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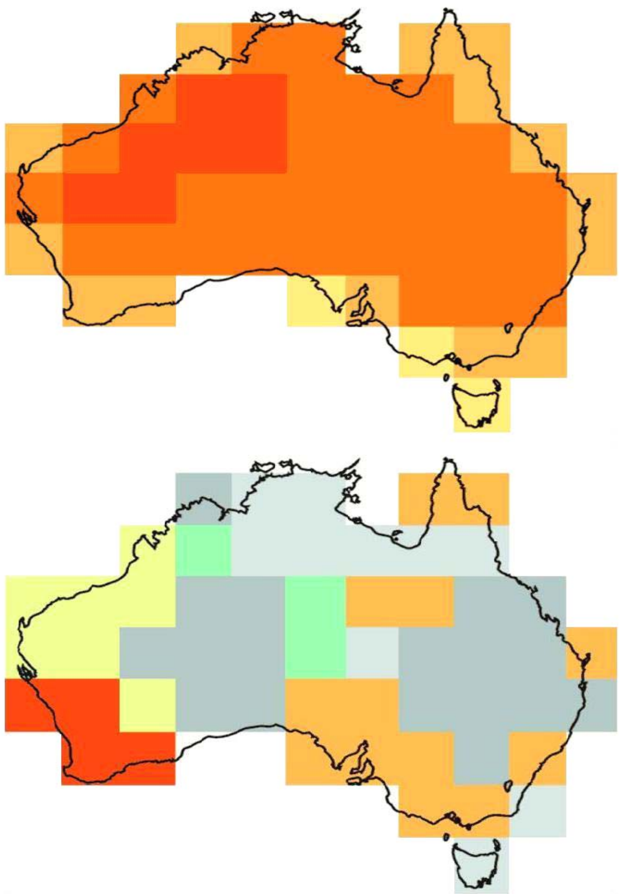

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Summary

The Climate Impact Group has prepared regional climate change projections for Australia. More detailed projections for individual states and other specific regions have also been prepared in recent years. Associated with this, CSIRO has developed climate change projection software, OzClim, which has seen wide application. The broad philosophy behind the construction of climate change projection information has not changed over the years. The purpose of this report is to review recent climate change projection work of CSIRO, particularly CSIRO (2001) and subsequent publications. A scenario or projection is a description of a plausible future climate constructed given certain assumptions about future changes to climate forcing (particularly patterns of anthropogenic emissions of greenhouse gases and aerosols, and stratospheric ozone depletion). Climate projections as produced by CSIRO allow for a range of different greenhouse gas and aerosol emissions scenarios and a range of different responses of the global climate system as given by a number of simulations from current global climate models (GCMs). A range of projections arise when multiple emission scenarios and/or models are considered.

This report describes the approach used for preparing quantitative ranges of change of *mean* climatic conditions from a set of climate model simulations. The main focus is on projections of temperature and precipitation although, more recently, the method has been applied to other variables such as potential evaporation, moisture balance and surface wind. The method was developed mainly for changes to mean conditions. Changes to climatic variability and extremes are also potentially very important to regional climate impacts, but have not in general been subject to the projection methods described here to date.

The method used in developing projections contains four main steps. The first is the choosing of a set of climate models from which regional climate change information will be obtained. This involves a quality control procedure in which skill scores were calculated for temperature, rainfall and sea level pressure. A demerit point system whereby models were rejected when the number of demerit points exceeded a particular threshold is used to select the models. In the second step, the model gridpoint values of the climate variable are linearly regressed against the model's globally averaged temperature, yielding a pattern of response as a function of global warming. In the third step, the different patterns of change from the various models are used to form ranges of change. The final step involves scaling the second lowest and second highest response pattern by the global warming projections for a particular future date.

The Australia-wide projections of summer and winter temperature and rainfall change for 2030 and 2070 released in 2001 are compared with high resolution projections that were developed for various Australian States or Territories and regions over recent years. The higher resolution temperature projections were generally consistent with the Australia-wide projections except that much greater detail was captured particularly in the coastal zone with generally narrower ranges of change and upper limits of change that were lower than inland locations. The more recent, higher resolution rainfall projections for summer showed some differences from the 2001 projections in that the different selection of models used in the recent projections tended to yield a greater tendency toward drying conditions in the future across much of Australia where the 2001 projections indicated a greater tendency toward increases across much of the east coast, Cape York Peninsula and the northern border of Western Australia and Northern Territory. The more recent winter rainfall projections were generally more

consistent with the 2001 projections in projecting a greater tendency towards drier conditions across mainland Australia and rainfall increases in Tasmania. The main differences were in eastern Queensland where a tendency towards drying conditions is now projected whereas in the 2001 projections, much of the region was uncertain with either increases or decreases possible.

The projections were also compared with the observed changes to date to see if they are broadly consistent. The projections differ from the observations over northwest Australia where the observations indicate a cooling and moistening trend. However, over the eastern half of the continent and southwest WA, the projections are similar to observations in indicating warming and drying trends as well as capturing the coastal gradient in temperature trends that range from least warming at the coast to greatest warming inland.

As climate change projection techniques continue to develop, it is anticipated that the presentation of projections will evolve towards ranges of uncertainty being presented as probability distributions, and different models or simulations being given different weightings based on their ability to simulate the present climate. The linearity assumption behind the pattern scaling technique will be investigated more extensively for range of currently considered variables such as rainfall and new variables such as wind, pressure, sea surface temperature, sea level rise and extremes in some of these variables.

Notwithstanding the uncertainties that arise from the development of regional climate change scenarios using global and regional climate models, the emission scenarios that are used to drive the climate models will continue to contribute large uncertainty to climate projections.

1 Introduction

Despite international efforts to reduce emissions of greenhouse gases, substantial increases in carbon dioxide concentrations are inevitable during the course of the 21st century and continued global warming and climate change will occur. For society to consider its options and responses to the changing climate, it is necessary to identify how various regions of the globe may be affected by future climate change and its impacts, and to identify adaptations to reduce vulnerability and to embrace potential benefits. This task requires the best available estimates of the future regional climate change and its impacts and the casting of this information, including uncertainties, in a form that is relevant to current planning and decision-making.

To this end CSIRO has documented projected changes in regional climate for Australia, with releases in 1992, 1996 and 2001 (CSIRO 1992, 1996, 2001). More detailed projections for individual states and other specific regions have also been prepared in recent years (Whetton et al., 2002; McInnes et al., 2003; Hennessy et al., 2004a; McInnes et al., 2004; Suppiah et al., 2004; Hennessy et al., 2004b, Cai et al., 2004, Walsh et al., 2004, McInnes et al., 2005). Associated with this, CSIRO has developed the climate change projection software, OzClim, which has seen wide application. This information has been prepared under contract for clients in Federal and State governments, but has been used by a wider range of stakeholders. This has included natural resource managers, farmers, policymakers, impact researchers and the general public.

The broad philosophy behind the production of this climate change projection information has not changed over the years and has been described before (Whetton et al., 1996). Two key elements of the approach have been (i) the assessment of reliability of the climate models used through validation against observed climate and the investigation and (ii) representation of the key uncertainties in projecting regional change. However, beyond that there are many more specific issues that arise in attempting to produce a summary climate change statement for wide application which appropriately represents current scientific understanding of regional climate change and its uncertainties.

The purpose of this report is to review recent climate change projection work of CSIRO, particularly CSIRO (2001) and subsequent publications. This entails describing the philosophy behind the approach, documenting the approach used, key concerns and how they are addressed, and identifying ways to improve such products in the future. The report also summarises the most robust and interesting features of projected climate changes in the Australian region that have emerged from this work.

The focus of this report is on the approach to preparing quantitative ranges of change of *mean* climatic conditions, mainly temperature and precipitation. It is for changes to mean conditions, that the methods described in this report were developed. Changes to climatic variability and extremes are also potentially very important to regional climate impacts, but to date have not generally been subject to the projection methods described here.

2 Background

2.1 Terminology

Here we use the term 'projections' to describe the CSIRO climate change information products which are outlined here. CSIRO has also used the terms 'scenarios' for such products in the past. A scenario or projection is a description of a plausible future climate constructed given certain assumptions about future changes to climate forcing (particularly patterns of anthropogenic emissions of greenhouse gases and aerosols, and stratospheric ozone depletion).

There are many possible climate pathways and the precise one that the Earth will follow in the future will depend on a broad range of factors. These include human behaviour, the degree to which human behaviour includes a specific response to the threat of climate change, the sensitivity of the global and regional climate systems to changes in climate forcing, and natural climate fluctuations due to internal factors or external forcing (e.g. volcanoes and solar activity).

Climate scenarios or projections as produced by CSIRO allow for a range of different greenhouse gas and aerosol emissions scenarios and a range of different responses of the global climate system as given by a range of simulations from current global climate models (GCMs). As our understanding of both future human behaviour and the response of the global climate system is not complete, we avoid the use of the words 'forecast' or 'prediction' to describe our climate change projections. Indeed, avoiding such terminology is particularly appropriate when one considers that current projections of future global warming that are based on certain assumptions of human behaviour may bring about changes in that behaviour with a subsequent effect on the climate outcome.

The distinction we now draw between 'scenarios' and 'projections' is more technical. Following the recent lead of the Intergovernmental Panel on Climate Change (IPCC) (2001) we use 'projections' to describe the change to climate that is simulated on the basis of a particular given set of input conditions (a given emissions scenario, and climate model in which it is used). A range of projections arise when multiple emission scenarios and/or models are used. In IPCC parlance (and elsewhere) a climate change 'scenario' or set of 'scenarios' are the necessary inputs for impact studies. Scenarios can be based on projections but will often require specific formulation so the impact model can use the climate change information. So 'projections' are best viewed as the consequences of a particular set of emissions scenarios, whereas climate change scenarios are required inputs for impact assessment. CSIRO (2001) and related products are certainly 'projections' and are named as such, but for some impact assessment work they also serve as scenarios.

It is significant that this material has applications in policy development as well as impacts research. Such application highlights the extreme importance of fully exploring and representing uncertainty in the projections. In this context a very detailed scenario of climate change obtained from the latest high resolution model is not useful unless its results are set in the context of the broader range of possible change.

Projecting how regional climate may change in response to increasing concentrations of greenhouse gases is fraught with uncertainty. Results of simulations with GCMs are our main source of information, but despite large improvements in recent years these tools remain approximations of the real world. Of course models can never be perfect, but with careful interpretation, they can provide guidance on how regional climate may change. Furthermore, future climate change is also dependent on future emissions of greenhouse gases and aerosols, and ozone depletion, each of which is strongly dependent of future human behaviour, e.g. technological development, economic growth and population change. Nevertheless, assessments of regional climate change are needed so that the possible impacts of this change can be estimated. Such estimates enable the costs and benefits of various alternative emissions reduction strategies to be assessed.

2.2 Outline of the approach used

The purpose of this document is to describe the methods used to construct the ranges of temperature and precipitation change in CSIRO's projections for the Australian region (CSIRO, 2001) and in subsequent regional assessments. The SRES (2000) range of projected global warming (IPCC 2001) was combined with projected regional changes obtained from a range of climate models. The objective was to quantify ranges of uncertainty where possible. In this document we describe the following steps:

- Choosing a set of climate models from which regional climate change information will be obtained
- Extracting the regional climate change pattern from these models
- Forming ranges of change from the model results
- Combining the regional information with the global warming projections

In general terms the approach is similar to that used in previous scenarios (CSIRO 1992, 1996) and is described in Whetton et al. (1996).

3 Data and Methods

3.1 Development and maintenance of GCM and regional model database

Development of regional projections requires a database of climate model simulations. The database needs to be up to date because the more recent simulations are conducted using more advanced models and are likely to be more detailed and reliable. The database also needs to be comprehensive so that differences between models in simulated regional climate change are adequately documented in the database.

