Climate Change Projections for the Australian Region

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Abstract: This paper will describe a new set of climate change projections for the Australian region and the methods by which they have been constructed. The projected ranges of future change in temperature and rainfall take into account uncertainty in future emissions of greenhouse gases and in the sensitivity of the global climate system to increased greenhouse gases. The latter is expressed as differences in both the global average response and the regional response pattern in each model. The projections are based upon the global warming projections prepared for the Third Assessment Report of the Intergovernmental Panel on Climate Change and supplemented by Australian regional detail obtained from the results of nine climate models. In summary, the projected warming range for most of Australia is 0.4 to 2°C by 2030 and 1 to 6°C by 2070. Slightly less warming is indicated for some coastal areas and Tasmania and slightly more warming in the northwest. Ranges of annual rainfall change are broad, but are biased towards a decrease in the southwest (–20% to +5% in 2030 and –60% to +10% in 2070), and in parts of the southeast and Queensland (–10% to +5% by 2030 and –35% to +10% by 2070). Most other locations show ranges of change that vary from –10% to +10% by 2030 and –35% to +35% by 2070, relative to 1990. Decreases are most pronounced in winter and spring.

Keywords: Climate modelling; Climate change; Uncertainty

1. INTRODUCTION

Despite international efforts to reduce anthropogenic emissions of greenhouse gases, some changes in future climate are inevitable. Planned adaptations to potentially harmful impacts need to be assessed if they are to minimise this harm and to take advantages of potential benefits. Impact and adaptation assessment requires projections of regional climate change that account for key uncertainties. One or two selected scenarios amongst the full range of future climate are not sufficient if the results of impact modelling are to be used in adaptation planning.

This paper will describe a new set of climate change projections for the Australian region [CSIRO, 2001] and the methods by which they have been constructed. The full range of projected global warming as given by the Intergovernmental Panel on Climate Change [IPCC, 2001] was combined with projected regional changes obtained from nine climate models.

This paper focuses on changes in average temperature and rainfall. Projected changes in other climate variables may be prepared using a similar approach.

2. METHODS

2.1 Ranges of Projected Global Warming

The global warming projections upon which the regional projections are based are those given by IPCC (2001). The range of warming for 1990-2100 allows for the full range of the latest IPCC greenhouse gas and sulfate aerosol emission scenarios (known as the 'SRES scenarios'). Scenarios A1B, A1T, A1F1, A2, B1 and B2 represent different futures with regard to technology, population and the economy. Concentrations of carbon dioxide (Figure 1) and other greenhouse gases increase throughout the 21st century. For example, carbon dioxide concentrations increase from about 370 parts per million (ppm) in the year 2000 to 550 ppm by 2100 for the B1 scenario, and to 960 ppm for A1F1.

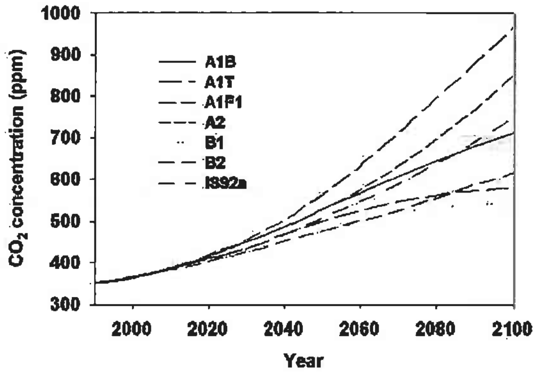

Figure 1. Atmospheric carbon dioxide (CO_2) concentrations based on various SRES emission scenarios and the IS92a mid-case scenario used by the IPCC in 1996. From IPCC [2001].

The IPCC global warming projections also allow for variations across a range of climate models in their global average response to enhanced greenhouse conditions. This is done through the use of a simplified climate model tuned to mimic the behaviour (in global-average terms) of the more complex atmosphere-ocean global climate models (AOGCMs). Using current computing resources, it is not feasible to run AOGCMs over the full range of SRES scenarios, but this can be done with the simplified model.

Figure 2 shows the resulting range of warming across the scenarios based on the average response of a group of current global climate models (dashed lines) and the range where model-to-model variations are allowed for as well (solid lines). Note that uncertainty about future human behaviour (variations in emissions) is a major contributor to uncertainty in future warming. Global mean warming ranges from 1.4 to 5.8°C by the year 2100, relative to 1990, which is a warming rate of 0.1 to 0.5°C per decade.

