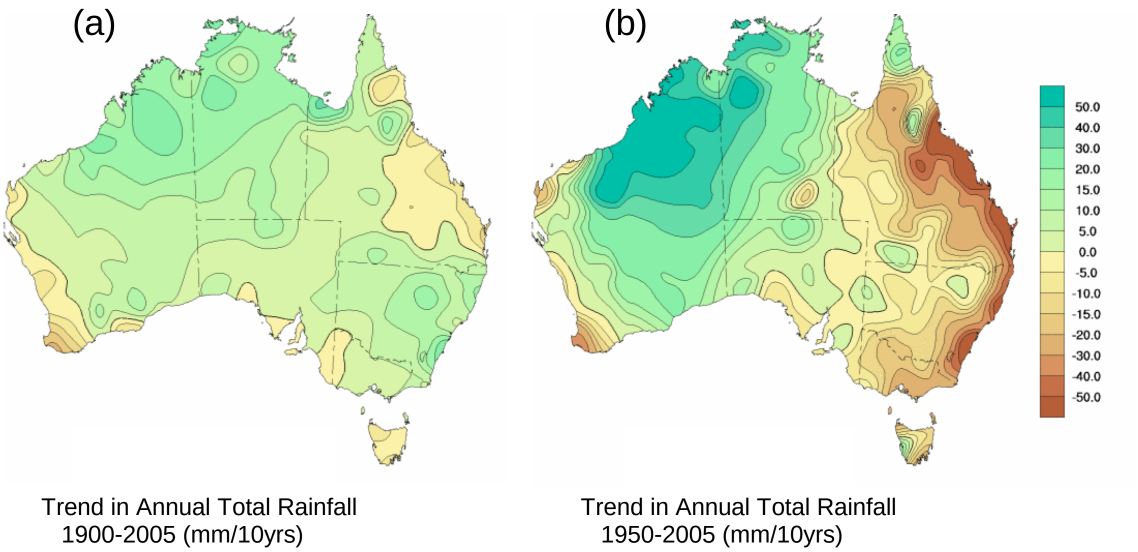

Figure 5: Rainfall trends in Australia for (a) 1900 to 2005 and (b) 1950-2005. Trends are shown as mm per 10 years. Source: Australian Bureau of Meteorology.

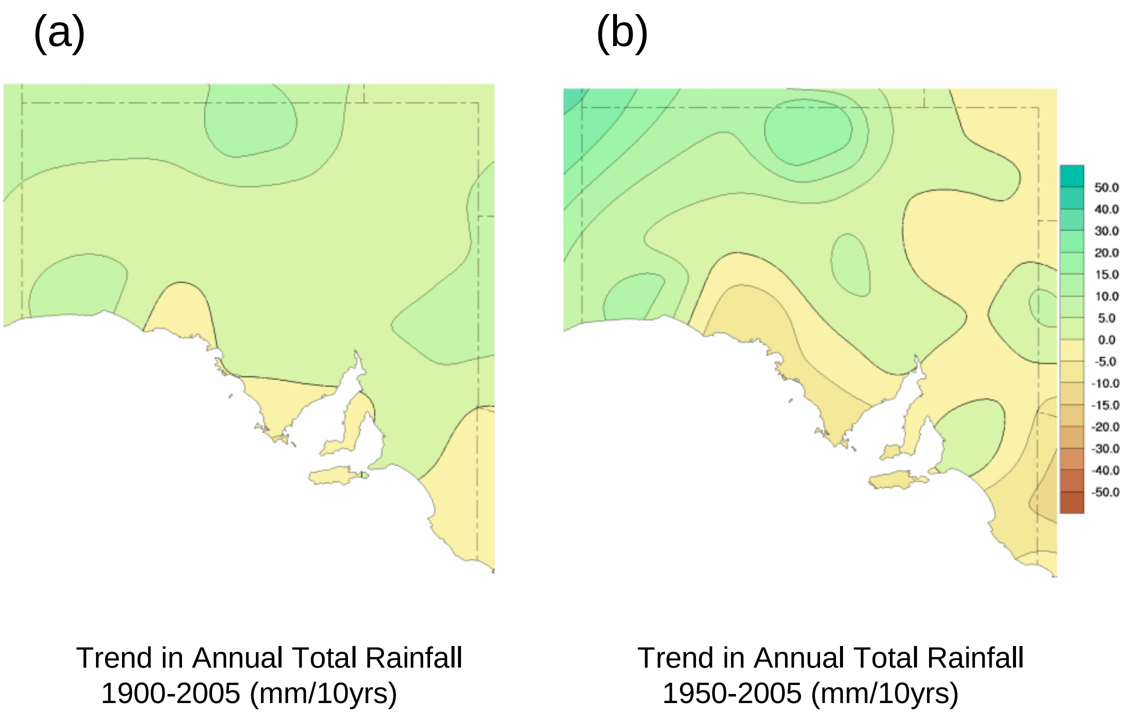

Figure 6: Rainfall trends in South Australia for (a) 1900 to 2005 and (b) 1950-2005. Trends are shown as mm per 10 years. Source: Australian Bureau of Meteorology.

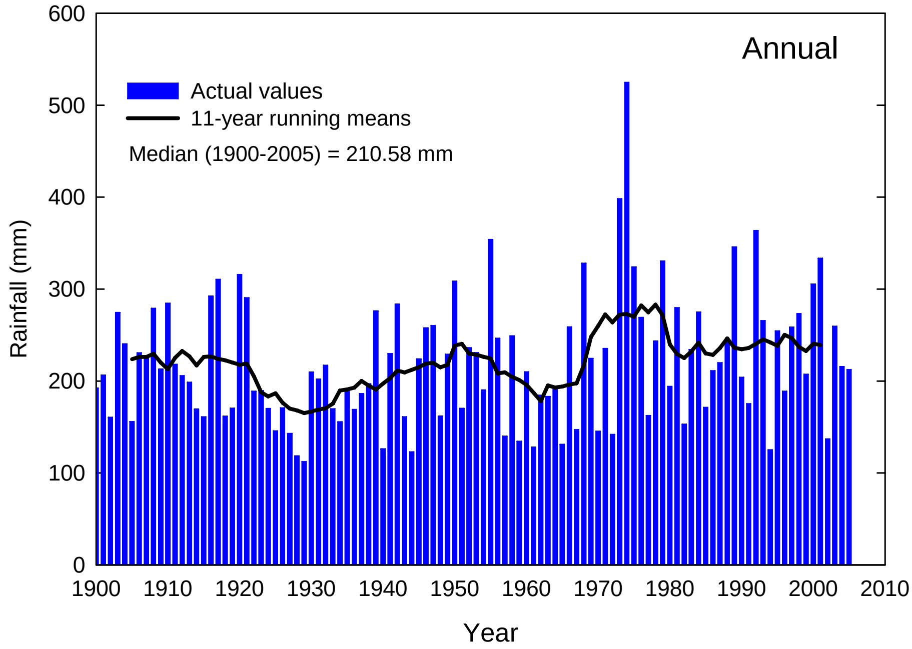

Figure 7: Annual rainfall variations in South Australia. Blue bars indicate actual values and the black line depicts the 11-year running mean. Source: Australian Bureau of Meteorology.

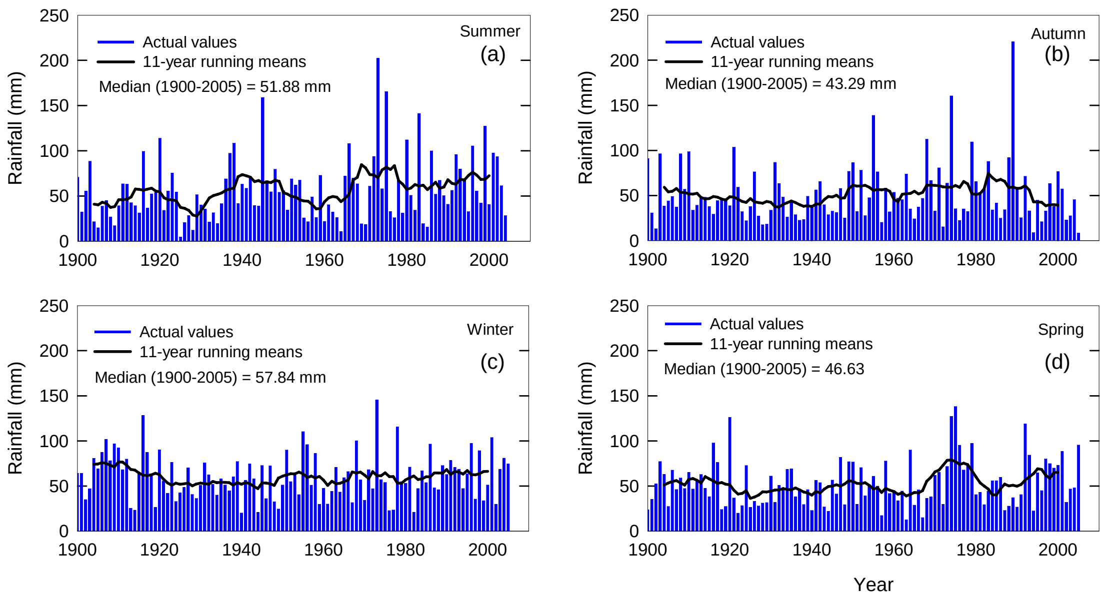

Figure 8: Seasonal rainfall variations in South Australia. Blue bars indicate actual values and the black lines depict 11-year running means. Source: Australian Bureau of Meteorology.

2.4 Evaporation trends

Evaporation is an essential component of the hydrological cycle as its magnitude is often comparable to rainfall, and so it is critical to the water balance of any location. Evaporation can be divided into potential and actual evaporation. More strictly, the term evapotranspiration should be used, which refers to the combination of evaporation from non-vegetated surfaces and transpiration from plants. Potential evaporation is the potential of the local air to evaporate available water from open water or soil, and transpire water from plants. Actual evaporation is the resulting water evaporated, which depends on the amount of energy absorbed by a plant, water or soil surface, the water available to be evaporated and the capacity of the airmass to remove that water. There are three different types of potential evaporation commonly in use, but we report on trends in pan evaporation in South Australia.

1. Pan evaporation is routinely measured by meteorological agencies as the evaporation from a 1.2 m diameter pan, whose depth of water is about 0.5 m. Pan evaporation is used to represent potential evaporation but its measurement is highly error prone. When assessing surface moisture balance, hydrologists often prefer to calculate potential evaporation from models using climatic variables such as temperature, humidity, solar radiation or sunshine hours and wind speed.
2. Point potential evaporation is most similar to pan evaporation and measures evaporation at a point.
3. Areal potential evaporation takes into account the ability of evaporation over large areas to modify the passing airmass, so it is less than point potential evaporation or pan evaporation. Areal potential evaporation is estimated over areas larger than about 10 hectares (e.g. lakes, forests, large paddocks).

In Australia, the overall decreasing trend in annual pan evaporation since 1970 is similar in magnitude to the trend in the northern hemisphere (Roderick and Farquhar, 2004). However, smaller magnitudes of decline in Australia have been found in a recent study by Kirono and Jones (2006), in which they checked inhomogeneities and discontinuities of the data. Declines in pan evaporation are generally found in the south-eastern and north-western parts of the country, while increases are observed in central Australia. In summer, increases have occurred in eastern Australia, but decreases have occurred over much of the western half of Australia.

Since the high-quality evaporation data were not available from the Australian Bureau of Meteorology (D. A. Jones and Dean Collins, per. comm.) at this stage, we have used data for only three sites that were corrected for inhomogeneities by CSIRO (Kirono et al., 2006). They are Woomera, Ceduna and Mount Gambier. The first is situated well inland, whilst the other two are located close to the coast. The annual pan evaporation is 3213, 2260, and 1264 mm per year for Woomera, Ceduna, and Mount Gambier respectively. Table 1 shows trends in annual and seasonal pan evaporation for each site from 1974 to 2004. At Woomera, there is a statistically significant increasing trend in seasonal pan evaporation at a rate of 1.2 to 5.8 mm year^{-2}. Pan evaporation records at Ceduna and Mount Gambier show positive and negative trends, but they are not statistically significant. Variations in trends may be related to the fact that pan evaporation measurement is very much dependent on local conditions (Chiew and McMahon, 1992; Rayner, 2006). The annual trends at these three stations do not necessarily match the total seasonal trend values. This is due the fact that the aggregation of seasonal values into annual values will smear out the interannual variability and trends in annual values.

Table 1: Trends in annual and seasonal pan evaporation for three sites in South Australia for 1970-2004 (from Kirono et al, 2006). Note: The sign * shows that the trend is statistically significant at the 95% level.

Location	**Pan Evaporation trend (mm year^{-2})**				
	Annual	**Autumn**	**Winter**	**Spring**	**Summer**
Woomera	11.5*	1.2*	2.2*	3.1*	5.8*
Ceduna	-0.7	0.3	0.3	0.2	-0.9
Mount Gambier	-1.3	-0.9	0.4	-0.5	-0.3

3. SIMULATING CURRENT REGIONAL CLIMATE

In this chapter, an assessment of simulations of Global Climate Models (GCMs) and Regional Climate Models (RCMs) is carried out to in order to construct climate change scenarios for South Australia. GCMs are the best available tools to simulate climate processes and their related spatial and temporal variations of temperature and rainfall. Since GCMs have coarse horizontal resolutions (about 200 to 400 km between gridpoints), small-scale meteorological phenomena are not adequately simulated. RCMs have finer resolution (about 50 km between gridpoints) are used to simulate small-scale meteorological phenomena and their related temperature and rainfall patterns, particularly over complex topographical regions. However, these RCMs are dependent on GCMs to provide the boundary conditions.

While these climate models still have shortcomings, there has been enormous progress over the past five years in our understanding of important climate processes and their representation in climate models. Confidence in the reliability of these models for climate projections has also improved, based on tests of the ability to simulate:

- the present average climate;
- year-to-year variability;
- extreme events, such as storms and heatwaves;
- climates from thousands of years ago; and
- observed climate trends in the recent past.

As climate models continue to develop, they will more comprehensively represent the climate system with reduced uncertainty. At present, climate models can credibly simulate climatology at global and continental scales for most variables of interest for climate change. Regional models and downscaling techniques can make a contribution to understanding climate change at smaller scales.

Climate change projections should be based on as many GCMs and RCMs as possible to ensure that uncertainty due to differences between models is captured. A prerequisite for the inclusion of a model in climate projections is that it adequately simulates present-day climate conditions. In this chapter, an analysis is made of the ability of a range of climate models to simulate South Australia's current average climate conditions. Table 2 shows names of climate modelling groups, model symbols used in this report and model horizontal resolution.

3.1 Model validation over South Australia

Statistical methods were used to objectively test the ability of each model to simulate South Australia's present climate. Observed and simulated patterns for 1961-1990 were compared by calculating the pattern correlation coefficient, which measures pattern similarity, and root mean square error (RMS), which measures differences in magnitude. A pattern correlation coefficient of 1.0 indicates a perfect match between the observed and simulated spatial pattern, and an RMS error of 0.0 indicates a perfect match between observed and simulated magnitudes. In case of rainfall, pattern correlation and RMS error statistics have been calculated using seasonal total values, but the RMS error values in Figure 13 are shown as mm per day. Total RMS error values for each season were divided by the number of days in a season and expressed as mm per day. A domain that covers South Australia (125-145ºE, 25-40ºS) was selected to validate the temperature and rainfall simulations. However, a larger domain that covers Australia (110-160ºE, 10-45ºS) was used to assess mean sea-level pressure (MSLP). Further details of the methods described in this section are given by Whetton et al. (2005).

Figure 9 shows the observed seasonal pattern of MSLP for the period from 1961-1990 and Figure 10 shows the pattern correlation and RMS error for 25 models. The correlation coefficient of most models is very good (above 0.8), except for BCC which shows correlations less than 0.8 in three seasons and IPSL which shows correlations less than 0.8 in all four seasons. Models such as CCCMAT47, GISS-AOM, MICRO-H and MICRO-M show correlations less than 0.8 in two seasons. The RMS error is greater than 2 hPa in some models, particularly in BCC, CCCMAT47, GISS-E-H, GISS-E-R, IPSL, MICRO-H and HADCM3. Some models also show errors greater than 5 hPa in two or three seasons. However, an error of 5 hPa is considered small compared to the mean value of 1015 hPa. Most models perform very well in summer and autumn when the south-north pressure gradient is strong. The models perform moderately well in winter and spring when the pressure gradient is weak.

Table 2: The 23 climate change simulations undertaken for the IPCC Fourth Assessment Report and available through the Program for Climate Model Diagnosis and Intercomparison (PCMDI) with the addition of CSIRO's regional models CC50 and CC60. The 13 models that perform best over South Australia are shown in bold letters.

Climate Modeling Group & Country	Model Symbols	Horizontal resolution
		km
Beijing Climate Center, China	BCC	~200-
Bjerknes Centre for Climate Research, Norway	**BCCR**	~200
Canadian Climate Centre, Canada	CCMA T47	~300
Canadian Climate Centre , Canada	CCMA T63	~200
Meteo-France, France	CNRM	~200
CSIRO Australia	**CC50**	~50
CSIRO, Australia	**CC60**	~60
CSIRO, Australia	CSIRO-MARK3	~200
Geophysical Fluid Dynamics Lab, USA	**GFDL 2.0**	~300
Geophysical Fluid Dynamics Lab, USA	**GFDL 2.1**	~300
NASA/Goddard Institute for Space Studies, USA	GISS-AOM	~300
NASA/Goddard Institute for Space Studies, USA	GISS-E-H	~400
NASA/Goddard Institute for Space Studies, USA	GISS-E-R	~400
LASG/Institute of Atmospheric Physics. China	**IAP**	~300
Institute of Numerical Mathematics, Russia	INMCM	~400
Institut Pierre Simon Laplace, France	IPSL	~300
Centre for Climate Research, Japan	**MIROC-H**	~125
Centre for Climate Research, Japan	MIROC-M	~300
Meteorological Research Institute , Japan	**MRI**	~300
Max Planck Institute for meteorology DKRZ, Germany	**MPI-ECHAM5**	~200
Meteorological Institute of the University of Bonn, Meteorological Research Institute of KMA, Germany/Korea	**MIUB**	~400
National Center for Atmospheric Research, USA	**NCAR-CCSM**	~150
National Center for Atmospheric Research, USA	NCAR-PCM	~300
Hadley Centre, UK	**HADCM3**	~300
Hadley Centre, UK	**HADGEM1**	~125

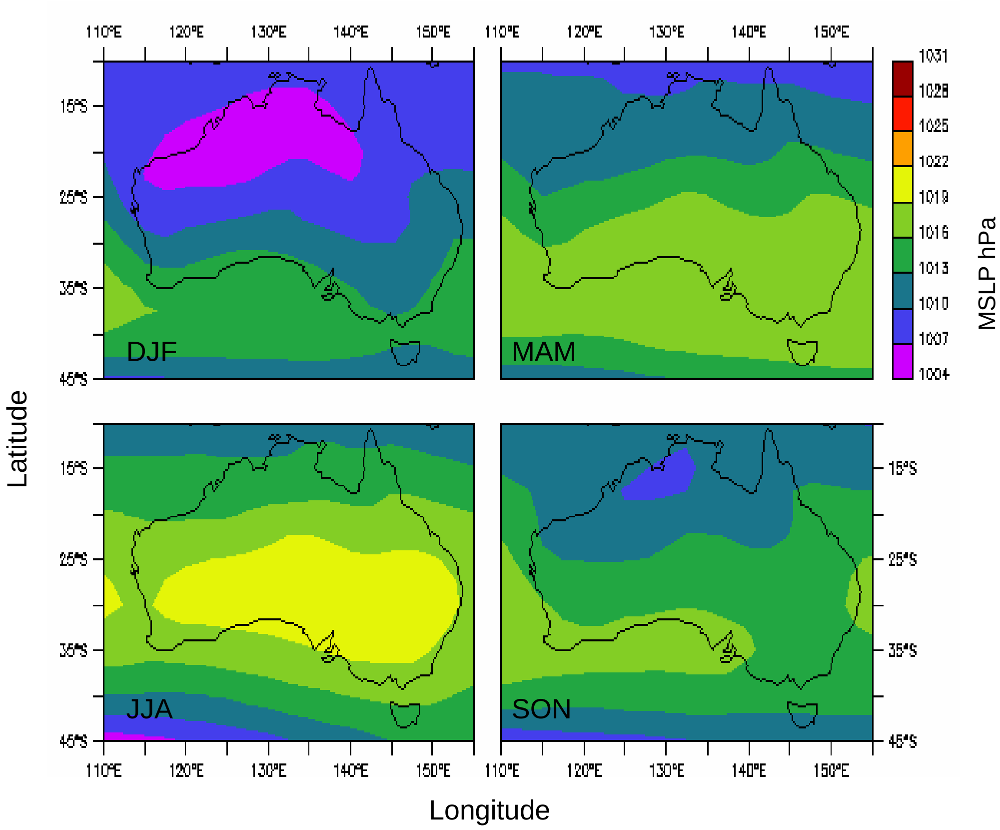

Figure 9: Average seasonal mean sea level pressure (hPa) from 1961-1990 over the Australian region. Source: NCEP Re-analysis.

