Australian Government
Department of the Environment and Heritage
Australian Greenhouse Office

Climate change scenarios for initial assessment of risk in accordance with risk management guidance

CSIRO

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Important Notice

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Prepared for the Australian Greenhouse Office,
Department of the Environment and Heritage by:
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CSIRO Marine and Atmospheric Research
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Contents

1. Introduction

1

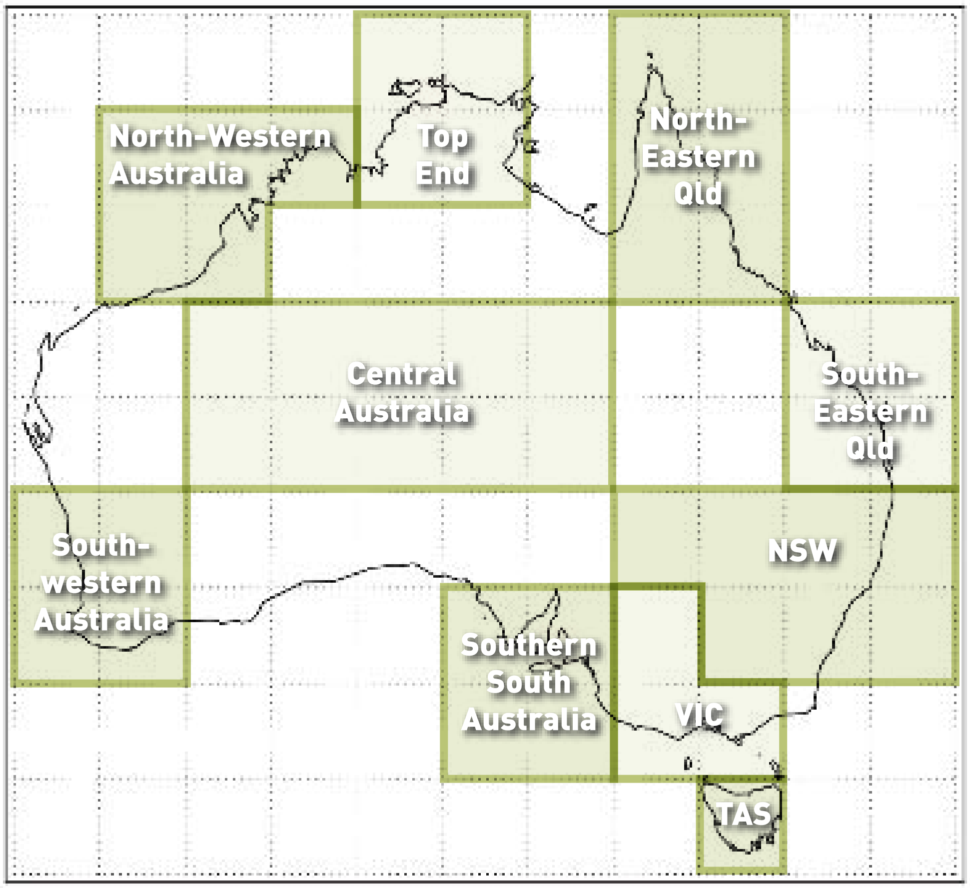
Climate change is likely to have significant impacts on Australia (Allen Consulting Group 2005: Pittock 2003: Preston and Jones 2006). The Australian Greenhouse Office (AGO) asked CSIRO to prepare regional climate change scenarios for use in initial assessment of risks as recommended in the publication "Climate Change Impacts and Risk Mangement: A Guide for Government and Business". Specifically, scenarios were needed for 2030 for changes in

- average annual temperature, rainfall, potential evaporation and sea-level;
- average daily extremes of temperature, rainfall, cyclone intensity and fire danger.
- average annual solar radiation and humidity, and extreme daily wind-speed (each of which were found to be small, and are therefore not reported in detail).

This information has been provided in various forms in a range of CSIRO reports over the past six years, but community feedback has indicated that the material is sometimes hard to understand.

Therefore, in this report, the scenarios have been simplified. The ranges of uncertainty have been converted to a low scenario and a high scenario. Data are presented in a table for each of ten regions, with a non-technical description of potential impacts by the year 2030. These regions (Figure 1) are similar to those used in the CSIRO poster at **http://www.cmar.csiro.au/e-print/open/cechet_2002a.pdf**

Figure 1: The ten regions overlaid on the 400 x 400 km grid to which all climate models data were interpolated.



2. Understanding Climate Change

2.1

2.1 Observed climate change

The Earth has warmed by 0.7˚C on average since 1900 (Jones and Moberg 2003). Most of the warming since 1950 is due to human activities that have increased greenhouse gases (IPCC 2001). There has been an increase in heatwaves, fewer frosts, warming of the lower atmosphere and upper ocean, retreat of glaciers and sea-ice, an average rise in global sea-level of approximately 17 cm and increased heavy rainfall in many regions (Alexander *et al*. 2006: Church and White 2006: IPCC 2001:Vinnikov *et al*. 2006). Many species of plants and animals have changed their location or behaviour in ways that provide further evidence of global warming (Hughes *et al*. 2003).

From 1910 to 2004, the Australian-average maximum temperature rose 0.6˚C and the minimum temperature rose 1.2˚C, mostly since 1950 (Nicholls and Collins 2006). It is very likely that increases in greenhouse gases and aerosols have significantly contributed to this warming in the second half of the 20th century (Karoly and Braganza 2005a: 2005b). From 1957 to 2004, the Australian-average shows an increase in hot days (35˚C or more) of 0.10 days/year, an increase in hot nights (20˚C or more) of 0.18 nights/year, a decrease in cold days (15˚C or less) of 0.14 days/year and a decrease in cold nights (5˚C or less) of 0.15 nights/year (Nicholls and Collins 2006). The north-western two-thirds of Australia has become wetter since 1950, while southern and eastern Australia has become drier (Smith 2004). Droughts have become hotter and therefore more intense (Nicholls 2004). From 1950-2005, extreme daily rainfall has increased in north-western and central Australia and over the NSW western tablelands, but decreased in the southeast, southwest and central east-coast (Gallant *et al*. 2006). Most extreme events are changing faster than the means or more moderate extreme events (Alexander *et al*. submitted). South-east Australian snow depths at the start of October have declined 40% in the past 40 years (Nicholls 2005). There is no trend in the frequency of tropical cyclones in the Australian region from 1981-2003, but an increase in intense systems (very low central pressure) (Hennessy 2004: Kuleshov 2003). Relative sea-level rise averaged 1.2 mm/year from 1920 to 2000 (Church *et al*. 2004).

