A Comparison of Australian Climate Change Projections based on IPCC TAR and AR4 Climate Model Simulations

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EXTENDED ABSTRACT

The purpose of this paper is to compare Australian climate change projections from two sources, (i) from models used in the Intergovernmental Panel of Climate Change (IPCC) 4th Assessment Report (AR4) in 2007 (Suppiah et al 2007) and (ii) from models used in the IPCC 3rd Assessment Report (TAR) in 2001 (IPCC 2001). We compare simulations of mean sea level pressure, temperature and rainfall averaged over 1961-1990, as well as temperature and rainfall projections for the 21st century. Previous projections were constructed based on the results of a set of selected global climate models (GCMs). The GCMs and regional climate models were selected using the results of pattern correlation and root mean square (RMS) error values and this method is referred to as the “first method”. Since the completion of the study by applying the first method to AR4 model results by Suppiah et al. (2007), we have developed probabilistic projections in which each AR4 model is assigned a weight based on its ability to simulate the present climate. The latest method is referred to as the “second method” in this study. Since the projections based on the AR4 models were developed using two different methods explained above, the results from both methods are compared with each other, along with results based on the TAR models.

The CSIRO (2001) climate change projections were based on results from a set of nine models that performed well in the Australian region. Eight of the model simulations were undertaken for the IPCC TAR and the other is a regional climate model from CSIRO. The updated projections based on Method 1 (Suppiah et al. 2007) are based on 15 models selected from 23 AR4 models based on their superior performance in the Australian region. In both sets of projections, Method 1 was used, i.e. the same statistical tests were used to assess each model’s ability to simulate the climate of 1961-1990, and models that performed poorly over the Australian region were not selected to generate projections. Therefore, a comparison of the CSIRO (2001) and updated projections gives insight into the robustness of the earlier projections, and the dependence of the results on the number and recent developments of the GCMs.

The IPCC’s SRES (2000) emission scenarios have been used in projections by both CSIRO (2001) and Suppiah et al. (2007), but the latter also includes projections for scenarios in which CO_2 concentrations are stabilized at either 450 parts per million (ppm) by 2100 or 550 ppm by 2150.

Spatial patterns of warming in both studies show very similar patterns, indicating strong inland warming and less warming along the coast. Although the spatial patterns of warming between these projections are similar, the recent study based on AR4 models simulations shows a slight narrowing of the range.

Rainfall changes are more complex than temperature changes. Winter and spring rainfall show decreases in both projections, although the lower range of the updated projections indicates increased drier conditions over winter rainfall dominated over southern and eastern Australia. The range of summer and autumn rainfall changes shows increases and decreases in both projections. However, the upper range of rainfall changes indicates wetter condition in summer rainfall in the updated projections, while the range of increases in autumn rainfall is reduced in the updated projections.

A comparison between the probabilistic results and those of Suppiah et al (2007) will also be presented in the conference, even though the methods and outputs are not directly comparable.

1. INTRODUCTION

Greenhouse gas concentrations have increased rapidly as a result of human activities since 1750 and now far exceed pre-industrial values determined from ice-cores spanning hundreds of thousands of years (IPCC 2007a, Figure 1). Most of the global warming observed since the mid-20th century is very likely due to the increase in greenhouse gases (IPCC 2007a). During the past century, Australian's mean temperature increased by 0.9°C mostly since 1950 (Figure 2), with an increase in heat waves, fewer frosts, more rain in the north-west, and less rain in the south and east (Nicholls 2006). There is a discernible human influence on Australian temperatures since 1950 and on rainfall decreases in southwestern Australia since the 1970s (Nicholls 2006).