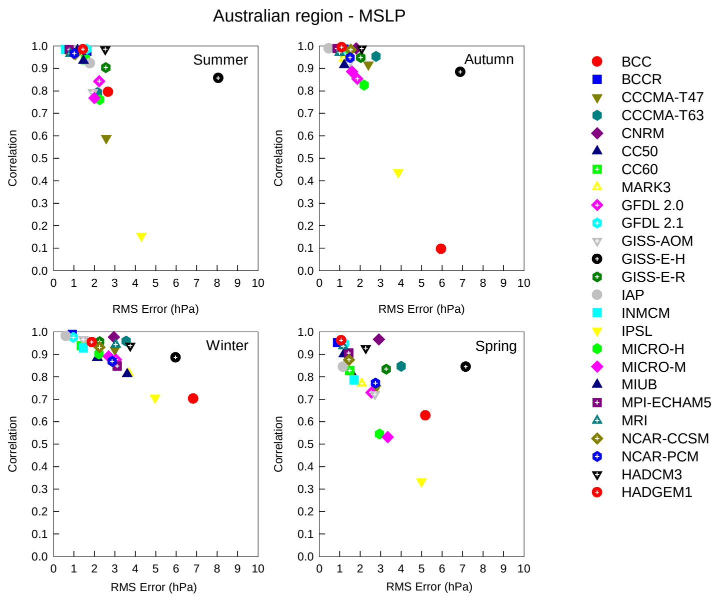

Figure 10: Pattern correlation and RMS error for observed versus model MSLP for the Australian region. Details of models are given in Table 1. In these diagrams, the better the model performance, the closer to the top left-hand corner of each diagram the result will lie.

Figure 11 presents the seasonal temperature averaged over the period 1961-1990 and Figure 12 shows the pattern correlation and RMS error for temperature for 25 models over South Australia. Correlations for all models are excellent in spring and summer, and good for most models in autumn and winter. In winter, pattern correlations drop below 0.7 for a few models. RMS error values are less than 2°C for most models in each season. GISS-AOM performs poorly in winter, BCCR has large RMS errors in summer and autumn, INMCM has a large RMS error in spring and NCAR-PCM has a large RMS error in winter. In winter, mid-latitude synoptic systems and local topography strongly dominate the seasonal temperature patterns.

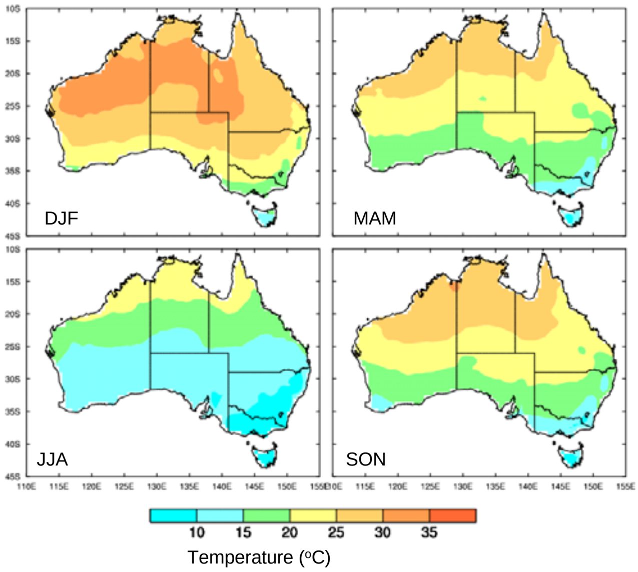

Figure 11: Observed seasonal average temperature (°C) for the period 1961-1990. Source: Australian Bureau of Meteorology.

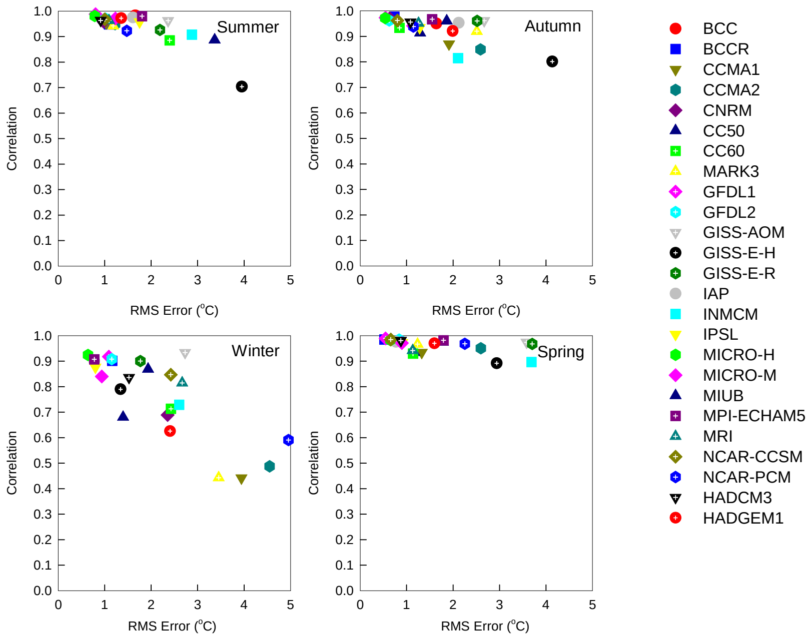

Figure 12: Pattern correlation and RMS error for observed versus model temperature over South Australia

Figure 13 shows observed seasonal patterns of rainfall in Australia. Figure 14 indicates that, over South Australia, most models have an RMS error of 0.5-1.0 mm/day in all seasons, equivalent to an error of around 100% since seasonal rainfall is about 0.7 mm/day. Hence, models have some difficulty simulating the regional magnitude of rainfall, but it is a tough test since rainfall has such large decadal variability. Pattern correlations are greater than 0.8 in winter, greater than 0.6 in summer, with a range of 0.4 to 0.9 in autumn and spring (although four models have correlations of 0.4 or less).

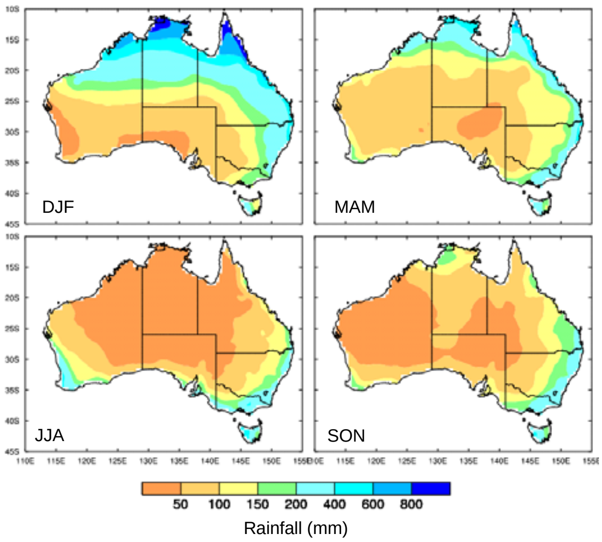

Figure 13: Observed seasonal total rainfall (mm) for the period 1961-1990. Source: Australian Bureau of Meteorology.

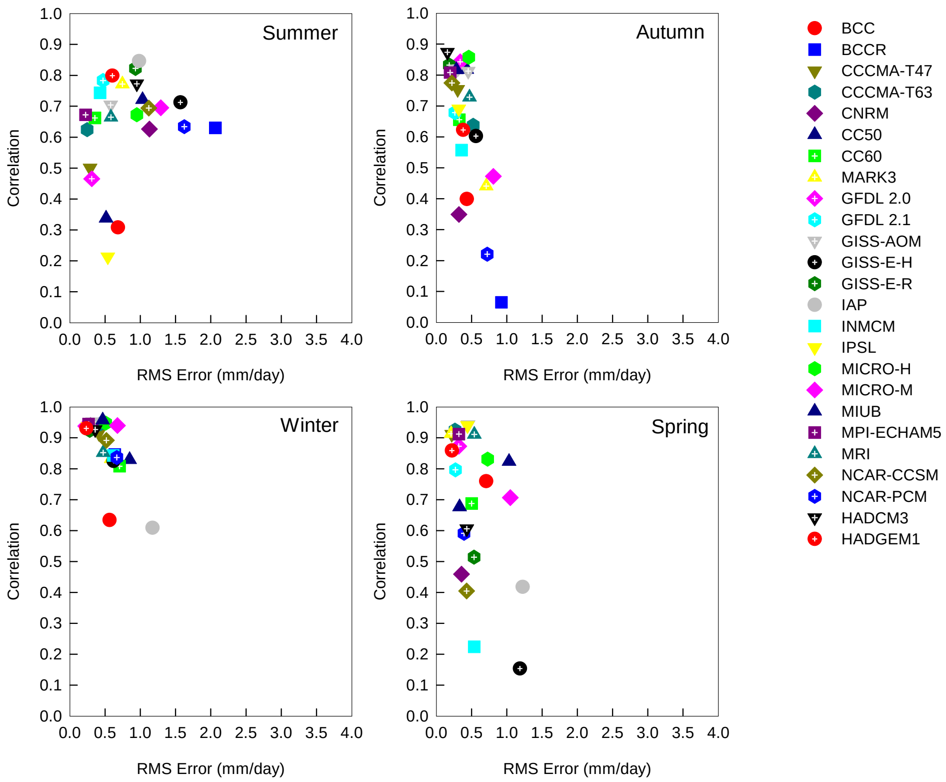

Figure 14: Pattern correlation and RMS error for observed versus model rainfall for South Australia.

3.2 Overall assessment of model performance

The performance of 25 climate models in reproducing key aspects of South Australia's current climate has been the focus of this chapter. The rationale for this assessment is that a model should be able to reproduce key aspects of the present climate if it is to be used to provide guidance for changes in future climate.

Deciding on what is acceptable performance is not straightforward. A good performance at simulating current climate does not guarantee that the enhanced greenhouse simulation is accurate. Nor do errors in the current climate performance mean that the enhanced greenhouse simulated changes in climate are unreliable. This means that focusing on the results of the very best performing models may, therefore, inadequately represent the underlying uncertainty in projecting regional climate change. Thus, our approach to validation has been to view a model as acceptable unless the current climate errors are of a nature, which in our judgment, significantly reduce the likelihood that the enhanced greenhouse simulation is reliable. Absence of key climate feature (e.g. high pressure belt) in the region of interest would be an example of an unacceptable failure. The representation of model processes is important for judging the reliability of enhanced greenhouse changes, and for this reason we have placed emphasis on multivariable assessment, and on spatial patterns. Visual examination of model output maps is used in conjunction with statistical tests, to judge thresholds of unacceptability on the statistical tests. This approach is used here to form an assessment of the acceptability of the 25 simulations under consideration.

The correlation coefficient between observed and simulated MSLP is excellent in summer and autumn when the south-north pressure gradient is strong. The correlations are generally good in winter and spring when high latitude weather phenomena and topographical characteristics determine weather patterns. The south-north pressure gradient is also weaker during these seasons. For temperature, correlations for all models are excellent in spring and summer, and good for most models in autumn and winter. RMS errors are small for most models. For rainfall, most models have an RMS error of 0.5 to 1 mm/day in all seasons. Pattern correlations are greater than 0.8 in winter, between 0.6 and 0.8 in summer, with a range of 0.4 to 0.9 in autumn and spring.

To compare the overall performance of each model, a simple demerit point system based on thresholds was devised. This is the same point system that was used in McInnes et al. (2003b) and is described in more detail in Whetton et al. (2005). Models with an RMS error greater than 2.0 or a pattern correlation below 0.8 for MSLP, temperature and rainfall were assigned a demerit point. A maximum of 12 points would indicate failure to satisfactorily reproduce either pattern or magnitude for each variable in each season. An additional point was assigned if the RMS error was greater than 4.0 or if the pattern correlation fell below 0.6. On the basis of this system, it is clear from Table 3 that some models perform better than others. We excluded models with more than 7 points in the construction of mean temperature and rainfall projections for South Australia. On this basis, 12 models (BCC, CCCMA-T47, CCCMA-T63, CNRM, CSIRO-MARK3, GISS-AOM, GISS-E-H, GISS-E-R, INMCM, IPSL, MICRO-M and NCAR-PCM) were rejected. Climate change projections based on the remaining 13 models are discussed in the next chapter.

Table 3: Demerit points based on pattern correlation and RMS Error of MSLP, temperature and rainfall between observed and model simulations for 1961-1990.

Model Number	Models	Temperature -score	Rainfall-score	MSLP-score	Total
1	BCC	5	6	9	20
2	BCCR	0	6	0	6
3	CCCMA-T47	3	3	6	12
4	CCCMA-T63	6	2	5	13
5	CNRM	2	5	2	9
6	CSIRO-CC50	2	2	1	5
7	CSIRO-CC60	3	3	0	6
8	CSIRO-MARK3	4	3	3	10
9	GFDL 2.0	0	2	4	6
10	GFDL 2.1	0	3	0	3
11	GISS-AOM	4	1	3	8
12	GISS-EH-	5	4	5	14
13	GISS-E-R	3	2	4	9
14	IAP	1	3	0	4
15	INMCM	5	5	1	11
16	IPSL	0	3	9	12
17	MICRO-H	0	1	6	7
18	MICRO-M	0	4	5	9
19	MIUB	0	2	1	3
20	MPI-ECHAM5	0	1	1	2
21	MRI	1	2	1	4
22	NCAR-CCSM	1	4	1	6
23	NCAR-PCM	4	5	3	12
24	HADCM3	0	2	4	6
25	HADGEM1	2	2	0	4

4. PROJECTED CLIMATE CHANGE

4.1 Global warming scenarios

To estimate future climate change, scientists have developed scenarios. These are not forecasts or predictions of what will actually happen. They allow analysis of “what if?” questions based on various assumptions about human behaviour, economic growth and technological change.

Some IPCC scenarios assume “business as usual” without explicit policies to limit greenhouse gas emissions, although some scenarios include other environmental policies that indirectly affect greenhouse gases. These are described in the Special Report on Emission Scenarios (SRES, 2000). Other IPCC scenarios include actions to reduce CO_2 emissions and stabilize CO_2 concentrations at some level above the current value of 380 ppm. These would postpone or avoid some of the more serious damages associated with higher rates of warming. Probabilities have not been assigned to any of the scenarios. The global warming scenarios described below are used in the development of regional climate change scenarios for South Australia, so it is important to understand the basis of the global warming scenarios.

4.1.1 SRES-based global warming scenarios

The SRES (2000) scenarios represent a broad range of the main demographic, economic and technological driving forces of greenhouse gas and sulphur emissions for the 21st century. The Terms of Reference for the scenarios required that they did not include additional climate initiatives that explicitly assume implementation of the United Nations Framework Convention on Climate Change (UNFCCC) or the emission targets of the Kyoto Protocol. Each of the 40 SRES scenarios represents a variation within one of four 'storylines': A1, A2, B1 and B2.

- A1 describes a world of very rapid economic growth in which the population peaks around 2050 and declines thereafter and there is rapid introduction of new and more efficient technologies. The three sub-groups of A1 are fossil fuel intensive (A1FI), non-fossil fuel using (A1T), and balanced across all energy sources (A1B).
- A2 depicts a world of regional self-reliance and preservation of local culture. In A2, fertility patterns across regions converge slowly, leading to a steadily increasing population and per capita economic growth and technological change is slower and more fragmented slower than for the other storylines.
- B1 describes a convergent world with the same population as in A1, but with an emphasis on global solutions to economic, social and environmental sustainability, including the introduction of clean, efficient technologies.
- B2 places emphasis on local solutions to economic, social and environmental sustainability. The population increases more slowly than that in A2. Compared with A1 and B1, economic development is intermediate and less rapid, and technological change is more diverse.

Figure 15 shows the SRES (2000) anthropogenic (human-induced) emission scenarios for carbon dioxide, methane, nitrous oxide and sulphur dioxide. Carbon cycle models are used to convert emissions into well-mixed atmospheric concentrations, allowing for uptake of emissions by the land and ocean, land and ocean climate feedbacks, and chemical reactions in the atmosphere. By the year 2100, carbon cycle models give estimates of atmospheric CO_2 concentrations ranging from 540 to 970 ppm (an increase of 44 to 159% relative to 380 ppm in the year 2005). Methane concentrations are projected to change by -11 to +112% and nitrous oxide concentrations may rise 12 to 46%. Concentrations of tropospheric ozone, hydrofluorocarbons and perfluorocarbons are also projected to increase. The SRES (2000) scenarios include the possibility of increases or decreases in anthropogenic aerosols (e.g. black carbon, sulphate aerosols, biomass, aerosols and organic carbon aerosols) depending on the extent of fossil fuels use.

The greenhouse gas concentrations are converted to a radiative forcing of the climate system using mathematical formulae. Positive forcing warms the earth, while negative forcing cools the earth. CO_2 dominates the radiative forcing and has a warming effect. At present, CO_2 accounts for 56% of the total greenhouse gas forcing (including tropospheric ozone), but by 2050 and 2100 CO_2 may represent about 70-80% of the total forcing (IPCC, 2001). The next most influential gas, methane, accounts for 17% of the present forcing, decreasing to about 10% by 2050, and 0 to 10% by 2100. All SRES scenarios give positive forcing for the well-mixed greenhouse gases, except for methane in the B1 scenario by the year 2100.

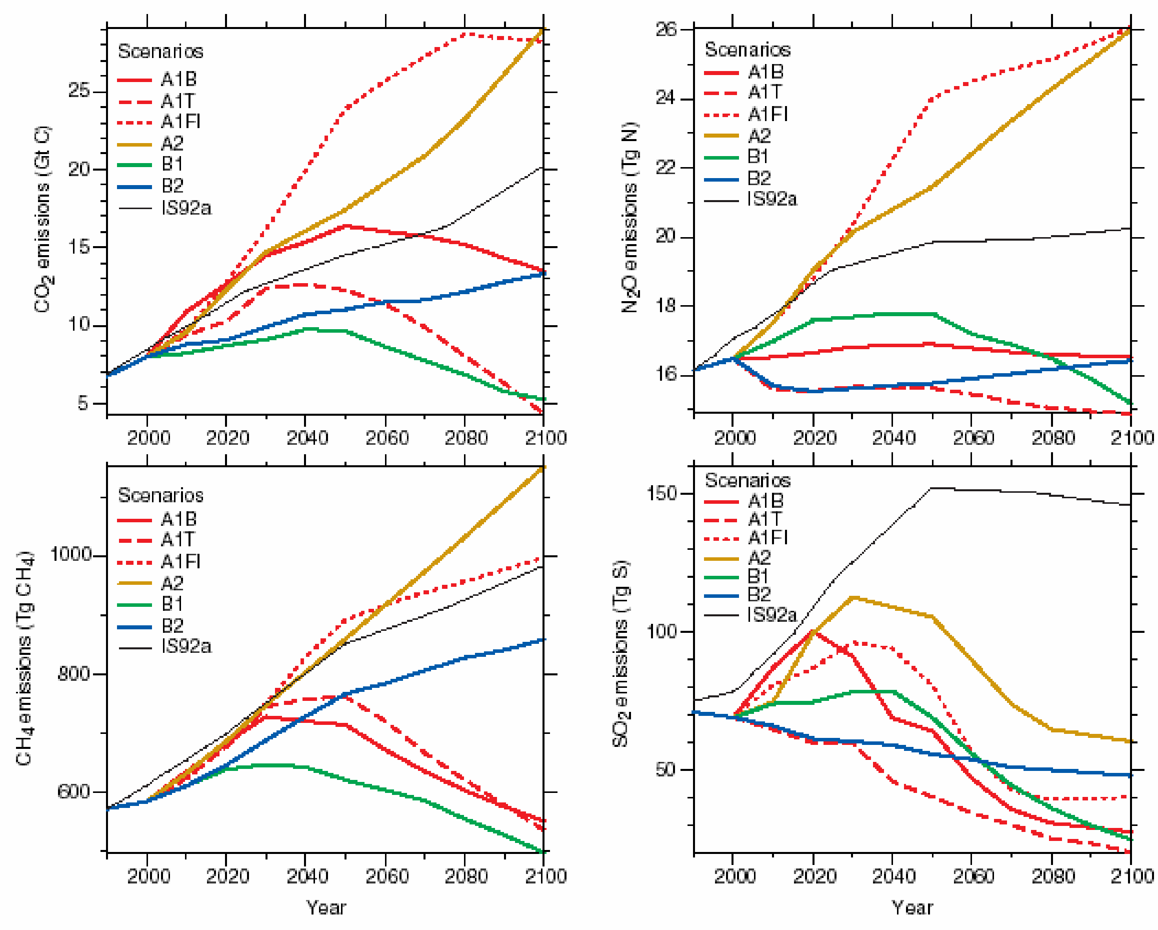

Figure 15. Anthropogenic emissions of carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) and sulphur dioxide (SO_2) for six SRES scenarios. The IS92a scenario is also shown (from the IPCC Second Assessment Report in 1996). Source (IPCC, 2001).

Climate models need massive computing resources to perform a simulation with just one emission scenario. Each simulation has a unique climate sensitivity and pattern of climate change. Comparing and synthesising results from different models is a big job. Much simpler climate models have been developed to allow exploration of the sensitivity of climate to a wide range of inputs and assumptions. These simple models can be run on a desktop computer. They provide information about global-average warming and sea-level rise for various emission scenarios and other parameters. The simple models rely on the more-complex climate models for climate sensitivity, rates of ocean heat uptake and patterns of climate change. The global average warming for the SRES scenarios (Figure 16) is 0.4 to 1.3°C by the year 2030, 0.75 to 2.6°C by 2050, 1.1 to 4.0°C by 2070 and 1.4 to 5.8°C by 2100, relative to 1990. Global-average sea-level rise is 3 to 17 cm by 2030, 5 to 32 cm by 2050, 7 to 52 cm by 2070 and 9 to 88 cm by 2100, relative to 1990. As mentioned in Chapter 1, in the past 100 years, the global-average temperature increased about 0.7°C and sea level rose about 17 cm, so the SRES-based projections represent an acceleration of past changes.