2.2 Future changes in greenhouse gases

To estimate future climate change, scientists have developed greenhouse gas and aerosol emission scenarios for the 21st century. These are not 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. This report uses scenarios developed by the Intergovernmental Panel on Climate Change (IPCC), which are described in the Special Report on Emission Scenarios (SRES 2000). These 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, e.g. policies to reduce air pollution. More information is available in Appendix 1.

2.3

2.3 Future changes in global temperature

Computer models of the climate system are the best tools available for simulating climate variability and change. These models include representations of the atmosphere, oceans, biosphere and polar regions. While the 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 (IPCC 2001), based on tests of the ability to simulate:

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

Present average temperature and pressure are better simulated than rainfall. Simulation of variability due to monsoons, the El Niño Southern Oscillation and the North Atlantic Oscillation has improved. Small-scale extreme events are harder to simulate, but tropical cyclone-like features are captured. Models can reproduce various aspects of climate changes that happened in the mid-Holocene (6,000 years ago) and the Last Glacial Maximum (21,000 years ago). Simulations that include estimates of natural and human influences can reproduce the observed large-scale changes in surface temperature over the 20th century, including the global warming that has occurred during the past 50 years.

To estimate future changes, climate models have been driven by the emission scenarios described in Section 2.2 and Appendix 1. The simulations yield a global average warming of 0.54 to 1.24°C by the year 2030. The warming is not globally-uniform. There is greater warming over the land and polar regions than elsewhere. While global-average rainfall increases, those increases are mostly nearer the poles and in the tropics, and decreases are simulated in the middle latitudes such as southern Australia.

2.4 Future changes in Australian climate

Scenarios presented in this report are based on those available in May 2006. Most scenarios were extracted from the CSIRO contribution to a consultancy report (BRANZ 2006) for the AGO. Projected changes in selected climate variables over Australia were derived from various climate model simulations, driven by the SRES (2000) emission scenarios. Each of these models was found to have an acceptable simulation of Australia's present (1961-1990) average climate.

The scenarios incorporate quantifiable uncertainties associated with (i) the range of future emission scenarios and (ii) the range of global climate sensitivity (defined as the simulated global warming for a doubling of carbon dioxide concentration from 280 ppm to 560 ppm). Uncertainties from (i) and (ii) are encapsulated in the IPCC (2001) range of global warming, i.e. 0.54 to 1.24°C by 2030. The scenarios also incorporate a third source of uncertainty – model-to-model differences in the regional patterns of climate change. CSIRO's methods for creating the scenarios are documented elsewhere (Whetton *et al.* 2005).

Scenarios are updated as new model simulations become available and as new scenario methods are developed. This is a dynamic area of research. Consequently, scenarios for some climate variables are newer than others, and are based upon as few as 1 model or as many as 15 models, e.g. 1 model for extreme daily rainfall (Abbs 2004: McInnes et al. 2002:Walsh *et al*. 2001:Whetton *et al*. 2002), 2 models for fire danger scenarios (Hennessy *et al*. 2006), 7 models for potential evaporation (BRANZ 2006), and 15 models for temperature and rainfall (Suppiah *et al*., 2006). Hence the scenarios are *not* internally consistent for all climate variables. CSIRO is in the process of creating a set of internally consistent scenarios, using the OzClim climate scenario generator – see **http://www.cmar.csiro.au/ozclim/index.html**

Note that the scenarios in the consultancy report (BRANZ 2006) were designed for general communication purposes. They were presented as maps with different ranges of uncertainty for various regions, focusing on one climate variable at a time rather than a combination of climate variables. The ranges of uncertainty are based on the second-lowest and second-highest pattern of climate change amongst the models at each grid-cell. Hence, different models may contribute to the range of uncertainty at each grid-cell. This is useful for communicating uncertainty, but it is not suitable for application in impact studies that combine changes in *more than* one climate variable. For example, it would be inappropriate to create a scenario based on the most extreme increases in all climate variables because some combinations may be physically implausible, such as a large increase in rainfall *and* solar radiation. For impact studies, model-specific changes in climate variables must be used, to ensure internal consistency.

A brief summary of potential impacts accompanies each regional scenario. More detail is provided in two recent reports (Pittock 2003:Preston and Jones 2006). The impact assessments were generally undertaken using older scenarios (CSIRO 2001), *not* the updated scenarios in the tables below. Nevertheless, the general conclusions about potential impacts are likely to be robust.

3. Climate Change

Scenarios for 10 Regions

3

Bearing in mind the caveats described in section 2.4, simplified scenarios have been created for ten regions, in an attempt to synthesise information from the BRANZ (2006) report, with updated scenarios for temperature, rainfall and solar radiation. These scenarios are suitable for the purpose of an initial assessment of risk using the process outlined in "Climate Change and Risk Management: a Guide for Government and Business", but not for use in impact studies. The ten regions are:

1. North-western Australia
2. South-western Australia
3. Southern South Australia
4. Tasmania
5. Victoria
6. NSW
7. South-eastern Queensland
8. Northern-eastern Queensland
9. Central Australia
10. Top End of the Northern Territory

The scenarios for 2030 in each region are presented as changes relative to 1990, since 1990 is the reference year used by the IPCC. The scenarios represent changes in average climatic conditions. The conditions of any individual year will continue to be strongly affected by natural climatic variability and cannot be predicted. For each region, two scenarios are presented for each climate variable: (i) a low global warming scenario (0.54°C by 2030) which assumes the lowest SRES emission scenario and lowest climate sensitivity and (ii) a high global warming scenario (1.24°C by 2030) which assumes the highest SRES emission scenario and highest climate sensitivity. A central estimate of change is given for each variable. For some variables, a range of uncertainty is also given — this is based on differences between climate models on regional patterns of climate change, where this information is available, e.g. not all models agree on a decrease in rainfall.

For some variables, scenarios for 2030 were not available. In these cases, a footnote indicates the year for which the scenarios are applicable. In some seasons, regional rainfall is currently very low, so percentage changes for the year 2030 (sometimes large) would not be very meaningful. Hence, these are not shown.

3

Change in climate for North Western Australia by 2030, relative to 1990[a]

North-western Australia is likely to become **warmer**, with more **hot days** and fewer cold nights. For example, the annual number of days above 35°C could average 64-141 in Broome (now 54), 168-214 in Kalumburu (now 140), and 168-214 in Halls Creek (now 156)[1]. **Increased peak summer energy demand** for cooling is likely, with reduced energy demand in winter for heating[2].

Warming and population growth would increase annual heat-related deaths in those aged over 65 and contribute to the spread of vector-borne, water-borne and food-borne diseases, e.g. the mosquito that carries Dengue Fever may reach Port Hedland by 2050[3].

A small decrease in annual rainfall combined with higher evaporative demand would probably result in **less river flow**, but this has not been quantified. **More frequent and severe droughts** are likely.