The 2005 database (Table 1) consists of the set of simulations available through the IPCC Data Distribution Centre (DDC) (http://ipcc-ddc.cru.uea.ac.uk/), supplemented by some additional global and regional simulations from CSIRO. The DDC simulations have passed various quality control requirements such as the existence of adequate model documentation and the inclusion of the observed increase in greenhouse forcing through the twentieth century (a 'warm start' simulation). These simulations reflect the 'state-of-the-science'. Global climate models have an effective spacing between gridpoints of 200-600 km. The range of simulations in the CSIRO database is more extensive than that in the DDC. We also include simulations undertaken with the CSIRO stretched-grid global-atmospheric model 'CCAM' (McGregor and Dix, 2001) and the CSIRO regional climate model 'DARLAM', both of which have 50-125 km resolution over Australia.

3.2 Climate model selection for regional climate change projections

A set of the simulations in Table 1 is selected for development of regional projections. The intention of this is that the selected group be the subset of model runs most likely to provide relevant and reliable information for the region concerned. Relevance and reliability are usually assessed by considering how well each of the models simulate current climate (model validation or evaluation).

Relevance relates to the adequacy of the model in simulating the large-scale climatic features which are to be the focus of study under enhanced greenhouse conditions. If a model fails to adequately represent such features, it is then appropriate to exclude the enhanced greenhouse results of that model. For example, if one is interested in the onset of summer monsoon rainfall under enhanced greenhouse conditions, then one needs a model that adequately simulates a monsoon in the region of interest. If one is interested in climatic features which are only present at fine spatial or temporal scale, then one may exclude from consideration all coarse resolution simulations because they do not have any relevant information (at least not directly). As the purpose of the regional projection work to be described here was to develop projections in average conditions at a relatively broad scale (100 km plus) all models in the database had the potential to provide relevant results.

Using model validation to assess the reliability (in qualitative or quantitative terms) of the model's simulation of enhanced greenhouse changes in regional climatic features of interest is a more complex task. Here the underlying concern is to validate the model's processes which are active in producing the simulated changes in regional climate. Comparison of the climatic feature of interest against observations (as described above) contributes to this assessment, but there is a need to consider model climate more broadly. For example, if precipitation is the variable of primary interest, it is appropriate to consider the model's simulation of synoptic circulation patterns associated with rainfall occurrence. In addition, model performance over a broader region of interest, and in all seasons, is relevant. Accuracy in simulating observed regional trends during the 20th century is potentially very relevant, but has been little used to date due to weak signal to noise and incomplete representation of forcing in the models.

Climate model validation results can be used to weight the enhanced greenhouse results of climate models (e.g. Giorgi and Mearns 2002), but these methods do not have the complexity to appropriately address the issue of reliability of processes as described here through the consideration of multiple variables, e.g. rainfall and pressure. It is still the case that choosing appropriate variables for validation, determining the appropriate domain for validation (this may need to be larger than the region of interest), weighing-up performance of one variable against another, and drawing overall conclusions on whether a model is performing acceptably well are difficult issues for which there is as yet no generally accepted methodology.

The choice of method and the conclusions drawn will therefore have a subjective element. The impact of this can be reduced by keeping the approach as simple and as transparent as possible so that readers can easily determine whether they agree with the conclusions drawn.

Table 1: *Enhanced greenhouse simulations available to the Climate Impact Group for impact assessment prior to and post 2003. The non-CSIRO simulations were obtained from the IPCC Data Distribution Centre (http://ipcc-ddc.cru.uea.ac.uk/). DAR125 is a Regional Climate Model.*

Centre	**Model Symbol**	**Emissions Scenarios post-1990 (historical forcing prior to 1990)**			**Simulation Years Available**	**Horizontal resolution (km)**
		Group A (Pre 2001)	**Group B (2001- 2003)**	**Group C (Post 2003)**		
Canadian Climate Centre	CCCM1	1% increase in CO_2 p.a.			1900–2100	~400
Canadian Climate Centre	CCCM2.1		IS92a		1961-2100	~400
Canadian Climate Centre	CCCM2.2			CO_2+ aerosol SRES- A2, B2	1900-2100	~400
CCSR, Japan	CCSR	IS92a		SRES- A1, A1F1, A1T, A2, B1, B2	1890-2100	~500
CSIRO, Australia	Mark2.1	IS92a			1881–2100*	~400
CSIRO, Australia	Mark2.2	SRES A2 (x 4) SRES B2			1881–2100*	~400
CSIRO, Australia	DAR125	IS92a			1961-2100	125
CSIRO, Australia	Mark3		SRES A2		1961-2100	~200
CSIRO, Australia	CC50		SRES A2		1961-2100	~50
DKRZ, Germany	ECHAM3/LSG	IS92a			1880-2085	~600
DKRZ, Germany	ECHAM4/OPYC3	IS92a			1860–2099	~300
DKRZ Germany	ECHAM4/OPYC3			CO_2+O_3 + aerosol, SRES- A2, B2	1990-2100	~300
GFDL USA	GFDL.1	1% increase in CO_2 p.a.			1958–2057	~500
GFDL USA	GFDL.2			Varying insolation + aerosol, SRES- A2, B2	1961-2100	~500
Hadley Centre, UK	HadCM2	1% increase in CO_2 p.a. (x 4)			1861–2100	~400
Hadley Centre, UK	HadCM3.1	IS92a			1861-2099	~400
Hadley Centre, UK	HadCM3.2			CO_2+O_3 + aerosol, SRES- A2, B2	1950-2099	~400
NCAR-CGM USA	NCAR.1	IS92a			1960-2099	~500
NCAR-CGM USA	NCAR.2			SRES A2	2000-2099	~300
NCAR-PSM USA	NCARPSM			CO_2+ aerosol SRES-A1B, A2, B2	1980-2099, 1980-2099, 2000-2099	~300

In each of the regional studies described in Table 1, the degree of correspondence between regional observed and simulated patterns of temperature, mean sea level pressure (MSLP) and precipitation were assessed by calculating skill scores such as root mean square (RMS) error and pattern correlation statistics and by visual examination of the corresponding maps. A pattern correlation coefficient of 1.0 indicates a perfect match between observed and simulated spatial patterns and an RMS error of 0.0 indicates a perfect match between observed and simulated magnitudes. However, these perfect scores will never be achieved because there will always be some difference due to the model and the observations having different samples of climatic variability. Figure 1 illustrates the RMS and pattern correlation results for MSLP over Australia. In these figures, models in the top-left corner indicate a good match with observed spatial pattern with realistic magnitudes of observed parameters. Models in the bottom-right show the opposite results. Realistic patterns of mean sea level pressure are important because they implicitly relate to the circulation patterns (i.e. wind and locations of highs and lows) in the models and influence other variables such as rainfall. In all the regional studies conducted over Australia (e.g. Whetton et al., 2002; McInnes et al., 2003; Hennessy et al., 2004a; McInnes et al., 2004; Hennessy et al., 2004b, Cai et al., 2004, Walsh et al., 2004), skill scores were calculated over rectangular domains that focused on the area of interest with a broader region used for MSLP. Figure 2 shows the domains used in the various regional studies conducted over Australia while Table 2 provides a summary of the models used in each of these studies.

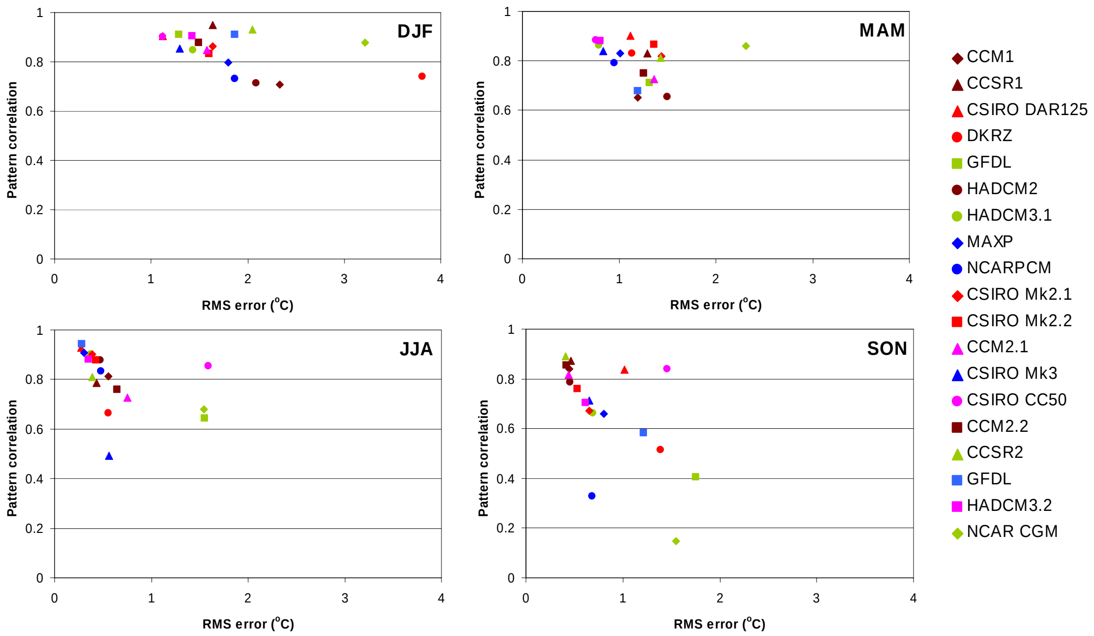

Figure 1: *Seasonal RMS and pattern correlation values for MSLP calculated over the region 110 to 160°E and 10 to 45°S in 19 climate models (see Table 1).*

In the first instance, the skill scores were useful for identifying gross failure to represent a major component of the climate system – a result that would render the simulation as irrelevant. This was a rare outcome. Usually the large-scale features of Australian climate (i.e. latitudinal temperature gradients, seasonality of precipitation and major circulation features such as the high pressure belt, Australian monsoon and the trade-winds) were well simulated. An 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.

The results of these tests were also used to sort simulations, where appropriate, into better and poorer performing models. Results across all seasons and variables were taken into account. Although the scores on the statistical tests objectively ranked models, deciding where to draw the line of acceptability is somewhat arbitrary. For several recent regional projections (e.g. McInnes et al., 2003, 2004; Hennessy et al., 2004a,b; Cai et al., 2004), a simple demerit point system based on thresholds was used. In the South Australian assessment, models were assigned a point if they had either an RMS error greater than 2.0, or a pattern correlation below 0.8 for pressure and below 0.6 for temperature and rainfall. This amounted to a total of 24 possible demerit points (2 performance measures x 4 seasons x 3 climate variables) and models were excluded from the projections with at least seven demerit points. In nearly all subsequent regional studies, this demerit system with minor variations has been used to rank model performance. For example, in the Northern Territory (Hennessy et al. 2004a), Tasmania (McInnes et al. 2004) and New South Wales (Hennessy et al. 2004a), models were excluded if they has at least nine, ten or nine points, respectively.