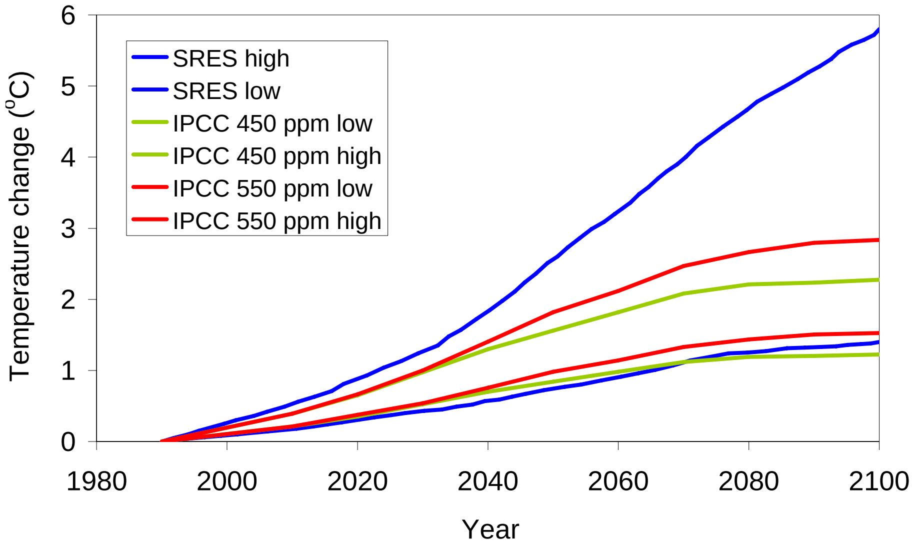

Figure 16: Comparison of projected global warming estimates based on the IPCC SRES scenarios and the IPCC scenarios for CO_2 stabilisation at 550 and 450 ppm.

4.1.2 Global warming scenarios based on CO_2 stabilisation

One way of slowing global warming is to stabilise greenhouse gas concentrations. A range of CO_2 stabilisation scenarios were considered by the IPCC (2001). Figure 17 shows the time paths of CO_2 emissions that would lead to stabilisation of CO_2 concentrations at 450, 550, 650, 750 and 1000 ppm sometime between the year 2100 and 2300. Lower CO_2 concentration targets would require an earlier reversal of emissions growth and earlier decreases to levels below current emissions. The shaded area shows the range of uncertainty in estimating CO_2 emissions corresponding to each concentration scenario, as represented in carbon cycle models. Also shown for comparison are CO_2 emissions for the A1B, A2, and B1 SRES scenarios. In all cases except the 1000 ppm scenario, stabilising CO_2 concentrations at a higher level than present (380 ppm) would require a reduction from the current level of 8 GtC (million tonnes of carbon) per year to around 3 GtC per year within the next 100 to 300 years, i.e. at least a 60% reduction in global emissions relative to present. For example, the path to stabilising at 550 ppm by 2150 would require emissions to peak at 40% above present (11.2 GtC) by the year 2025, then drop to 20% above present (9.5 GtC) by the year 2050, falling to 35% below present (5.2 GtC) by the year 2100. Alternatively, the path to stabilising at 450 ppm by the year 2090 would require emissions to peak at 20% above present (9.5 GtC) by the year 2010, then decrease to 38% below present (5.0 GtC) by the year 2050, and 70% below present (2.3 GtC) by the year 2100.

In the IPCC (2001) warming projections for CO_2 stabilisation, it is assumed that emissions of gases other than CO_2 follow the mid-range A1B scenario until 2100 and are constant thereafter. The global warming slows as growth in CO_2 concentration slows, and warming continues after the time at which the CO_2 concentration is stabilized (indicated by black spots in Figure 17c) but at a much weaker rate. For the 550 ppm stabilisation path, the warming by 2100 is reduced to between 1.5 and 2.9ºC, compared with 1.4 to 5.8ºC without emission reductions. For the 450 ppm stabilisation path, the warming by 2100 is reduced to between 1.2 and 2.3ºC. The global warming scenarios for CO_2 stabilisation at both 450 ppm and 550 ppm, for low and high climate sensitivity, are also shown in Figure 16.

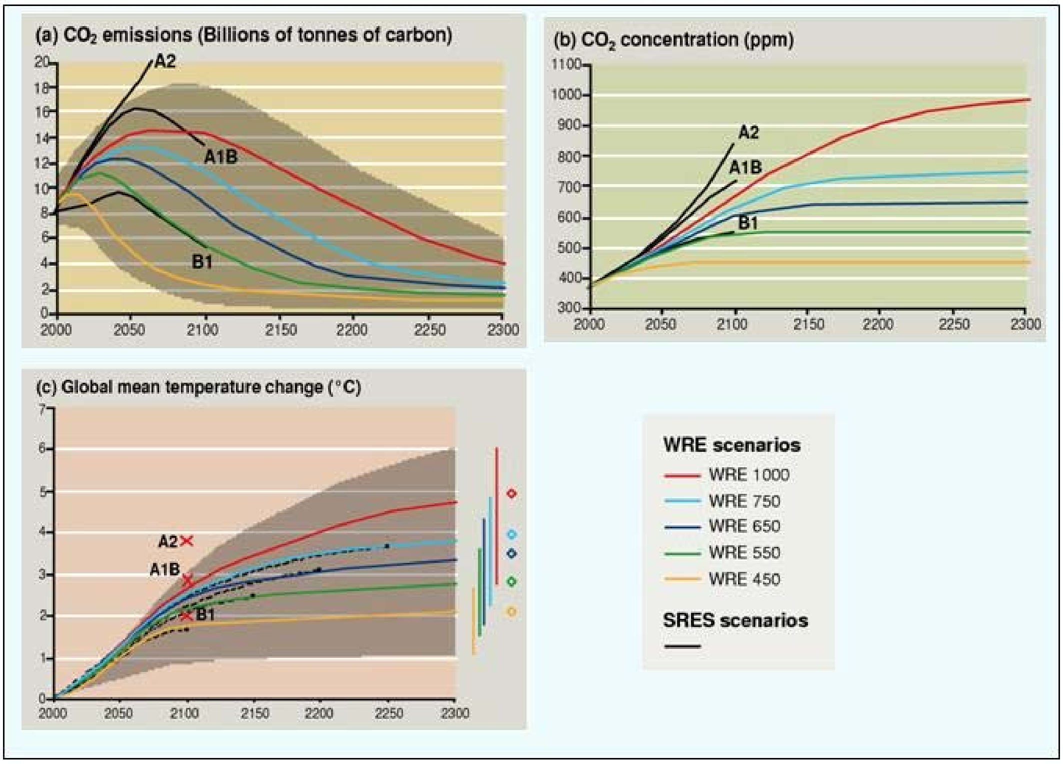

Figure 17: (a) Time paths of CO_2 emissions that would lead to (b) stabilization of the concentration of CO_2 in the atmosphere at 450, 550, 650, 750, and 1000 ppm. The shaded area shows the range of uncertainty in estimating CO_2 emissions corresponding to each concentration scenario. CO_2 emissions for the A1B, A2, and B1 SRES scenarios do not include explicit actions to reduce greenhouse gas emissions. (c) The corresponding global warming includes coloured bars on the right-hand side showing the range at the year 2300 and the diamonds show the equilibrium (very long-term) warming. Red crosses show warmings in the year 2100 for the A1B, A2, and B1 scenarios and the dashed lines show warmings for the S profiles, an alternate set of CO_2 stabilization profiles (not shown in panels (a) or (b)). From IPCC (2001d).

4.2 Projected changes in average temperature and rainfall for South Australia

In this section, various aspects of temperature and rainfall changes under enhanced greenhouse conditions are discussed for eight NRM regions and for South Australia as a whole. First, annual and seasonal temperature and rainfall changes are given for South Australia for 2030 and 2070 for SRES scenarios and for two CO_2 stabilisation scenarios. Second, annual and seasonal temperature and rainfall changes are given for the eight NRM regions. Finally, we discuss the time at which an enhanced greenhouse signal in temperature and rainfall might be distinguished from natural variability.

Figure 18 shows the pattern of regional average temperature change in summer, autumn, winter and spring for the 13 climate models. The results are given as a local warming per °C of global warming by linearly regressing the local seasonal mean temperatures against global average temperatures smoothed by an 11-year running mean. This method assumes that the local temperature signal evolves over time like that of the smoothed global temperature (Mitchell, 2003). The degree of change for a particular future date can then be calculated by multiplying the selected values on the map by the global warming values at that date, from Figure 16.

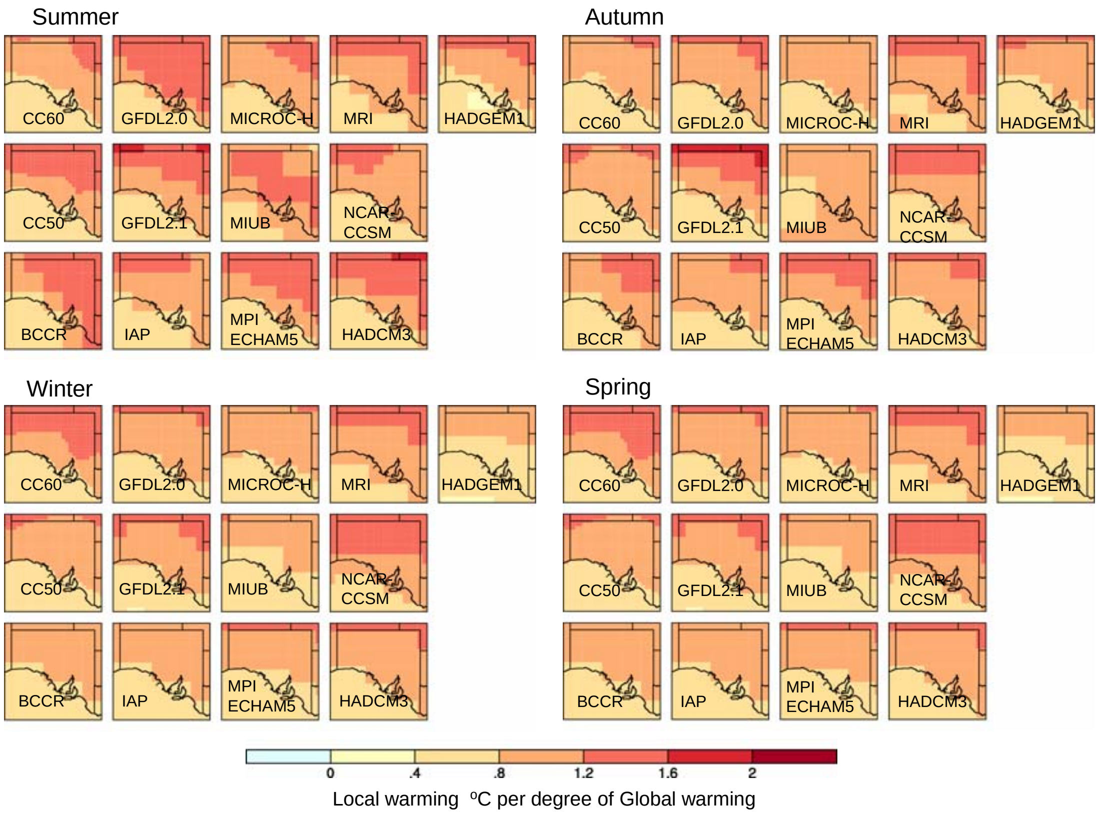

Figure 18: Pattern of warming in 13 climate models for (a) summer, (b) autumn, (c) winter and (d) spring. Units are °C per °C of global warming. Model details are given in Table 2.

All models show greater warming inland. Coastal areas warm between 0.4 and 0.8°C, while inland areas warm between 0.8 and 1.6°C. Warming is greatest in summer and spring. Warming is delayed in the middle to higher latitudes of the Southern Hemisphere compared to other regions (IPCC, 2001) due to the high heat capacity of this largely oceanic region, and air from this zone affects southern Australia more in winter.

Patterns of seasonal rainfall changes from the 13 models are shown in Figure 19. In summer, MICRO-H, GFDL 2.0, MIUB, MRI, NCAR-CCSM and BCCR give increases over inland areas and decreases over the Bight. CC60 and MPI-ECHAM5 show decreases over inland areas and increases over the Bight. The other models, HADGEM1, CC50, GFDL 2.0, IAP and HADCM3 show decreases over the domain. During autumn, MIUB, BCCR and HADCM3 show increases and other models show predominantly decreases. In winter, all models except HADCM1 show decreases. In spring, all other models except MIUB and NCAR-CCSM show strong decreases. These patterns of change determine the long term trends in rainfall anomalies shown later in Figures 23 and 24.

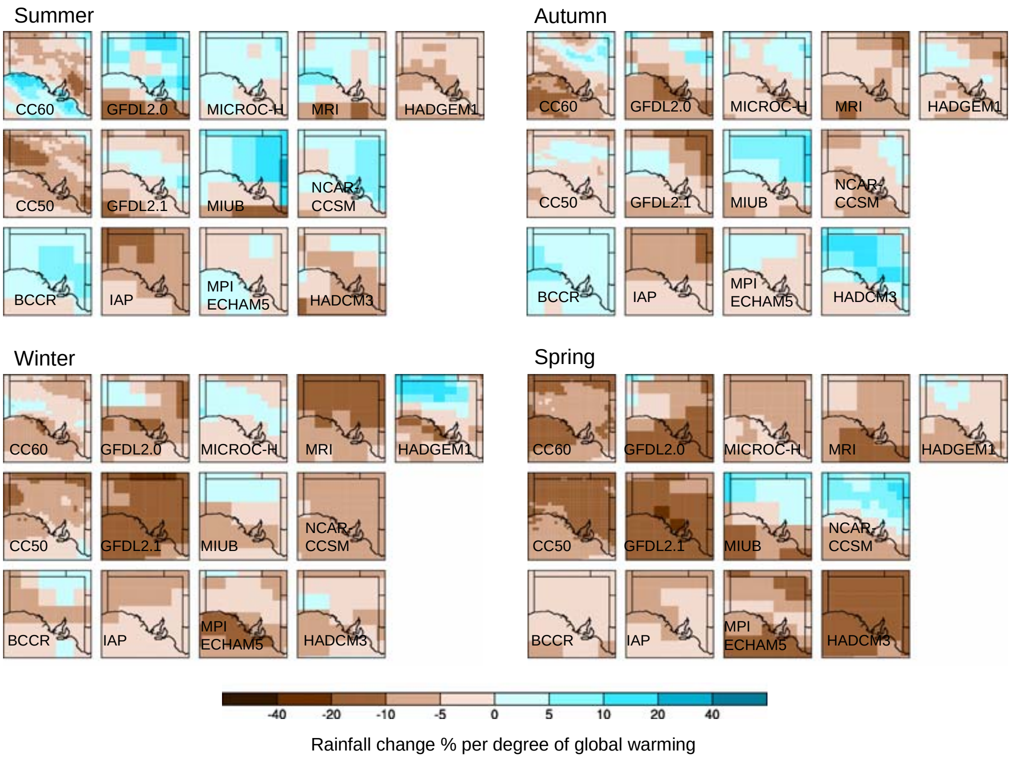

Figure 19: Pattern of annual rainfall change in 13 models in percent change per °C degree of global warming for each season.

As mentioned earlier current GCMs simulate increases and decreases in rainfall under climate change conditions. Figure 20 shows the consistency among 13 models, which are used to construct climate change projections for South Australia, in the direction of annual rainfall change over Australia. Some models indicate increases and some show decreases, particularly over southern part of the continent. For South Australia, most models show decreases or strong decreases. There are differences in the direction of change among seasons.

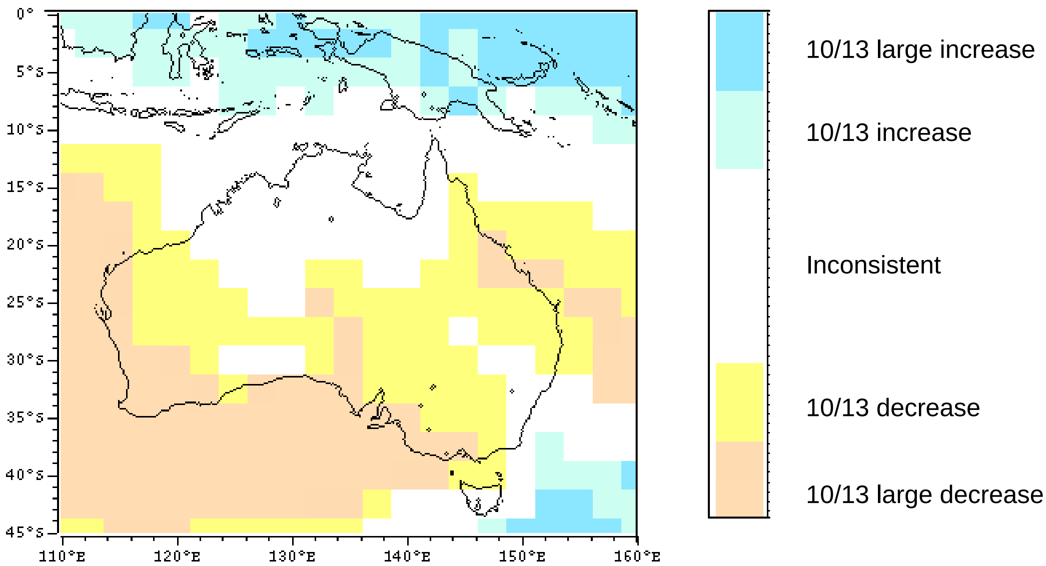

Figure 20: Inter-model consistency in direction of simulated annual rainfall change in 13 models used to construct climate change projections for South Australia.

This section provides a summary of projected future changes in temperature and rainfall over South Australia based on the simulations of 13 models. The ranges of change incorporate quantifiable uncertainties associated with the range of future emission scenarios, the range of global responses of climate models, and model-to-model differences in the regional pattern of climate change. The ranges are based on:

- the full range of IPCC global warming projections given in Figure 16, which provide information on the magnitude of the global climate response over time. These ranges take into account a range of possible future emissions of greenhouse gases as well as uncertainty associated the sensitivity of the climate system. In addition, we have given climate change scenarios for CO_2 concentrations stabilised at 450 ppm by 2100 and for 550 ppm by 2150, also shown in Figure 17.
- the regional climate response in terms of local change per °C degree of global warming. A range of local values is derived from the differing results of 13 climate model simulations presented in Figures 18 and 19.

Summary results for temperature and rainfall are presented in Figures 21 and 22 as colour-coded maps for the average climate change conditions by around 2030 and 2070 relative to a 30-year average centred on 1990, i.e. from 1975 to 2004. The conditions of any individual year will continue to be strongly affected by natural climatic variability which cannot be easily predicted. Figures 21 and 22 were produced using the method described by Whetton et al. (2005). The results of the 13 models selected from those listed in Table 3 were interpolated to a common grid with a horizontal resolution of 2 degrees both latitudinally and longitudinally. For each grid cell, the temperature range is bounded by the second lowest and second highest warmings given by the 13 models. In the case of rainfall, the range of change for each grid cell is bounded by the second highest decrease in rainfall and the second greatest increase in rainfall given by the 13 models. This approach reduces the influence of outlying model results.

The SRES temperature projections are also presented as averaged changes over three geographical regions in Tables 4a and 4b. By 2030, the region from the coast to 200 km inland shows annual-mean warming between 0.2 and 1.6°C, regions 200 to 600 km inland warm by 0.4 to 1.8°C and regions more than 600 km inland warm by 0.6 to 1.8ºC. By 2070, the region within 200 km of the coast warms by 0.5 to 4.7°C, regions 200 to 600 km inland warm by 0.8 and 5.5°C and regions more than 600 km inland warm by 1.2 to 5.5ºC. If CO_2 concentrations are stabilised at 550 ppm by the year 2150, the upper limit of warming is reduced by 23% by 2030 and 38% by 2070. If CO_2 concentrations are stabilised at 450 ppm by the year 2100, the upper limit of warming is reduced by 25% by 2030 and 48% by 2070.

Table 4a: Projected temperature changes relative to the average from 1975 to 2004 using SRES emission scenarios for three geographical regions by 2030.

Geographical Regions	Annual	Summer	Autumn	Winter	Spring
0 – 200 km from coast	0.2 to1.6	0.2 to 1.6	0.2 to 1.6	0.2 to 1.6	0.2 to 1.6
200 – 600 km inland from coast	0.4 to 1.8	0.5 to 1.8	0.4 to 1.8	0.4 to 1.8	0.6 to 1.6
Beyond 600 km inland from coast	0.6 to 1.8	0.6 to 2.0	0.6 to 1.8	0.5 to 1.8	0.6 to 2.0

Table 4b: Projected temperature changes relative to the average from 1975 to 2004 using SRES emission scenarios for three geographical regions by 2070.