2.2 Selecting Climate Models for Regional Analysis

Patterns of climate change for the Australian region are readily obtainable from global and regional climate model simulations. Typically, there are significant differences between models with regard to climate changes simulated at the regional scale, particularly for rainfall. Thus to represent this uncertainty, a range of model results needs to be used in preparing regional projections.

Recent simulations from more advanced models are likely to be more reliable. As a first step we chose to use the set of AOGCM simulations available through the IPCC Data Distribution Centre (DDC) (http://ipcc-ddc.cru.uea.ac.uk/).

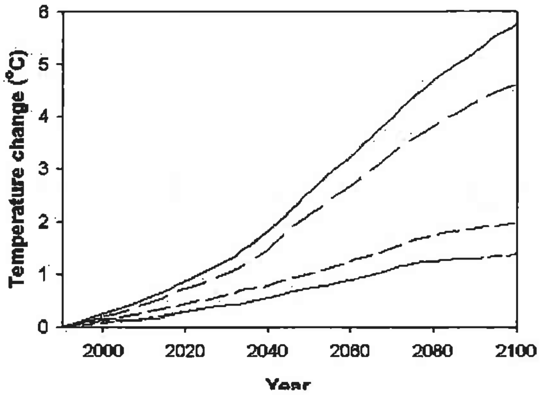

Figure 2. Projections for global-average warming relative to 1990 for a range of SRES greenhouse gas and sulfate aerosol emission scenarios for an average climate model response (dashed lines) and with allowance for model to model differences solid lines). From IPCC [2001].

This set of model runs had passed various quality control requirements such as the existence of adequate model documentation and the inclusion in the simulation of the observed increase in greenhouse forcing through the twentieth century (a 'warm start' simulation). These may be considered 'state-of-the-science' simulations. Most have points spaced about 300 km apart over the globe. Simulations with nine AOGCMs were available from a range of international modelling centres including CSIRO. To this set of models we added a recent simulation with the CSIRO regional model ('DARLAM'), which had been run at 125 km resolution over the Australian region.

As a second step we then assessed the ability of each model to simulate Australia's climate. Seasonal mean temperature, rainfall and mean sea level pressure averaged over the period 1961-1990 were considered. Models were assessed against observations by comparing maps and by objective statistics (pattern correlation and RMS error). The approach is similar to that used by Whetton et al. [1994]. Although deficiencies are present in each simulation, in all but one case the large-scale features of Australian climate (i.e. latitudinal temperature gradients, seasonality of rainfall and major circulation features such as the high pressure belt and the trade-winds) were well simulated. The exception concerned the simulation of mean sea level pressure by the Japanese CCSR/NIES model in which the trade-wind circulation was absent from the east-coast of Australia in summer. This was considered highly unrealistic, and a decision was made to exclude the results of this simulation from further analysis. The remaining simulations (listed in Table 1) were then used for developing the regional projections.

Table 1: Details of the model simulations used in preparing in regional climate change information. Further information about these simulations may be found at the IPCC Data Distribution Centre (http://ipcc-ddc.cru.uea.ac.uk/)

Centre	Model	Emission scenarios post-1990 (historical forcing prior to 1990)	Years
Canadian CCMA	CGCM1	1% increase in CO_2 pa	1900–2100
DKRZ, Germany	ECHAM3/LSG	IS92a	1880-2085
GFDL, USA	GFDL r15a	1% increase in CO_2 pa	1958–2057
Hadley Centre, UK	HADCM2	1% increase in CO_2 pa (four simulations)	1861–2100
Hadley Centre, UK	HADCM3	IS92a	1861-2099
DKRZ, Germany	ECHAM4/OPYC3	IS92a	1860–2099
NCAR, USA	PCM	IS92a	1960-2099
CSIRO, Australia	Mk2	IS92a, SRES A2 (four simulations), SRES B2	1881–2100*
CSIRO, Australia	DARLAM	IS92a	1961-2100

* pre-1990 period common to the SRES simulations

Note that the model evaluation undertaken was with respect to average climatic conditions. In principle, models could also be assessed with respect to how they simulate the evolution of regional climate over the instrumental period (primarily the 20th century). However, there are practical difficulties with this. The observed climatic evolution is a combination of trends forced by anthropogenic increases in concentrations of greenhouse gases and sulfate aerosols, variations due to changes in natural climate forcing (such as solar variations and volcanic eruptions) and changes forced by natural internal variations in climate. For the DDC simulations, the effect of changes in other forcing are not fully represented, and for any AOGCM simulation, the chaotic sequence of natural internal climatic fluctuations as observed cannot be represented. This is important because, at the regional scale, greenhouse related climate changes to date are likely to be weak relative to natural internal variability. This means that to draw useful conclusions from a comparison of observed and simulated climatic evolution over the twentieth century, powerful statistical techniques are required. These have been developing for application at the global scale, and the extension of this to application at the regional scale is a research priority.