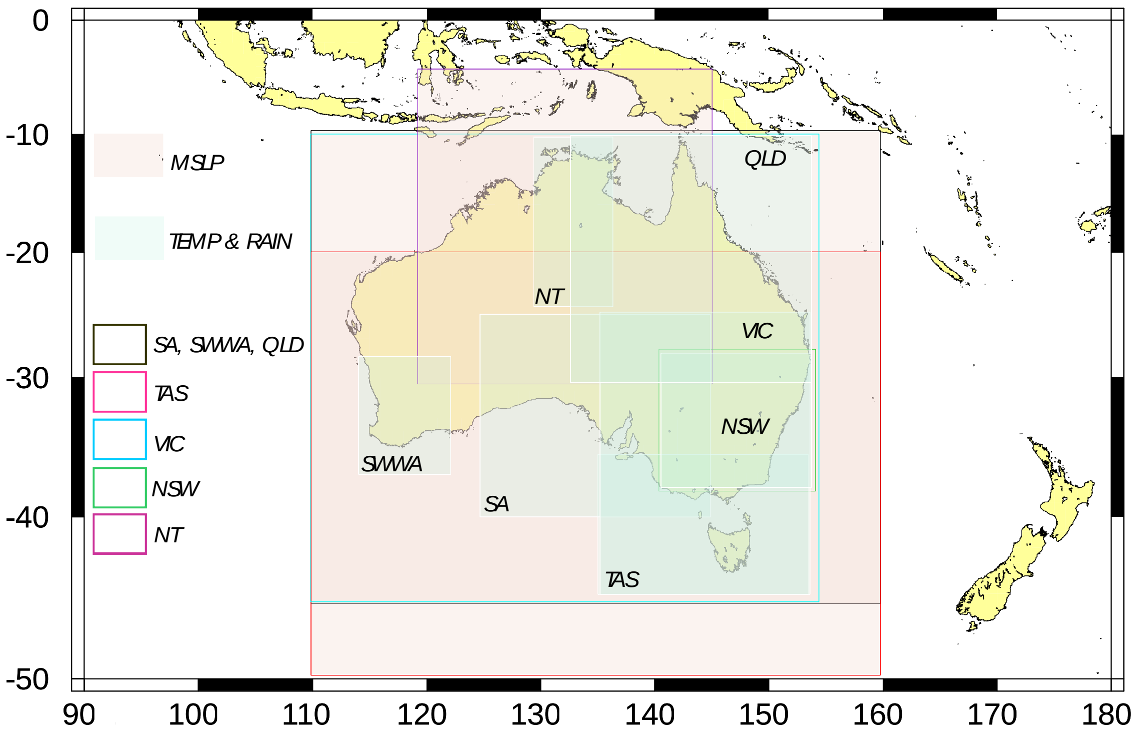

Figure 2: *Summary of regions over which climate models were validated for the different regional studies.*

Table 2 provides summary statistics on the classification across the regional studies. There was a tendency for some simulations to be inferior in most Australian regions: GFDL, CCSR and ECHAM3. The better performing models were considered more reliable and were used in climate change projections. However, in some of the studies the climate change results of the full set of models and the optimal set were compared to see if this classification significantly affected the results (see section 4.3)

More focused tests of model performance were employed in some studies, to address particular questions. For Victoria, Suppiah et al. (2004) measured whether climate models could simulate the observed tendency for rainfall in the southeast and southwest to vary more independently than elsewhere in the state. Models performed well on this test, which provided justification for analysing the enhanced greenhouse rainfall results of the models down to the spatial scale represented by these parts of the state.

Table 2: *Model simulations assessed (see Table 1 for Group A and B models) in the development of climate projections carried out by the Climate Impact Group for various states and regions in Australia. Column 2 lists the details of the scenarios in terms of the variables developed; T=temperature, R=rainfall, PE=potential evaporation, MB=atmospheric moisture balance (difference of precipitation and potential evaporation),* W_{10}*=10m windspeed; seasons considered; 4Seas = 4 standard seasons, Ann = annual average, 2Seas = 2 half year seasons based on May to Oct. and Nov. to April; projection years under SRES emissions scenarios or* CO_2 *stabilization scenarios that stabilize at either 450ppm or 550ppm. A* and C* refers to all but the CCSR model in the particular column of Table 1.*

State / Region (year undertaken)	Variables projected, year and scenario	Models	Models Omitted	Comments
Victoria (2001)	T, R, PE, MB 4Seas+Ann 2030, 2070 SRES	A*	None	ECHAM3 and GFDL noted as being poorer than other models
South Australia (2003)	T, R, PE, MB 4Seas+Ann 2030, 2070 SRES	A*+B	ECHAM3, GFDL.1	Assessment using demerit system based on spatial skill scores. ECHAM3 MSLP too low and rain too high over north and central Australia in spring and summer. GFDL high bias in MSLP year-round, too cold and wet over southern Australia in winter and spring
Queensland (2003)	T, R 4Seas+Ann 2030, 2070 SRES	A*+B	ECHAM3, GFDL.1	Assessment using demerit system based on spatial skill scores. ECHAM3 monsoon trough too deep in summer and spring. Poor east coast temperature pattern due to coarse resolution. GFDL high bias in MSLP year-round, too wet over Qld in winter and spring
Northern Territory (2004)	T, R, PE, MB 2Seas 2030, 2070 SRES	A*+B	ECHAM3, GFDL.1 NCAR CCM1	Assessment using demerit system based on spatial skill scores and rainfall annual cycle. NCAR too wet and hot in spring and summer, ECHAM3 summer rainfall pattern unrealistic. CCM1 and GFDL had weak annual rainfall cycle, wet season totals too low
Tasmania (2004)	T, R, PE, MB, W_{10} 4Seas+Ann 2030, 2070 SRES	A+B+C	ECHAM3, GFDL.1 CCM1 CCSR (all) NCAR (all)	Assessment using demerit system based on spatial skill scores. All models had unrealistic temperature patterns over SE Australia and were too cold in winter. GFDL/NCAR were biased high/low in MSLP respectively
New South Wales (2004)	T, R, PE, MB 4Seas+Ann 2030, 2070 SRES, 450, 550	A+B+C	ECHAM3 GFDL.1 CCSR (all) NCARCGM	Assessment using demerit system based on spatial skill scores. Rainfall well simulated in all models. CCSR, GFDL1, GFDL2 and ECHAM3 had large MSLP biases in all seasons. Large RMS errors in temperature were evident in the CCSR models, ECHAM3, GFDL1, CSIRO Mark2.1 and NCARCGM
Queensland (2004)	T, R, PE, MB 4Seas+Ann 2030, 2070 SRES	A+B+C	ECHAM3 GFDL.1 CCSR (all) NCARCGM	Assessment using demerit system based on spatial skill scores. Strength of sub-tropical ridge too high or too low in some models in winter and spring. Errors in temperature where coarse resolution models failed to capture east coast orography
SW Western Australia (2004)	T, R 2Seas 2030, 2070 SRES, 450, 550	A*+ B+C*	ECHAM3 ECHAM4(all) NCAR (all) GFDL (all)	Assessment using spatial skill scores on summer and winter half years. Simulation of MSLP in winter poor in low resolution GCMs. Poor rainfall in summer in some models

Suppiah et al. (2004) also directly assessed rainfall-producing processes in the model by comparing against observations the simulated correlation between rainfall anomalies and pressure anomalies. This link was simulated well by most models in winter and autumn, but less well in spring and summer. The authors concluded that the spring and summer rainfall projections should be viewed as less reliable.

Pattern correlations for MSLP were generally well captured by most models across the Australian region throughout the year. However, RMS errors were high in models that contained systematic biases such as the GFDL and ECHAM3 (DKRZ) models in summer (see Figure 1).

In summer, temperature patterns were generally well captured by the models in the south where the continental heating effect is dominant. However, RMS errors were large in some models. In winter, temperature patterns were much poorer in the south where topographic variations have a stronger influence. The coarser resolution models were generally the poorer performers.

Pattern correlations for rainfall tended to be poorest in the south in spring, summer and autumn while RMS errors tended to be small. However, in the north, RMS errors were large in some models during summer, and this often indicated a failure of the model to adequately capture the magnitude of monsoon rainfall.

3.3 Extracting the regional climate change pattern

Climate change patterns are often prepared by simply taking the difference of two thirty year periods such as 2070 to 2100 and 1960 to 1990. The difference at each grid point is then divided by the difference in global temperature to obtain a pattern of change per degree of global warming.

A disadvantage with this approach is that large portions of the simulation are not used in preparing the pattern of change, and this is of particular concern if the chosen intervals are strongly affected by a particular phase of higher frequency variability. An alternative that avoids this disadvantage is to linearly regress the local seasonal mean temperature (or rainfall) against global average temperature, then take the gradient of the relationship at each grid point as the change per degree of global warming. The grid point values can then be mapped to obtain a pattern of model response. For some variables, the response is expressed as a percentage change per degree of global warming with reference to the model climate of 1961-1990. In particular, percent change is used for precipitation to reduce the effect of errors in the baseline climate on the magnitude of the simulated change.

The regression approach has been used by CSIRO in all recent projections and was first used by Whetton et al. (2000). The approach has seen limited use elsewhere, but has recently been assessed by Mitchell (2003) where it was found to be a desirable and robust method. The approach, however, will not capture any systematic model responses which are not varying linearly with global temperature.

The potential benefit of using the regression approach in extracting patterns of change is illustrated in Figure 3. On the assumption that different models agree to some extent on their simulated patterns of change, we would expect this agreement to be better when the signal to noise is maximized in each model. For six models, the agreement between models on patterns of simulated rainfall change is greater for the regression method than the 30-year difference method.

The linear regression method is advantageous in that it decouples the model's response from the particular emissions scenario used in the simulation. The resultant change per degree of global warming can be rescaled by a given amount of global warming to produce a pattern of change that would apply for a given future date and global warming scenario. For example, a local rainfall change of 2% per degree of global warming can be scaled by the IPCC global warming estimate of 0.37-0.85°C by 2020, giving a local rainfall change of 0.74-1.70% by 2020. In addition, projections can be evaluated for emissions scenarios that have not been directly simulated in GCM experiments. Such rescaling of model results to a given global warming scenario has been commonly used in the construction of climate change projections 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, Ruosteenoja et al. 2003).

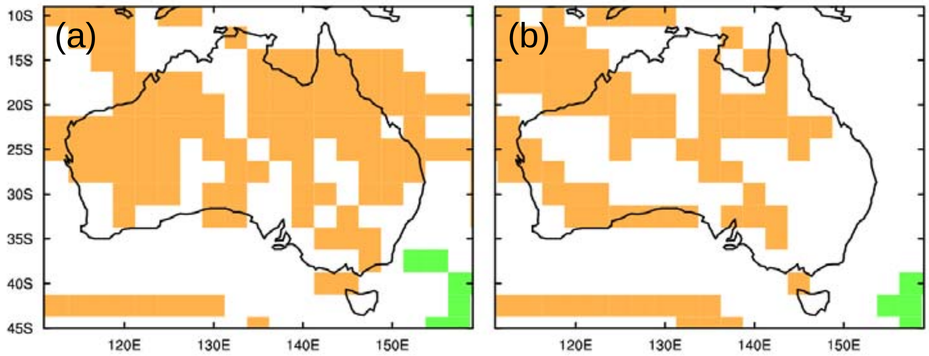

Figure 3: *Illustration of the improved signal-to-noise response of (a) the regression method compared to (b) the 30-year difference approach for pattern extraction. Areas where all six models agree on the direction of the change are shaded in orange for decreasing precipitation and green for increasing precipitation.*

In situations where there was more than one simulation for a given model (e.g. for models in which simulations existed for a number of different emissions scenarios), the patterns were extracted from each simulation and averaged into a single response. The exception was the Tasmanian study (McInnes et al., 2004) in which the new SRES scenarios were used for the first time. In that study it was decided to retain the older IS92a simulations of the Mark 2, HadCM3 and ECHAM4 models separate from the SRES simulations. This was due to the several years that had elapsed since the initial running of the IS92a simulations and the subsequent SRES simulations. In the case of the CSIRO Mark 2 model, this could be justified on the grounds that changes to the model physics had been undertaken in the time between the simulations. However, although there were small variations in the patterns of change from the older IS92a compared with the later SRES A2 simulations, it was found that the inter-model differences in patterns of change tended to be much larger that the intra-model differences. This is illustrated in Figure 4 which shows the annually averaged patterns of change for MSLP, temperature and rainfall in the IS92a simulation and the SRES simulations. Since the patterns of change fell in the mid-range of change for the variables considered, there was no effect of retaining the older IS92a patterns as separate entities. For these reasons, regional scenarios developed since the Tasmanian projections have simply averaged all patterns of change for a given model (e.g. Hennessy et al., 2004 a, b; Cai et al., 2004).