Geographical Regions	Annual	Summer	Autumn	Winter	Spring
0 – 200 km from coast	0.5 to 4.7	0.5 to 4.7	0.5 to 4.7	0.5 to 4.7	0.5 to 4.7
200 – 600 km inland from coast	0.8 to 5.5	1.0 to 5.5	0.8 to 5.5	0.8 to 5.5	1.2 to 6.2
Beyond 600 km inland from coast	1.2 to 5.5	1.2 to 6.2	1.2 to 5.5	1.0 to 5.5	1.2 to 6.2

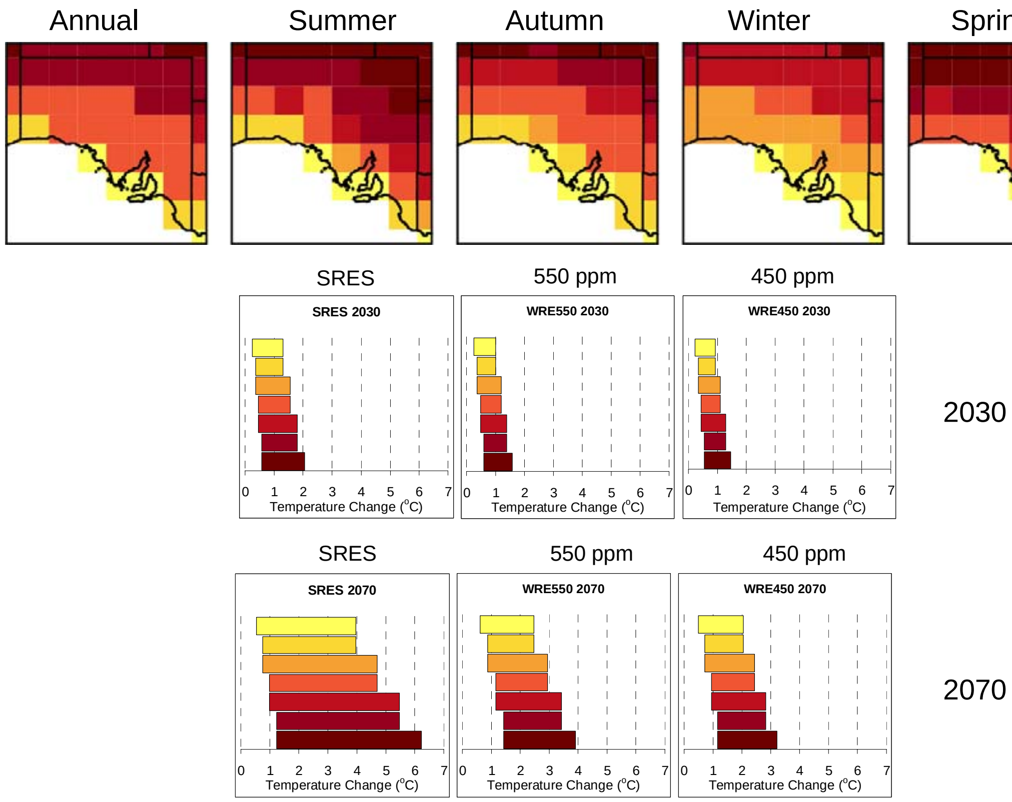

Figure 21: Average seasonal and annual warming ranges (°C) for 2030 and 2070 relative to the average from 1975 to 2004 for SRES scenarios, and for CO_2 stabilisation at 450 ppm by 2100 (WRE450) and 550 ppm by 2150 (WRE550). The coloured bars show ranges of change for areas with corresponding colours in the maps.

Projected rainfall changes are more complex than the temperature projections, as rainfall shows stronger spatial and temporal variation, as well as large variations between models. Projected rainfall changes for 2030 and 2070 are shown in Figure 22, while Tables 5a and 5b give changes in rainfall for specific geographical regions. A tendency for decreases is dominant. Under the SRES scenarios for 2030, the region within 200 km of the coast shows annual rainfall changes between -15 and 0%, while regions further inland show changes between -15 and +7%. By 2070, the region from the coast to 200 km inland shows annual rainfall changes between -45 and 0%, while regions further inland show changes between -45 and +25%. Summer and autumn show increases and decreases, but decreases dominate winter and spring.

If CO_2 concentrations are stabilised at 550 ppm by the year 2150, the upper limit of warming is reduced from 2.0 to 1.6°C by 2030 and from 6.2 to 3.9°C by 2070. If CO_2 concentrations are stabilised at 450 ppm by the year 2100, the upper limit of warming is reduced from 2.0 to 1.5°C by 2030 and from 6.2 to 3.2°C by 2070.

For stabilised CO_2 concentrations at 550 ppm, the range of rainfall changes reduces from [-22 to +15%] to [-17 to +12%] by 2030 and by 2070, the range of rainfall changes reduces from [-68 to +45%] to [-43 to +28%]. For stabilised CO_2 concentrations at 450 ppm, the range of rainfall changes reduces from [-22 to +15%] to [-16 to +11%] by 2030, and from [-68 to +45%] to [-35to +23%] by 2070.

Previous scenarios presented by McInnes et al. (2003) for South Australia were based on twelve models while new scenarios presented this section were based on thirteen models. A comparison between old and new temperature scenarios in this study shows a small increase in the lower end and a small decrease in the upper end of the ranges. In the old scenarios, autumn and summer showed greatest warming, while in the new scenarios, summer and spring show greatest warming.

Rainfall changes in the old and new scenarios do not differ significantly, with both indicating rainfall decreases in future. Winter and spring show strongest decreases.

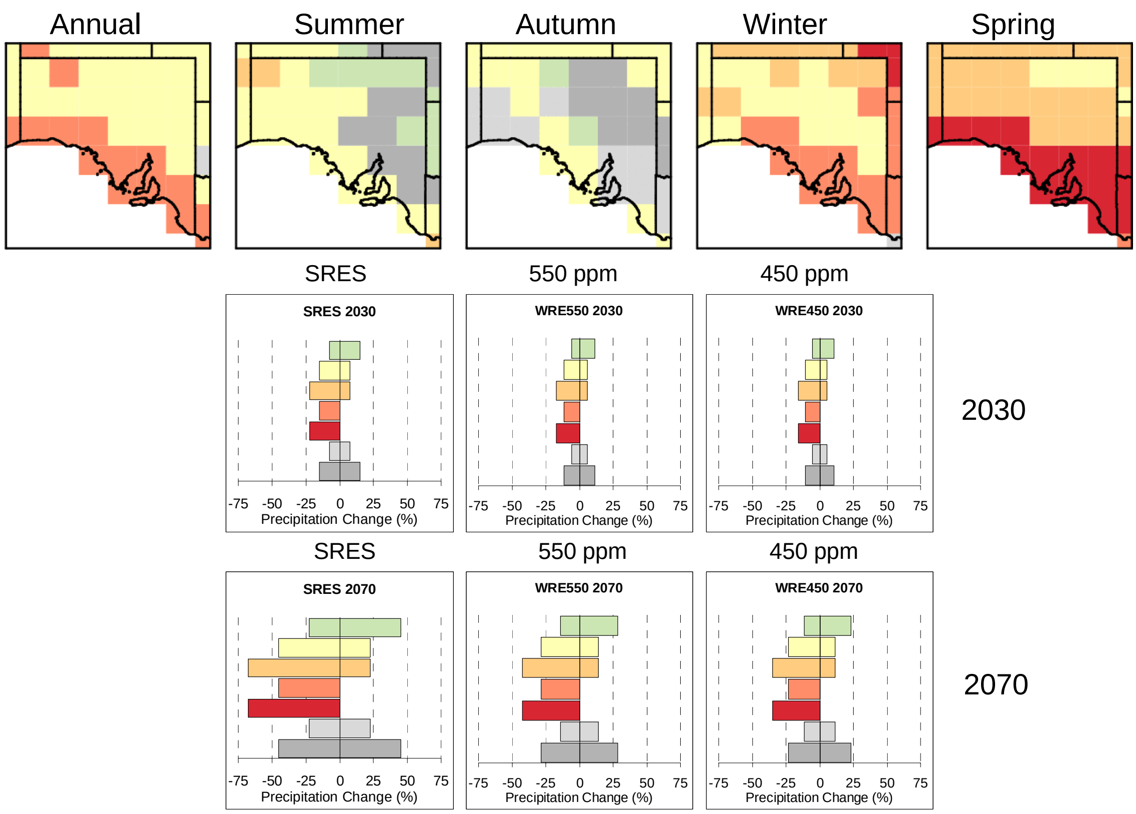

Figure 22; Average annual and seasonal rainfall change (%) for 2030 and 2070 relative to the average from 1975 to 2004 for SRES scenarios, and for CO_2 stabilisation at 450 ppm by 2100 (WRE450) and 550 ppm by 2150 (WRE550). The coloured bars show ranges of change for areas with corresponding colours in the maps.

Table 5a: Projected percentage rainfall changes using SRES emission scenarios for three geographical regions by 2030.

Geographical Regions	Annual	Summer	Autumn	Winter	Spring
0 – 200 km from coast	-15 to 0	-15 to +15	-15 to +7	-15 to 0	-20 to 0
200 – 600 km inland from coast	-15 to +7	-15 to +15	-7 to +15	-15 to +7	-20 to +7
Beyond 600 km inland from coast	-15 to +7	-7 to +15	-15 to +15	-15 to +7	-15 to +7

Table 5b: Projected percentage rainfall changes using SRES emission scenarios for three geographical regions by 2070.

Geographical Regions	Annual	Summer	Autumn	Winter	Spring
0 – 200 km from coast	-45 to 0	-45 to +45	-45 to +25	-45 to 0	-70 to 0
200 – 600 km inland from coast	-45 to +25	-45 to +45	-25 to +45	-45 to +25	-70 to +25
Beyond 600 km inland from coast	-45 to +25	-25 to +45	-45 to +45	-70 to +25	-45 to +25

4.3 Projected average temperature and rainfall changes for NRM regions of South Australia

In this section, we present annual and seasonal average temperature and rainfall changes for 2030 and 2070 for SRES scenarios and for two CO_2 stabilisation scenarios for eight NRM regions (Figure 23). Since experiments are not available to provide data on the impact of global stabilisation of atmospheric concentrations at 550 ppm CO_2 equivalent scenarios, we have provided temperature and rainfall changes for 2030 and 2070 for stabilised atmospheric concentration scenarios at 450 and 550 ppm using an interpolated method. The results are shown in Tables 6 through 11. Temperature and rainfall changes are projected relative to the climatology of 30 years (1975-2004) centred 1990.

The method used to produce the ranges of change for the regions was equivalent to the method used to produce the ranges of change in Figures 21 and 22. For each region, an average change was calculated for each of the 13 models, the two outlying changes were discarded and the range of change was chosen to span the 11 remaining changes. Note that a range of change given for a region may not be exactly consistent with the ranges of change for the corresponding grid boxes in Figures 21 and 22. There are three reasons for this. Firstly, the models contributing the outlying changes that are discarded before a range of change is determined vary from grid cell to grid cell and hence between an NRM region and the grid cells corresponding to it. Therefore a range of change for an NRM region may be based on output from a slightly different set of 11 models. Secondly, it has been possible to give the ranges of change in Tables 6 through 11 to a greater precision than the discrete ranges of change in Figures 21 and 22. Finally, the number of ranges presented in Figures in 21 and 22 has been reduced by incorporating some ranges that corresponded to only a few grid cells.

Figure 23: South Australian NRM and DEH regions: Source: Department of Water, Land and Biodiversity Conservation, South Australia.

Inland or northern regions such as Alinytjara Wilurara and South Australian Arid lands show greater warming, while other coastal or southern regions, such as the South East and South Australian Murray Darling Basin regions, show less warming. One reason for this difference in warming is that in drier northern region trapped heat is released as sensible heat rather than evaporation. Rainfall changes show both increases and decreases, but decreases dominate the overall pattern of change. Spring shows large decreases and other seasons indicate moderate decreases.Simulated temperature and rainfall anomalies for the 20th and 21st centuries for South Australia and also for the eight NRM regions are shown in Figures 24 and 25**.** For temperature, the enhanced greenhouse signal seems to emerge from natural variability after 2000 in most of the regions. For rainfall, the enhanced greenhouse signal is much harder to detect. Some models show a decline as early as 2000 for most it is not until 2050 that the greenhouse signal is clear.

4.3.1 South East region

Projected annual and seasonal changes in temperature and rainfall for 2030 and 2070 for the South East region are given in Tables 6 and 7 for SRES scenarios. By 2030, the annual temperature increases between 0.4 and 1.1°C, summer warms between 0.4 and 1.4°C, autumn warms by 0.4 and 1.2°C, winter warms by 0.3 to 1.0°C and spring warms by 0.4 to 1.2°C. By 2070, the annual temperature increases between 0.9 and 3.5°C, summer warms by 0.9 to 4.1°C, autumn warms by 0.8 to 3.7°C, winter warms by 0.7 to 3.2°C and spring warms by 0.8 to 3.5°C. The annual rainfall decreases by 1 to 10% by 2030 and by 2 to 30% by 2070. Spring shows a strong decrease, while other seasons show moderate decreases. Tables 8 through 11 give results for the two CO_2 stabilisation scenarios, which clearly show reduced warming and smaller rainfall changes.

4.3.2 Adelaide and Mt. Lofty region

Annual and seasonal changes in temperature and rainfall for 2030 and 2070 for the Adelaide and Mt. Lofty Ranges region are given in Tables 6 and 7 for SRES scenarios. Since this region is situated near the coast, it shows less warming compared to inland or northern regions. By 2030, the annual temperature increases between 0.4 and 1.2°C, spring warms by 0.4 to 1.2°C, summer warms by 0.4 to 1.3°C, autumn warms by 0.4 to 1.2°C and winter warms by 0.4 to 1.1°C. By 2070, annual temperature show increases between 0.8 and 3.5°C, summer warms by 0.8 to 4.0°C, autumn warms by 0.8 to 3.7°C, winter warms by 0.8 to 3.4°C and spring warms by 0.8 to 3.8°C. Annual rainfall decreases by 1 to 10% by 2030 and by 3 to 30% by 2070. Summer, winter and spring show stronger decreases than autumn. CO_2 stabilisation scenarios give reduced warming and smaller rainfall changes (Tables 8 to 11).

4.3.3 Kangaroo Island

Projected annual and seasonal changes in temperature and rainfall for 2030 and 2070 for Kangaroo Island are given in Tables 6 and 7 for SRES scenarios. By 2030, the annual temperature increases between 0.3 and 1.0°C, summer and autumn warm by 0.3 to 1.1°C while winter and spring warm by 0.3 to 1.0°C. By 2070, the annual temperature increases between 0.6 and 3.0°C, summer warms by 0.6 to 3.4°C, winter and spring warm by 0.6 to 3.1°C and autumn warms by 0.7 to 3.3°C. The annual rainfall decreases by 1 to 11% by 2030 and by 3 to 30% by 2070. Spring shows a strong decrease, while other seasons indicate moderate decreases. CO_2 stabilisation scenarios give reduced warming and smaller rainfall changes (Tables 8 to 11).

4.3.4 South Australian Murray Darling Basin region

Projected annual and seasonal changes in temperature and rainfall for the South Australian Murray Darling Basin region for 2030 and 2070 are given in Tables 6 and 7 for SRES scenarios. By 2030, the annual temperature increases between 0.5 and 1.3°C, summer warms by 0.5 to 1.5°C, autumn warms by 0.5 to 1.3°C, winter warms by 0.4 to 1.3°C and spring warms by 0.5 to 1.4°C. By 2070, the annual temperature increases between 1.0 and 4.0°C, summer warms by 1.1 to 4.7°C, autumn warms by 1.0 to 3.9°C, winter warms by 0.8 to 3.8°C and spring warms by 1.0 to 4.4°C. The annual rainfall shows changes of -8 to 0% by 2030 and -25 to +1% by 2070. Spring shows a strong decrease, while other seasons show moderate decreases. CO_2 stabilisation scenarios give reduced warming and smaller rainfall changes (Tables 8 to 11).

4.3.5 Northern and Yorke region

Projected annual and seasonal changes in temperature and rainfall for 2030 and 2070 for the Northern and Yorke region are given in Tables 6 and 7 for SRES scenarios. By 2030, the annual temperature increases between 0.4 and 1.2°C, summer warms by 0.4 to 1.4°C, spring warms by 0.5 to 1.4°C and autumn and winter warm by 0.4 to 1.2°C. By 2070, the annual temperature increases between 1.0 and 3.8°C, summer warms by 0.9 to 4.3°C, spring warms by 1.0 to 4.1°C, autumn warms by 0.9 to 3.8°C and winter warms by 0.8 to 3.8°C. The annual rainfall decreases by 0 to 9% by 2030 and by 1 to 30% by 2070. Spring shows a strong decrease, while other seasons indicate moderate decreases. CO_2 stabilisation scenarios give reduced warming and smaller rainfall changes (Tables 8 to 11).

4.3.6 Eyre Peninsula

Projected annual and seasonal changes in temperature and rainfall for 2030 and 2070 for Eyre Peninsula are given in Tables 6 and 7 for SRES scenarios. By 2030, the annual temperature increases between 0.4 and 1.2°C, summer and spring warm by 0.4 to 1.3°C, autumn warms by 0.4 to 1.1°C and winter warms by 0.4 to 1.2°C. By 2070, the annual temperature increases between 0.9 and 3.5°C, summer warms by 0.8 to 4.0°C, spring warms by 0.9 to 3.8°C, autumn warms by 0.8 to 3.5°C and winter warms by 0.8 to 3.6°C. The annual rainfall decreases by 1 to 10% by 2030 and by 2 to 30% by 2070. Spring shows a strong decrease, while other seasons indicate moderate decreases. CO_2 stabilisation scenarios give reduced warming and smaller rainfall changes (Tables 8 to 11).

4.3.7 South Australian Arid Lands

Projected annual and seasonal changes in temperature and rainfall for 2030 and 2070 for the South Australian Arid Lands are given in Tables 6 and 7 for SRES scenarios. Since this regions is situated inland, it shows greater warming. By 2030, the annual temperature increases between 0.6 and 1.5°C, summer and spring warm by 0.6 to 1.7°C, and autumn and winter warm by 0.5 to 1.5°C. By 2070, the annual temperature increases between 1.2 and 4.7°C, summer warms by 1.3 to 5.1°C, spring warms by 1.3 to 5.3°C, autumn warms by 1.2 to 4.6°C and winter warms by 1.1 to 4.7°C. The annual rainfall shows changes of -9 to +1% by 2030 and -25 to +4% by 2070. Spring and winter show strong decreases, while other summer and autumn indicate moderate decreases. CO_2 stabilisation scenarios give reduced warming and smaller rainfall changes (Tables 8 to 11).

4.3.8 Alinytjara Wilurara region

Projected annual and seasonal changes in temperature and rainfall for 2030 and 2070 for the Alinytjara Wilurara region are given in Tables 6 and 7 for SRES scenarios. Since this region is located inland, it shows greater warming. By 2030, the annual temperature increases between 0.5 and 1.4°C, summer and winter warm by 0.5 to 1.5°C, autumn warms by 0.5 to 1.4°C and spring warms by 0.6 to 1.6°C. By 2070, the annual temperature increases between 1.2 and 4.4°C, summer warms by 1.1 to 4.5°C, spring warms by 1.2 to 4.9°C, autumn warms by 1.1 to 4.3°C and winter warms by 1.0 to 4.5°C. The annual rainfall decreases by 0 to 8% by 2030 and by 0 to 25% by 2070. Summer, winter and spring show strong decreases compared to changes in autumn. CO_2 stabilisation scenarios give reduced warming and smaller rainfall changes (Tables 8 to 11).

Table 6a: Range of warming (°C) by 2030 for each NRM region for SRES scenarios.

NRM regions	Annual	Summer	Autumn	Winter	Spring
South East	0.4 to 1.1	0.4 to 1.4	0.4 to 1.2	0.3 to 1.0	0.4 to 1.2
Adelaide and Mt Lofty Ranges	0.4 to 1.2	0.4 to 1.3	0.4 to 1.2	0.4 to 1.1	0.4 to 1.2
Kangaroo Island	0.3 to 1.0	0.3 to 1.1	0.3 to 1.1	0.3 to 1.0	0.3 to 1.0
SA Murray Darling region	0.5 to 1.3	0.5 to 1.5	0.5 to 1.3	0.4 to 1.3	0.5 to 1.4
Northern and Yorke	0.4 to 1.2	0.4 to 1.4	0.4 to 1.2	0.4 to 1.2	0.5 to 1.4
Eyre Peninsula	0.4 to 1.2	0.4 to 1.3	0.4 to 1.1	0.4 to 1.2	0.4 to 1.3
SA Arid Lands	0.6 to 1.5	0.6 to 1.7	0.5 to 1.5	0.5 to 1.5	0.6 to 1.7
Alinytjara Wilurara	0.5 to 1.4	0.5 to 1.5	0.5 to 1.4	0.5 to 1.5	0.6 to 1.6

Table 6b: Range of warming (°C) by 2070 for each NRM region for SRES scenarios

NRM regions	Annual	Summer	Autumn	Winter	Spring
South East	0.9 to 3.5	0.9 to 4.1	0.8 to 3.7	0.7 to 3.2	0.8 to 3.5
Adelaide and Mt Lofty Ranges	0.8 to 3.5	0.8 to 4.0	0.8 to 3.7	0.8 to 3.4	0.8 to 3.8
Kangaroo Island	0.6 to 3.0	0.6 to 3.4	0.7 to 3.3	0.6 to 3.1	0.6 to 3.1
SA Murray Darling Basin region	1.0 to 4.0	1.1 to 4.7	1.0 to 3.9	0.8 to 3.8	1.0 to 4.4
Northern and Yorke	1.0 to 3.8	0.9 to 4.3	0.9 to 3.8	0.8 to 3.8	1.0 to 4.1
Eyre Peninsula	0.9 to 3.5	0.8 to 4.0	0.8 to 3.5	0.8 to 3.6	0.9 to 3.8
SA Arid Lands	1.2 to 4.7	1.3 to 5.1	1.2 to 4.6	1.1 to 4.7	1.3 to 5.3
Alinytjara Wilurara	1.2 to 4.4	1.1 to 4.5	1.1 to 4.3	1.0 to 4.5	1.2 to 4.9

Table 7a: Range of rainfall changes in percentage by 2030 for each NRM region for SRES scenarios.

