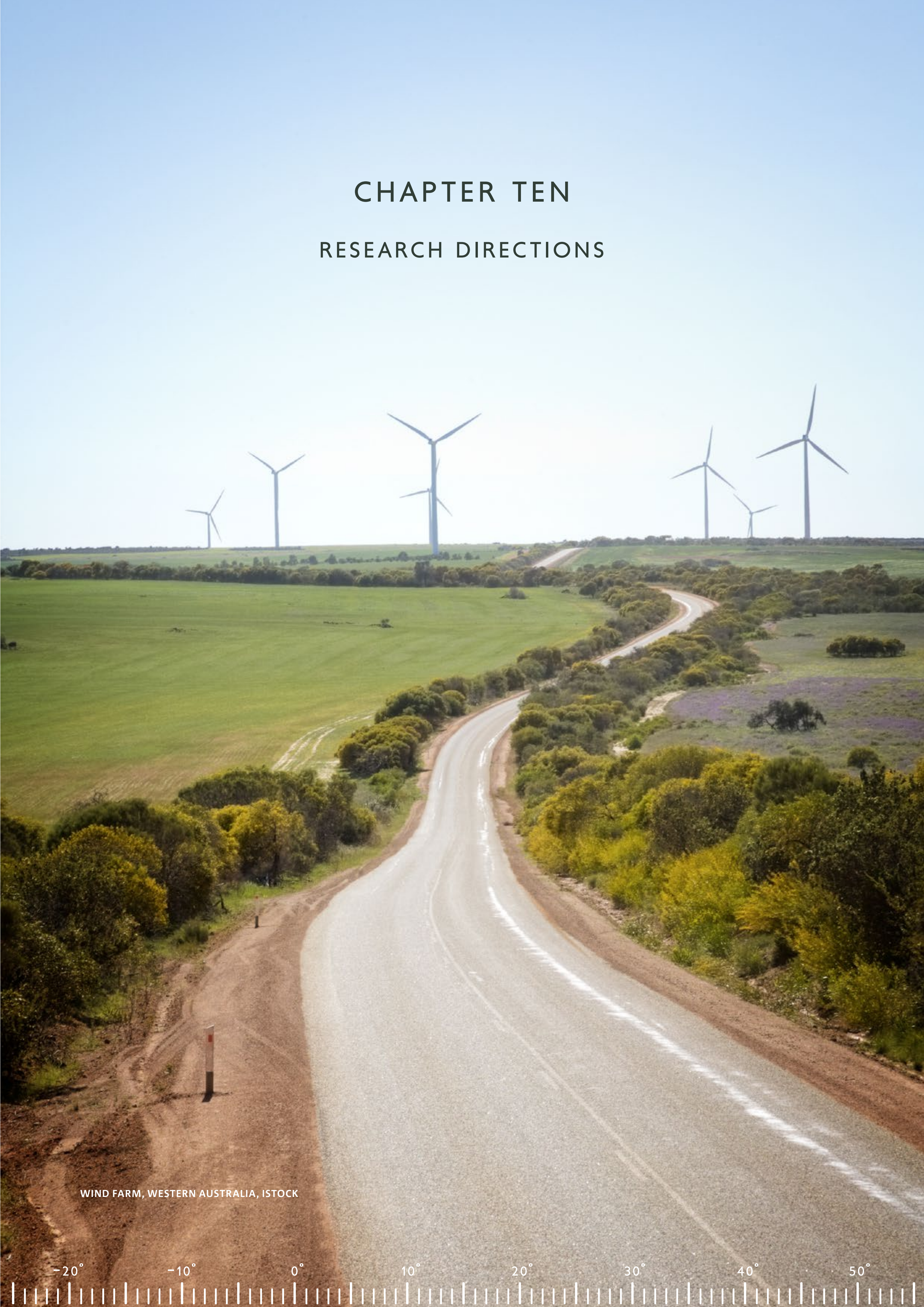
# CHAPTER TEN

## RESEARCH DIRECTIONS



WIND FARM, WESTERN AUSTRALIA, ISTOCK

# CHAPTER 10 RESEARCH DIRECTIONS

The projections presented in this Report are the most comprehensive and broadly based ever produced for Australia. This has been made possible by Australian scientists working to make significant advances in our observational networks, understanding of regional climate drivers and how these may change in the future, analysis of climate model simulations, and consultation with end-users. There has been substantial leveraging of the Australian Climate Change Research Program. Australia's participation in global fora, such as the fifth Climate Model Intercomparison Project (CMIP5), has enabled the projections and underpinning research to benefit from improved international scientific understanding of the global climate system, as represented in the recent reports of the IPCC.