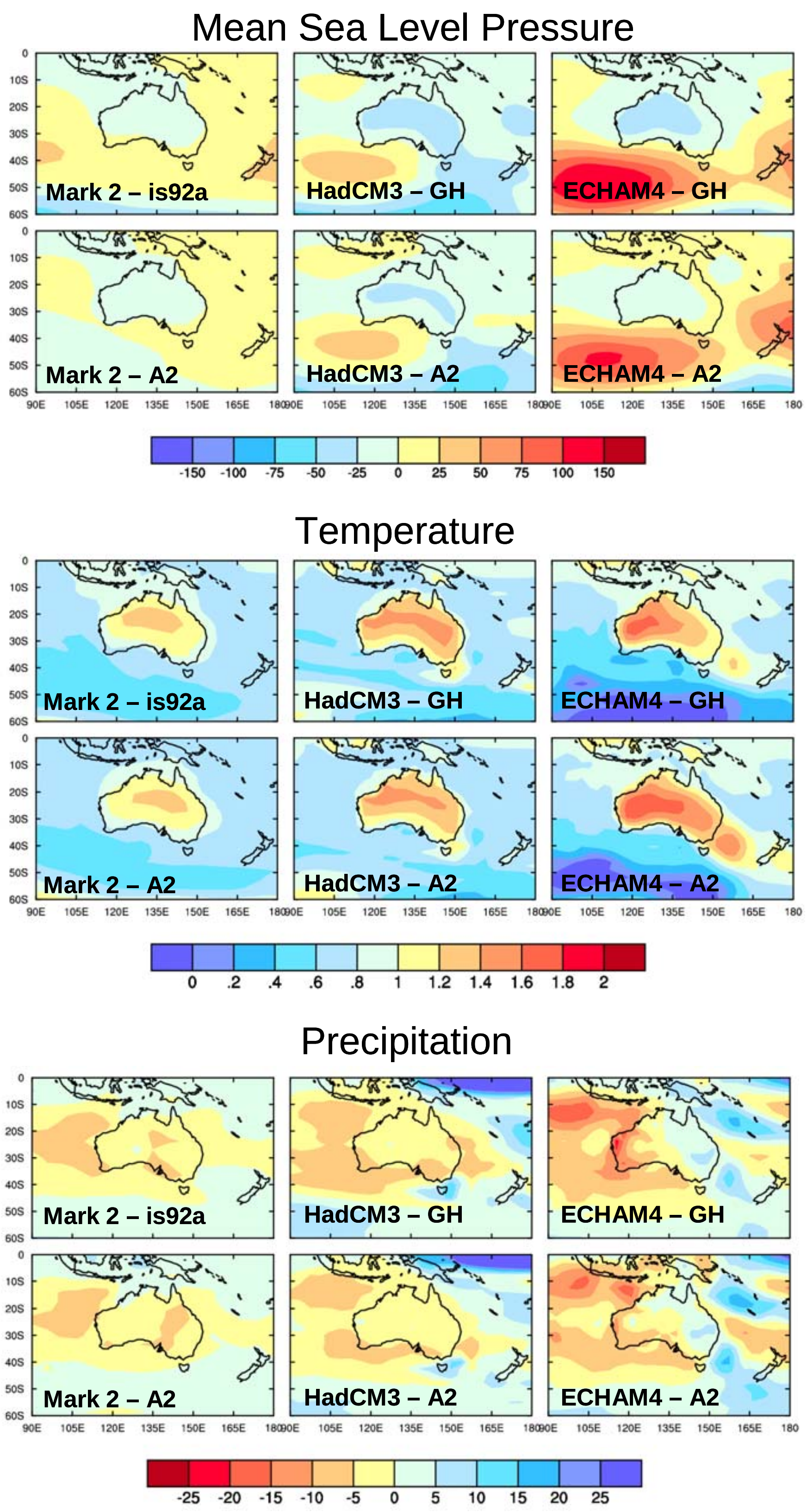

Figure 4: *The annually averaged patterns of change for (a) Mean Sea Level Pressure (MSLP), (b) temperature and (c) rainfall in the Mark 2 model forced with the IS92a and A2 emissions scenarios and the HadCM3 and ECHAM4 models forced with the 1% per annum increase in CO_2 (GH) and the A2 emissions scenarios. Units for (a) to (c) are Pascals per °C of global averaged change, local temperature change per global averaged change in °C and percentage change in rainfall per °C of global averaged temperature change respectively.*

3.4 Forming ranges of change from the model results

The next step in the development of the regional projections requires quantification of the range of change at each grid point so that patterns of change can be presented in a single map for a given variable. First, a common grid is chosen and models are interpolated to this grid. It is no finer that the finest resolution model selected. The range of climate change at each grid point is then identified. So as to reduce the influence of outlier results, the range is bounded by the second highest and second lowest result at each grid point. This follows the practice of Whetton et al. (1996) and CSIRO scenario statements of 1992 and 1996, but as the number of simulations used in recent studies is larger (at least nine, compared to five in earlier studies) the current method encompasses a larger portion of the uncertainty range.

Discrete increments are chosen for the range of change at each grid point. This is illustrated in Figure 5. For the total range spanned by the models from the second lowest to the second highest value, the interval ranges from -25% to +15%, so discrete intervals of 5% were used. This produces 36 possible ranges but only 17 appear in the maps.

To simplify the information conveyed, the number of ranges was reduced by incorporating some ranges into others. The choice of which ranges are preserved and which ranges are incorporated into other ranges is based on various subjective considerations. These include the amount of change or detail in the pattern of change relative to the base climatology, the total area represented by a particular range and so on. Generally, ranges are combined such that a broader range absorbs a narrower range. However, combining a broader range into a narrower range is sometimes undertaken for precipitation where only small areas representing the broader range exist or a large range of change in percentage terms occurs relative to a low value in base climatology so that there is little change in absolute terms. This occurs in Figure 5 where the -25% to +15% range is absorbed into the -20% to +5% range. Two ranges (-20 to +15% and -5 to +15%), could be ignored since they occurred only over ocean regions and the final projections were presented over land only.

The final step is to assign a particular set of colours to the reduced set of ranges. This is also a subjective exercise. In the case of rainfall, a selection of warm colours, evocative of a drying landscape, is used for the precipitation ranges of change that are centred on negative values while green shades are used for areas that are more likely to undergo increases in rainfall. Grey tones are generally reserved for ranges of change that are centred on zero to indicate that the direction of change is highly uncertain.

3.5 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. 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 in 2030 would be the upper limit of the 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 rainfall change is negative this is combined with the upper limit of the projected global warming.)

3.6 Ranges of projected global warming

The global warming projections upon which the regional projections are based (Figure 6) are those given by IPCC (2001). The range of warming for 1990-2100 allow for the full range of SRES (2000) greenhouse gas and sulfate aerosol emission scenarios plus variations across a range of climate models in their global average response to enhanced greenhouse conditions.

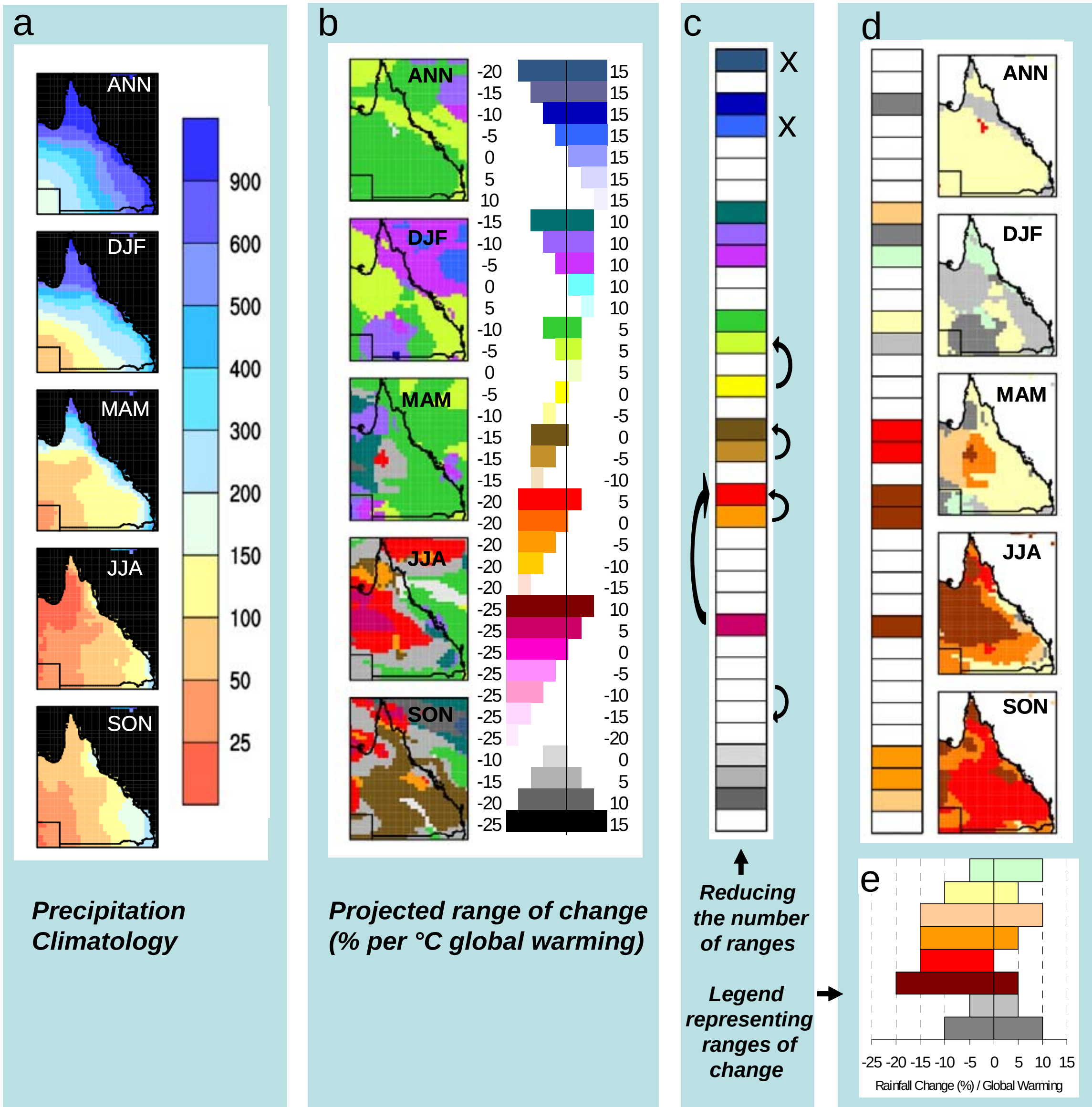

Figure 5: *The various steps involved in creating maps of future change from a selection of GCMs. (a) shows current climatology (in mm) to which the change patterns can be applied. (b) shows maps where colours represent a particular range of change according the range spanned by the group of GCMs (c) shows that of the 36 possible ranges, only 17 appear in the maps and of these the number of ranges can be reduced further by ignoring ranges that occur only over the ocean and by combining ranges (d) shows the final diagram after suitable colours are selected for the remaining ranges and (e) shows the legend with each range represented by a colour.*

The IPCC projected temperature increases were not based directly on the output of atmosphere-ocean global climate models (AOGCMs). Instead they were obtained from the output of a highly simplified climate model tuned to mimic the behaviour (in global-average terms) of the more complex 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. For further information on the IPCC global warming scenarios see IPCC (2001).

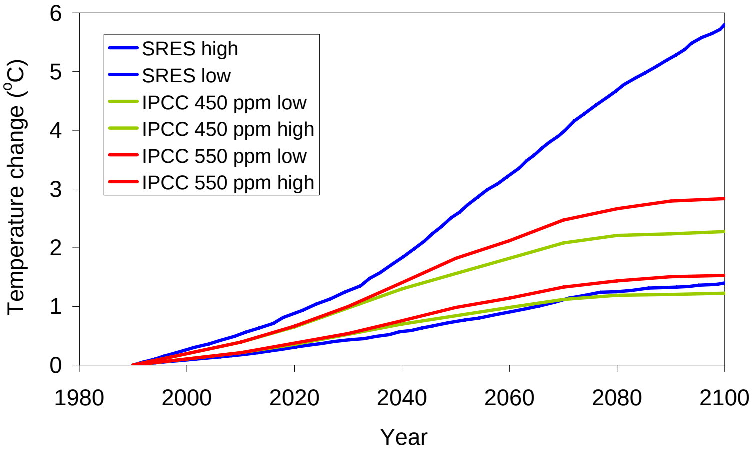

Figure 6: *Full range of global-average warming relative to 1990 based on the SRES emissions scenarios, and WRE 450 and 550 ppm CO_2 stabilization scenarios under low and high estimates of global climate sensitivity. From IPCC (2001).*

3.7 Presentation of regional projections

The projections can be presented for a given time in the future. The years of 2030 and 2070 have been commonly chosen since they represent short and longer term planning horizons. While most of the regional projections have presented results based on the SRES range of scenarios, Hennessy et al., (2004b) presented results for 2030 and 2070 based on the SRES scenarios as well as CO_2 stabilization scenarios in which stabilization occurs at 450 ppm by 2100 and 550 ppm by 2150. Temperature scenarios for New South Wales (Figure 7) including the stabilization scenarios show the impact that mitigation strategies can have on lowering the upper limit of potential warming.