NRM regions	Annual	Summer	Autumn	Winter	Spring
South East	-10 to -1	-11 to +4	-7 to +2	-9 to 0	-19 to -2
Adelaide and Mt Lofty Ranges	-10 to -1	-11 to +6	-7 to +2	-11 to -1	-20 to -2
Kangaroo Island	-11 to -1	-10 to +2	-10 to +1	-11 to -1	-18 to -2
SA Murray Darling Basin region	-8 to 0	-10 to +9	-6 to +3	-10 to -1	-19 to -1
Northern and Yorke	-9 to 0	-9 to +7	-6 to +2	-11 to -1	-20 to -1
Eyre Peninsula	-10 to -1	-9 to +4	-10 to +3	-12 to -2	-20 to -2
SA Arid Lands	-9 to +1	-7 to +8	-7 to +10	-12 to 0	-16 to +4
Alinytjara Wilurara	-8 to 0	-10 to +5	-6 to +6	-13 to +3	-20 to +4

Table 7b: Range of rainfall changes in percentage by 2070 for each NRM region for SRES scenarios. Values above 20 are rounded to the nearest 5.

NRM regions	Annual	Summer	Autumn	Winter	Spring
South East	-30 to -2	-30 to +11	-20 to +6	-30 to -1	-55 to -5
Adelaide and Mt Lofty Ranges	-30 to -3	-30 to +17	-20 to +5	-35 to -3	-60 to -4
Kangaroo Island	-30 to -3	-30 to +7	-30 to +4	-35 to -3	-55 to -4
SA Murray Darling Basin region	-25 to +1	-30 to +27	-19 to +9	-30 to -2	-60 to -3
Northern and Yorke	-30 to -1	-25 to +22	-19 to +7	-35 to -3	-60 to -3
Eyre Peninsula	-30 to -2	-25 to +13	-30 to +8	-35 to -4	-60 to -4
SA Arid Lands	-25 to +4	-25 to +24	-20 to +29	-35 to -1	-50 to +13
Alinytjara Wilurara	-25 to 0	-30 to +14	-18 to +18	-40 to +9	-60 to +12

Table 8a: Range of warming (°C) by 2030 for each NRM region on a path that stabilizes CO_2 at 450 ppm by the year 2100.

NRM regions	Annual	Summer	Autumn	Winter	Spring
South East	0.4 to 0.8	0.4 to 1.0	0.4 to 0.9	0.3 to 0.8	0.4 to 0.8
Adelaide and Mt Lofty Ranges	0.4 to 0.8	0.4 to 0.9	0.4 to 0.9	0.3 to 0.8	0.4 to 0.9
Kangaroo Island	0.3 to 0.7	0.3 to 0.8	0.3 to 0.8	0.3 to 0.7	0.3 to 0.7
SA Murray Darling Basin region	0.5 to 0.9	0.5 to 1.1	0.4 to 0.9	0.4 to 0.9	0.5 to 1.0
Northern and Yorke	0.4 to 0.9	0.4 to 1.0	0.4 to 0.9	0.4 to 0.9	0.4 to 1.0
Eyre Peninsula	0.4 to 0.8	0.3 to 0.9	0.4 to 0.8	0.4 to 0.8	0.4 to 0.9
SA Arid Lands	0.5 to 1.1	0.6 to 1.2	0.5 to 1.1	0.5 to 1.1	0.6 to 1.3
Alinytjara Wilurara	0.5 to 1.0	0.5 to 1.1	0.5 to 1.0	0.4 to 1.1	0.5 to 1.2

Table 8b: Range of warming (°C) by 2070 for each NRM region on a path that stabilizes CO_2 at 450 ppm by the year 2100.

NRM regions	Annual	Summer	Autumn	Winter	Spring
South East	0.8 to 1.8	0.8 to 2.1	0.8 to 1.9	0.7 to 1.6	0.8 to 1.8
Adelaide and Mt Lofty Ranges	0.8 to 1.8	0.8 to 2.1	0.8 to 1.9	0.7 to 1.8	0.8 to 1.9
Kangaroo Island	0.6 to 1.6	0.6 to 1.8	0.6 to 1.7	0.6 to 1.6	0.6 to 1.6
SA Murray Darling Basin region	1.0 to 2.0	1.1 to 2.4	0.9 to 2.0	0.8 to 2.0	1.0 to 2.3
Northern and Yorke	0.9 to 2.0	0.9 to 2.2	0.9 to 1.9	0.8 to 1.9	0.9 to 2.1
Eyre Peninsula	0.9 to 1.8	0.7 to 2.0	0.8 to 1.8	0.8 to 1.8	0.9 to 2.0
SA Arid Lands	1.2 to 2.4	1.2 to 2.6	1.1 to 2.4	1.0 to 2.4	1.2 to 2.7
Alinytjara Wilurara	1.1 to 2.3	1.1 to 2.3	1.0 to 2.2	0.9 to 2.3	1.2 to 2.6

Table 9a: Range of rainfall changes in percentage by 2030 for each NRM region on a path that stabilizes CO_2 at 450 ppm by the year 2100

NRM regions	Annual	Summer	Autumn	Winter	Spring
South East	-7 to -1	-8 to +3	-5 to +1	-7 to 0	-13 to -2
Adelaide and Mt Lofty Ranges	-7 to -1	-8 to +4	-5 to +1	-8 to -1	-14 to -2
Kangaroo Island	-8 to -1	-7 to +2	-7 to +1	-8 to -1	-13 to -2
SA Murray Darling Basin region	-6 to 0	-7 to +6	-4 to +2	-7 to -1	-14 to -1
Northern and Yorke	-7 to 0	-6 to +5	-4 to +2	-8 to -1	-14 to -1
Eyre Peninsula	-7 to -1	-6 to +3	-7 to +2	-9 to -2	-15 to -2
SA Arid Lands	-6 to +1	-5 to +6	-5 to +7	-9 to 0	-12 to +3
Alinytjara Wilurara	-6 to 0	-7 to +3	-4 to +4	-10 to +2	-14 to +3

Table 9b: Range of rainfall changes in percentage by 2070 for each NRM region on a path that stabilizes CO_2 at 450 ppm by the year 2100. Values above 20 are rounded to the nearest 5.

NRM regions	Annual	Summer	Autumn	Winter	Spring
South East	-15 to -2	-17 to +6	-11 to +3	-14 to -1	-30 to -5
Adelaide and Mt Lofty Ranges	-16 to -3	-17 to +9	-11 to +2	-17 to -3	-30 to -3
Kangaroo Island	-17 to -3	-16 to +3	-16 to +2	-18 to -3	-30 to -3
SA Murray Darling Basin region	-13 to 0	-16 to +14	-10 to +5	-15 to -2	-30 to -3
Northern and Yorke	-14 to -1	-14 to +11	-10 to +4	-18 to -3	-30 to -3
Eyre Peninsula	-15 to -2	-14 to +7	-15 to +4	-19 to -3	-30 to -3
SA Arid Lands	-14 to +2	-12 to +12	-11 to +15	-19 to -1	-25 to +7
Alinytjara Wilurara	-12 to 0	-16 to +7	-9 to +9	-20 to +4	-30 to +6

Table 10a: Range of warming (°C) by 2030 for each NRM region on a path that stabilizes CO_2 at 550 ppm by 2150.

NRM regions	Annual	Summer	Autumn	Winter	Spring
South East	0.4 to 0.9	0.4 to 1.1	0.4 to 1.0	0.4 to 0.8	0.4 to 0.9
Adelaide and Mt Lofty Ranges	0.4 to 0.9	0.4 to 1.0	0.4 to 0.9	0.4 to 0.9	0.4 to 1.0
Kangaroo Island	0.3 to 0.8	0.3 to 0.9	0.3 to 0.8	0.3 to 0.8	0.3 to 0.8
SA Murray Darling Basin region	0.5 to 1.0	0.5 to 1.2	0.5 to 1.0	0.4 to 1.0	0.5 to 1.1
Northern and Yorke	0.5 to 1.0	0.5 to 1.1	0.4 to 1.0	0.4 to 1.0	0.5 to 1.1
Eyre Peninsula	0.4 to 0.9	0.4 to 1.0	0.4 to 0.9	0.4 to 0.9	0.5 to 1.0
SA Arid Lands	0.6 to 1.2	0.6 to 1.3	0.6 to 1.2	0.5 to 1.2	0.6 to 1.4
Alinytjara Wilurara	0.6 to 1.1	0.5 to 1.1	0.5 to 1.1	0.5 to 1.2	0.6 to 1.3

Table 10b: Range of warming (°C) by 2070 for each NRM region on a path that stabilizes CO_2 at 550 ppm by 2150

NRM regions	Annual	Summer	Autumn	Winter	Spring
South East	1.0 to 2.2	1.0 to 2.6	1.0 to 2.3	0.9 to 2.0	0.9 to 2.2
Adelaide and Mt Lofty Ranges	1.0 to 2.2	0.9 to 2.5	1.0 to 2.3	0.9 to 2.1	1.0 to 2.4
Kangaroo Island	0.7 to 1.9	0.7 to 2.1	0.8 to 2.0	0.7 to 1.9	0.7 to 2.0
SA Murray Darling Basin region	1.2 to 2.5	1.3 to 2.9	1.2 to 2.5	1.0 to 2.4	1.2 to 2.7
Northern and Yorke	1.1 to 2.4	1.1 to 2.7	1.1 to 2.4	1.0 to 2.4	1.1 to 2.6
Eyre Peninsula	1.1 to 2.2	0.9 to 2.5	1.0 to 2.2	0.9 to 2.2	1.1 to 2.4
SA Arid Lands	1.4 to 2.9	1.5 to 3.2	1.4 to 2.9	1.2 to 2.9	1.5 to 3.3
Alinytjara Wilurara	1.3 to 2.8	1.3 to 2.8	1.3 to 2.7	1.1 to 2.8	1.4 to 3.1

Table 11a**:** Range of rainfall changes in percentage by 2030 for each NRM region on a path that stabilizes CO_2 at 550 ppm by 2150.

NRM regions	Annual	Summer	Autumn	Winter	Spring
South East	-7 to -1	-8 to +3	-5 to +1	-7 to 0	-15 to -2
Adelaide and Mt Lofty Ranges	-8 to -1	-8 to +4	-6 to +1	-8 to -1	-15 to -2
Kangaroo Island	-8 to -1	-8 to +2	-8 to +1	-9 to -1	-14 to -2
SA Murray Darling Basin region	-7 to 0	-8 to +7	-5 to +2	-7 to -1	-15 to -1
Northern and Yorke	-7 to 0	-7 to +6	-5 to +2	-9 to -1	-15 to -1
Eyre Peninsula	-8 to -1	-7 to +3	-7 to +2	-9 to -2	-16 to -2
SA Arid Lands	-7 to +1	-6 to +6	-5 to +7	-9 to 0	-13 to +3
Alinytjara Wilurara	-6 to 0	-8 to +4	-5 to +5	-10 to +2	-15 to +3

Table 11b: Range of rainfall changes in percentage by 2070 for each NRM region on a path that stabilizes CO_2 at 550 ppm by 2150. Values above 20 are rounded to the nearest 5.

NRM regions	Annual	Summer	Autumn	Winter	Spring
South East	-18 to -3	-20 to +7	-13 to +4	-17 to -1	-35 to -6
Adelaide and Mt Lofty Ranges	-19 to -3	-20 to +11	-14 to +3	-20 to -4	-40 to -4
Kangaroo Island	-20 to -3	-20 to +4	-19 to +2	-21 to -3	-35 to -4
SA Murray Darling Basin region	-16 to 0	-19 to +17	-12 to +6	-18 to -3	-35 to -4
Northern and Yorke	-17 to -1	-17 to +14	-12 to +4	-21 to -3	-40 to -4
Eyre Peninsula	-19 to -3	-17 to +8	-18 to +5	-23 to -4	-40 to -4
SA Arid Lands	-16 to +2	-14 to +15	-13 to +18	-25 to -1	-30 to +8
Alinytjara Wilurara	-15 to 0	-20 to +9	-11 to +11	-25 to +5	-40 to +7

4.4 Trends and fluctuations in simulated temperature and rainfall for NRM regions of South Australia

In this section, we visually assess when an enhanced greenhouse signal in annual temperature and rainfall might be distinguished from natural variability in the 21st century. Figure 24 shows the simulated evolution of temperature and rainfall during the 20th and 21st century for South Australia. These are shown as anomalies from the simulated average for 1975-2004 in order to highlight the period when simulated natural variability starts to be overtaken by the enhanced greenhouse effect. However, the magnitude of regional warming is dependent upon the climate model used and the SRES scenario. Although we have used simulations from 13 GCMs to construct climate change projections for South Australia in sections 4.2 and 4.3, here we present simulations for only the eleven GCMs that used the SRES A2 scenario for consistency. IAP and MICRO-H are not included in this analysis as these models used the A1B scenario, which is significantly different to A2 scenario. Uncertainty due to differences in projected emissions is more pronounced later in the century.

Simulations of temperature in the upper panel of Figure 24 show that GFDL 2.0, BCCR and NCAR CCSM are at the upper end of warming, while CC60 is at the lower end of warming. The enhanced greenhouse signal seems to emerge from natural variability after 2000 and becomes stronger in the second-half of the 21st century. Of course, the rate of increase in the 21st century depends on the emission scenario – the B1 scenario would have given a slower rate of warming while A1FI would have given a faster rate (see Figure 15).

Model to model variations are large in simulated annual and seasonal rainfall compared to anomalies which determine the projected ranges of rainfall changes under enhanced greenhouse conditions. Simulations of rainfall in the lower panel of Figure 24 show long-term trends and variations on decadal to multi-decadal time scales. Simulated rainfall anomalies show wider ranges at the end of the 21st century. If we examine the rainfall anomalies of GFDL 2.1 very closely, it is evident that the period from 2000 to 2100 shows a decreasing trend. In addition, the rainfall anomalies of this model show fluctuations in the order of 20 to 30 years with large amplitudes, in which rainfall declines from 2000 to 2030 and from 2040 to 2070 and increases from 2030 to 2040 and from 2070 to 2090. Another example is the MPI-ECHAM5, which shows decreasing trends from 2000 to 2030 and from 2070 to 2100 and an increasing trend from 2030 to 2070. However, an overall decline in rainfall is found from the year 2000 to 2100. This indicates that wet periods can occur in the future even though there is an overall declining trend under enhanced greenhouse conditions. In particular, models such as GFDL 2.1 and CC50 show decreases from the year 2000, but other models indicate decreases in the second half of the 21st century with large decadal fluctuations. Given the large variability in rainfall and the differences between model simulations, it will be difficult to detect an enhanced greenhouse signal in annual rainfall before 2050 in South Australia. However more rigorous attribution studies are needed to separate the natural and anthropogenic trends.

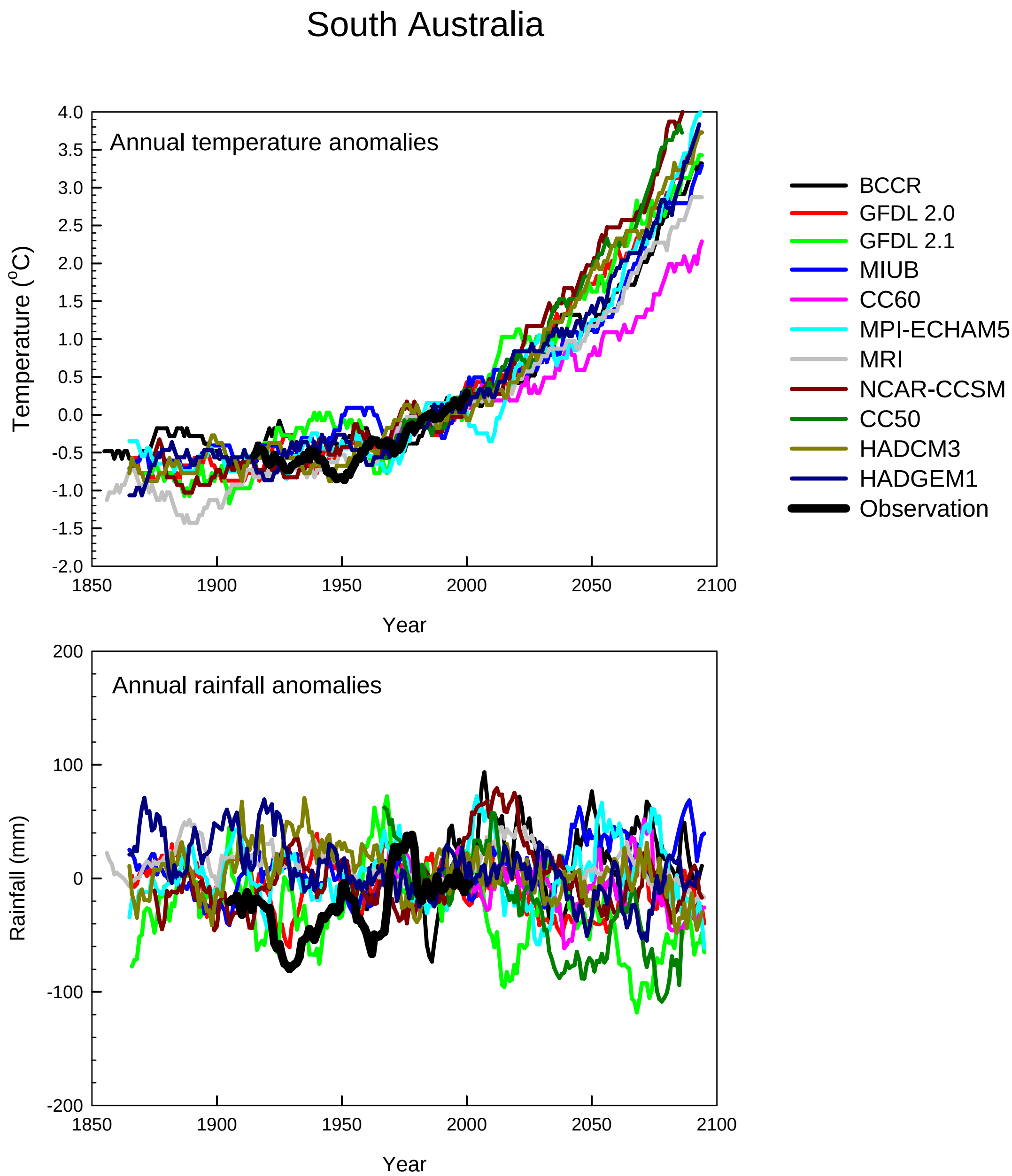

Figure 24: Observed and simulated temperature and rainfall anomalies in the 20th and 21st century simulations of 11 models for South Australia. The annual anomalies are from a 30-year period (1975 to 2004) and smoothed by an 11-year running mean.

4.4.1 South East region

Simulated temperature and rainfall variability for the South East region are shown in the left panel in Figure 25a. Simulated temperature anomalies show small model to model variations although CC60 appears to be an outlier after 2050. The warming clearly accelerates after the year 2000, indicating a detectable enhanced greenhouse signal. Simulated rainfall anomalies during the 20th and 21st centuries indicate decadal-scale variations with large differences between models. However, an overall decline in rainfall is apparent from the year 2050 which becomes dominant during the second half of the 21st century. Such a decline suggests that the greenhouse gas induced signal tends to emerge from natural variability after 2050.

4.4.2 Adelaide Mt. Lofty Ranges regions

Simulated temperature and rainfall variations for the Adelaide and Mt. Lofty Ranges region are shown in the right panel in Figure 25a. Temperature anomalies show that the signal due to increases in greenhouse gases emerges around the year 2000 and becomes strong in the second half of the 21st century, as in the South East region. The enhanced greenhouse signal in rainfall seems to emerge around 2050. In particular, models like HADGEM1 and CC50 show decreasing trends with strong decadal variability, indicating an alteration of wet and dry periods every 10-20 years.