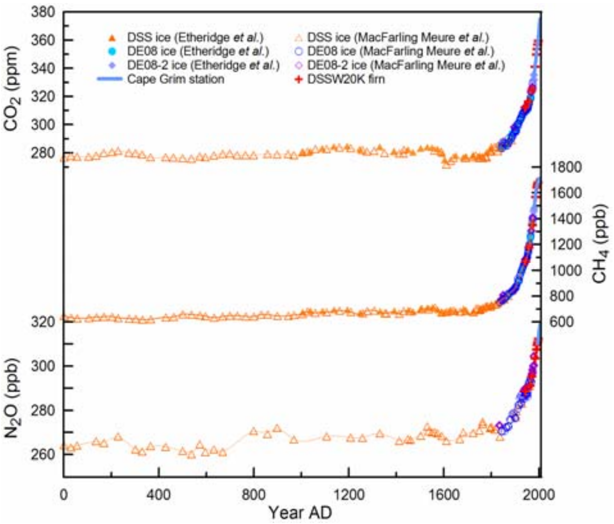


Figure 1. Long-term trends in the concentrations of carbon dioxide (CO_2) methane (CH_4), nitrous oxide (N_2O) during the last 2000 years. The observed data are from Cape Grim, Tasmania. Source: MacFarling et al. (2006).

Global Climate Models (GCMs) are the best available tools for simulating future climates based on various greenhouse gas and aerosol emission scenarios. A warming of about 0.4°C per decade is simulated by 2025, and 1.1 to 6.4°C by 2100 (IPCC 2007a). More warming is likely over polar regions and over the land, compared with the tropics and oceans (IPCC 2007a). The IPCC (2007a) assessment provides limited information about projected changes in Australia's climate, i.e. it summarizes impacts on temperature and rainfall averaged over northern and southern regions. Therefore, regional projections have been generated independently by CSIRO, taking into account the IPCC global warming estimates. The most recent regional projections build upon 20 years of experience within CSIRO (Pittock 1988, CSIRO 1992, 1996, 2001). Details for the methodology and models used in recent years for producing regional climate change projections are given in Whetton et al. (2005).

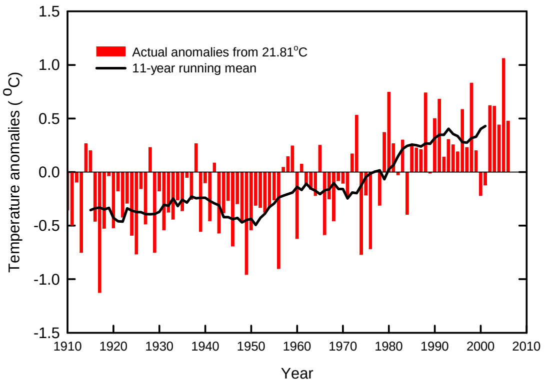


Figure 2. Trends in Australian mean temperature from 1910 to 2006. Source: Australian Bureau of Meteorology.

We compare Australian climate change projections from two sources, (i) from models used in the IPCC AR4 in 2007 (Suppiah et al. 2007) and (ii) from models used in the IPCC TAR in 2001 (IPCC 2001). We compare simulations of temperature and rainfall averaged over 1961-1990, as well as temperature and rainfall projections for the 21st century. These projections were based on a common method (Method 1) involving statistical tests of each model's ability to simulate the climate of 1961-1990, and models that performed poorly were not selected to generate projections.

We have also developed probabilistic projections in which each AR4 model is assigned a weight based on its ability to simulate the present climate (Method 2). This allows a comparison of AR4 model projections using Methods 1 and 2. A comparison between Method 1 and Method 2 will be presented in the meeting, as the projections based on Method 2 will be available in the later part of the year.

2. CLIMATE MODEL DATA

Monthly data from GCMs were obtained from the IPCC Model Output website at http://www-pcmdi.llnl.gov/projects/cmip/index.php. Some of the models have single simulations for a given emission scenario, while others have multiple simulations. For models with multiple simulations, we have computed ensemble-mean changes in climate. The simulations of the 20th century climate were driven by observed changes in greenhouse gases and aerosols. Some simulations included direct and indirect effects of aerosols, some included ozone depletion, and some included volcanic aerosols and solar variations. Each of these factors has a significant effect on the Earth's radiative balance, which determines the Earth's temperature. Radiative forcing is not directly observed and particularly uncertain for aerosol. The 21st century simulations were driven by the SRES A2 and A1B emission scenarios (SRES 2000).