2.3 Extracting the Regional Climate Change Pattern from These Models

Each of the climate change simulations listed in Table 1 was analysed to extract Australian regional patterns of mean temperature change and rainfall change. The simulations available from the DDC with changing sulfate aerosol forcing were based on the earlier IS92 scenarios of IPCC in which sulfate aerosols increase strongly. As sulfate aerosols are now projected to change much less under the SRES scenarios, it was considered more appropriate to use the simulations with fixed aerosols available through the DDC. For the CSIRO model, we also analysed a number of simulations with two SRES-based emission scenarios (one B2 simulation and an ensemble of four A2 simulations) that include varying aerosols.

The climate response was calculated at each grid point in terms of local temperature change (in degrees C) and local rainfall change (in mm/day) per degree of global warming using the full simulation period available. This is done by linearly regressing the local seasonal mean temperature (or rainfall) against global average temperature and taking the slope of the relationship at each grid point as the estimated response. In the case of rainfall, the result was converted to percent change per degree of global warming by using the simulated rainfall for 1961-1990 as a baseline. The grid point values were mapped to obtain the pattern of model response. Where there was more than one simulation for a given model (CSIRO and HadCM2), patterns were extracted from each simulation and averaged into a single response pattern. The response pattern was not found to vary systematically with emission scenario in the CSIRO model (the only case where this could be assessed).

The seasonal and annual response patterns from each of the nine models were interpolated on to a common 5 degree by 5 degree grid. At each grid point, the nine values were ranked. A range of model response at each grid point was determined using the second highest and second lowest model values (use of the full range was considered as giving undue weight to outlier results). To simplify the presentation of the results, the ranges for each grid point and season were then classified into (the narrowest possible of) a set of standard ranges. The standard ranges were chosen for efficient representation of the results. For temperature they were 0.7 to 1.1, 0.7 to 1.3, 0.9 to 1.5, 0.9 to 1.7 and 0.7 to 1.8 degrees Celsius per degree of global warming. For rainfall they were –3 to +15, -3 to +9, -9 to +15, -15 to +9, -9 to +3, -15 to +3, -3 to +3, -9 to +9 and –15 to +15 percent per degree of global warming.

2.4 Combining the Regional Information with the Global Warming Projections

A regional change per degree of global warming may be multiplied by the global warming for a given date to obtain the projected regional climate for that date. The global warming projection may be different to the one that originally applied in the simulation from which the regional change was obtained. Such rescaling of model results to a given global warming scenario has been commonly used in climate scenario formation to assist with the representation of uncertainty [CSIRO, 1992, 1996; Rotmans et al., 1994; Hulme et al., 1996; Kenny et al., 1995, Hulme and Sheard, 1999].

Using this method, the ranges of change per degree of global warming prepared here are combined with the IPCC [2001] global warming scenarios to obtain regional ranges of change for 2030 and 2070. For example, the upper limit to the projected warming range for a given location in 2030 would be the upper limit of the relevant range of local warming per degree of global warming multiplied by the upper limit of the global warming range for 2030. Correspondingly the lower limits for projected regional warming range are based on the combination of the lower end of the global and regional ranges. (The approach is the same for precipitation change. However, where the lower limit of the range of percent rainfall response is negative this is combined with the upper limit of the projected global warming.)

3. PROJECTED RANGES

3.1 Temperature

Simulated ranges of warming for Australia are shown in Figure 3. By 2030, annual average temperatures are 0.4 to 2.0°C higher over most of Australia, with slightly less warming in some coastal areas and Tasmania, and the potential for greater warming in the northwest. By 2070, annual average temperatures are increased by 1.0 to 6.0°C over most of Australia with spatial variation similar to those for 2030. The range of warming is greatest in spring and least in winter. In the northwest, the greatest warming occurs in summer.

Model results indicate that future increases in daily maximum and minimum temperature will be similar to the changes in average temperature.