As Figure 7 demonstrates, the projected regional warming is dependent on the given amount of global warming. This means that in interpreting diagrams such as Figure 7, it should be realised that it is not likely that a warming at one end of the range of possibility would occur at one site in combination with a warming at the other end of the range at another site.

4 Key features of climate change in Australia

In this section, general characteristics of the climate change projections over Australia are presented and discussed. In addition, selected results from the Australia-wide projections and the regional scale projections are shown and compared with observed trends. To facilitate the latter, the section begins with an analysis of observed regional climatic changes.

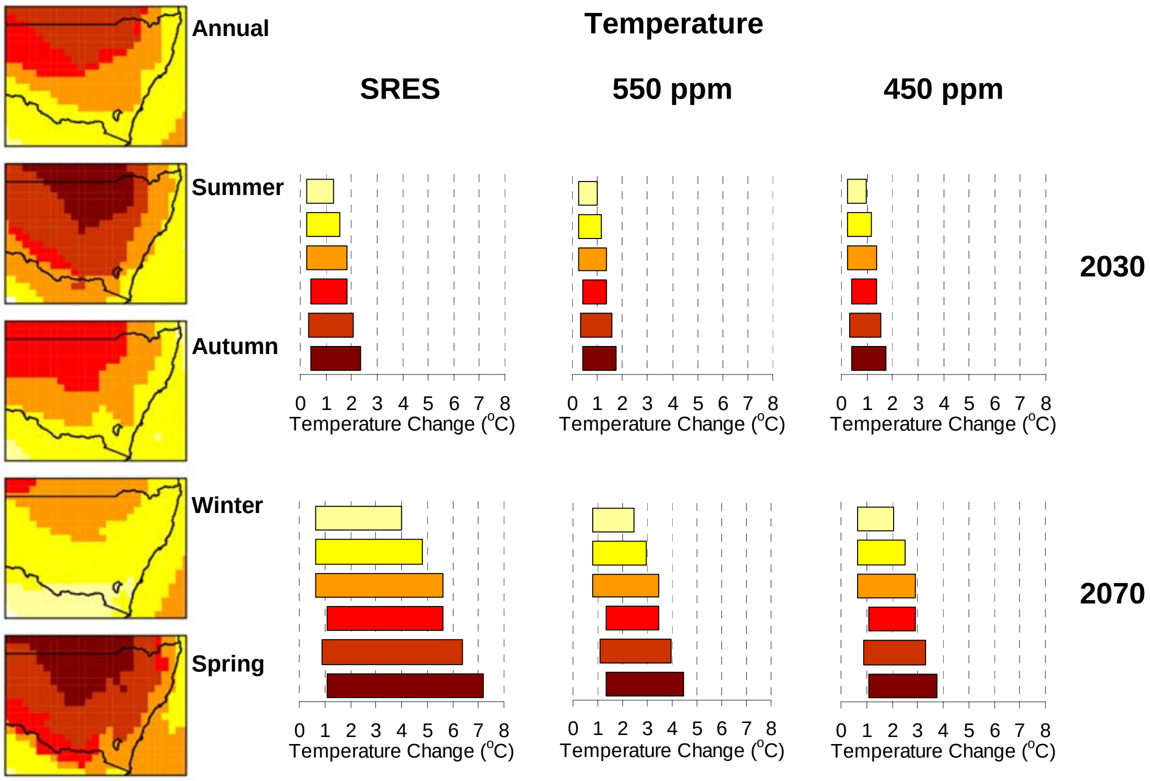

Figure 7: *NSW temperature projections presented with SRES and stabilization scenarios.*

4.1 Observed temperature and rainfall change over Australia

To assess observed regional climate changes, we have regressed observed Australian temperature and rainfall against observed annual global temperature (thereby using a similar procedure to that used for developing climate change projections). Observed annual global temperature anomalies (Figure 8) have been used in the regression analysis. The results for temperature (Figure 9) are qualitatively similar to the observed spatial pattern of change based on trend analysis (see for example http://www.bom.gov.au/cgi-bin/silo/reg/cli_chg/trendmaps.cgi). Since 1950, the changes range from around –0.8°C in the northwest to +1.5°C in the east. An interesting feature is the evidence of a coastal gradient on the eastern half of the continent with stronger warming occurring inland compared to the coast which is not apparent in the trend analysis. In winter, the greatest warming is found over southern Queensland while the least warming occurs in southern New South Wales and Victoria and a cooling trend in summer has occurred on the northern border between Western Australia and Northern Territory.

Observed changes in summer rainfall per degree of global warming are shown in Figure 10, for 1900-2004 and 1950-2004. Much of the continent shows weak increases per degree of global warming for 1900-2004, with slightly greater increases in the northwest of the continent and the eastern half of New South Wales. Rainfall decreases occur over much of the Queensland coast. From 1950-2004, the pattern is similar, but the areas of increase and decrease are stronger than in the full period. In particular, more extensive drying occurs over the eastern half of the continent and southwest WA. In general, the regression approach shows less sensitivity to the interval chosen compared with the trend analysis**.** The changes in winter rainfall over the two periods (Figure 11) indicate much weaker changes in rainfall, except in southwestern Australia and along the east coast from Victoria to southern Queensland where strong drying has occurred particularly since 1950. While some evidence supports a human contribution to rainfall changes, it is less convincing than that for increasing temperature (Nicholls and Collins, 2005).

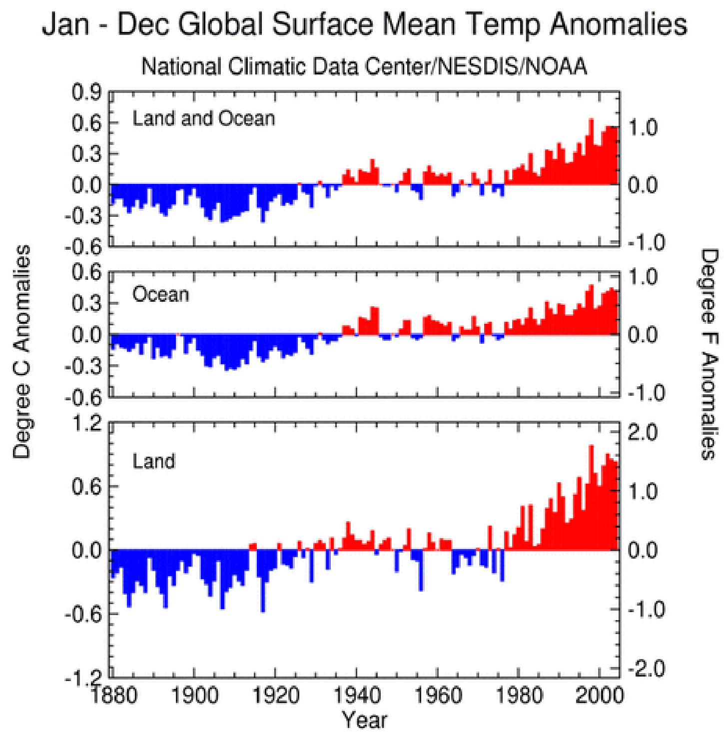

Figure 8: *Global-average temperature anomalies from 1860 to 2003, relative to the average for 1961-1990. From NOAA (2005)***.**

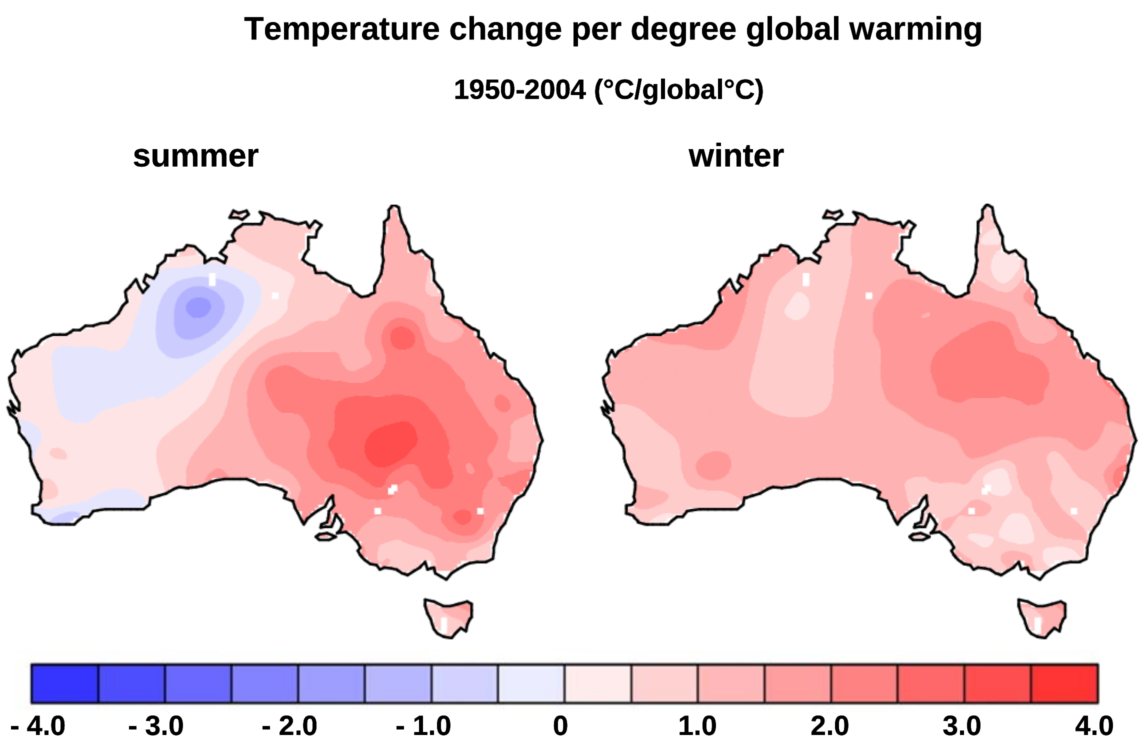

Figure 9: *The change in observed temperature per degree of global warming over the interval from 1950 to 2004 using regression analysis (right).*

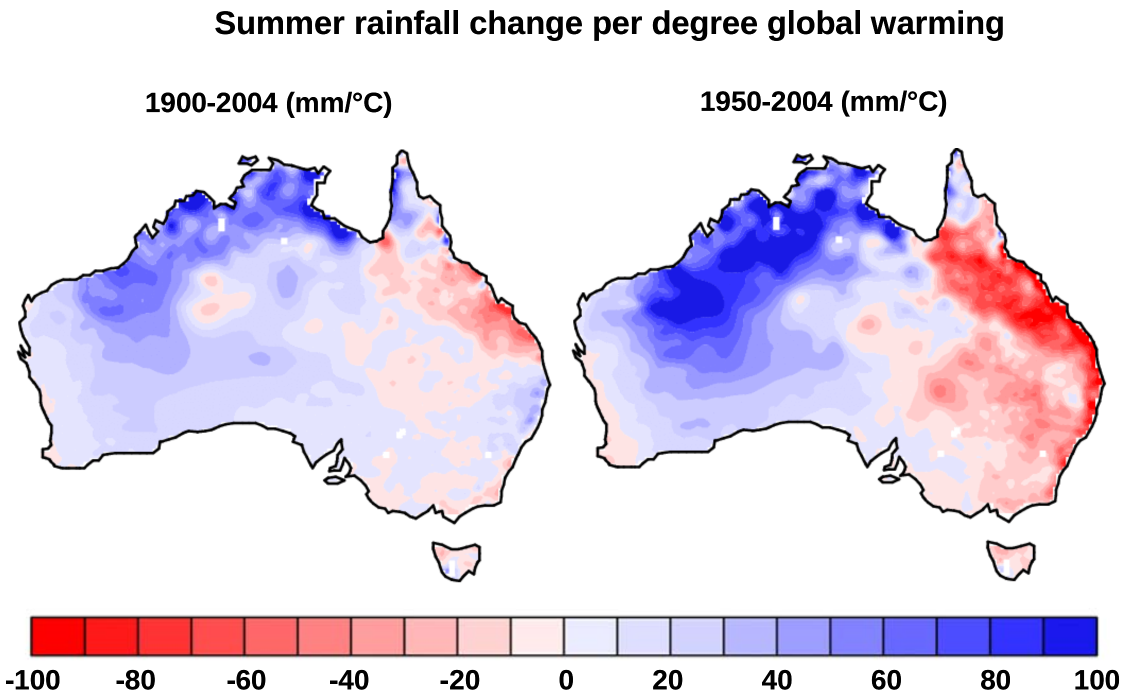

Figure 10: *The change in observed summer rainfall per degree of global warming over the intervals 1900 to 2001 and 1950 to 2001 using regression analysis.*