Controlled experiments have shown grain yield increases under elevated atmospheric carbon dioxide concentrations. However, it is not known whether this will translate to field conditions in Australia due to water and nutrient limitations and elevated temperatures. More hot days and a decline in rainfall or irrigation could reduce yields. Livestock will be adversely affected by greater heat stress[4].

In cities, changes in average climate and sea-level will affect building design, standards and performance, energy and water demand, and coastal planning[5]. Increases in extreme weather events are likely to lead to **more cyclone-damage, flash flooding**, strains on sewerage and drainage systems, greater insurance losses, possible black-outs, and **challenges for emergency services**.

1 Suppiah *et al.* 2006;
2 Howden and Crimp 2001;
3 McMichael *et al.* 2003;
4 Howden *et al.* 2003;
5 PIA 2004;
a These scenarios should not be used in detailed impact assessments (consult CSIRO for model specific scenarios);

Feature		Low Global Warming Scenario		High Global Warming Scenario	
		Estimate of Change	Uncertainty	Estimate of Change	Uncertainty
Annual average temperature		+0.6°C	±0.2°C	+1.3°C	±0.6°C
Average sea level		+3cm		+17cm	
Annual average rainfall		-1.5%	±5%	-3.5%	±11%
Seasonal average rainfall	Summer	-1.5%	±5%	-3.5%	±11%
	Autumn	0%	±6.5%	0%	±15%
	Winter	N/A[b]		N/A[b]	
	Spring	N/A[b]		N/A[b]	
Annual average potential evaporation		+1.6%	±1.1%	+3.7%	±2.5%
Annual average number of hot days (>35°C)		+10 days		+90 days	
Tropical cyclone wind-speeds		+5%		+10%	
Extreme daily rainfall intensity (1 in 20 year event)[c]		N/A		N/A	
Carbon dioxide concentration		+73ppm		+102ppm	

b Percentage changes are not provided for seasons with very low rainfall;
c Results not available.

3

Change in climate for South-western Australia by 2030, relative to 1990[a]

South-western Australia is likely to become **warmer**, with more **hot days** and fewer cold nights. For example, the number of days above 35°C could average 29-43 in Perth (now 27)[1]. **Increased peak summer energy demand** for cooling is likely, with reduced energy demand in winter for heating[2].

Warming and population growth may increase annual heat-related deaths in those aged over 65, e.g. from 294 deaths at present in Perth to 657-689 by 2020 and 1254-1548 by 2050[3]. Higher temperatures may also contribute to the spread of vector-borne, water-borne and food-borne diseases.

Water resources are likely to be **further stressed** due to projected growth in demand and climate-driven changes in supply for irrigation, cities, industry and environmental flows. A **decrease in annual rainfall** with higher evaporative demand would lead to a tendency for **less run-off** into rivers, e.g. -25% to +10% for the Canning River[4], -14% for Thompson Brook[5] and -31% by 2050 for the Stirling catchment[6]. **More frequent and severe droughts** are likely.

Controlled experiments have shown grain yield increases under elevated atmospheric carbon dioxide concentrations. However, it is not known whether this will translate to field conditions in Australia due to water and nutrient limitations and elevated temperatures.

Low to moderate warming may also **help plant growth** especially **frost sensitive crops** such as wheat, but more hot days and a decline in rainfall or irrigation could reduce yields. Warmer winters can **reduce the yield of stone fruits** that require winter chilling and livestock would be adversely affected by greater heat stress[7].

In forestry, the CO_2 benefits may be offset by decreased rainfall, increased bushfires and changes in pests[8].

In cities, changes in average climate and sea-level will affect building design, standards and performance, energy and water demand, and coastal planning[9]. Increases in extreme weather events are likely to lead to **increased flash flooding**, strains on sewerage and drainage systems, greater insurance losses, possible black-outs, more fires and **challenges for emergency services**.

1. Suppiah *et al*. 2006;
2. Howden and Crimp 2001;
3. McMichael *et al*. 2003;
4. Chiew and McMahon 2002;
5. Chiew *et al*.2003;
6. Berti *et al*.2004;
7. Howden *et al*.2003;
8. Howden *et al*.1999.
9. PIA 2004.

a. These scenarios should not be used in detailed impact assessments (consult CSIRO for model specific scenarios);

Feature	Low Global Warming Scenario		High Global Warming Scenario	
	Estimate of Change	Uncertainty	Estimate of Change	Uncertainty
Annual average temperature	+0.5°C	±0.3°C	+1.1°C	±0.7°C
Average sea level	+3cm		+17cm	
Annual average rainfall	-5%	±5%	-11%	±11%
Seasonal average rainfall Summer	-3%	±6.5%	-7.5%	±15%
Autumn	-3%	±6.5%	-7.5%	±15%
Winter	-5%	±5%	-11%	±11%
Spring	-5%	±5%	-11%	±11%
Annual average potential evaporation	+1.9%	±1.4%	+4.3%	±3.1%
Annual average number of hot days (>35°C)	+1 day		+20 days	
Annual average number of cold nights (<0°C)	N/A		N/A	
Annual average number of very high and extreme forest fire danger days[b]	N/A		N/A	
Extreme daily rainfall intensity (1 in 20 year event)[b]	N/A		N/A	
Carbon dioxide concentration	+73ppm		+102ppm	

b Results not available;

3

Change in climate for Southern South Australia by 2030, relative to 1990[a]

Southern S.A. is likely to become **warmer**, with more **hot days** and fewer cold nights. For example, the number of days above 35˚C could average 19-29 in Adelaide (now 17) and 54-75 in Woomera (now 51), while the number of days below 0˚C could average 6-15 in Clare (now 19) and 1-4 in Mt Gambier (now 5)[1]. **Increased peak summer energy demand** for cooling is likely, with reduced energy demand in winter for heating[2].

Warming and population growth may increase annual heat-related deaths in those aged over 65, e.g. from 200 deaths at present in Adelaide to 342-371 by 2020 and 482-664 by 2050[3]. Higher temperatures may also contribute to the spread of vector-borne, water-borne and food-borne diseases.

Water resources are likely to be **further stressed** due to projected growth in demand and climate-driven changes in supply for irrigation, cities, industry and environmental flows. A **decline in annual rainfall** with higher evaporative demand would lead to **less run-off** into rivers, e.g. a decline of 0 to 25% for Scott Creek in the Gulf of St Vincent[4]. **Droughts** are likely to become **more frequent and more severe**.

Controlled experiments have shown grain yield increases under elevated atmospheric carbon dioxide concentrations. However, it is not known whether this will translate to field conditions in Australia due to water and nutrient limitations and elevated temperatures.

Low to moderate warming may also **help plant growth** especially frost sensitive crops such as wheat, but more hot days and a decline in rainfall or irrigation could reduce yields. Warmer winters can **reduce the yield of stone fruits** that require winter chilling and livestock would be adversely affected by greater heat stress[5].