The CSIRO (2001) climate change projections were mainly based on IPCC TAR climate data. There were 12 climate model results, from which we chose eight that performed well in the Australian region (namely CSIRO Mark2, CCM1, ECHAM4, ECHAM5, GFDL, NCAR PCM, HADCM2 and HADCM3), plus the CSIRO's regional climate model Division of Atmospheric Limited Area Model at 125 km (DARLAM 125).

In the IPCC AR4 archive, simulations of 23 climate models are available, from which we chose 15 that performed well in the Australian region (Suppiah et al. 2007). These models are BCCR, CNRM, CSIRO Mark3, GFDL 2.0, GFDL 2.1, IAP, INMCM, MIROC-H, MIROC-M, MIUB, MPI-ECHAM5, MRI, NCAR-CCSM, HADCM3 and HADGEM1. The assessment of model performance is described below.

3. ASSESSMENT OF MODEL RELIABILITY

The reliability of climate models in the Australian region has been tested by comparing observed and simulated patterns of average (1961-1990) temperature, precipitation and mean sea-level pressure (MSLP), for the four seasons. Pattern correlation and root mean square (RMS) error statistics were used to test whether the models adequately reproduce each of these fields in the Australian region (110-155ºE, 11-45ºS). A pattern correlation coefficient of 1.0 indicates a perfect match between the observed and simulated spatial pattern, and an RMS error of 0.0 indicates a perfect match between the observed and simulated magnitudes. Since models have different horizontal grids, observed and model average seasonal MSLP, temperature and rainfall data were interpolated on to a common grid (0.5°×0.5°) before calculating pattern correlation and RMS error statistics. The RMS error is based all grid points over the Australian region, and is calculated in the units hPa, °C and mm for seasonal MSLP, temperature and rainfall, respectively. When selecting models, seasonal RMS error for MSLP and temperature are used, but for rainfall seasonal total RMS error values were divided by the number of days in the season and used as mm per day.

In recent years, to select the GCMs that perform "best", we have used a subjective demerit point system (Whetton et al. 2005): one point for an RMS error greater than 2 for MSLP in hPa, for temperature in degree centigrade and for rainfall in mm per day or a pattern correlation less than 0.8 in any given season. An extra demerit point was allocated to models with an RMS error greater than 4 or a pattern correlation below 0.6. Models were considered acceptable if they had less than 8 demerit points across all seasons, for MSLP, temperature and rainfall. If we would have applied the current demerit point system, we would have selected only five models. They are CSIRO Mark2, ECHAM5, HADCM2 and HADCM3) and the DARLAM 125. However visual examination of model output maps is also used in conjunction with statistical tests, to judge the unacceptability of statistical results. The combined process has led to select nine models to construct climate change projections in 2001.

Based on the statistical analyses, 15 AR4 models were judged to have satisfactory performance over the Australian region (Suppiah et al. 2007). While the above criteria were not applied when selecting the TAR models to construct climate change projections in 2001, the models were tested with same statistics. The eight TAR models with strongest pattern correlations and smallest RMS error statistics were selected, plus CSIRO's DARLAM 125 model which also had excellent regional reliability.

In both of the analyses, selected models capture observed large-scale circulation features since their pattern correlations are strong. MSLP and temperature are better simulated than rainfall. Although models capture large scale rainfall patterns, models have difficulty simulating rainfall over the regions where topography plays an important role. The models capture the MSLP, temperature and rainfall patterns better in summer and autumn when continental-scale features dominate the climate. In particular, there is a strong north-south gradient in temperature and rainfall during summer and autumn. However, the models are less skillful in capturing observed temperature and rainfall pattern during winter and spring. Such failure of capturing the observed patterns of rainfall and temperature during spring and winter may be related to model deficiencies. In particular, the models fail to simulate the location and other characteristics of storm tracks during these seasons. Moreover, the effect of topography is also underestimated due to relatively coarse resolutions of the models.

4. CONSTRUCTION OF REGIONAL CLIMATE CHANGE PROJECTIONS

SRES (2000) emission scenarios were used in the projections described by CSIRO (2001) and Suppiah et al (2007), but the latter also includes projections for scenarios in which CO_2 concentrations are stabilized at either 450 parts per million (ppm) by 2100 or 550 ppm by 2150.