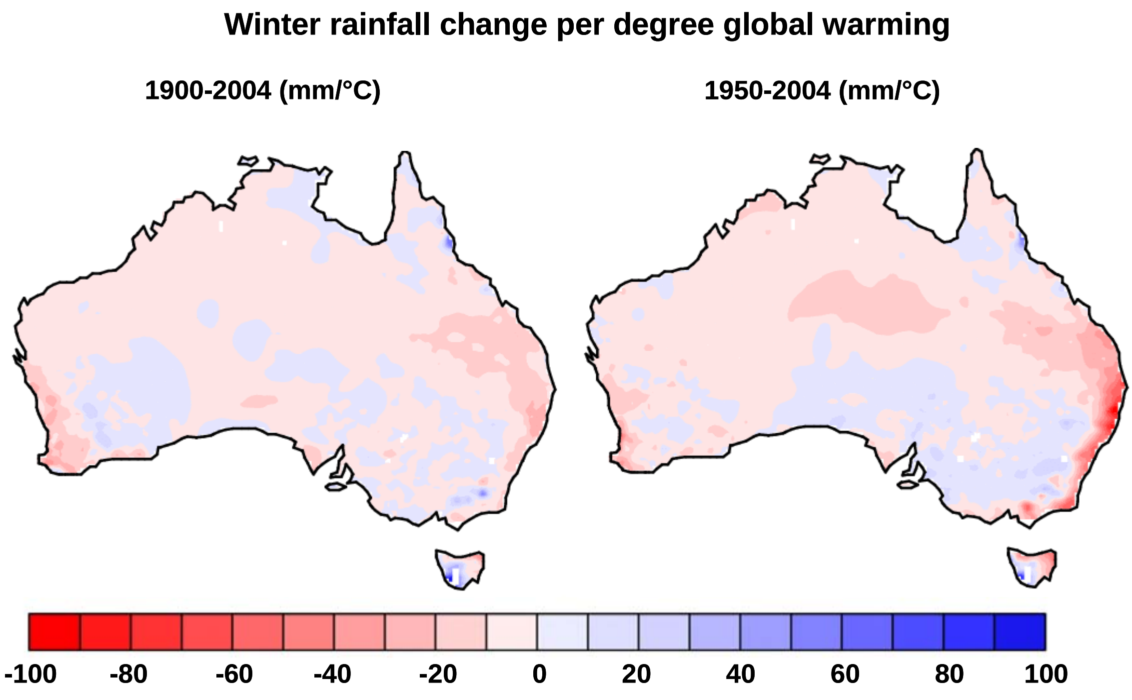

Figure 11: *The change in observed winter rainfall per degree of global warming over the intervals 1900 to 2001 and 1950 using regression analysis.*

4.2 Global Characteristics of Climate Model Simulations

To assist with the interpretation of the climate projections, it is useful to consider the global patterns of change simulated by the various GCMs. Figure 12 presents maps of agreement between ten GCMs (those used in recent regional projections) on the simulated direction of change. Areas for which at least eight out of ten models agree on the sign of the change are coloured while grey areas indicate regions for which the direction of change is less certain. Where models agree on the direction of change such changes may be considered a robust indication from current modelling. However it should be noted that model disagreement will include cases where models agree on little change in a variable.

Warming is indicated over almost the entire globe with increases exceeding 1°C per degree global warming across continental areas including large parts of the northern hemisphere. The only region of uncertainty is a small region of the Southern Ocean south of Australia over which some models simulate cooling. This region is an area of active heat uptake by the oceans. In some models, the heat uptake is sufficiently large to cool the overlying atmosphere (Whetton et al. 1996).

In contrast to temperature, rainfall change is much less certain with models simulating either increase or decrease across large areas of the low and mid-latitudes. There is strong agreement on rainfall increase in the high latitudes of both hemispheres. The uncertainty associated with estimating changes in rainfall is higher than for temperature for at least three reasons. First, regional rainfall may increase or decrease under enhanced greenhouse conditions. Secondly, the greenhouse signal is much weaker for precipitation than it is for temperature because of higher natural variability of precipitation. Finally, the spatial representation of precipitation occurrence by climate models is generally poorer than it is for temperature.

The pattern of pressure change shows a tendency toward increased pressure in the 40-60ºS latitude band. This is related to the delayed warming in southern high latitudes due to the downward transport of heat by the ocean as discussed previously. There is also some agreement amongst models on decreased pressure over Australia. Both these features are also present in the seasonal analyses, although the increased pressure band extends slightly further north in winter and the decreased pressure over the continent is stronger in summer.

The change in wind pattern in the southern hemisphere is strongly related to the pattern of pressure change with the band of increasing winds in the southern ocean overlapping and extending slightly to the north of the band of decreasing pressure. Decreasing pressure is also indicated across the Australian continent while increasing pressure occurs to the southwest of Australia and across the southern Pacific Ocean.

4.3 Temperature Projections for Australia

Figures 13 and 14 illustrate the projections for summer and winter temperature in 2070 that were developed for CSIRO (2001) and the various regional projections (Whetton et al., 2002; McInnes et al., 2003; Hennessy et al., 2004a,b; McInnes et al., 2004; Cai et al., 2004 and Suppiah et al., 2004). Note that in the Northern Territory (NT) and southwest Western Australia (SWWA), summer and winter projections are based on six month intervals from November to April and May to October, which coincide with the wet and dry seasons respectively, while all other regions used the standard three month seasons for summer and winter from December to February and June to August respectively.

The pattern of projected temperature change is mainly one of a narrower range of warming in coastal areas, and a broader range of warming and greater warming at the high end of the range in inland areas. There is also tendency for less warming in winter as compared to summer.

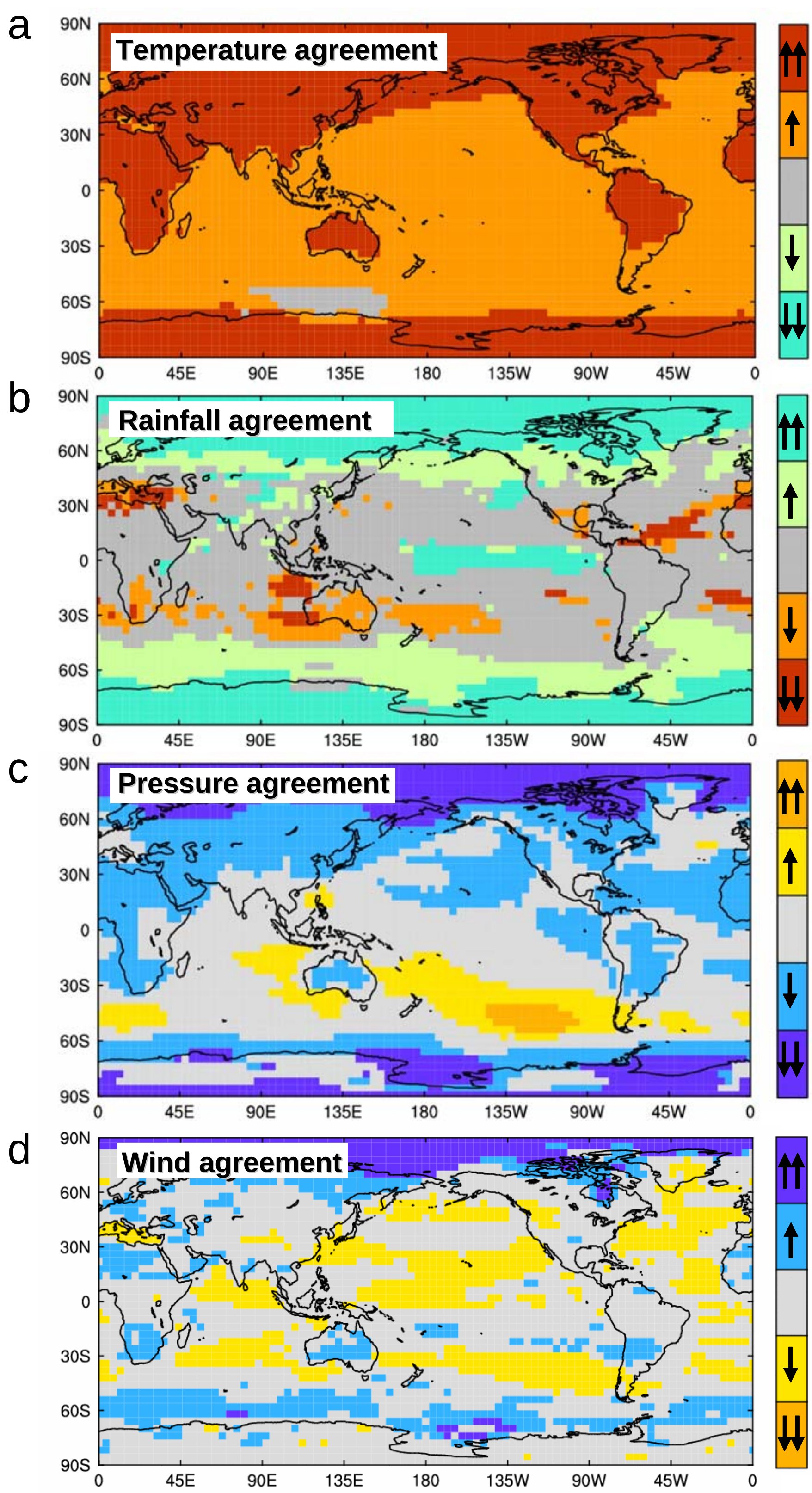

Figure 12: *Maps of agreement between 10 climate models on the direction of change. Non-grey areas indicate regions where at least 8 out of 10 models agreed on a particular direction of change with upward pointing arrows indicating increase and downward arrows indicating decrease. Double arrows indicate agreement on a strong change defined as being outside the limits of (a) ± 1°C per °C of global warming, (b) ± 5% per °C of global warming, (c) ± 50 Pa per °C of global warming and (d) ± 3% per °C of global warming*

Figure 13 shows that most of the ranges at the regional scale are similar to the Australia-wide projections but the finer resolution used in the regional projections means that coastal gradients in the range of change are more detailed. For example, the Australian projections indicate increases of temperature in the range of 0.8 to 5.2°C along the coast between western Victoria and Adelaide and over SWWA whereas the regional projections indicate warming in the range of 0.8 to 4.8°C over the same regions.