In forestry, the CO_2 benefits may be offset by decreased rainfall, increased bushfires and changes in pests[6].

In cities, changes in average climate and sea-level will affect building design, standards and performance, energy and water demand, and coastal planning[7]. Increases in extreme weather events are likely to lead to **increased flash flooding**, strains on sewerage and drainage systems, greater insurance losses, possible black-outs, more fires and **challenges for emergency services**.

1. Suppiah *et al.* 2006;
2. Howden and Crimp 2001;
3. McMichael *et al.* 2003;
4. Chiew and McMahon 2002;
5. Howden *et al.* 2003;
6. Howden *et al.* 1999;.
7. PIA 2004.

a. These scenarios should not be used in detailed impact assessments (consult CSIRO for model specific scenarios);

Feature	Low Global Warming Scenario		High Global Warming Scenario	
	Estimate of Change	Uncertainty	Estimate of Change	Uncertainty
Annual average temperature	+0.4°C	±0.2°C	+0.9°C	±0.6°C
Average sea level	+3cm		+17cm	
Annual average rainfall	-3%	±3%	-7.5%	±7.5%
Seasonal average rainfall Summer	-3%	±6.5%	-7.5%	±15%
Autumn	-1.5%	±5%	-3.5%	±11%
Winter	-5%	±5%	-11%	±11%
Spring	-5%	±5%	-11%	±11%
Annual average potential evaporation	+1.6%	±1.1%	+3.7%	±2.5%
Annual average number of hot days (>35°C)	+2 days		+15 days(near coast) +25 days (highlands)	
Annual average number of cold nights (<0°C)	-1 day		-5 days(near coast) -15 days (highlands)	
Annual average number of very high and extreme forest fire danger days[b]	N/A		N/A	
Extreme daily rainfall intensity (1 in 20 year event)	0%		+10%	
Carbon dioxide concentration	+73ppm		+102ppm	

b No results available for fire danger;

3

3

Change in climate for Tasmania by 2030, relative to 1990[a]

Tasmania is likely to become **warmer**, with more hot days and **fewer cold nights**. For example, the number of days above 35°C could average 1-2 in Hobart (now 1), while the number of days below 0°C in Launceston could average 12-29 (now 35)[1]. Increased peak summer energy demand for cooling is likely, with **reduced energy demand** in winter for heating[2].

Warming and population growth may increase annual heat-related deaths in those aged over 65, e.g. from 5 deaths at present in Hobart to 8 by 2020 and 10-14 by 2050[3]. Higher temperatures may also contribute to the spread of vector-borne, water-borne and food-borne diseases.

Water resources are likely to be **further stressed** due to projected growth in demand and climate-driven changes in supply for irrigation, cities, industry and environmental flows. An increase in annual rainfall with higher evaporative demand leads to uncertain changes in run-off into rivers, e.g. ±10% in the Forth River[4].

Fire risk is unlikely to change much in Hobart, but the average number of days with very high or extreme fire danger in Launceston (now 1.5) could rise to 1.5-1.9 by 2020, and 1.6-3.1 by 2050[5].

A **10-40% reduction in snow cover** is likely[6], with impacts on alpine ecosystems.

Controlled experiments have shown grain yield increases under elevated atmospheric carbon dioxide concentrations. However, it is not known whether this will translate to field conditions in Australia due to water and nutrient limitations and elevated temperatures.

Low to moderate warming may also **help plant growth** especially **frost sensitive crops** such as wheat, but more hot days and a decline in rainfall or irrigation could reduce yields. Warmer winters can **reduce the yield of stone fruits** that require winter chilling and livestock would be adversely affected by greater heat stress[7].

In forestry, the CO_2 benefits may be offset by decreased rainfall, increased bushfires and changes in pests[8].

In cities, changes in average climate and sea-level will affect building design, standards and performance, energy and water demand, and coastal planning[9]. Increases in extreme weather events are likely to lead to **increased flash flooding**, strains on sewerage and drainage systems, greater insurance losses, possible black-outs, and **challenges for emergency services**.

1. Suppiah *et al.* 2006;
2. Howden and Crimp 2001;
3. McMichael *et al.* 2003;
4. Chiew and McMahon 2002;
5. Hennessy *et al.* 2006;
6. Hennessy *et al.* 2003;
7. Howden *et al.* 2003;
8. Howden *et al.* 1999;
9. PIA 2004.

a. These scenarios should not be used in detailed impact assessments (consult CSIRO for model specific scenarios);

Feature	Low Global Warming Scenario		High Global Warming Scenario	
	Estimate of Change	Uncertainty	Estimate of Change	Uncertainty
Annual average temperature	+0.5°C	±0.2°C	+1.1°C	±0.4°C
Average sea level	+3cm		+17cm	
Annual average rainfall	+1.5%	±5%	+3.5%	±11%
Seasonal average rainfall — Summer	-3%	±6.5%	-7.5%	±15%
Autumn	0%	±6.5%	0%	±15%
Winter	+1.5%	±5%	+3.5%	±11%
Spring	-1.5%	±5%	-3.5%	±11%
Annual average potential evaporation	+1.9%	±0.8%	+4.4%	±1.9%
Annual average number of hot days (>35°C)	0		+1 day	
Annual average number of cold nights (<0°C)	-2 day		-25 days	
Annual average number of very high and extreme forest fire danger days[b]	0		+0.5 day	
Extreme daily rainfall intensity (1 in 40 year event)[c]	+20%		+80%	
Carbon dioxide concentration	+73ppm		+102ppm	

b. Percentage changes for forest fire danger days are for 2020 (changes for 2030 are not available);
c. Changes in the 1-in-20 year rainfall intensity were not available.

3

Change in climate for Victoria by 2030, relative to 1990[a]

Victoria is likely to become **warmer**, with more hot days and fewer cold nights. For example, the number of days above 35°C could average 10-16 in Melbourne (now 9) and 36-50 in Mildura (now 33), while the number of days below 0°C in Mildura could average 1-4 in (now 6)[1]. **Increased peak summer energy demand** for cooling is likely, with reduced energy demand in winter for heating[2].

Warming and population growth may increase annual heat-related deaths in those aged over 65, e.g. from 289 deaths at present in Melbourne to 582-604 by 2020 and 980-1318 by 2050[3]. Higher temperatures may also contribute to the spread of vector-borne, water-borne and food-borne diseases.

Water resources are likely to be **further stressed** due to projected growth in demand and climate-driven changes in supply for irrigation, cities, industry and environmental flows. A **decline in annual rainfall** with higher evaporative demand would lead to a tendency for **less run-off** into rivers, i.e. a decline of 0-45% in 29 Victorian catchments[4]. For Melbourne, average streamflow is likely to drop 3-11% by 2020 and 7-35% by 2050[5].