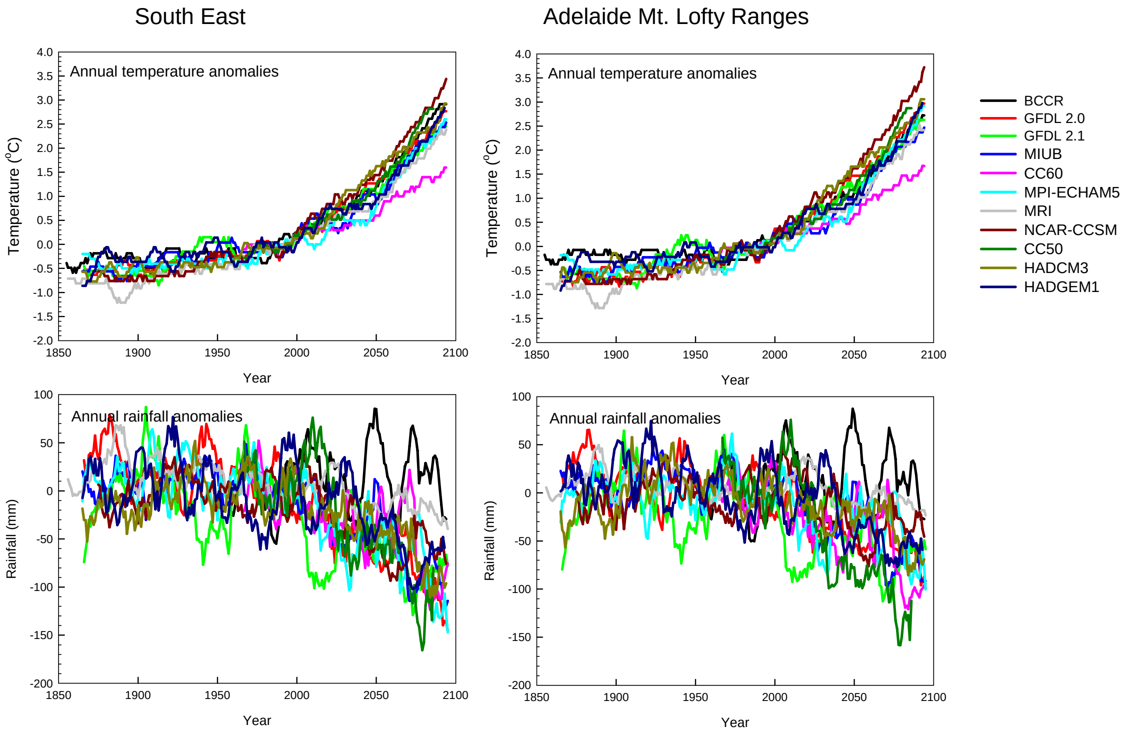

Figure 25a: Simulated temperature and rainfall anomalies from the beginning to the end of simulation of 11 models for South East and Adelaide and Mt. Lofty Ranges regions. The annual anomalies are smoothed by an 11-year running mean.

4.4.3 Kangaroo Island

Simulated temperature and rainfall variations for Kangaroo Island are shown in the left panel in Figure 25b. The strong increase in temperature simulated after 2000 represents the signal due to increasing greenhouse gases. Simulated rainfall anomalies show strong model-to-model variations with an underlying decreasing trend from 2000, which is about 50 years earlier than other regions. For example, models such as GFDL 2.1 and CC50 show strong decrease with strong decadal variability. The decreasing trend becomes stronger during the second half of the 21st century.

4.4.4 South Australian Murray Darling region

Simulated temperature and rainfall variations for the South Australian Murray Darling region are shown in the right panel in Figure 25b. Temperature anomalies show a steady increase from the year 2000 onward. Most of the models show no clear trend in rainfall anomalies. With the exception of BCCR, most models show a slight decreasing trend after 2050.

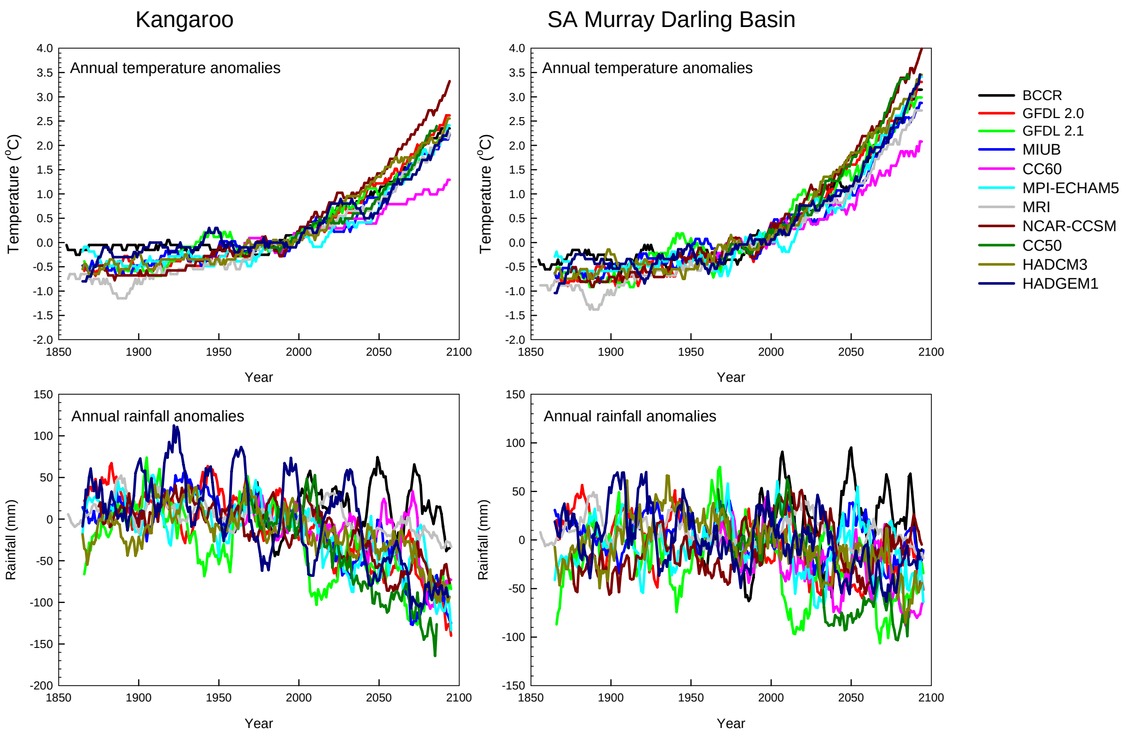

Figure 25b: Simulated temperature and rainfall anomalies from the beginning to the end of simulations of 11 models for Kangaroo Island and South Australian Murray Darling Basin regions. The annual anomalies are smoothed by an 11-year running mean. Note the difference in vertical scales for rainfall.

4.4.5 Northern and Yorke

Simulated temperature and rainfall variations for the Northern and Yorke region are shown in the left panel in Figure 25c. Rapid increases in temperature after 2000 represent the enhanced greenhouse signal. Rainfall anomalies show strong decadal variations with a moderate decrease under enhanced greenhouse conditions from around 2050. Models such as BCCR, MIUB and GFDL 2.1 show large variations with an overall decreasing trend.

4.4.6 Eyre Peninsula

Simulated temperature and rainfall variations for Eyre Peninsula are shown in the right panel in Figure 25c. The enhanced greenhouse signal in temperature emerges from natural variability after the year 2000. Simulated rainfall shows large model-to-model variations with an overall decrease from about 2000, similar to Kangaroo Island. It seems that southern regions may see the emergence of a greenhouse signal in rainfall earlier than northern regions.

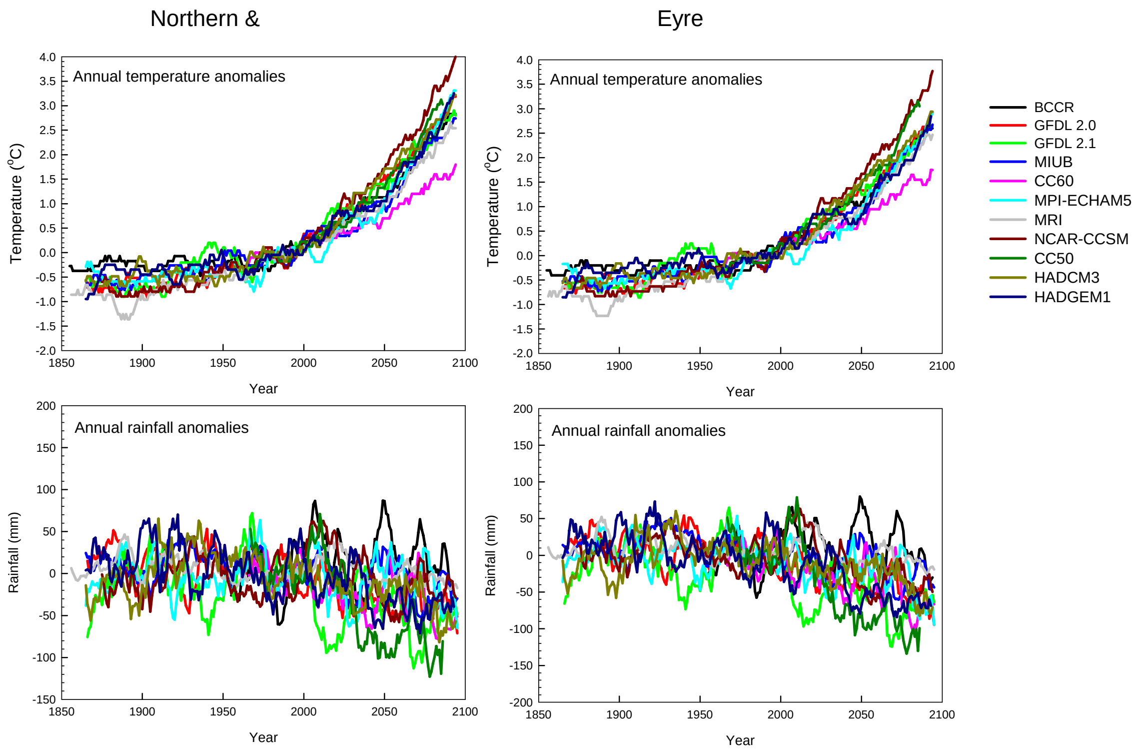

Figure 25c: Simulated temperature and rainfall anomalies from the beginning to the end of simulations of 11 models for Northern & Yorke region and Eyre Peninsula.. The annual anomalies are smoothed by an 11-year running mean. Note the difference in vertical scales for rainfall.

4.4.7 South Australian Arid Lands

Simulated temperature and rainfall variability for the South Australian Arid Lands region are shown in the left panel in Figure 25d. Since this region is located inland, greater warming is simulated, so the enhanced greenhouse signal appears to emerge from natural variability around 1950. Rainfall shows strong decadal variations. Some models show moderate increases (e.g MUIB) and some show decreases (e.g, GFDL 2.1), but most of the models do not indicate a clear trend during the 21st century. Therefore the enhanced greenhouse signal in rainfall would be difficult to detect.

4.4.8 Alinytjara Wilurara region

Simulated temperature and rainfall variability for the Alinytjara Wilurara region are shown in the right panel in Figure 25d. Temperature anomalies in this region are similar to the South Australian Arid Lands, so the enhanced greenhouse signal appears to emerge from natural variability around 1950. Rainfall shows a slight decrease after 2050 with large model to model variations. Therefore the enhanced greenhouse signal in rainfall would be difficult to detect.

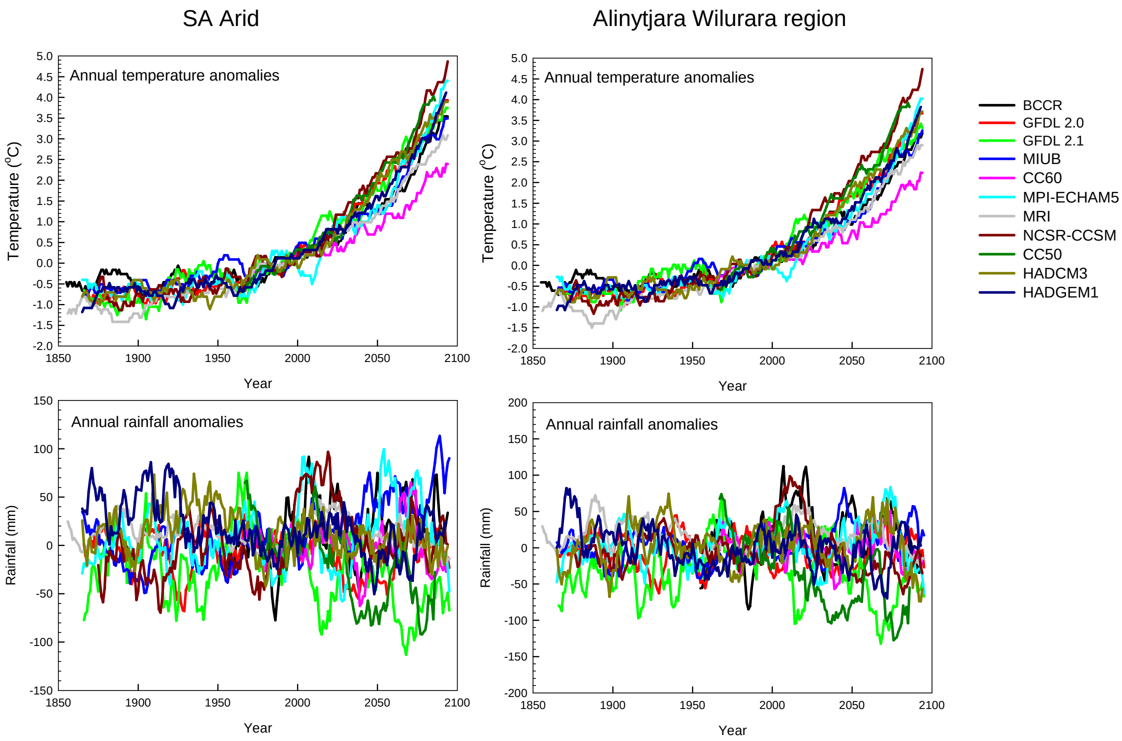

Figure 25d: Simulated temperature and rainfall anomalies from beginning to end of simulations of 11 models for South Australian Arid Lands and Alinytjara Wilurara regions. The annual anomalies are smoothed by an 11-year running mean. Note the difference in vertical scales for rainfall .

In summary, the greenhouse-induced signal in temperature emerges from natural variability around the year 2000 in most regions, but emerges by around 1950 in the Alinytjara Wilurara region the South Australian Arid Lands since these regions warm faster. In case of rainfall, uncertainty due to differences between models is more pronounced later in the century. Large decadal fluctuations in rainfall make it difficult to detect an enhanced greenhouse signal until after 2050, although the signal emerges by around 2000 in southern regions like Kangaroo Island and the Eyre Peninsula. Spring shows largest decreases in rainfall. Significantly reduced warming and rainfall changes are projected for the two CO_2 stabilisation scenarios.

5. MANAGING CLIMATE RISK

The two broad strategies that societies have at their disposal for avoiding or reducing the adverse effects of climatic changes are mitigation and adaptation. Mitigation refers to the reduction of human emissions of greenhouse gases, which constrains the rate and magnitude of future climate change. In contrast, adaptation builds resilience and seeks to reduce the vulnerability of human and natural systems to climate change, enabling them to better cope. Deciding upon what mitigation and adaptation actions are justified and required to provide sufficient protection to environmental systems, however, is a non-trivial task. Increasingly the challenge of addressing climate change is being presented as an exercise in risk management.

The previous CSIRO report for the South Australian government introduced a framework for risk assessment and management of climate change and its consequences (McInnes et al., 2003b). Risk was defined as a combination of two factors:
• the probability that an adverse event will occur,
• the consequences of that adverse event (USPCC, 1997).

This interaction was subsequently expressed as:

Risk = probability × consequence

The risk, therefore, increases as the consequences grow and/or as the likelihood of a particular consequence rises (Figure 26). At one end of the risk spectrum lie consequences that are of marginal impact and unlikely to occur, resulting in low risk. At the opposite end lie high probability, catastrophic consequences. Though this is a simple conceptual model of risk, much of the recent work regarding risk assessment and management of climate change has focused on these two components of risk: quantifying the likelihood of different magnitudes of climate change and identifying consequences of critical concern.

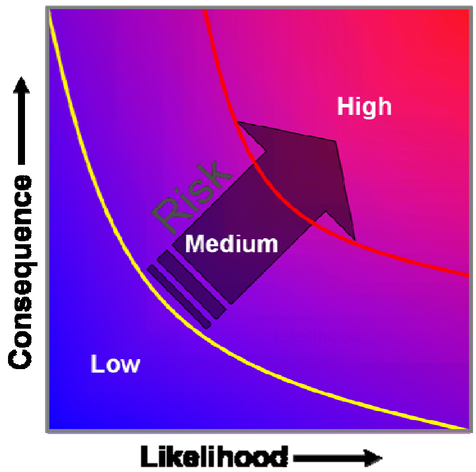

Figure 26: Conceptual model of risk

This chapter summarises recent developments in the application of risk assessment and management to the issue of climate change. First, evidence demonstrating the penetration of risk management into assessment and decision-making is discussed. This is followed by a summary of recent publications in the peer-reviewed literature regarding the application of risk assessment and management methods in the quantification of the impacts of climate change to Australia and South Australia (for a recent overview of impacts see also Preston and Jones, 2006). Finally, the role of risk perception in communication is discussed along with key knowledge gaps and barriers to further applications of risk assessment and management.

5.1 The rise of risk management

Risk assessment and management are standard tools used across sectors to aid in decision-making to enhance positive outcomes and reduce negative outcomes. It is now routinely discussed and increasingly utilised as a guiding framework for assessing the consequences of climate change and evaluating potential responses, both internationally and in Australia (AGO, 2006). A review of the international peer-reviewed literature indicates that risk assessment and management were first mentioned in the context of climate change as early as 1992. However, a sharp increase was detected post-2000 as shown in Figure 27, fuelled perhaps in part by the Third Assessment Report of the IPCC (2001), which identified tools for risk assessment and management as priority research needs.

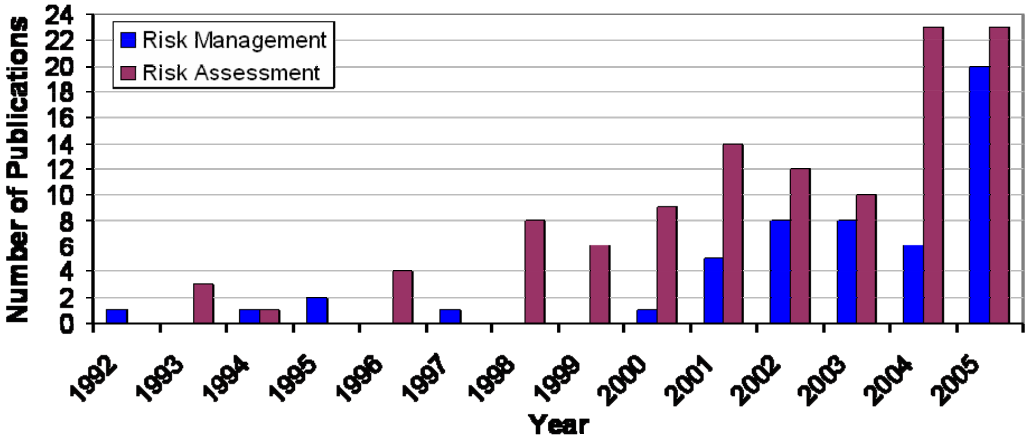

Figure 27: Number of peer-reviewed publications appearing in the ISI Web of Science data base corresponding with key word searches of risk assessment and global warming/climate change and risk management and global warming/climate change. Database accessed 13 April, 2006.

In response, a number of guidance documents have emerged for risk assessment and management of climate change and its downstream consequences (Table 12). A primary focus of these documents, particularly recently, has been in the identification of adaptation options that may reduce vulnerability of exposed systems to climate change. For example, the *UNDP Adaptation Framework* (Lim et al., 2005), provides detailed guidance on executing stakeholder-driven risk assessments of both current and future climate risks, and designing appropriate response strategies. *Assessments of Impacts and Adaptations to Climate Change (AIACC) in Multiple Regions and Sectors* was launched in 2002 to provide research-based vulnerability assessment and adaptation in developing countries. More recently, the United Kingdom Climate Impacts Program (UKCIP) released its framework for risk-based adaptation planning, entitled *Climate Adaptation: Risk, Uncertainty and Decision Making* (Willows and Connell, 2003).

Recently, the reduction of climate risk via adaptation measures has also featured prominently in the policy arena. The Australian government's National Climate Change Adaptation Programme represents a $14.2 million investment over four years which aims to commence preparing Australian governments and vulnerable industries and communities for the unavoidable impacts of climate change. The Natural Disaster Mitigation Program emerged in response to the 2002 report *Natural Disasters in Australia: Reforming Mitigation, Relief and Recovery Arrangements* (DOTARS, 2004), which recommended structural reform to shift the focus of disaster management toward risk-based management involving anticipatory, rather than reactive, actions. Similarly, the National Water Initiative includes consideration of the risks of climate change in the States and Territories in preparing water plans. The Council of Australian Governments has committed itself to the development of a National Adaptation Framework to promote nationally coordinated work on adaptation "*to better prepare Australia for the inevitable impacts of climate change and to provide business with an informed and more certain environment for investment decisions*" (COAG, 2006). Meanwhile, South Australia, Victoria, New South Wales and Queensland all mention risk assessment or risk management as priority activities within their state climate change strategies.

Table 12: Guidelines documents for climate change risk management.