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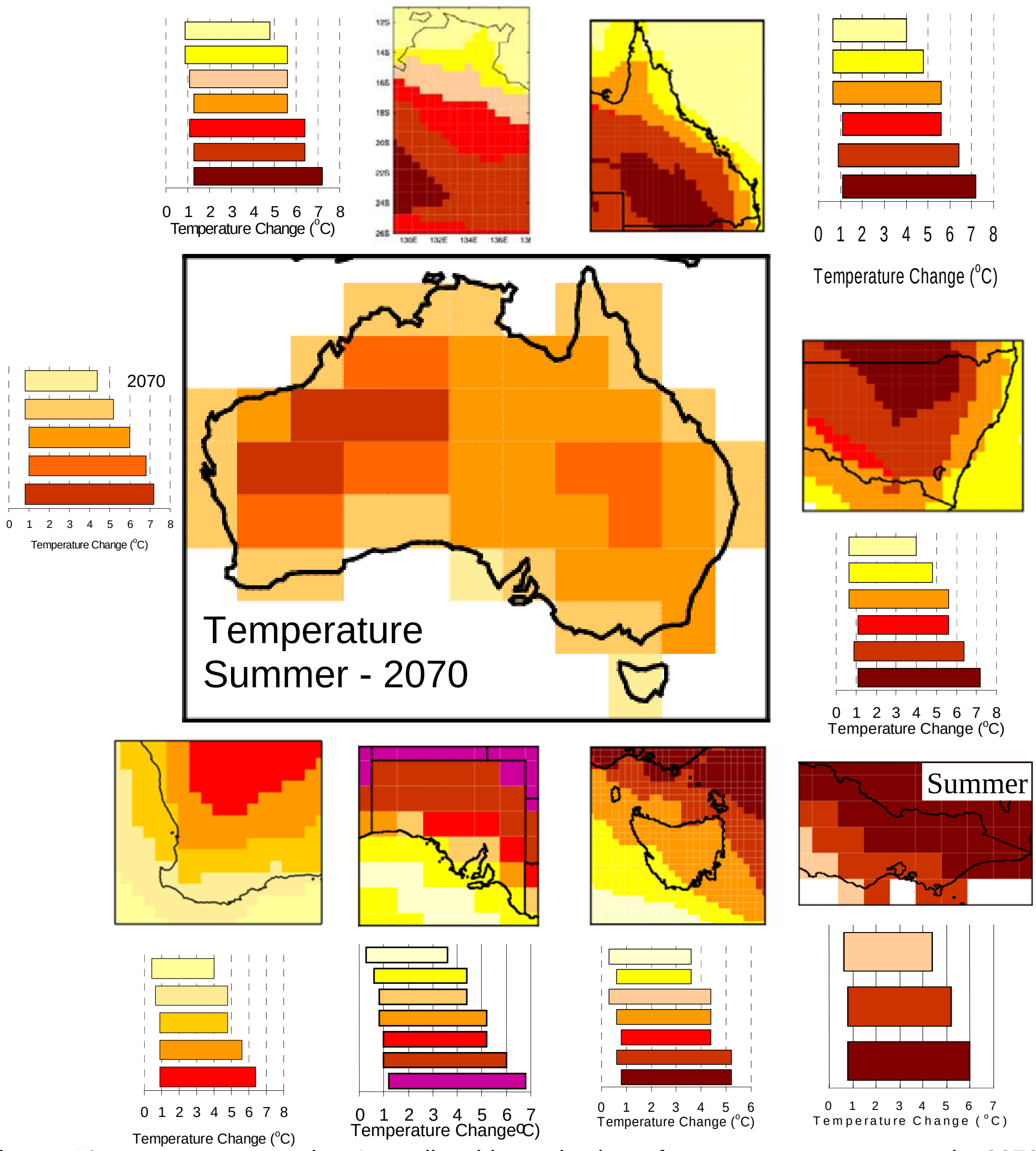

Figure 13: *Comparison of the Australia-wide projections for summer temperature in 2070 (CSIRO, 2001) with the various regionally based projections developed subsequently.*

A larger reduction in magnitude and range is seen along the southern New South Wales coast where the Australian projections indicate a change in the range of 1.0 to 6.0°C while the NSW regional study projects increases of between 0.6 and 4.8°C. The Victorian study does not capture the reduced range in temperature in the eastern coastal regions that is seen in the NSW study. The smaller number of models used in the Victorian study and the inclusion of, in particular, the GFDL model, which showed relatively greater warming in this region contributed to this result. As the spatial resolution used for the Australian-wide results is coarser than that of the contributing models, the increased detail in coastal areas seen in the finer resolution regional studies is likely to be more realistic.

In some parts of Australia, both magnitude and range increased. This is the case in south central Queensland and northern central NSW where the range in the Australian projections is 1.0 to 6.8°C and in the regional studies is 1.1 to 7.2°C. Two factors influenced this result. The first is the exclusion of the ECHAM3 model in later projections. This model had smaller temperature increases over this region. The second is the inclusion of the CSIRO regional model CC50 which exhibited pronounced warming in this part of Australia during summer.

The regional study for Tasmania shows a similar warming range to the Australian projections. This warming is 0.6 to 4.4°C across much of the state except in the southwest where the upper limit is only 3.6°C.

Figure 14 shows temperature projections for winter by the year 2070 from various studies. The Australian projections show stronger warming in the range 1.0 to 6.0°C, across north central Australia and lower warming in the range of 0.8 to 5.2°C across the south of the continent. Tasmania, southwestern Victoria, central South Australia and southwestern Western Australia experience the smallest magnitude of increase in the range of 0.8 to 4.4°C. As with summer regional projections, the winter projections in all regional studies except Victoria exhibit more detail in the coastal zone.

The Tasmanian study shows the most marked departure from the Australian projections for wintertime temperature with the magnitude and range of change lower across the western two-thirds of the State. The Victorian and NSW studies are broadly consistent with each other when the differences in the choice of ranges are considered (the two shades of yellow used in the NSW study have upper values slightly above and below the single range that dominates the Victorian map). However, the regional map for Tasmania suggests that there is more structure in the pattern of temperature change over southern Victoria.

While reductions in range are a common feature of the regional projections near to the coast compared with the coarser resolution Australian projections, some increases in magnitude occur inland. For example, increases in the magnitude and range of change occur over inland areas of Northern Territory (1.3 to 6.4°C) and Queensland (1.1 to 7.2°C) and southwest Western Australia (0.9 to 6.4°C) compared to 1.0 to 6.0°C indicated in the Australian projections. Across northern Australia, the increase in the low end of the range in the recent studies can be attributed to the exclusion of models such as GFDL and NCAR which had lower ranges of change. The increase at the upper end of the range is attributed to inclusion of CC50 which exhibited larger magnitudes of change in this region.

Results of detection and attribution studies over Australia are summarized in Nicholls and Collins (2005). These studies compare observed climate changes with those simulated by climate models for the 20th century. While it is not appropriate to compare observed changes with those simulated for the 21st century in detection and attribution studies, such comparisons are often made to see whether past changes are likely to continue in future. We now compare how the projections of future climate change over Australia based on climate model simulations relate to observed changes in temperature shown in Figure 8. During summer, the temperature projections are qualitatively similar to the observed patterns of change over the eastern two-thirds of the continent with stronger warming inland compared to the coast. In the northwest of the continent, temperatures have been cooling over the past 50 years owing to the marked increase in rainfall over this period. However, the projections indicate strong increases in temperature over inland Western Australia during the 21st century. In winter, the projected temperature changes for the 21st century more closely resemble the patterns of change observed since 1950. In particular, both sets of patterns indicate weaker increases over Victoria, southwest Western Australia and Queensland. The main difference is a region of weaker increases in the observations situated over the border between Western Australia and Northern Territory.

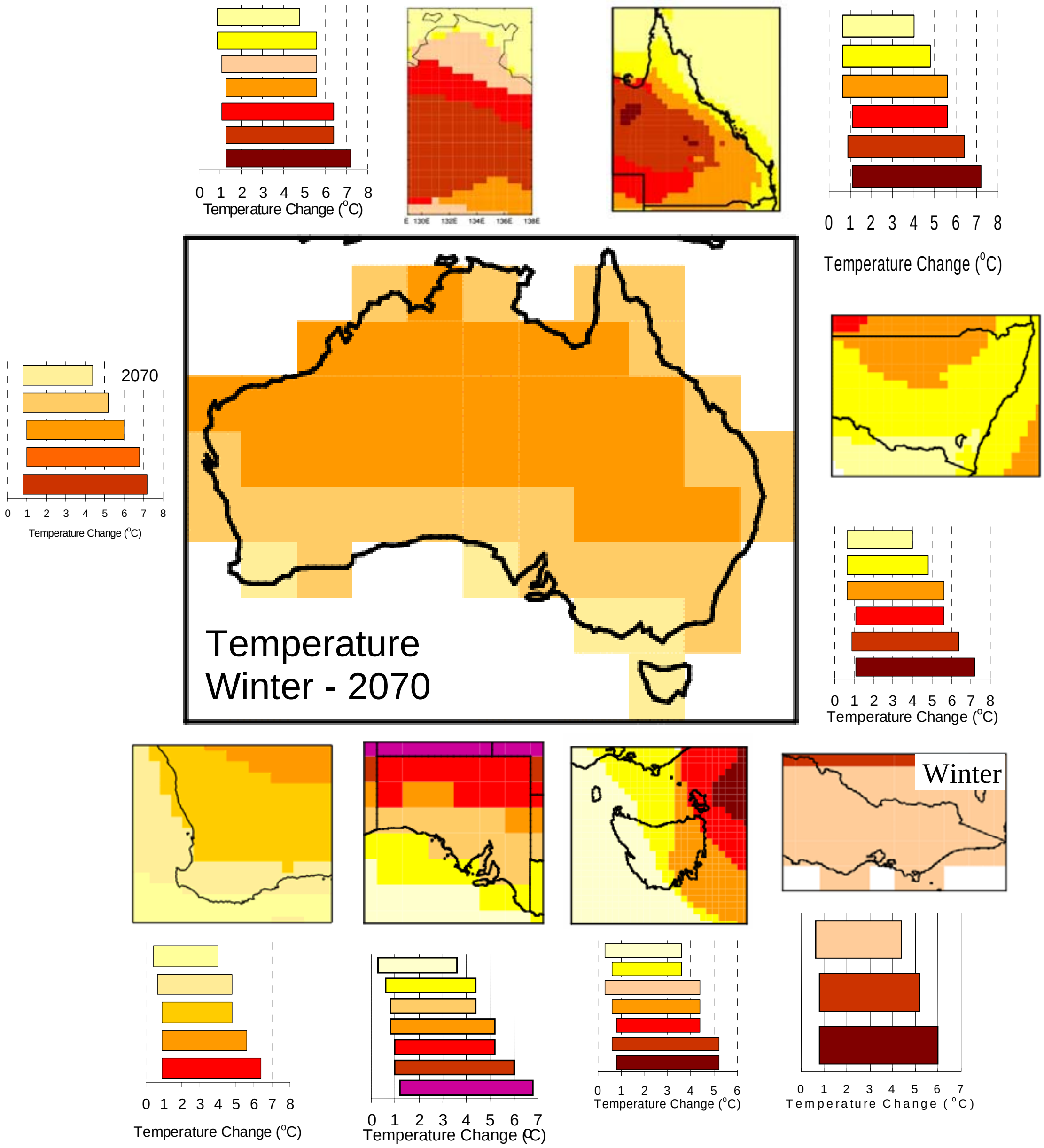

***Figure 14:** Comparison of the Australia-wide projections for winter temperature in 2070 (CSIRO, 2001) with the various regionally based projections developed subsequently.*

4.4 Rainfall Projections for Australia

Rainfall projections are more sensitive than temperature projections to the selection of models. A comparison of the Australia-wide projections shown in Figure 15 for summer rainfall indicates uncertainty in the direction of change across much of the country (areas shaded in grey tones). However, where there is consistency in the direction of change, this is generally for rainfall increase, especially inland. The regional projections on the other hand suggest a tendency towards drier conditions in the future. This is most pronounced for inland NT for which rainfall changes in the range of -40 to +20% occur compared to changes in the range of -10 to +40% in the Australia-wide projections. Note that projections for NT and southwestern Australia are for the 6-month wet and dry seasons from November to April and May to October respectively rather than the 3-month summer season of DJF and winter season of JJA.