Climate change projections are often based on time-slices within a given climate simulation, e.g. a thirty year period centered on 2030 or 2070. However, time-slices can be significantly affected by decadal-scale climate variability. The analysis of temperature and rainfall simulations has shown that the patterns of change tend to scale linearly with global warming, for a range of emission scenarios (Whetton et al. 2005). This property has been exploited in a way that avoids disadvantages associated with time-slices. The pattern scaling method linearly regresses simulated 20th and 21st century grid-point seasonal mean temperature (or rainfall) time series against simulated global mean annual temperature time series. The correlation for temperature between pattern scaled change and time-sliced change for 2010-2039 is 0.91, and for 2070-2099 is 0.99. However, the correlation is weak for rainfall. The correlation for rainfall between pattern scaled change and time-sliced change for 2010-2039 is 0.48, and for 2070-2099 is 0.89.The gradient of the line of best fit between each grid-point value and global temperature constitutes the model response, per degree of global warming. Linear regression as a means of pattern extraction is advantageous for two reasons: (1) it decouples the model's response from the particular emissions scenario used in the simulation. It allows the patterns to be rescaled by global warming values for emission scenarios that have not been directly simulated in GCM experiments (Whetton et al. 2005), and (2) the patterns of regional change per degree of global warming can be rescaled by the IPCC range of global warming for a given year, to produce a regional pattern of change for that year. This pattern scaling method has been used by CSIRO since 2001 (Whetton et al. 2001).

The development of the regional climate change 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. Usually, the finest resolution model is selected as a standard grid. The range of climate change is then identified at each grid point. To reduce the influence of outlier results, the range is bounded by the second highest and second lowest results at each grid point. This method has been used when producing climate change projections in the in past (CSIRO 1992, 996, 2001) as well in the in the recent study (Suppiah et al. 2007).

To derive regional projections for the years 2030 and 2070, the ranges of change per degree of global warming were combined with the IPCC (2001) global warming projections for 2030 and 2070 in the projections by CSIRO (2001) and Suppiah et al (2007). Although the IPCC has recently updated the global warming projections, these updated values were not available at the time of the calculation, For example, the upper limit to the projected warming range in 2030 would be the upper limit of the range of regional warming pre degree of global warming multiplied by the upper limit of the global warming range for 2030. Correspondingly, the lower limits for the 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 rainfall is negative, this is combined with the upper limit of the projected *global* warming).

The global warming projections are shown in Figure 3, for both SRES and CO_2 stabilisation scenarios. For the SRES scenarios, the range of global warming for 1990-2100 allows for two sources of uncertainty: (i) the full range of SRES (2000) greenhouse gas and sulfate aerosol emission scenarios, and (ii) the full range of "climate sensitivity", i.e. the global mean warming for a doubling of CO_2 from 280 parts per million (ppm) to 550 ppm. The combination of these uncertainties is given in the IPCC (2001) global warming values, namely 0.54 to 1.24^oC by 2030 and 1.17 to 3.77^oC by 2070, relative to 1990. For the 450 ppm scenario, the global warming is 0.52 to 0.89^oC by 2030 and 1.11 to 1.95^oC by 2070. For the 550 ppm scenario, the global warming is 0.57 to 0.96^oC by 2030 and 1.36 to 2.36^oC by 2070. Recently, IPCC (2007c) indicates that stabilising global warming at 1.7 to 2.1°C relative to the year 2000 would require stabilising CO_2-equivalent concentrations (including the effect of non-CO_2 greenhouse gases) at 490 to 535 ppm between 2100 and 2150. Stabilizing global warming at 2.5

to 3.3°C relative to the year 2000 would require stabilizing CO_2-equivalent concentrations at 590-710 ppm. However, updated global warming values for stabilised CO_2 equivalent concentrations by 2030 and 2070 were not available from IPCC at the time of the analysis done by Suppiah et al (2007).