Droughts are likely to become **more frequent and more severe**, with **greater fire risk**, e.g. by 2020, the number of days with very high or extreme fire danger could average 10-11 in Melbourne (now 9), 16-18 in Laverton (now 15) and 84-91 in Mildura (now 80)[6]. A **10-40% reduction in snow cover** is likely by 2020[7], with impacts on ski resorts and alpine ecosystems.

Controlled experiments have shown grain yield increases under elevated atmospheric carbon dioxide concentrations. However, it is not known whether this will translate to field conditions in Australia due to water and nutrient limitations and elevated temperatures.

Low to moderate warming may also **help plant growth** especially **frost sensitive crops** such as wheat, but more hot days and a decline in rainfall or irrigation could reduce yields. Warmer winters can **reduce the yield of stone fruits** that require winter chilling and livestock would be adversely affected by greater heat stress[8].

In forestry, the CO_2 benefits may be offset by decreased rainfall, increased bushfires and changes in pests[9].

In cities, changes in average climate and sea-level will affect building design, standards and performance, energy and water demand, and coastal planning[10]. Increases in extreme weather events are likely to lead to **increased flash flooding**, strains on sewerage and drainage systems, greater insurance losses, possible black-outs, and **challenges for emergency services**.

1. Suppiah *et al.* 2006;
2. Howden and Crimp 2001;
3. McMichael *et al.* 2003;
4. Jones and Durack 2005;
5. Howe *et al.* 2005;
6. Hennessy *et al.* 2006;
7. Hennessy *et al.* 2003;.
8. Howden *et al.* 2003;.
9. Howden *et al.* 1999;
10. PIA 2004.

a. These scenarios should not be used in detailed impact assessments (consult CSIRO for model specific scenarios);

Feature		Low Global Warming Scenario		High Global Warming Scenario	
		Estimate of Change	Uncertainty	Estimate of Change	Uncertainty
Annual average temperature		+0.5°C	±0.2°C	+1.1°C	±0.4°C
Average sea level		+3cm		+17cm	
Annual average rainfall		-1.5%	±5%	-3.5%	±11%
Seasonal average rainfall	Summer	0%	±6.5%	0%	±15%
	Autumn	-1.5%	±5%	-3.5%	±11%
	Winter	-1.5%	±5%	-3.5%	±11%
	Spring	-5%	±5%	-11%	±11%
Annual average potential evaporation		+2.2%	±1.1%	+5%	±2.5%
Annual average number of hot days (›35°C)		+1 day		+10 days (near coast) +20 days (inland)	
Annual average number of cold nights (‹0°C)		-1 day		-10 days (inland) -20 days (highlands)	
Annual average number of very high and extreme forest fire danger days[b]		+1 day		+11 days	
Extreme daily rainfall intensity (1 in 20 year event)[c]		+5%		+70%	
Carbon dioxide concentration		+73ppm		+102ppm	

b. % changes for forest fire danger are for 2020 (2030 changes unavailable);
c. Results for 2050 (changes for 2030 not available).

3

Change in climate for New South Wales by 2030, relative to 1990[a]

NSW is likely to become **warmer**, with more **hot days** and fewer cold nights. For example, the number of days above 35°C could average 4-7 in Sydney (now 3), 6-14 in Canberra (now 5) and 47-66 in Cobar (now 41), while the number of days below 0°C could average 35-57 in Canberra (now 62)[1]. **Increased peak summer energy demand** for cooling is likely, with reduced energy demand in winter for heating[2].

Warming and population growth may increase annual heat-related deaths in those aged over 65, e.g. from 14 deaths at present in Canberra to 37-41 by 2020 and 62-92 by 2050, and from 176 deaths at present in Sydney to 364-417 by 2020 and 717-1312 by 2050[3]. Higher temperatures may also contribute to the spread of vector-borne, water-borne and food-borne diseases.

Water resources are likely to be **further stressed** due to projected growth in demand and climate-driven changes in supply for irrigation, cities, industry and environmental flows. Little change in annual rainfall with higher evaporative demand would lead to a tendency for **less run-off** into rivers, e.g. 0% to -15% in the Macquarie Basin[4], -21% to +5% in the Namoi-Peel catchment[5], ±15% in Allyn River at Halton and -25% to +15% in Belar Creek at Warkton[6], -8% in Wollomombi River at Coninside, -15% in Wallumburrawang Creek at Bearbug, and -7% in Little River at Obley[7], and decreases of up to 20% in the ACT's Cotter and Queanbeyan catchments[8]. Run-off may decrease 10 to 25% by 2050 across the Murray-Darling Basin[9].

Droughts are likely to become **more frequent and more severe**, with **greater fire risk**, e.g. by 2020, the number of days with very high or extreme fire danger could average 13-14 in Richmond (now 11.5), 26-29 in Canberra (now 23), and 53-57 in Wagga (now 50)[10].

A **10-40% reduction in snow cover** is likely by 2020[11], with impacts on ski resorts and alpine ecosystems.

Controlled experiments have shown grain yield increases under elevated atmospheric carbon dioxide concentrations. However, it is not known whether this will translate to field conditions in Australia due to water and nutrient limitations and elevated temperatures.

Low to moderate warming may also **help plant growth** especially **frost sensitive crops** such as wheat, but more hot days and a decline in rainfall or irrigation could reduce yields. Warmer winters can **reduce the yield of stone fruits** that require winter chilling and livestock would be adversely affected by greater heat stress[12].

In forestry, the CO_2 benefits may be offset by decreased rainfall, increased bushfires and changes in pests[13].

In cities, changes in average climate and sea-level will affect building design, standards and performance, energy and water demand, and coastal planning[14]. Increases in extreme weather events are likely to lead to **increased flash flooding**, strains on sewerage and drainage systems, greater insurance losses, possible black-outs, and **challenges for emergency services**.

1. Suppiah *et al.* 2006;
2. Howden and Crimp 2001;
3. McMichael *et al.* 2003;
4. Jones and Page 2001;
5. O'Neil *et al.* 2003; Howe *et al.* 2005;
6. Chiew and McMahon 2002;.
7. Chiew *et al.* 2003;
8. Bates *et al.* 2003;
9. Beare and Heaney 2002;
10. Hennessy *et al.* 2006;
11. Hennessy *et al.* 2003;.
12. Howden *et al.* 2003;.
13. Howden *et al.* 1999;
14. PIA 2004.

a. These scenarios should not be used in detailed impact assessments (consult CSIRO for model specific scenarios);

Feature	Low Global Warming Scenario		High Global Warming Scenario	
	Estimate of Change	Uncertainty	Estimate of Change	Uncertainty
Annual average temperature	+0.6°C	±0.2°C	+1.3°C	±0.6°C
Average sea level	+3cm		+17cm	
Annual average rainfall	0%	±6.5%	0%	±15%
Seasonal average rainfall — Summer	+1.5%	±8%	+3.5%	±18.5%
Autumn	+1.5%	±8%	+3.5%	±18.5%
Winter	-3%	±6.5%	-7.5%	±15%
Spring	-3%	±6.5%	-7.5%	±15%
Annual average potential evaporation	+2.4%	±1.9%	+5.6%	±4.4%
Annual average number of hot days (>35°C)	+1 day		+25 days	
Annual average number of cold nights (<0°C)	-5 day		-30 days	
Annual average number of very high and extreme forest fire danger days[b]	+1 day		+10 days	
Extreme daily rainfall intensity (1 in 20 year event)[c]	0%		+6% (east) -5% (west)	
Carbon dioxide concentration	+73ppm		+102ppm	

b. % changes for forest fire danger are for 2020 (changes for 2030 are not available);

c. Results for 1 in 20 year event were unavailable.