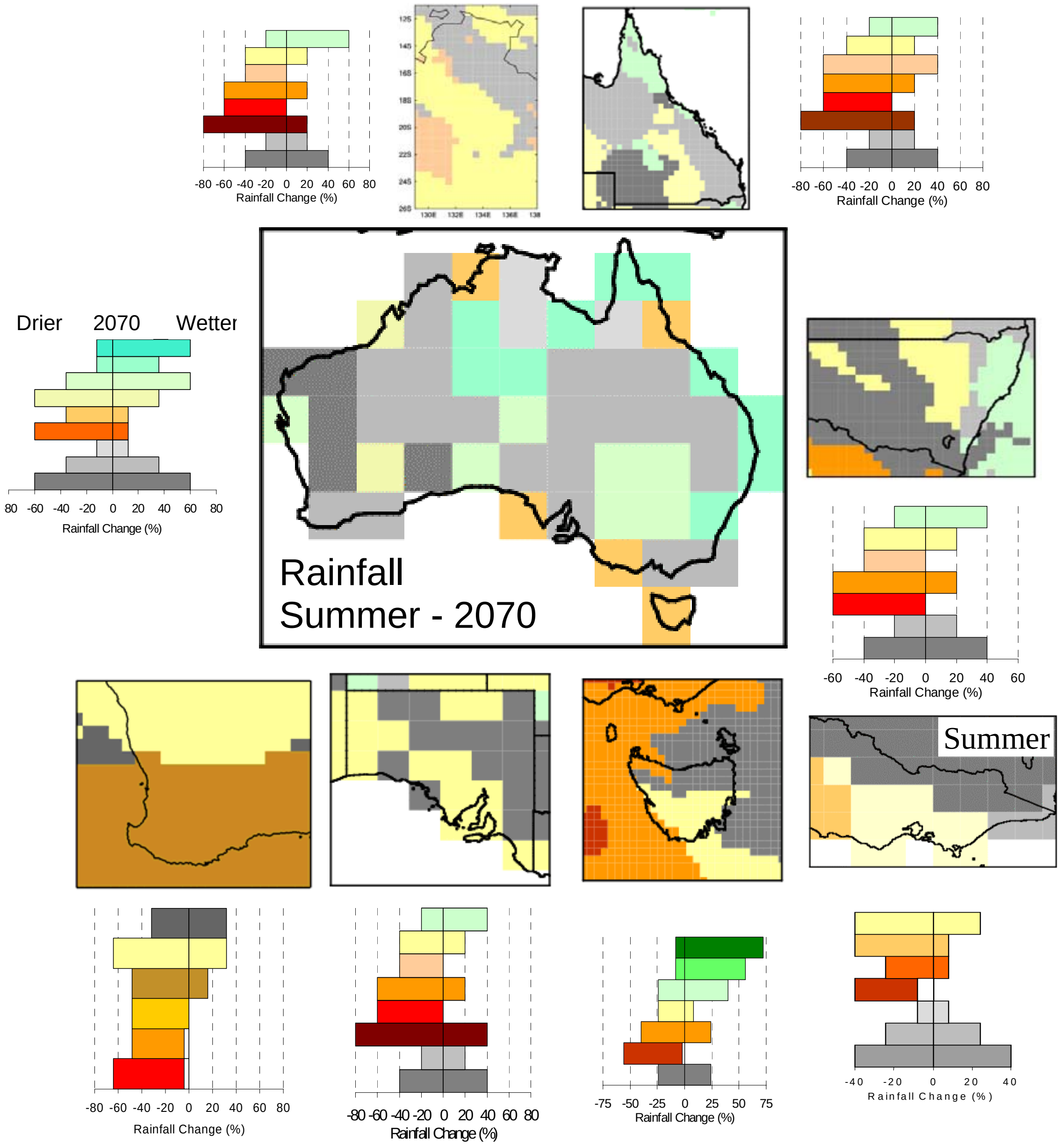

Figure 15: *Comparison of the Australia-wide projections for summer rainfall in 2070 with the various regionally based projections developed subsequently.*

The direction of change in rainfall in inland NSW has become largely uncertain (-40 to +40%) in the regional model projections compared with -40 to +60% in the Australian projections while in western SA, the range of change in the more recent regional projections suggests that decreases are more likely in the range -40 to +20% compared to -40 to +60% in the Australian projections.

A major reason for the shift toward rainfall decrease in the recent projections is the change in the group of models used. In particular the ECHAM3 model, which has been omitted in the recent regional projections, indicated a large increase in rainfall in response to global warming in summer and autumn across the entire continent except Tasmania. The NCAR-CGM model, also omitted from recent projections, indicated rainfall increases over the western half of the continent in summer.

During the winter months (Figure 16), much of the northern half of the continent experiences extremely low rainfall totals. Therefore, the Australian projections showed direction of change projections only for the southern, eastern and western parts of the continent. With the exception of Tasmania and a small region of southeast Australia, winter rainfall showed a greater tendency toward decrease than increase. The more recent regional projections are for the most part consistent with the Australian projections. The exception is southeastern Queensland for which the direction of change was uncertain in the Australian projections but changes in the range of -60 to +20 or -60 to +40% by 2070 are indicated in Queensland projections.

In another approach, we constructed climate change scenarios for southwestern Australia using 14 models rather than the selected set of nine models used in SWWA projections presented in Figures 14 and 15. Sensitivity to model selection was weak. The patterns differed only in minor respects to those presented in Figures 14 and 15.

We now compare the future rainfall projections with observed changes in rainfall shown in Figure 10. During summer, all states for which recent projections have been prepared, show large uncertainty, but more often than not, tend toward rainfall decreases even though rainfall increases are possible. Cape York Peninsula and coastal New South Wales are two areas for which recent projections indicate that rainfall increases are more likely. Patterns of observed rainfall change since 1950 show drying trends over eastern Australia and southwest Western Australia and increasing rainfall over north and central western Australia and Cape York Peninsula. As with temperature, the projections show the strongest differences from the observed changes over the northwest of the continent. The projections of winter rainfall change (Figure 11) indicate a strong tendency towards rainfall decreases over all states that have been studied except Tasmania for which rainfall increases are projected. The observed 20th century changes also show predominantly decrease, but centred mainly in southern and eastern coastal areas.

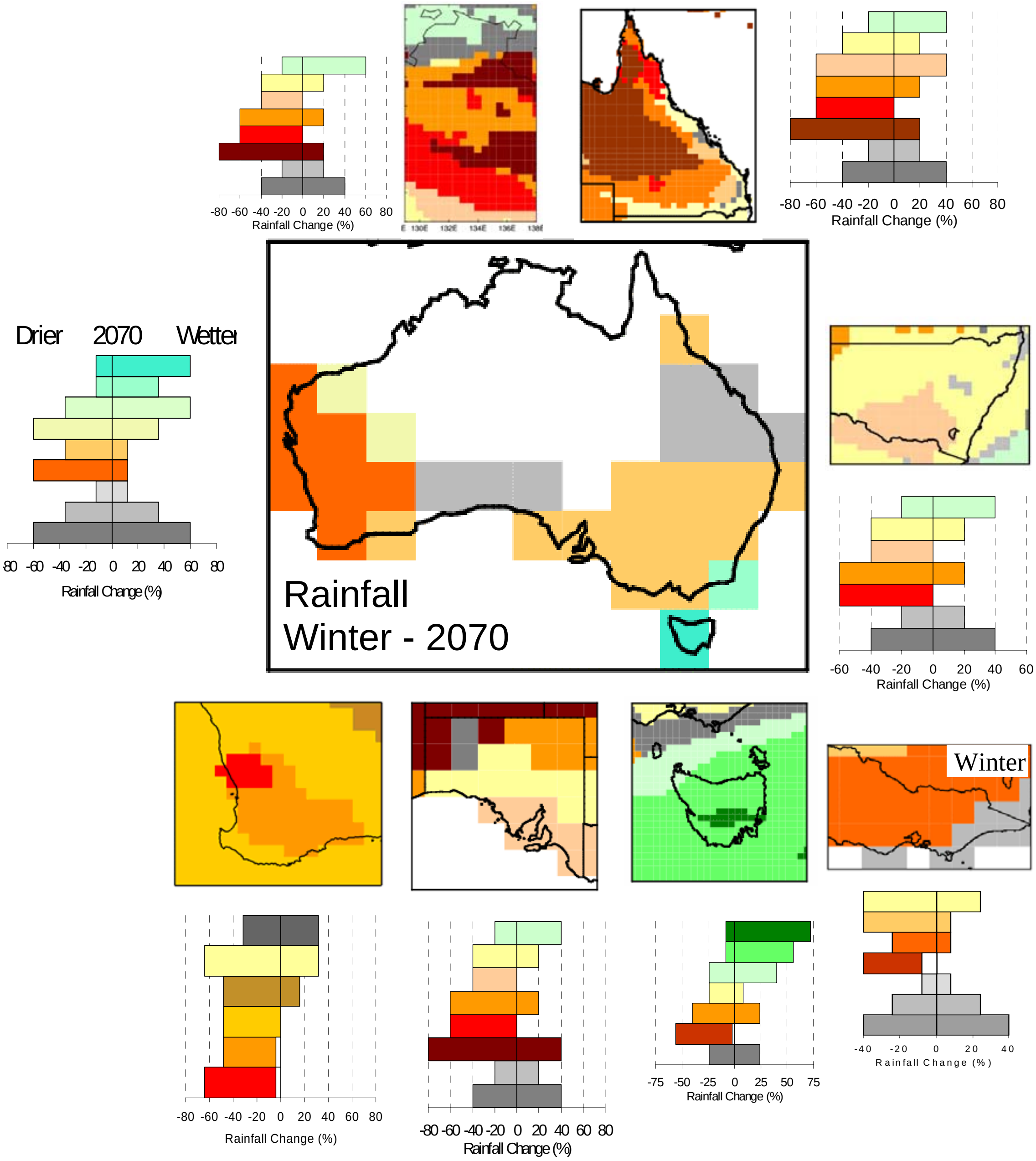

Figure 16: *Comparison of the Australia-wide projections for winter rainfall in 2070 with the various regionally based projections developed subsequently.*

5 Summary and Future Directions

This report has documented the methodology used recently by the CSIRO Climate Impact Group for generating climate projections on a national and regional basis. The key components of the approach are first, that the climate models are assessed as to whether they adequately reproduce key element of regional climate before use, and secondly that all relevant uncertainties are quantified and .represented in the final projected regional ranges of climate change. An important feature of the approach is the use of a regression method for pattern extraction which maximises the climate change signal to noise ratio in the climate model output used. Furthermore, the approach has facilitated the incorporation of additional model simulations as they have become available, thereby ensuring that a wider range of uncertainty is captured. Its flexibility also enables projections to be developed easily for different future times and different emissions scenarios. This has been utilized in the development of CSIRO's OzClim PC software for generating climate scenarios – see www.csiro.au/ozclim.

However, in future work there are a number of ways in which this approach to preparing projected ranges of climate change can be improved:

The current methodology presents the range of possible future climate conditions with no information about the most likely future values. However, stakeholders often request information on the average change across all models used in the projections as well as the range of change. We have generally been reluctant to provide a mid range or average scenario, because it can attract the primary attention and appreciation of uncertainty is lessened. However 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. Note that since the SRES emissions scenarios currently available were deliberately constructed to be equally plausible, each scenario would be assigned an equal likelihood of occurrence. New and Hulme (2000), Jones (2000), and Tebaldi et al (2004) provide examples of a probabilistic approach to developing regional climate change scenarios.

The preparation of climate change ranges as probability distributions could also incorporate the giving of different weightings to different simulations, in proportion to their ability to simulate the present climate. This contrasts with the method used here where a simulation was simply rejected or retained, with the threshold being somewhat subjective. Giorgi and Mearns (2004) use a weighting method, although they assess model performance only for the variable and location for which the projected range is being formed. There is 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 their ability to capture the link between rainfall variability and circulation changes associated with ENSO variability It is possible that model weighting could reflect other characteristics such as model resolution and model vintage.

The present-day GCMs are capable of simulating large-scale circulation features, such as, sub-tropical high pressure and high latitude westerly wind regimes, monsoons, intertropical convergence zone, south Pacific convergence zone, and so on, but they do not adequately simulate local to small scale circulation features, which are important for constructing regional climate change projections. Although, regional climate models are capable of simulating such local and small scale circulation features, they still rely on boundary conditions from global climate models. In the future, climate change experiments from GCMs with fine resolution and with improved physical parameterizations would capture small and local scale circulation features that could help to reduce the uncertainty with regional-scale climate change projections.

Notwithstanding the uncertainties that arise from the development of regional climate change scenarios using GCMs and regional climate models, the emissions scenarios that are used to force the climate models will continue to contribute large uncertainty to climate projections. In addition to future increases in greenhouse gases and aerosols, stratospheric ozone depletion, aerosol and natural changes in solar and volcanic activities are also unknown. This means that climate projections must always be treated as such and not viewed as forecasts.

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