Changes in daily temperature extremes can be influenced by changes in daily variability and changes in average maximum or minimum temperature. CSIRO modelling results for Australia indicate that future changes in variability are relatively small and the increases in average temperature mainly determine the change in extremes.

Increases in average temperature can lead to large changes in the occurrence of extremely hot or cold days. This was assessed by applying the changes in average temperature given in Figure 3 to the observed daily temperature record at some selected sites and then calculating the resulting change in the frequency of extremes. Results are given in Tables 2 and 3. It was found, for example, that the average number of days over 35°C each summer in Melbourne would increase from 8 at present to 9–12 by 2030 and 10–20 by 2070. In Perth, such hot days would rise from 15 at present to 16–22 by 2030 and 18–39 by 2070. On the other hand, sites currently with frequent frosty days, have the potential to become mostly frost-free by late in the century.

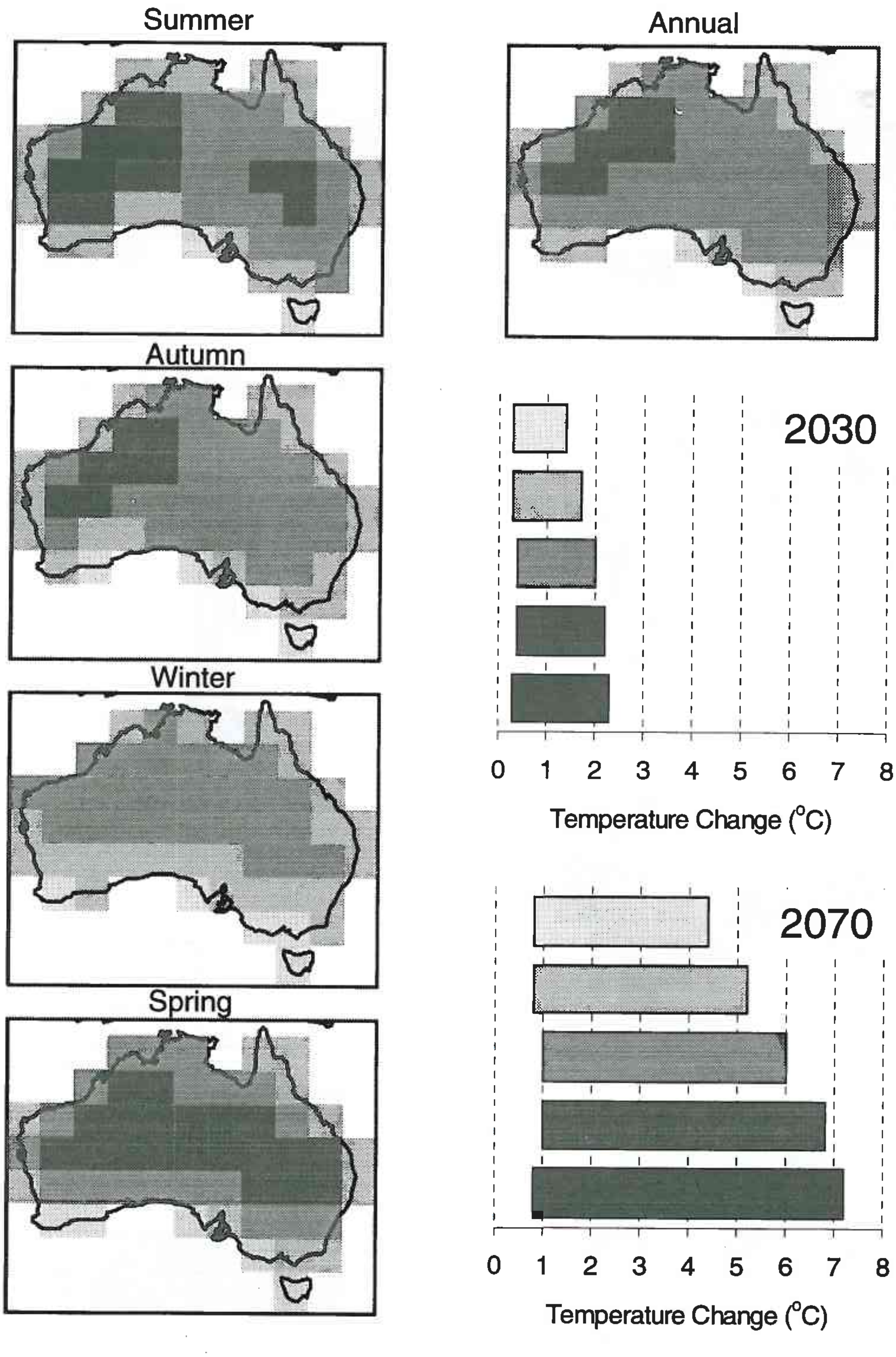

Figure 3. Average seasonal and annual warming ranges (°C) for around 2030 and 2070 relative to 1990. The bars show ranges of change for areas with the corresponding grey shading in the maps.