3

Change in climate for South-eastern Queensland by 2030, relative to 1990[a]

South-east Queensland is likely to become **warmer**, with more **hot days** and fewer cold nights. For example, the number of days above 35˚C could average 3-6 in Brisbane (now 3) and 76-106 in Charleville (now 65), while the number of days below 0˚C in Charleville could average 2-9 in (now 13)[1]. **Increased peak summer energy demand** for cooling is likely, with reduced energy demand in winter for heating[2].

Warming and population growth may increase annual heat-related deaths in those aged over 65, e.g. from 134 deaths at present in Brisbane to 165-189 by 2020 and 776-1368 by 2050[3]. Higher temperatures may also contribute to the spread of vector-borne, water-borne and food-borne diseases.

Water resources are likely to be **further stressed** due to projected growth in demand and climate-driven changes in supply for irrigation, cities, industry and environmental flows. A **decline in annual rainfall** with higher evaporative demand would lead to a tendency for **less run-off** into rivers. **Droughts** are likely to become **more frequent and more severe**, with greater fire risk[4].

Controlled experiments have shown grain yield increases under elevated atmospheric carbon dioxide concentrations. However, it is not known whether this will translate to field conditions in Australia due to water and nutrient limitations and elevated temperatures.

Low to moderate warming may also **help plant growth** especially **frost sensitive crops** such as wheat, but more hot days and a decline in rainfall or irrigation could reduce yields. Warmer winters can **reduce the yield of stone fruits** that require winter chilling and livestock would be adversely affected by greater heat stress[5].

In forestry, the CO_2 benefits may be offset by decreased rainfall, increased bushfires and changes in pests[6].

In cities, changes in average climate and sea-level will affect building design, standards and performance, energy and water demand, and coastal planning[7]. Increases in extreme weather events are likely to lead to **increased flash flooding**, strains on sewerage and drainage systems, greater insurance losses, possible black-outs, and **challenges for emergency services**.

1. Suppiah *et al.* 2006;
2. Howden and Crimp 2001;
3. McMichael *et al.* 2003;
4. Hennessy *et al.* 2006;
5. Howden *et al.* 2003;.
6. Howden *et al.* 1999;
7. PIA 2004.

a. These scenarios should not be used in detailed impact assessments (consult CSIRO for model specific scenarios);

Feature	Low Global Warming Scenario		High Global Warming Scenario	
	Estimate of Change	Uncertainty	Estimate of Change	Uncertainty
Annual average temperature	+0.6°C	±0.2°C	+1.3°C	±0.6°C
Average sea level	+3cm		+17cm	
Annual average rainfall	-1.5%	±5%	-3.5%	±11%
Seasonal average rainfall Summer Autumn Winter Spring	0% -3% -3% -3%	±6.5% ±6.5% ±6.5% ±6.5%	0% -7.5% -7.5% -7.5%	±15% ±15% ±15% ±15%
Annual average potential evaporation	+2.4%	±1.9%	+5.6%	±4.4%
Annual average number of hot days (>35°C)	0		+5 days (near coast) +50 days (inland)	
Annual average number of cold nights (<0°C)	0		-5 days	
Annual average number of very high and extreme forest fire danger days[b]	N/A		N/A	
Extreme daily rainfall intensity (1 in 20 year event)[c]	0%		30%	
Carbon dioxide concentration	+73ppm		+102ppm	

b. Results not available;
c. Results for 2040 (changes for 2030 not available).

3

Change in climate for North-eastern Queensland by 2030, relative to 1990[a]

North-east Queensland is likely to become **warmer**, with more **hot days** and warm nights. For example, the number of days above 35°C could average 4-14 in Cairns (now 3), 5-18 in Townsville (now 4), and 129-163 in Longreach (now 115)[1]. Increased **peak summer energy demand** for cooling is likely[2].

Warming and population growth may increase annual heat-related deaths in those aged over 65, e.g. from 1 death at present in Cairns to 4-5 by 2020 and 11-26 by 2050, and from 3 deaths at present in Townsville to 5-7 by 2020 and 10-34 by 2050[3].

Higher temperatures may also contribute to the spread of vector-borne, water-borne and food-borne diseases, e.g. the mosquito that carries Dengue Fever may reach Rockhampton by 2050.

Water resources are likely to be **further stressed** due to projected growth in demand and climate-driven changes in supply for irrigation, cities, industry and environmental flows. A decrease in annual rainfall with higher evaporative demand would tend to decrease run-off into rivers, e.g. -15% to +5% in the Fitzroy River[4], and between ±9% (low global warming) and ±20% (high global warming) for the Burnett River[5]. **Droughts** are likely to become **more frequent and more severe**.

Controlled experiments have shown crop yield increases under elevated atmospheric carbon dioxide concentrations. However, it is not known whether this will translate to field conditions in Australia due to water and nutrient limitations and elevated temperatures.

Livestock would be adversely affected by increased heat stress[6]. There may be changes in the prevalence of **plant diseases, weeds and pests** such as cattle tick and buffalo fly[7].

In cities, changes in average climate and sea-level will affect building design, standards and performance, energy and water demand, and coastal planning[8]. Increases in extreme weather events are likely to lead to **increased cyclone damage, flash flooding**, strains on sewerage and drainage systems, greater insurance losses, possible black-outs, and **challenges for emergency services**.

Corals on the **Great Barrier Reef** would be exposed to annual **bleaching** by 2030 (high global warming) or by 2050 (medium global warming)[9,10]. Given that the recovery time from a severe bleaching event is at least 10 years (50 years for full recovery), reefs may be dominated by non-coral organisms such as macroalgae by 2050[9,11]. Substantial impacts on biodiversity, fishing and tourism are expected. The distribution of rainforest types in North Queensland Wet Tropics may increase or decrease with warming, depending on the direction of rainfall change[12].