Future research directions to allow for the continued improvement of Australian climate projections include:

- increasing our understanding of the drivers of regional climate and extremes, such as the El Niño-Southern Oscillation and the Indian Ocean Dipole, and how they are likely to change in the future
- maintaining and enhancing an extensive observational network, to detect climate variability and change and track atmospheric and ocean processes that influence major climate drivers
- developing capability in multi-year and decadal predictions
- enhancing downscaling techniques
- ongoing participation in international modelling comparisons, to enable continued leveraging of extensive global research into model development
- support for end-users of projections, including targeted support, communication products and tailored projections for specific sectors of the community, government or economy.

## 10.1 UNDERSTANDING CLIMATIC VARIABILITY AND MONITORING CHANGE

It is through weather and climate extremes that most of us experience the impacts caused by climate change. Advances in our ability to estimate 21st century climate will come from improving our capacity to understand how important phenomena that influence variability and extremes, such as the El Niño-Southern Oscillation and the Indian Ocean Dipole, are likely to change in future. This will allow for improved projections of likely changes to droughts, floods, frosts, heatwaves, fires, hailstorms, extreme winds, tropical cyclones and the monsoon.

The Senate Inquiry into "Recent trends in and preparedness for extreme weather events" made ten recommendations, two of which were:

a. The committee recommends that the Bureau of Meteorology and CSIRO continue to improve projections and forecasts of extreme weather events at a more local level

b. The committee notes the linkage between climate change and extreme weather events and recommends that the Bureau of Meteorology and CSIRO conduct further research to increase understanding in the areas of:

    i. the interaction between large-scale natural variations, climate change and extreme weather events;

    ii. the impacts of climate change on rainfall patterns and tropical cyclones;

    iii. that Australia cooperatively engage, where appropriate, with international research initiatives in these areas

Multi-year and decadal predictions (2-10 years) are becoming a focus for international climate science efforts. Critical drivers of our climate such as the El Niño-Southern Oscillation often operate on multi-year to decadal scales. Planning and risk management decisions for many sectors are also made on these timescales. Researchers need to identify the variables that can be skilfully predicted and how far into the future some predictive skill remains evident. It is likely that near-term predictability will vary by region, so specific Australian studies continue to be needed.

Observational networks continue to provide vital information for detecting and attributing change, for undertaking process studies and for improving near-term predictions and long-term projections. The Bureau of Meteorology's observational network is an important national resource, providing the long-term and high quality data needed for climate research. The network is also monitoring variables for which we have little information, such as wind speed and evapotranspiration.

Ocean observational networks are also critical to understanding the storage and distribution of global heat and the drivers of our regional climate. Australia's investment in ocean monitoring is targeting areas of importance to Australia, including the Southern Ocean and tropics, while contributing to and benefiting from the global effort (*e.g.* Ocean Observations Panel for Climate, Global Ocean Observing System and Global Climate

Observing System). Extensive ocean observations and their assimilation into models will be essential for multi-year and decadal predictions.

Ocean observations are also important to understanding and projecting sea level rise, alterations to wave patterns, variations in regional sea level and investigating extreme events such as storm surges. Australia is particularly vulnerable to sea level rise and this remains an important area of further research.

## 10.2 NEW CLIMATE MODEL ENSEMBLES

The international research community is commencing the latest round of climate model comparisons: the Coupled Model Intercomparison Project phase 6 (CMIP6), run under the auspices of the World Climate Research Programme. By participating in these model intercomparisons, Australia has access to substantial research outputs from the global climate science community. The ACCESS model is used in Australia for weather and seasonal forecasting as well as longer-term climate projections, and our participation in global activities enables improved modelling capacity on all time scales. Australia needs to expand its data storage and analysis infrastructure to ensure we benefit from this research.

There is also a need to improve downscaling techniques. While a number of dynamical and statistical options exist, each has pros and cons. A more thorough assessment of the reliability of these techniques is needed in order to extract the greatest benefit.

## 10.3 TARGETED PROJECTION PRODUCTS AND COMMUNICATION

Research and experience overseas indicate that ongoing support from science agencies is required for users to effectively apply climate projections. Well-resourced climate projection support services are needed to meet the growing demand from researchers, planners and decision-makers to assess potential impacts, explore management options and implement effective adaptation strategies. The WMO Global Framework for Climate Services provides guidance on how this might be done. Vaughan and Desai (2014) review institutional arrangements of selected emerging climate services across local, national, regional, and international scales.