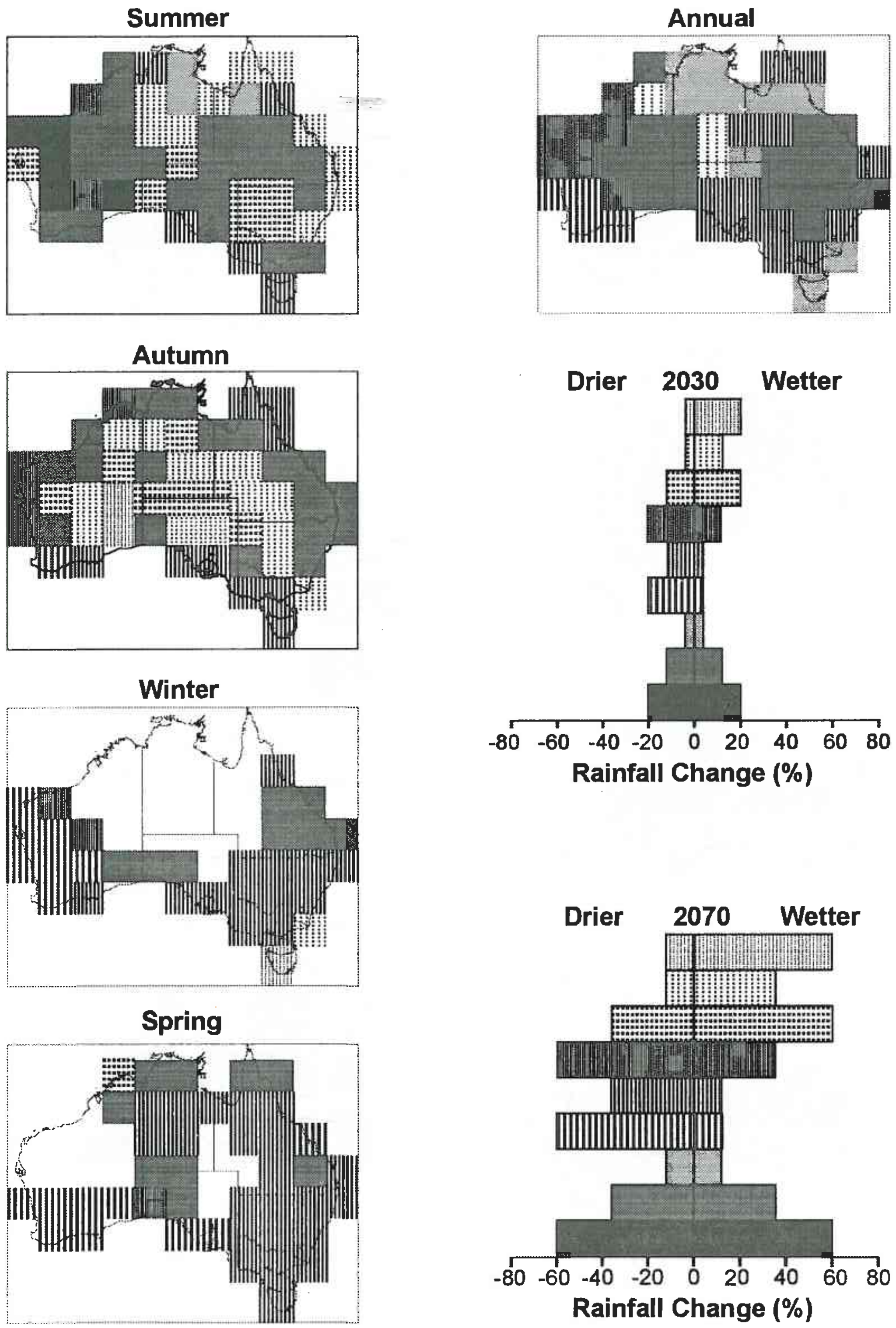

Figure 4. Ranges of average seasonal and annual rainfall change (%) for around 2030 and 2070 relative to 1990. The bars show ranges of change for areas with corresponding pattern in the maps. Ranges are not given for areas with seasonally low rainfall because percentage changes in rainfall cannot be as reliably calculated or applied in such regions.