1. Suppiah *et al.* 2006;
2. Howden and Crimp 2001;
3. McMichael *et al.* 2003;
4. Cai *et al.* in press;
5. Walsh *et al.* 2002;.
6. Howden *et al.* 2003;
7. Crimp *et al.* 2004;
8. PIA 2004;
9. Done *et al.* 2003;
10. Wooldridge *et al.* 2005;
11. Hoegh-Guldberg 1999;
12. Hilbert *et al.* 2001.

a. These scenarios should not be used in detailed impact assessments (consult CSIRO for model specific scenarios);

Feature	Low Global Warming Scenario		High Global Warming Scenario	
	Estimate of Change	Uncertainty	Estimate of Change	Uncertainty
Annual average temperature	+0.6˚C	±0.2˚C	+1.3˚C	±0.6˚C
Average sea level	+3cm		+17cm	
Annual average rainfall	-1.5%	±5%	-3.5%	±11%
Seasonal average rainfall — Summer	+1.5%	±5%	+3.5%	±11%
Autumn	-3%	±6.5%	-7.5%	±15%
Winter	N/A[b]	N/A[b]	N/A[b]	N/A[b]
Spring	0%	±9.5%	0%	±22.5%
Annual average potential evaporation	+1.6%	±1.6%	+3.7%	±3.7%
Annual average number of hot days (>35˚C)	+1 day (near coast) +15 days (inland)		+15 days (near coast) +50 days (inland)	
Tropical cyclone wind-speeds	+5%		+10%	
Extreme daily rainfall intensity (1 in 20 year event)[c]	0%		+25%	
Carbon dioxide concentration	+73ppm		+102ppm	

b. % changes are not provided for seasons with very low rainfall;
c. Results for 2050 (changes for 2030 not available).

3

Change in climate for Central Australia by 2030, relative to 1990[a]

Central Australia is likely to become **warmer**, with more **hot days** and fewer cold nights. For example, in Alice Springs, the number of days above 35˚C could average 99-127 (now 89), while the number of days below 0˚C could average 4-11 in (now 16)[1]. **Increased peak summer energy demand** for cooling is likely, with reduced energy demand in winter for heating[2].

Warming and population growth may increase annual heat-related deaths in those aged over 65[3]. Tourism may become less popular in the warmer months due to heat stress.

Higher temperatures may also contribute to the spread of vector-borne, water-borne and food-borne diseases. An increase of 10% in the annual number of diarrhoeal admissions among Aboriginal children living in central Australia is likely by 2050, assuming no change in other circumstances[3].

Water resources are likely to be **further stressed** due to projected growth in demand and climate-driven changes in supply. Little change in annual rainfall with higher evaporative demand would lead to a tendency for **less run-off** into rivers. **Droughts** are likely to become **more frequent and more severe**.

In cities, changes in average climate will affect building design, standards and performance, energy and water demand[4]. Increases in extreme weather events are likely to lead to **increased flash flooding**, strains on sewerage and drainage systems, greater insurance losses, possible black-outs, and **challenges for emergency services**.

1. Suppiah *et al.* 2006;
2. Howden and Crimp 2001;
3. McMichael *et al.* 2003;
4. PIA 2004.

a. These scenarios should not be used in detailed impact assessments (consult CSIRO for model specific scenarios);

3

Feature	Low Global Warming Scenario		High Global Warming Scenario	
	Estimate of Change	Uncertainty	Estimate of Change	Uncertainty
Annual average temperature	+0.7˚C	±0.2˚C	+1.7˚C	±0.6˚C
Annual average rainfall	0%	±6.5%	0%	±15%
Seasonal average rainfall — Summer	0%	±6.5%	0%	±15%
Autumn	0%	±6.5%	0%	±15%
Winter	N/A[b]		N/A[b]	
Spring	N/A[b]		N/A[b]	
Annual average potential evaporation	+2.5%	±1.4%	+5.6%	±3.1%
Annual average number of hot days (>35˚C)	+10 days		+40 days	
Annual average number of cold nights (<0˚C)	-5 days		-12 days	
Extreme daily rainfall intensity (1 in 20 year event)[c]	N/A		N/A	
Carbon dioxide concentration	+73ppm		+102ppm	

b. % changes are not provided for seasons with very low rainfall;
c. No estimates available.

3

Change in climate for the Top-end of the Northern Territory by 2030, relative to 1990[a]

The Top End is likely to become **warmer**, with more **hot days** and warm nights. For example, the number of days above 35˚C could average 18-107 in Darwin (now 11)[1]. **Increased peak summer energy demand** for cooling is likely[2].

Warming and population growth may increase annual heat-related deaths in those aged over 65, e.g. from 2 deaths at present in Darwin to 11-16 by 2020 and 37-126 by 2050[3]. Higher temperatures may also contribute to the spread of vector-borne, water-borne and food-borne diseases.

Water resources are likely to be **further stressed** due to projected growth in demand and climate-driven changes in supply for irrigation, cities, industry and environmental flows. Little change in annual rainfall with higher evaporative demand would lead to a tendency for **less run-off** into rivers. However, the only available run-off assessment (assuming a 2% increase in rainfall) gave a 6% increase in flow in Seventeen Mile Creek at Waterfall View[4]. A tendency for more frequent and severe droughts is likely, with **greater fire risk**.

Controlled experiments have shown crop yield increases under elevated atmospheric carbon dioxide concentrations. However, it is not known whether this will translate to field conditions in Australia due to water and nutrient limitations and elevated temperatures. More hot days and a decline in rainfall or irrigation could reduce yields. Livestock would be adversely affected by greater heat stress[5].

In cities, changes in average climate and sea-level will affect building design, standards and performance, energy and water demand, and coastal planning[6]. Increases in extreme weather events are likely to lead to **more cyclone-damage**, **increased flash flooding**, strains on sewerage and drainage systems, greater insurance losses, possible black-outs, and **challenges for emergency services**.

Low-lying coastal wetlands such as Kakadu National Park are at risk from sea level rise and changes to river flows[7].

1. Suppiah *et al.* 2006;
2. Howden and Crimp 2001;
3. McMichael *et al.* 2003;
4. Chiew *et al.* 2003;
5. Howden *et al.* 2005;
6. PIA 2004;
7. Hare 2003;

a. These scenarios should not be used in detailed impact assessments (consult CSIRO for model specific scenarios);

Feature	Low Global Warming Scenario		High Global Warming Scenario	
	Estimate of Change	Uncertainty	Estimate of Change	Uncertainty
Annual average temperature	+0.6˚C	±0.2˚C	+1.3˚C	±0.6˚C
Average sea level	+3cm		+17cm	
Annual average rainfall	0%	±3%	0%	±7.5%
Seasonal average rainfall Summer	-1.5%	±5%	-3.5%	±11%
Autumn	0%	±6.5%	0%	±15%
Winter	N/A[b]		N/A[b]	
Spring	+1.5%	±8%	+3.5%	±18.5%
Annual average potential evaporation	+1.6%	±1.6%	+3.7%	±3.7%
Annual average number of hot days (>35˚C)	+5 days		+100 days	
Tropical cyclone wind-speeds	+5%		+10%	
Extreme daily rainfall intensity (1 in 20 year event)[c]	N/A		N/A	
Carbon dioxide concentration	+73ppm		+102ppm	

b. % changes are not provided for seasons with very low rainfall;
c. Results not available.