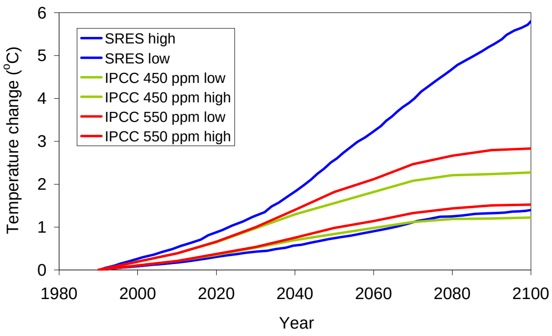


Figure 3 Range (low-high) of global-average warming relative to 1990 based on the SRES emission scenarios (IPCC, 2001), and 450 ppm and 550 ppm CO_2 stabilisation scenarios (Wigley et al. 1996).

5. A COMPARISION OF REGIONAL CLIMATE CHANGE PROJECTIONS FOR AUSTRALIA

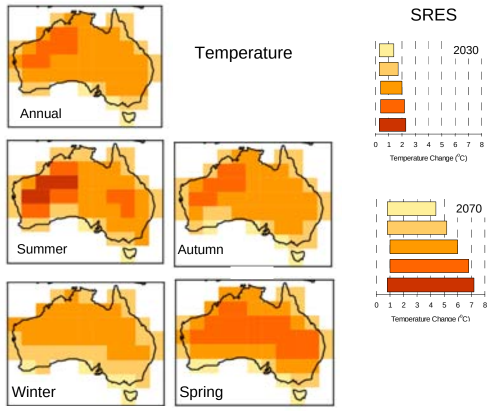
Temperature Projections

The spatial patterns of temperature change from CSIRO (2001) and Suppiah et al. (2007) are very similar as shown in Figures 4a and 4b. The CSIRO (2001) shown in Figure 4a indicates that the simulated annual warming for Australia by 2030 is 0.4 to 2.0°C with slightly less warming in some coastal areas and Tasmania, with greater warming in the northwest. By 2070, the annual warming is 1.0 to 6.0°C with regional variations similar to that for 2030.

Temperature changes based on the set of AR4 models are shown in Figure 4b. Simulated changes show annual-average warming by 2030 of 0.2 to 1.5°C in coastal areas and 0.5 to 1.9°C inland. By 2070, the warming is 0.4 to 4.5°C in coastal areas and 1.1 to 5.7°C inland. As expected, there is less warming for CO_2 stabilization scenarios.

In both projections, greatest warming occurs in spring with least warming in winter. Greatest warming over the northwest occurs in summer in both projections. Although the spatial patterns of warming between these projections are similar, the recent study based on AR4 models simulations shows a slight narrowing of the range, particularly for the second half of the 21st century, for example for 2070 from 0.9-7.2°C to 1.0 to 6.8°C for SRES emission scenarios.

(a)



(b)

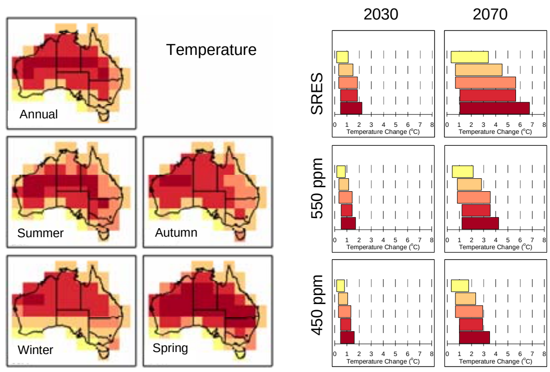


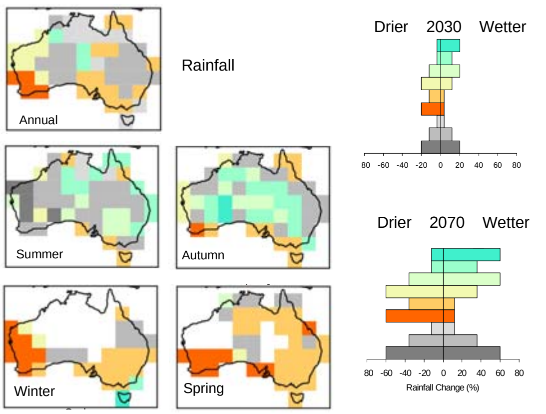
Figure 4. (a) Projected annual and seasonal warming for 2030 and 2070 based on IPCC TAR models for SRES emission scenarios (CSIRO (2001) and (b) based on IPCC AR4 models for SRES and CO_2 stabilisation scenarios (Suppiah et al. 2007).