1)	IPCC Technical Guidelines for Assessing Climate Change Impacts and Adaptations
2)	U.S. Country Studies Program (USCSP)
3)	UNEP Handbook on Methods for Climate Change Impact Assessment and Adaptation Strategies
4)	UNDP Adaptation Policy Framework (APF)
5)	Assessments of Impacts and Adaptations to Climate Change in Multiple Regions and Sectors (AIACC)
6)	Guidelines for the preparation of National Adaptation Programmes of Action (NAPA)
7)	United Kingdom Climate Impacts Programme (UKCIP) Climate Adaptation: Risk, Uncertainty and Decision Making[1]
8)	United Kingdom Climate Impacts Programme (UKCIP) Costing the Impacts of Climate Change in the UK [1]
9)	Sustainable Regional and Urban Communities Adapting to Climate Change
10)	Australia/New Zealand Risk Management Standard[2]
11)	Australian Greenhouse Office Risk Management Guide for Business and Government

[1]free registration required for viewing
[2]fee applies
See also the UNFCCC Toolkit for a comprehensive listing of assessment tools

5.2 Recent applications of risk assessment and management: application in Australia

One of the more recent developments on risk assessment and management in Australia is a national vulnerability assessment produced for the Australian Greenhouse Office entitled *Climate Change Risk and Vulnerability: Promoting an Efficient Adaptation Response in Australia* (Allen Consulting Group, 2005*)*. The report uses a vulnerability framework to prioritise the vulnerability of different biophysical and economic sectors to the effects of climate change, integrating the concepts of exposure, sensitivity and adaptive capacity. Priority sectors included ecosystems and biodiversity, agriculture, water supply, settlements and emergency services, and energy, while the priority regions included Cairns and the Great Barrier Reef, Murray Darling Basin, and southwest Western Australia. Although specific consequences and associated likelihoods were not explicitly identified in the report, it provides a basis for focusing future risk assessment efforts, and highlights potential targets for adaptation investments to reduce future vulnerability. This vulnerability assessment has been followed by a guidance document to assist government and business to begin thinking about climate and risk management (AGO, 2006).

In recent years, a number of quantitative risk assessments have also focused on specific sectors, specifically the coastal zone, agriculture, and water resources. Further discussion of risk assessment and management work in these areas is provided below.

5.2.1 Agriculture

Risk assessments methods have been applied in Australia's agriculture sector for several years. Howden et al. (1999) quantified the effects of climate change on wheat production for 11 sites around Australia based upon "likely" scenarios of climate change derived from multiple climate models and emissions scenarios. Subsequently, Howden and Jones (2001) estimated the risk of climate change to national wheat production, quantifying the likelihood of different impacts considering a range of different climate futures. More recently, Luo et al. (2005) assessed the risk of climate change exceeding critical yield thresholds for wheat production at Roseworthy, South Australia, providing information on the likelihood of regional farm failure. Howden and Hayman (2005) examined the probability of shifts in Goyder's line in South Australia, concluding there was a small probability of the line shifting north, but a larger probability of it shifting south, increasing pressure on marginal cropping zones. Howden et al. (1999) also performed risk assessments of climate change by the year 2100 for 700 ppm on wheat yields, nitrogen content, and gross margins in Minnipa, SA (Figure 28), with the most likely responses of +7 to +18%, -2 to -8%, and +5 to +28%, respectively. Howden and Jones (2001) also included Minnipa in their wheat risk assessment. They found mean regional productivity increased by about 6% but with an 18–25% chance of being below current levels (Figure 29). The mean value of regional production increased by $10-15 million per year with a 25–27% chance of being below current levels.

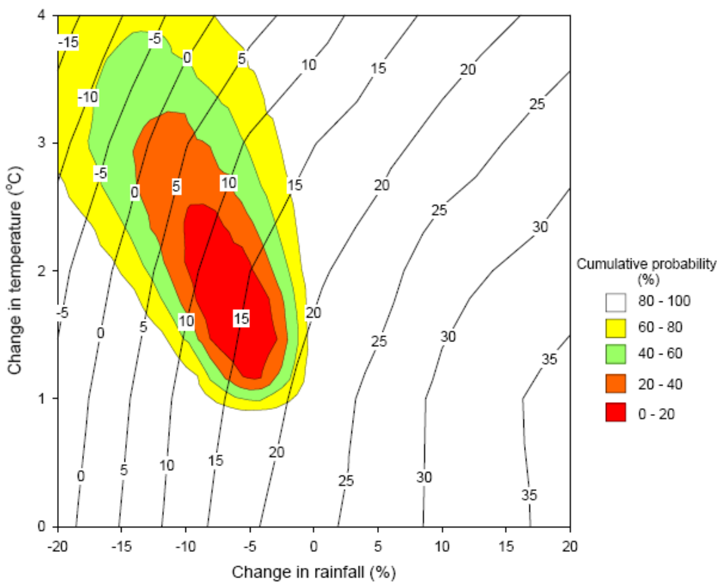

Figure 28: Likely climate change (with cumulative probability shown in colour) and wheat yields (with % change shown on contour lines) in 2100 in Minnipa, SA (Howden et al., 1999).

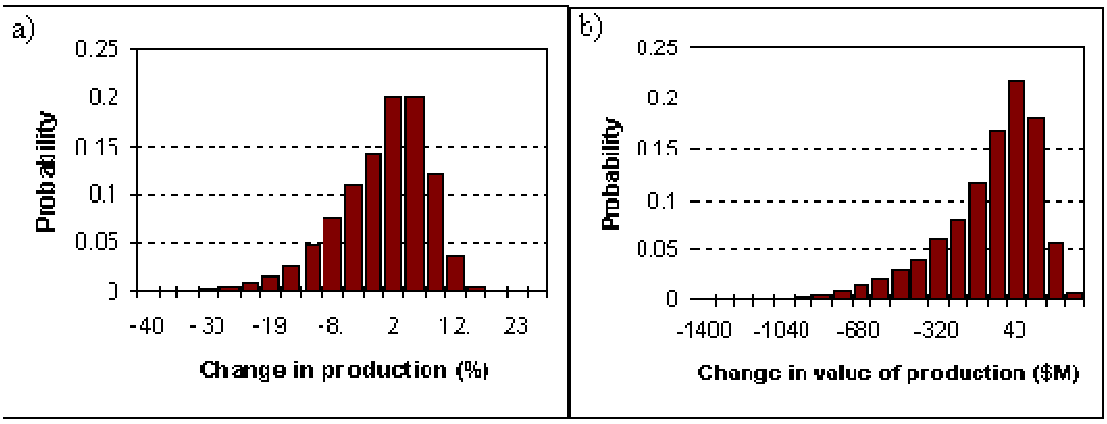

Figure 29: Probabilities associated with a range of changes in a) wheat production and b) production values in Minnipa, SA in 2070 (Howden and Jones, 2001).

5.2.2 Coastal impacts

Much of the work targeting the risk of climate change to the coastal zone has focused on quantifying the risk associated with specific natural hazards, such as storm surge return periods. McInnes et al. (2003a) compared changes in storm surges of different return periods at present and in response to a future scenario of climate change for the city of Cairns in northern Queensland. Higher sea-levels and more intense storms resulting from climate change by 2050 increased storm surge heights by approximately 20%, greatly expanding the area likely to be flooded. More recent work on storm surge in Gippsland, Victoria concluded that by 2070, climate change would increase 1-in-100 year storm surge heights by 38-46%, although most of this increase was due to sea-level rise (McInnes et al., 2005). Recently, probabilistic methods have been applied in quantifying beach erosion due to sea-level rise. Cowell et al. (2006), used stochastic modelling to generate a probability density function of beach erosion at Manly Beach, New South Wales, based upon uncertainties in a number of key variables. Such analysis provides greater information to decision-makers regarding climate change impacts over traditional assessment tools such as the Brunn rule (Zhang et al., 2004).

5.2.3 Water Resources

Perhaps the area where risk assessment and management tools have been most broadly applied is that of water resources. Jones and Page (2001) conducted a risk assessment of climate change on the Macquarie catchment in NSW, based upon two critical thresholds: environmental flows to the waterbird nesting area of the Macquarie marshes falling below 350GL for 10 consecutive years; and irrigation allowances falling below a level of 50% allocation for 5 consecutive years. By 2030, both thresholds had a 20–30% likelihood of being exceeded in a drought-dominated climate, less than 1% in a normal climate, and much less than 1% in a flood-dominated climate (Figure 30). By 2070 these risks were found to be 70–80%, 35–50% and 10–20%, respectively. This work has contributed to policy surrounding environmental flow regimes and investigations are underway to ascertain if the decadal shifts in climate are similar to those experienced in south-western Western Australia.

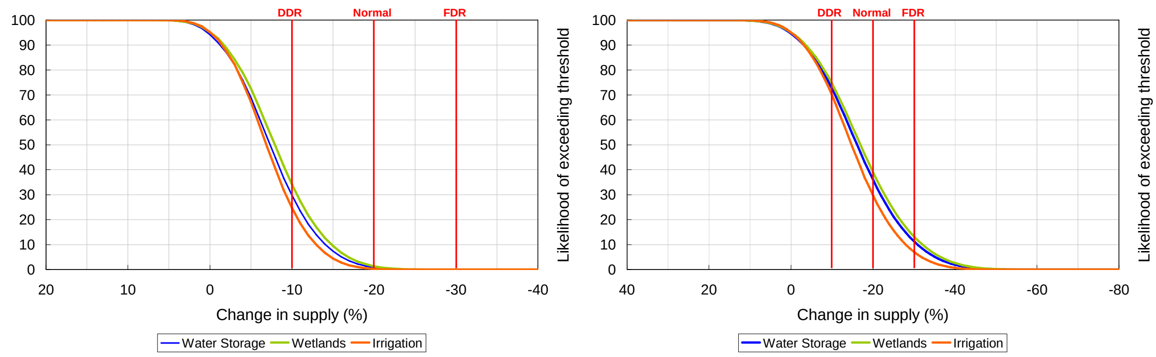

Figure 30: The likelihood of exceeding critical thresholds for irrigation allocations and environmental flows as a function of the decadal rainfall regime in 2030 (left) and 2070 (right) (Jones and Page, 2001). DDR is a drought dominated regime and FDR is a flood dominated regime.

CSIRO and Melbourne Water recently completed a joint study of climate change risks on Melbourne's Water Supply (Howe et al., 2005). Detailed quantitative analysis of the impact of reduced streamflows found that average long-term streamflows potentially would be reduced by 3 to 11% by 2020, and 7 to 35% by 2050. Results of the "mid-range" climate change scenario project revealed a 4% reduction in water supply by 2020, and 9% reduction by 2050. As a result of the study, a number of adaptation strategies are being implemented including expanding storage and water treatment capacity.

Beare and Heaney (2002) investigated the joint impacts of climate change and salinity on the hydrological cycle of the Murray-Darling Basin (MDB), considering how different trends may affect economic and environmental outcomes. There were slight to moderate reductions in water availability for dryland agriculture and moderate to substantial reductions in surface water flows (10–25% by 2050, 16–48% by 2100). The economic analysis showed costs to agriculture of $0.7–1.2 billion by 2100, but adaptation strategies, such as improvements in water use efficiency or water trading, had the potential to reduce the costs by almost 60%. A study extending the results from the Macquarie catchment to the southern MDB concluded that reductions in flow due to climate change were highly likely (Jones et al., 2002). Collectively, these studies have led to the incorporation of climate change into planning for the MDB.

Jones and Durack (2005) developed a simple hydrological model to estimate future changes in mean annual runoff for Victoria's catchments. In almost all cases, individual climate scenarios and models projected a decrease in annual runoff by 2030 (Figure 31). Projected reductions in runoff from different models were skewed, indicating declines in runoff were biased toward smaller reductions. For median global warming, reductions of 0 to 30% were simulated. However, worst-case scenarios for each catchment suggested the potential for significantly larger impacts.

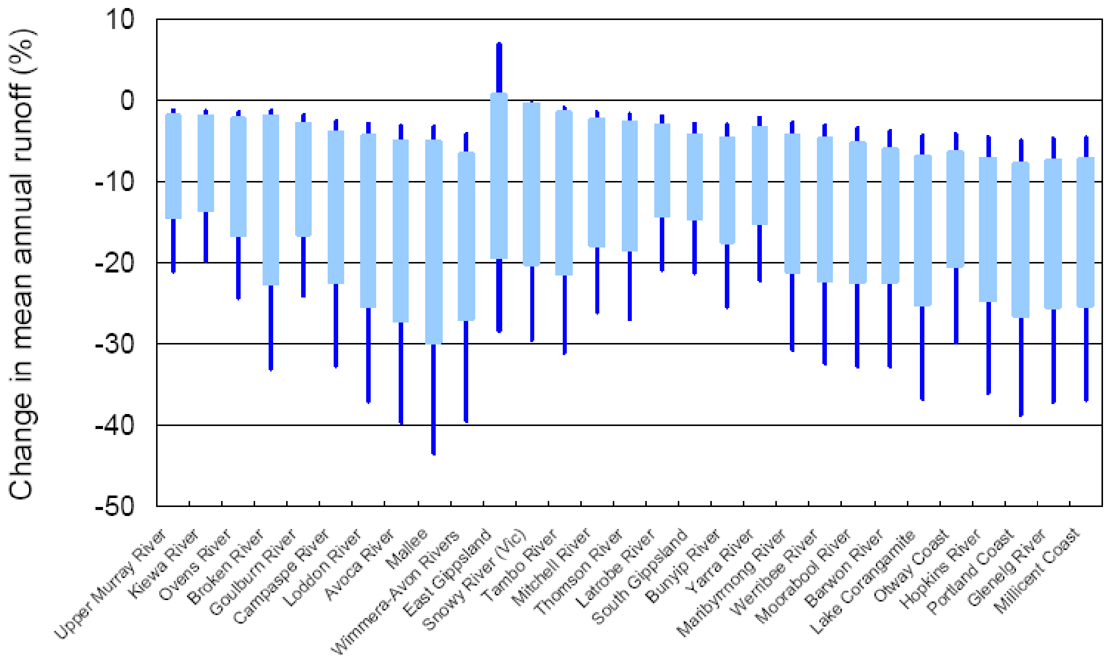

Figure 31: Range of possible change in runoff for 2030 across Victoria's major surface water management areas. The vertical lines measure the total range of change from ten climate models with a range of global warming of 0.54–1.24°C. The central boxes project the range of change at a 0.85°C (median) global warming (Jones and Durack, 2005).

5.3 Synthesis of risk assessments studies

The various aforementioned applications of risk assessment and management tools at the international to local level suggest some general trends with respect to how scientists and decision-makers are coping with uncertainty. Three of these trends are perhaps most critical:

I. ***Stakeholder Participation*** – Scientists and stakeholders are increasingly partnering to shape the analysis, the outcomes, and the manner in which they are communicated.

II. ***Quantification of Risk*** – Recent studies have attempted to incorporate a range of plausible uncertainty in climate change and system responses in order to acquire information on the likelihood of particular outcomes.

III. ***Decision-Making*** – Stakeholders are using information about future climate risk to make decisions about current management activities. This is a clear indication that decision-makers are increasingly capable of decision-making under uncertainty, and anticipatory adaptation of climate change is already underway.

Overall, it appears that risk assessment and management are gradually becoming a mainstream application in addressing climate change. Nevertheless, considerable work remains in formalising and standardising risk assessment and management methods, and mainstreaming climate change risk management into routine decision-making on behalf of the public and private sector. Ways in which this might be done are described in the report by AGO (2006), which was presented in two workshops in Adelaide on 31 May 2006.

5.4 Risk communication and public perception

Motivating action on climate change, whether it comprises efforts to reduce greenhouse gases or adaptation options to reduce vulnerability, depends upon people's awareness and perceptions of the issue – the messages they hear and how they subjectively interpret that information. Assessments of public opinion consistently find that a significant majority of the population is both aware of global warming and, albeit to a lesser extent, concerned. In Australia, concern for global warming would appear to be quite high, on par with concern for nuclear proliferation and international terrorism (Figure 32). Nevertheless, working in the United States, Sterman and Sweeney (2002) have found that when it comes to action, many individuals support a "wait-and-see" approach with respect to climate policy.

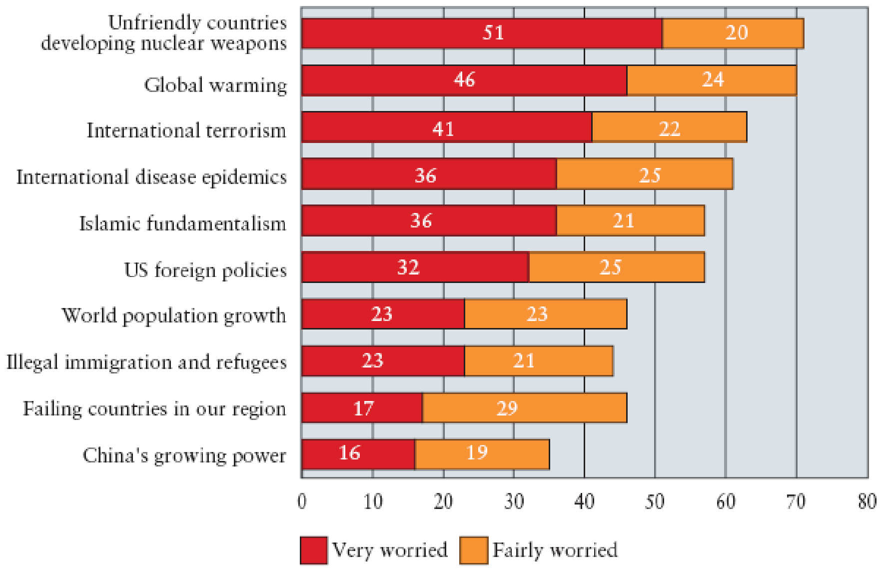

Figure 32: Percentage of Australian population "worried" about various national issues (Cook, 2005).

Recent work on climate change communication has identified persistent challenges in delivering clear messages to the public (Moser and Dilling, 2004). Some of these include:

I. Diverse communicators (e.g., scientists, policy-makers, the media) with varying credibility (Boycoff and Boycoff, 2004; Cameron, 2005)

II. Confusion about how the climate system works (Sterman and Sweeney, 2002)

III. Difficulty in identifying specific threats associated with climate change (Ohe and Ikeda, 2005)

IV. Low prioritisation of climate change relative to more immediate concerns (Moser and Dilling, 2004)

V. Limited understanding of how individuals' actions can reduce risk (CCSA, 2005).

Also, there is clearly significant variability among populations and individuals with respect to subjective perceptions of the costs and benefits of climate change, which arise from a range of social, political, economic and geographic factors. Public opinion polls commonly find that individual's belief in, and concern for, global warming is closely tied to associations with political or economic ideology (Leiserowitz, 2003). Palutikof et al. (2004) found residents of Scotland had more favourable perceptions of hot and dry summers than residents of England, a phenomenon believed to be related prior experience with climate and weather. Even

Hollywood has the power to influence awareness and perceptions of the climate change. Polling of Americans and Germans who watched the movie *The Day After Tomorrow* suggests that the movie increased individuals' perceptions of climate change as an abrupt phenomenon, and reinforced perceptions of the need to act (Leiserowitz, 2004; Reusswig et al., 2004). As a consequence, effective risk communication about climate change requires messaging that is sensitive to the values, experiences, and perceptions of the target audience.

To assist in overcoming communication challenges, various tools are increasingly emerging to provide climate change information, not only to assist in stakeholder education, but particularly to assist in decision-making. Climate scenario generators such as MAGICC/SCENGEN and OZCLIM are available at no cost, and can be used to explore potential changes in global and regional climate under a range of assumptions. SimCLIM is an open-framework modelling system for integrated hazard and climate impact analysis. In the United States, the Consortium for Atlantic Regional Assessment was recently developed as an internet-based tool providing information on historical and future climate and land-use (Dempsey and Fisher, 2006). The UKCIP's Adaptation Wizard is a simple on-line tool that leads users through the process of understanding climate change through to making decisions about adaptation, while the Scenario Gateway provides online access to UK climate scenarios. In conjunction with the risk assessment and management frameworks presented earlier in Table 12, these tools create the capacity for stakeholders to begin assessing risk and identifying decisions to reduce vulnerability to climate change. However, Dempsey and Fisher (2005) also suggest that a number of barriers persist in providing climate information to the public – the creation of communication tools does not necessarily lead to their uptake and use. This has also been observed in the UK, where local governments reported poor access to local information on climate change despite the fact that such materials were readily available through UKCIP (Demeritt and Langdon, 2004).

One of the most significant advances in the communication of climate change and its associated impacts is the expansion in the use of probabilities for communicating future climate changes. Although probabilities can be an aid in decision-making, it remains unclear to the extent to which probabilities are beneficial and under what conditions (Dessai and Hulme, 2003). One of the challenges relates to differences in how diverse individuals and populations interpret different estimates of likelihood. Put simply, even when given quantitative estimates of risk, individuals may interpret them in different ways. Severe consequences, such as natural disasters, are perceived to be of lower probability than minor consequences, even when the quantitative probability of the two events is identical (Patt and Schragg, 2003; Patt and Dessai, 2005). For example, individuals who watched *The Day after Tomorrow* were more likely to perceive climate change as a potentially violent and abrupt phenomenon, but, subsequently, one of lower probability (Reusswig et al., 2004). As a result, in communicating risk, it is important to isolate consequence and probability (Manning, 2003). This suggests that while scientists increasingly express the climate change and its consequences in probabilistic or risk terms, and this is potentially of greater value to stakeholders, it creates new challenges for risk communication to avoid misinterpretations.

5.5 Knowledge gaps and barriers

Despite the many aforementioned advances in the application of risk assessment and management to climate change, a number of challenges remain in both the execution of risk assessment studies and the application of that information to improve decision-making about climate change adaptation and mitigation. A few key challenges are discussed further below.