3

4. APPENDIX 1
IPCC SCENARIOS

4

The IPCC attributes most of the global warming observed over the last 50 years to greenhouse gases released by human activities. To estimate future climate change, the IPCC (SRES 2000) prepared forty greenhouse gas and sulfate aerosol emission scenarios for the 21st century that combine a variety of assumptions about demographic, economic and technological driving forces likely to influence such emissions in the future. They do not include the effects of measures to reduce greenhouse gas emissions, such as the Kyoto Protocol.

Each scenario represents a variation within one of four 'storylines': A1, A2, B1 and B2. The experts who created the storylines (described below) were unable to arrive at a most likely scenario, and probabilities were not assigned to the storylines.

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).

The A2 storyline 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 than for the other storylines.

The B1 storyline 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.

The B2 storyline 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.

Projected carbon dioxide and sulfate aerosol emissions, and carbon dioxide concentrations are shown in Figure 1-A1 (a, b, c). Emissions of other gases and other aerosols were included in the scenarios but are not shown in the figure. By incorporating these scenarios into computer models of the climate system, the IPCC (2001) estimated a global-average warming of 0.5-1.2°C by the year 2030, 0.7- 2.5°C by 2050 and 1.4-5.8°C by 2100 (Figure 1-A1d). This allowed for uncertainty in projecting future greenhouse gas and aerosol concentrations (behavioural uncertainty) and uncertainty due to differences between models in their response to atmospheric changes (scientific uncertainty). Projected sea-level rise is shown in Figure 1-A1e.

The range of uncertainty in projections of global warming increases with time. Half of this range is due to uncertainty about human socio-economic behaviour, and consequent emissions of greenhouse gases and sulfate aerosols. The other half of the range is due to different climate model responses to these scenarios of greenhouse gases and sulfate aerosols. Probabilities were not assigned to each scenario.

Climate simulations indicate that warming will be greater near the poles and over the land, and that global-average rainfall will increase. More rainfall is likely nearer the poles and in the tropics, and less rainfall is expected in the middle latitudes such as southern Australia.

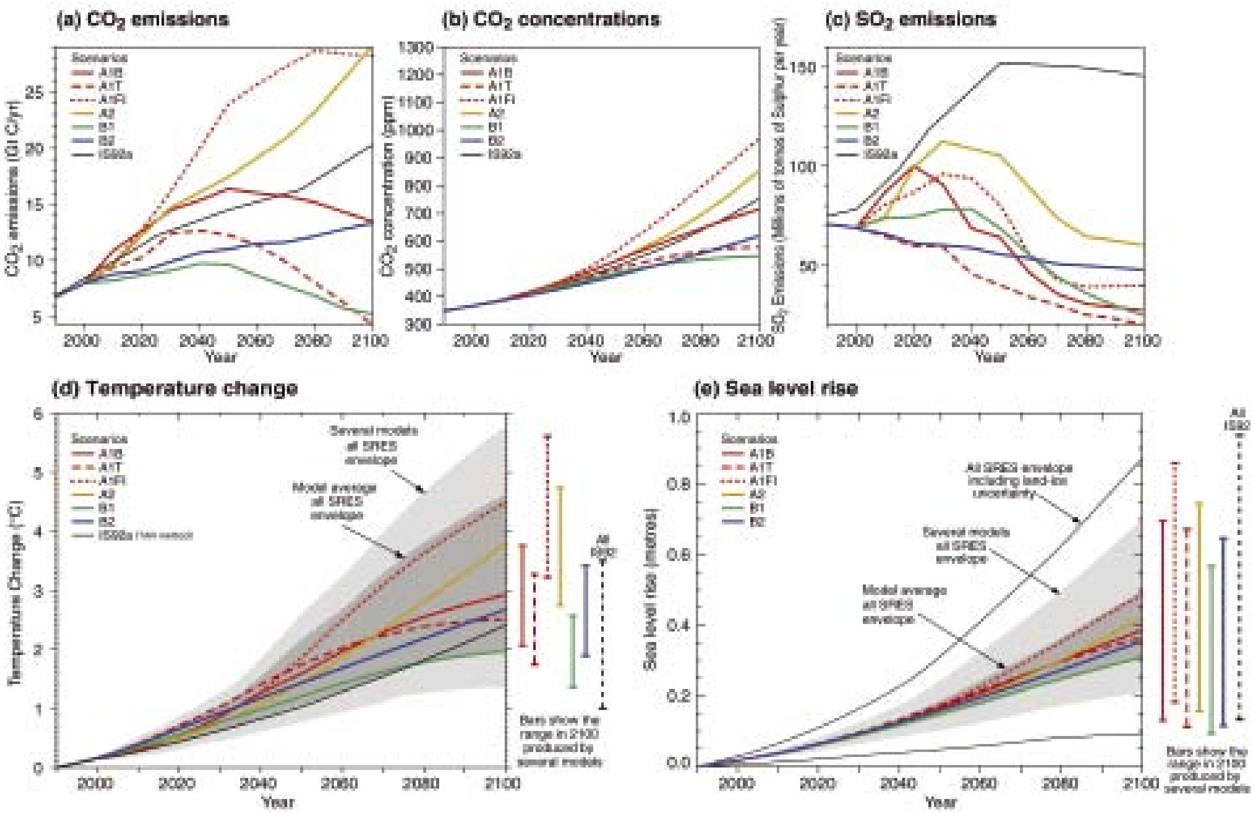


Figure 1-A1: (a) carbon dioxide (CO_2) emissions for the six illustrative SRES (2000) scenarios, and the superseded IS92a scenario, (b) CO_2 concentrations, (c) anthropogenic sulphur dioxide (SO_2) emissions, (d) and (e) show the projected temperature and sea level responses, respectively. Source: IPCC (2001).

The IPCC defined confidence levels that represent "the degree of belief among the authors in the validity of a conclusion, based on their collective expert judgment of observational evidence, modelling results and theory that they have examined". The confidence levels are:

- Very high (95% or greater);
- High (67-94%);
- Medium (33-66%);
- Low (5-32%);
- Very low (4% or less).

For the global warming data in Figure 1-A1, we have very high confidence that the lower warming limits will be exceeded and that the higher limits will not be exceeded.

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5

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