Rainfall Projections

Annual average rainfall shows decreases, with largest reductions along the south and west coasts in both projections. The spatial patterns in winter and spring are very similar between the projections of CSIRO (2001) and Suppiah et al (2007), indicating dominant decreases in the south and east, especially in AR4 simulations (Figures 5a and 5b).

The TAR simulations showed considerable uncertainty in the direction of summer rainfall change in many areas, but in the AR4 simulations the upper end of rainfall change indicates wetter conditions in the east (except over Victoria and Tasmania). In TAR simulations, autumn rainfall showed increases over inland and decreases along the south and north-east coasts. Although the AR4 simulations give a similar pattern of rainfall change, the lower end of the range indicates drier conditions in the north-east and the upper end of the range shows wetter conditions in New South Wales. Overall, the seasonal patterns of rainfall change simulated by the TAR and AR4 models are similar, but the lower end of the range in AR4 simulations shows drier conditions covering large areas in southern and eastern Australia. A uniform pattern of rainfall change has been projected particularly over the winter dominated regions. As expected, there is less rainfall change for CO_2 stabilization scenarios.

(a)



(b)

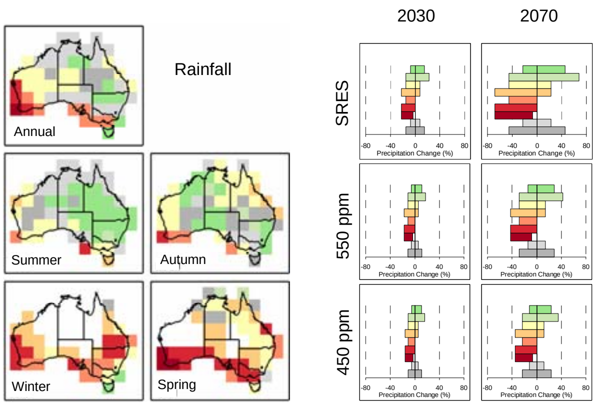


Figure 5. Projected annual and seasonal rainfall changes for 2030 and 2070 based on (a) IPCC TAR models for SRES emission scenarios (CSIRO, 2001) and (b) IPCC AR4 models for SRES and CO_2 stabilization scenarios (Suppiah et al. 2007).

6. CONCLUSIONS

We have compared Australian temperature and rainfall projections by CSIRO (2001) and Suppiah et al (2007) based IPCC TAR and AR4 simulations, respectively. The statistical methods used to select the most reliable models are the same. However, a demerit point system was introduced in the recent study by Suppiah et al (2007). The reliability assessment led to the selection of nine models for the CSIRO (2001) projections, while 15 models were selected by Suppiah et al. (2007).

The IPCC SRES (2000) emission scenarios were used in both analyses. However, in the recent study, emission scenarios that stabilise CO_2 concentrations at 450 ppm by 2100 or 550 ppm by 2150 are also used to estimate changes in temperature and rainfall by 2030 and 2070.

Both projections show greater warming over inland areas than coastal areas. Most warming occurs in spring, and least warming in winter. However, the recent study based on AR4 models simulations shows a slight narrowing of the range, particularly during the second half of the 21st century.

Projected annual rainfall shows decreases, with largest reductions along the south and west coasts in both projections. In summer, there is considerable uncertainty in future rainfall changes in many areas, although the upper end of the rainfall change in AR4 simulations shows wetter conditions in the east. In TAR simulations, autumn rainfall showed increases over inland and decreases along the south and north-east coasts. The AR4 simulations produce the similar pattern of rainfall change in autumn, but the lower end of the range indicates drier conditions in the north-east and the upper end shows wetter conditions in New South Wales. The spatial patterns of projected decreases in rainfall in winter and spring are very similar in both projections, but the lower end of the range in AR4 simulations indicates increased drier conditions in the southern and eastern Australia, particularly over the winter-dominated regions. As expected, there is less rainfall change for CO_2 stabilization scenarios.

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