3.2 Rainfall

Figure 4 shows ranges of change in Australian rainfall for around 2030 and 2070. Projected annual average ranges tend towards decrease in the southwest (–20% to +5% by 2030 and –60% to +10% by 2070, rounded to the nearest 5%), and in parts of the southeast and Queensland (–10% to +5% by 2030 and –35% to +10% by 2070). In some other areas, including much of eastern Australia, projected ranges are –10% to +10% by 2030 and –35% to +35% by 2070. The ranges for the tropical north (–5% to +5% by 2030 and –10% to +10% by 2070) represent little change from current conditions.

Table 2. The average number of summer days over 35°C at capital cities (excluding Darwin) for present conditions, 2030 and 2070.

	Present	2030	2070
Hobart	1	1-2	1-4
Sydney	2	2-4	3-11
Brisbane	3	3-6	4-35
Canberra	4	6-10	7-30
Melbourne	8	9-12	10-20
Adelaide	10	11-16	13-28
Perth	15	16-22	18-39

Table 3. The average number of winter days below 0°C at selected sites for present conditions, 2030 and 2070.

	Present	2030	2070
Canberra (ACT)	44	31-42	6-38
Orange (NSW)	38	18-32	1-27
Launceston (TAS)	21	10-18	0-14
Tatura (VIC)	15	6-13	0-9
Wandering (WA)	14	5-11	0-9
Dalby (QLD)	10	3-7	0-6
Nuriootpa (SA)	9	2-7	0-5

In summer and autumn, projected rainfall ranges for most locations are –10% to +10% by 2030 and –35% to +35% by 2070 or tend towards increase (–10% to +20% by 2030 and –35% to +60% by 2070). The latter occur mainly in parts of southern inland Australia in summer and inland areas in autumn. In some parts of northern and eastern Australia in summer and inland Australia in autumn the tendency for wetter conditions is –5% to +10% by 2030 and –10% to +35% by 2070. However, for the far southeast of the continent and Tasmania, projected rainfall tends to decrease in both seasons (–10% to +5% by 2030 and –35% to +10% by 2070).

In winter and spring most locations tend towards decreased rainfall (or are seasonally dry). Ranges are typically –10% to +5% by 2030 and –35% to +10% by 2070. Projected decreases are stronger in the southwest (–20% to +5% by 2030 and –60% to +10% by 2070) while Tasmania tends toward increases in winter (–5% to +20% by 2030 and –10% to +60% by 2070).

Where average rainfall increases, there would be more extremely wet years, and where average rainfall decreases there would be more dry spells. Most models simulate an increase in extreme daily rainfall leading to more frequent heavy rainfall events and flooding. This occurs where average rainfall increases and can occur where average rainfall decreases slightly. Reductions in extreme daily rainfall occur where average rainfall declines significantly.

When considering the impact of changes in average rainfall, allowance should also be made for changes in evaporation. The climate change simulations considered here show increases in potential evaporation across Australia [CSIRO, 2001], primarily as a consequence of higher temperature. The increases occur in all seasons and, annually averaged, range from 0 to 8% per degree of global warming over most of Australia, and up to 12% over the eastern highlands and Tasmania. When the simulated increases in potential evaporation are considered in combination with simulated rainfall change, the overall pattern shows decreases in moisture balance on a nationwide basis. Average decreases in annual water balance range from about 40 to 120 mm per degree of global warming. These decreases in moisture balance would mean greater moisture stress for Australia.

4. DISCUSSION

We presented here projected ranges of change in future climate due the enhanced greenhouse effect which made quantitative allowance for some key uncertainties. We have taken into account uncertainty in projecting future emissions and uncertainty due to model to model differences in the simulated climate response. However, there is uncertainty regarding how models in general represent the climate system and its response to enhanced greenhouse conditions, particularly with regard to clouds, biological feedbacks and the oceans. The coarse spatial resolution of climate models also remains a limitation on their ability to simulate the details of regional climate change. Thus changes outside the ranges given here cannot be ruled out, nor can confidence levels be reliably quantified. In addition to changes due to the enhancement of the greenhouse effect, future climate will be affected by other factors, such as solar radiation variations, volcanic eruptions and internal natural variability of the climate system.

5. ACKNOWLEDGEMENTS

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