5.5.1 Scientific uncertainty

Persistent scientific and technical uncertainty regarding climate change continues to pose challenges for risk assessment and management, particularly at the local level. Probabilistic tools have assisted in dealing with this uncertainty, but further refinement and uptake of such tools is required. Data availability and quality can severely limit the scope of assessment activities. In addition, there are issues with respect to translating scientific information and uncertainty into adaptation strategies to reduce risk and vulnerability. For example, although risk assessment methods can be used to estimate the likelihood of different climate and system outcomes, as yet there are no standard benchmarks that can be used for planning and design purposes. What is an appropriate margin of safety, hedge, or level of precaution when planning for climate change? In the absence of such benchmarks, decision-makers have little objective guidance in the interpretation of the uncertainty of future climate changes and system sensitivities. This is likely to result in highly divergent risk management criteria among different entities, which may ultimately lead to social, political, and legal conflict.

5.5.2 Uncertainty in adaptation costs and benefits

Although adaptation is widely recognised as a critical strategy for reducing the risk of the adverse effects of climate change, assessment of its costs and benefits has proven difficult. Adaptation mechanisms are frequently discussed in the assessment of climate change impacts, but they are rarely quantified. At present, the only developed methods for assessing the potential benefits of adaptation policies are economic cost-benefit and cost-effectiveness analysis (Marsden Jacobs, 2004). Though established economic tools, they remain controversial and are difficult to rigorously apply in the context of climate change, particularly when non-market impacts are involved (Morgan et al., 1999). Furthermore, incorporating adaptation into assessments of climate risks often necessitates knowledge regarding adaptive capacity years or decades into the future, which cannot be known with confidence (Patt et al., 2005).

5.5.3 Resources for assessment and adaptation

Although the international community has given consideration to mechanisms for providing technical and financial support to facilitate climate change adaptation among developing nations (Brouwer and Aerts, 2006), it is increasingly apparent that developed nations face challenges as well. Climate change impacts are experienced at the local level, and as such, it is here where communication and adaptation strategies may be most effectively deployed. However, local governments are often quite limited with respect to technical capacity for vulnerability and risk assessment as well as capital funds for adaptation projects. Nevertheless, the burden on local governments to manage climate risk is likely to grow with continued climatic and socio-economic change. Local governments may benefit from the creation of effective partnerships among local governments and/or with state and federal government, mainstreaming adaptation into existing decision processes, and developing novel financing mechanisms to enhance adaptation resources.

5.5.4 Social and institutional barriers

Just as Dempsey and Fisher (2005) found that the existence of communication tools does not necessarily lead to their uptake and use, having the potential and capability to manage risk through adaptation does not necessarily lead to their implementation. The communication challenge continues to hinder action by the public and policy-makers. Furthermore, barriers to action are often a product of operational characteristics of public and private institutions. Institutions may fail to assess or respond to climate risk due to a perceived lack of mandate or policy guidance, lack of understanding of the issue among leadership, or low prioritisation of the issue relative to other commitments. Expanding risk-based decision-making on climate change is, therefore, dependent on fostering institutional education, adaptive capacity, and decision authority.

6. FUTURE DIRECTIONS FOR CLIMATE CHANGE SCENARIOS

6.1 The need for fine resolution climate change projections

There is strong demand for climate change projections to be as locally specific as possible. In general, impacts occur at the local scale, and many of the impact assessment models, particularly for agriculture and hydrology, require locally specific climate data as inputs. Since climate is strongly influenced by topographical variations, in regions where these are important (such as in the southeast of South Australia), the coarse resolution information generated by climate models will be lacking in detail. However, not all decisions on appropriate adaptation action require fine resolution climate data. For example, it is more critical to invest in building an understanding of the response of species to regional climate projections or to understand impact on ecosystem function, particularly in the arid zone, than it is to have fine resolution climate change projections.

Producing fine resolution climate information based on coarse resolution climate model output is known as downscaling. There are three methods commonly used in downscaling:

- ***Simple interpolation****:* a fine resolution observed climate database (gridded or individual stations) is employed in conjunction with simulated climate changes interpolated from the coarse grid of the climate models. This approach has the advantage of being very simple to apply, and this facilitates the consideration of multiple emission scenarios and model results (i.e. good exploration of uncertainty). It can be readily applied for the projected climate changes given in this report, and it is also the method employed within CSIRO's OzClim scenario generator. This approach, however, is not as suitable for representing more complex aspects of climate change.

- ***Dynamical downscaling****:*detailed information is produced through the application of a fine resolution regional climate model or a stretched-grid global climate model that has fine resolution in the region of interest. The models are driven by the boundary conditions from global climate models. This approach has the advantages of producing climate change information that reflects local climate forcing such as local topography, and fine resolution weather features such as extreme rainfall events. However, dynamical downscaling results are not often routinely available for a given region, and undertaking a new experiment is a large computational exercise. It is also usually only feasible to apply dynamic downscaling to *one* of the available host global climate models. This approach thus has the disadvantages of being expensive, and being limited in its ability to represent uncertainty due to inter-model differences in simulated climate change. Finally, fine resolution models will still have biases in their ability to represent current climate, and thus when applying their results, adjustments (such as the use of the simple interpolation method described above) will still be required.

- ***Statistical downscaling****:* local climate change information is produced by applying observed relationships between broad-scale and local-scale climates to the output of the climate models. A range of approaches are available, and the best approach will depend on the particular application. This approach has many of the advantages of dynamical downscaling, but with less expense and with an ability to reach the spatial scale of individual stations (usually without current climate biases). However there are disadvantages with this approach. One needs to make the assumption that the relationships employed to predict local climate from broad-scale climate information will remain the same under enhanced greenhouse conditions. This may or may not be true, and necessitates careful selection of the predictor variables in each case (Charles et al. 1999). Although less computationally expensive, the fact that it requires expert knowledge to apply appropriately in a given case restricts its availability. Finally, because this approach has rather specialised requirements regarding climate model output, the ability to represent multiple model results (a key uncertainty) is potentially limited.

For any particular regional impact study, a decision needs to be made as to whether downscaling may be required and if so, whether statistical or dynamical downscaling would be best. One may also apply statistical downscaling to further enhance the output of dynamical downscaling. This decision will depend on the particular case in hand, but in making this decision, the principle is to maximize the relevance of the scenarios used to the research or policy question being addressed while staying within resource limitations (Mearns et al., 2003).

The key issue is that it is very difficult to have fine resolution downscaled scenarios while continuing to represent the uncertainty stemming from the different global climate models. Practical limitations are such that fine resolution scenarios based on either statistical or dynamical downscaling will be based on just one model or a limited set of models. Thus exclusive use of downscaled information sets aside a major uncertainty in regional climate change projection.

The role of fine resolution information should then be as follows:

1. As an additional future climate change projection which can be used along side the changes simulated by the coarse resolution host model, and those simulated by other global climate models. This would be in cases where, although the fine resolution information is arguably more realistic, the coarse resolution GCM projected changes are nevertheless plausible, and that ignoring the inter-model differences at the GCM scale could not be justified.
2. For exclusive use in climate change projections when required. This would be in circumstances where coarse resolution GCM information is judged as inappropriate, such as when small scale topographic effects are very strong or where extreme weather (particularly precipitation or winds) associated with extreme synoptic events is under examination.

6.2 Alternative approaches for future climate change scenarios

The current methodology used to produce climate change scenarios presents the range of possible future climate conditions with no information about the most likely values. An alternative and a better solution would be to assign probability distributions to the range of possible changes that incorporate the three levels of uncertainty inherent in the climate projections due to (i) future emissions, (ii) climate sensitivity and (iii) regional variability. This then becomes a joint probability problem where the probability of each source of uncertainty needs to be combined. At present, CSIRO is developing a method for combining the three levels of uncertainty using Monte-Carlo techniques to provide ranges of change that correspond to various confidence intervals, with threshold exceedance probabilities.

The preparation of climate change ranges as probability distributions could also incorporate assigning weightings to each model, based on their ability to simulate the present climate. This contrasts with the method used in Chapter 3 where a simulation was allocated demerit points, then rejected or retained based upon a subjective threshold for the total number of demerit points. There is also a need to develop a method of weighting models which allows for assessment of multiple variables over appropriate domains, as is used in our current methodology. Process-based tests could also been included, such as assessing a model's ability to capture the link between rainfall variability and mid and high latitude circulation changes and also associated with ENSO variability.

Alternative emission scenarios should also be explored. This is because the SRES range of scenarios is in need of revision. Recent studies indicate the potential for the biospheric CO_2 sink to change over time. While higher levels of carbon dioxide may act as a fertiliser and enhance plant growth, vegetation in some parts of the world may change due to decreases in rainfall, higher temperatures and evaporation, and also due to increases in fire frequencies. The biospheric sink may start to decline in the second half of this century, and by the final decades it may turn into a net carbon source (Field and Raupach, 2004; Jenkins *et al.*, 2005), meaning that the rate of increase in atmospheric concentrations of CO_2 will speed up for a given emissions level. Soils may become an extra source of CO_2 emissions before the middle of the next century. The extra CO_2 from the terrestrial biosphere may produce an additional warming of 0.1 to 1.5°C by the year 2100 (Friedlingstein *et al.*, 2006). This is not included in the IPCC's (2001) global warming scenarios that have been used in this report, so some of the results may be conservative. There is a need to revisit this issue after the IPCC has released its Fourth Assessment Report in 2007.

7. CONCLUSIONS AND RECOMMENDATIONS

This report updates some chapters of the previous CSIRO report on climate change in South Australia (McInnes et al., 2003b). In particular, this report updates information on observed global and regional climate, and scenarios based on a new set of GCMs for South Australia as well as for eight NRM regions. This project does not update information about changes in extreme weather, nor does it update potential impacts.

Global climate change

New evidence since the Third Assessment Report of the IPCC (2001) indicates:

- The global average surface temperature has increased by about 0.7°C during the last century.
- Heatwaves and heavy rainfall have increased in many regions, while glaciers, ice-sheets and frosts have decreased.
- Oceans are becoming more acidic.
- The global average sea level has risen 1.7 mm per year since 1900.
- There have been shifts in plant and animal locations and seasonal behaviour consistent with global warming.
- The unusual nature of the warming of the past 50 years relative to the past 1000-2000 years, based on the so-called Hockey Stick graph, has been supported by many other independent studies.
- The influence of human activities has been detected in land-ocean temperature contrasts, the annual cycle of surface temperature over land, the hemispheric temperature contrast, regional (not just global) warming, the height of the tropopause (between the troposphere and stratosphere) and the heating of the oceans.
- New information about climate feedbacks indicates a greater likelihood of warming at the higher end of the uncertainty range.
- Projected changes in climate extremes could have major consequences.

Main conclusions about observed and projected regional climate change

From 1910 to 2005, Australia's average temperature increased by 0.89ºC, with minimum temperatures increasing twice as fast as maximum temperatures. The rate of increase has accelerated since 1950.

From 1910 to 2005, South Australia's average temperature increased by 0.96ºC, with the minimum temperature increasing by 1.13ºC and maximum temperature by 0.79ºC. Since 1950, the rate of warming has accelerated Compared to national trends, South Australian maximum temperature has risen faster, while minimum temperature have risen slower.

Annual and seasonal rainfall shows fluctuations on multi-decadal time scales. In South Australia, the 1920s and 1960s were dry decades while the 1970s was a wet period. Since 1950, much of the northern half of South Australia became wetter while southern coastal regions around Eyre Peninsula and the far south-east of the state became drier.

Among 25 climate models, 13 satisfactorily captured the observed spatial patterns MSLP, temperature, and rainfall. These 13 models were used to construct temperature and rainfall projections for South Australia, including eight NRM regions.

Annual and seasonal temperature projections for South Australia were constructed for SRES emission scenarios (with no policies to reduce emissions) and for scenarios that stabilise CO_2 concentrations at 450 ppm by 2100 or 550 ppm by 2150. Inland or northern regions show greater warming compared with southern regions. Spring and summer show greater warming than winter and autumn. Significantly reduced warming is projected for the CO_2 stabilisation scenarios.

Projected rainfall changes are more complex than the temperature projections, as rainfall projections show stronger spatial and temporal variations as well as large variations between models. Annual average rainfall tends to decrease. There are significant differences in projected changes among the seasons. Summer and autumn show increases and decreases, but decreases dominate winter and spring. As for temperature, the magnitudes of projected rainfall changes are significantly smaller for the CO_2 stabilisation scenarios.

The enhanced greenhouse signal in temperature can be distinguished from natural variability around the year 2000 For rainfall, large natural variability and differences between model simulations indicates that it will be difficult to detect an enhanced greenhouse signal in annual rainfall before 2050 in South Australia. However, an enhanced greenhouse signal appears to emerge from natural variability around 2000 for Kangaroo Island and the Eyre Peninsula. More rigorous attribution studies are needed to separate the natural and anthropogenic trends.

There is a strong demand for appropriate downscaling methods to obtain fine resolution climate information from coarse resolution climate model simulations where topography and extreme weather phenomena are important, such as southern part of South Australia. Fine resolution climate change information can be derived through statistical and dynamical downscaling methods. However, as this addresses only one of a range of uncertainties associated with projecting regional climate change, the expense involved in this approach needs to be considered. Fine resolution climatic information for use in impact assessment can also be prepared using simple interpolation of simulated changes onto a fine-resolution observed climate database.

Atmospheric greenhouse gas concentrations are likely to reach more than doubled pre-industrial levels this century. Hence, some degree of climate change across South Australia is inevitable, and the impacts are likely to become increasingly apparent over the coming decades. There will be changes in both the mean values and in the magnitudes and frequency of climate extremes. Likely changes in extreme daily temperature, rainfall, wind-speeds and storm surges were presented in the previous CSIRO report (McInnes et al., 2003b). This suggests that long-term planning should not be predicated on the assumption that future climate characteristics will be as they were over the past 100 years. Significant adaptation to a changing climate will be necessary.

Recommendations for further research

1. Despite public concern about climate change, effective communication of climate change science, impacts, and adaptation remains challenging. Droughts under climate change conditions could be more severe due to higher temperatures, decreased rainfall and greater evaporative demand (Mpelasoka et al., 2006). An increase in fire frequency and intensity is also likely under these conditions (Hennessy et al., 2006). These changes will have impacts on water resources, agriculture, forestry, energy, tourism, natural ecosystems and management of parks. Significant changes in management may be required to minimise costs, maximise benefits and ensure sustainability.

2. Strategies for addressing climate change and its potential consequences are increasingly being viewed by both public and private institutions in a risk management context. Risk-based tools have been applied to build better understanding of the likelihood of different magnitudes of climate impacts to agriculture, water resources and coastal infrastructure. In addition, there is a growing interest in using such information in current planning decisions.

3. Adaptation remains challenging. Novel tools for fostering discussions about climate change with different audiences are emerging at an ever-growing rate, but they must compete for the public's attention with a range of other priority issues.

4. Scientists and public and private institutions must work collectively to build upon recent advances in assessing and communicating climate risk. There continues to be demand for tools for decision-making under uncertainty, and clarification of the costs and benefits of different adaptation strategies is needed to assist in the identification of appropriate societal responses. Finally, access to resources – human, financial, and technical – for assessment and adaptation remains limited, particularly for local governments, which are likely to be the focal points for climate change impacts and adaptive responses.

5. Uncertainties in relation to the estimation of future climate can be reduced by (1) developing climate change scenarios based on improved global and regional climate model simulations, (2) improving the ability of GCMs to simulate climatic processes that influence South Australia, (3) using methods that allow presentation of probabilistic projections and (4) using statistical and dynamical downscaling methods.

6. Climate impact and adaptation assessment should be done through:

    - Development of versatile climate impact and adaptation models and methodologies for a number of key sectors and activities. In some cases, existing models that are being used for climate variability risk assessment can be modified for climate change applications. Priorities should be on the basis of potential sensitivity, impact model availability and stakeholder interest. Possible sectors include agriculture, forestry, fisheries, water resources, coasts, health, indigenous communities, biodiversity, transport, land planning, energy, urban infrastructure, emergency services and tourism.

    - Impact assessments will require close collaboration between scientists and stakeholders. Where appropriate, integrated (cross-sectoral and socio-economic) impact and adaptation assessment should be carried out.

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GLOSSARY OF TERMS

Adaptation: Response measures to *moderate*, *benefit*, and/or *cope* with climate change impacts.

Aerosol: A collection of airborne solid or liquid particles, with a typical size between 0.01 and 10 µm and residing in the atmosphere for at least several hours. Aerosol may be of either natural or anthropogenic origin.

Anthropogenic: Of human origin; man made

Climate model: Complex computer models that represent the atmosphere-ocean climate system based on mathematical equation governing the behaviour of the various components of the system and including treatments of physical processes and interactions.

Climate scenario: A plausible and often simplified representation of the future climate, based on an internally consistent set of climatological relationships, that has been constructed for explicit use in investigating the potential consequences of anthropogenic climate change, often serving as input to impact models. Climate projections often serve as the raw material for constructing climate scenarios, but climate scenarios usually require additional information such as the observed current climate. A climate change scenario is the difference between a climate scenario and the current climate.

Climate sensitivity: The magnitude of a climatic response to a perturbing influence. In mathematical modelling of the climate system, it is the difference between simulations as a function of a change in a given parameter. In IPCC reports, equilibrium climate sensitivity refers to the equilibrium change in global mean surface temperature following a doubling of the atmospheric (equivalent) CO_2 concentration. In general, equilibrium climate sensitivity refers to the equilibrium change in surface temperature following a unit change in radiative forcing (°C/W m^{-2}).

Climate system: The climate system is the highly complex system consisting of five major components: the atmosphere, the hydrosphere, the cryosphere, the land surface and the biosphere, and the interactions between them. The climate system evolves in time under the influence of its own internal dynamics and because of external forcings such as volcanic eruptions, solar variations, and human-induced forcings such as the changing composition of the atmosphere and land-use change.

Climate variability: Climate variability refers to variations in the mean state and other statistics (such as standard deviations, the occurrence of extremes, etc.) of the climate on all temporal and spatial scales beyond that of individual weather events. Variability may be due to natural internal processes within the climate system (internal variability), or to variations in natural or anthropogenic external forcing (external variability).

Drought: The phenomenon that exists when precipitation has been significantly below normal record levels, causing serious hydrological imbalances that adversely affect land resource production systems.

Emission scenario: A plausible representation of the future development of emissions of substances that are potentially radiatively active (e.g., greenhouse gases, aerosols), based on a coherent and internally consistent set of assumptions about driving forces (such as demographic and socio-economic development, technological change) and their key relationships. Concentration scenarios, derived from emissions scenarios, are used as input into a climate model to compute climate projections.

Evaporation: The process whereby liquids (such as water) are turned into gas.

Evapotranspiration: the combined process of evaporation from the earth's surface and transpiration from vegetation.

Global surface temperature: The global surface temperature is the area-weighted global average of (i) the sea surface temperature over the oceans (i.e., the sub-surface bulk temperature in the first few meters of the ocean), and (ii) the surface air temperature over land at 1.5 m above the ground.

Greenhouse effect: Greenhouse gases effectively absorb infrared radiation, emitted by the earth's surface, by the atmosphere itself due to the same gases, and by clouds. Atmospheric radiation is emitted to all sides, including downward to the earth's surface. Thus greenhouse gases trap heat within the surface-troposphere system. This is called the "natural greenhouse effect". Atmospheric radiation is strongly coupled to the temperature of the level at which it is emitted. In the troposphere, the temperature generally decreases with height. Effectively, infrared radiation emitted to space originates from an altitude with a temperature of, on average, -19°C, in balance with the net incoming solar radiation, whereas the earth's surface is kept at a much higher temperature of, on average, +14°C. An increase in the concentration of greenhouse gases leads to an increased infrared opacity of the atmosphere, and therefore, to an effective into space from a higher altitude at a lower temperature. This causes a radiative forcing, an imbalance that can only be compensated for by an increase of the temperature of the surface-troposphere system. This is the "enhanced greenhouse effect".

Risk*:* The combination of the probability of an event and its consequences

Risk Management*:* The systematic application of management policies, procedures, and practices to the tasks of analysing, evaluating and controlling risk.

SRES scenarios: The IPCC Special Report on Emission Scenarios (SRES) is based on a range of assumptions about population, energy sources and regional or global approaches to development and socio-economic arrangements. The scenarios do not include any specific greenhouse gas mitigation activities. These SRES scenarios are used as a basis for the climate projections in the IPCC Working Group I contribution to the Third Assessment report (IPCC, 2001). Details are available in IPCC reports.

Stabilisation: The achievement of stabilisation of atmospheric concentrations of one or more greenhouse gases (e.g., carbon dioxide or a CO_2-equivalent basket of greenhouse gases).

Uncertainty: An expression of the degree to which a value (e.g., the future state of the climate system) is unknown. Uncertainty can result from lack of information or from disagreement about what is known or even knowable. It may have many types of sources, from quantifiable errors in the data to ambiguously defined concepts or terminology, or uncertain projections of human behaviour. Uncertainty can therefore be represented by quantitative measures (e.g. a range of values calculated by various models) or by qualitative statements (e.g. reflecting the judgement of a team of experts).

Vulnerability: The extent to which climate change may damage or harm a system; it depends not only a system's sensitivity, but also on its ability to adapt to new climatic conditions.