Some sectors require specific projection products to answer important questions. For example, further research on runoff is needed if researchers are to reliably translate projected rainfall changes into likely changes to soil moisture, run-off and river flows. More detailed modelling of fire weather, fuel and ignition is needed to understand how climate change will affect fire frequency, duration and intensity.

This Australian projections program has involved strong linkages between development of climate change products and their application by the NRM community. As well as continuing to strengthen these linkages, this integrated approach could be applied productively in other important sectors, such as for cities, agriculture, coastal communities, disaster management, energy and mining.

People sometimes require information tailored for their specific context. To maximise the impact of the new projections, they could readily be regionalised in ways beyond the eight natural resource management clusters that are addressed in this Report. State-based projections could be developed and communicated, as has been done by the NSW/ACT Regional Climate Modelling project (NARClim), the Victorian Climate Initiative (VicCI) and the Goyder Institute (for South Australia). Projections for Australia's big cities could be prepared and supported.

The extensive stakeholder interactions undertaken by climate change researchers in this program, and in the allied impacts and adaptation program, highlight the need for regular provision of a wide range of communication products, support and training. There is demand for general information on climate change and its causes, as well as specific information on the likely regional changes and adaptation and mitigation options. It is evident that there is demand to build capability in understanding and applying climate science information by institutions, communities and decision-makers. Climate researchers need to further build their capability and capacity to support this interaction.

A growing body of evidence from social scientists demonstrates that some communication methods and approaches work far better than others. Social science needs to continue to inform the way in which we communicate climate information.

## 10.4 CONCLUSIONS

Australia now has arguably the world's most comprehensive and up to date climate change projections. These projections provide an excellent basis for adaptation and risk management activities.

There is clear community demand for support in interpreting and applying the projections. This is a demand that is likely to exceed the agencies' ability and resources to respond. There are a number of other communication products that could be readily produced with modest additional resources, such as separate State and Territory projections, sector-specific information and projections for Australia's major urban areas.

The reality of climate change means that observations of the land, atmosphere and oceans must continue in order to track the extent of the changes. A focus on changes to weather and climate extremes will help target adaptation work, as it is these extremes that produce the greatest impacts on many sectors. Multi-year to decadal predictions that account for both climatic variability and the underpinning climate change will be valuable for near-term decision making and investments.

# APPENDIX A COMPARISON OF CMIP3 AND CMIP5 CHANGES OVER AUSTRALIA

## A.1 INTRODUCTION

This Appendix compares projected changes based on CMIP5 with those based on CMIP3, as used for Climate Change in Australia (CSIRO and BOM, 2007). In 2007, the range of change in each variable was presented in a probabilistic form, with the change at each location, for a given scenario and time in the future, being represented as a probability density function (PDF). The method used relies on the pattern scaling approximation, as described in section 6.2, with further details given by Watterson (2008). In order to derive comparable results the method is applied again using CMIP5 data. The range in the PDFs allows for both the uncertainty in the global warming and in the local response to it (or 'change per degree'), with both factors based on the ensemble of models. For CMIP3, 23 models were used, while suitable data are available from up to 40 CMIP5 models (Section 3.3.1). For some variables, the local response factors were derived from fewer models, as noted below. The model change per degree data are first interpolated to a common one-degree grid of points at which the local changes are calculated.

The scaling approximation is very helpful for this comparison, as results can be presented for the same standard case as considered in the earlier sections. This was for the change in 2080-2099 relative to 1986-2005 under the RCP8.5 scenario, for which the best (or median) estimate of global warming is 3.7 °C. Given that the mean global sensitivity of the CMIP3 models is very similar to that of CMIP5 (see section 3.6), scaling the 2007 PDFs to this same median global warming gives an indication of projections based on CMIP3 model responses for this case. The 2007 projections focused on the SRES A1B scenario, and the time 2070, when the median global warming was 2.1 °C. Only the A1FI scenario produced a warming as large as 3.7 °C within the 21st century (consistent with Figure 3.2.2).

Results are presented here for six surface variables that are important to climate impacts. The focus is on the Australian maps of annual changes for three percentiles, the median, denoted P50, and the P10 and P90 values representing the upper and lower values across the likely range. Some seasonal results from CMIP5 are shown in the sections for each variable in chapter 7, and brief comparisons are made. Note that the P10 to P90 ranges are larger than they would be for a specific global warming of 3.7 °C because the uncertainty in global sensitivity is also included. As noted in Section 3.6, the uncertainty in global warming, relative to the mean, is similar in the two ensembles. Thus we can attribute the differences in the final PDFs from CMIP3 and CMIP5 largely to the local response factors. The relative comparisons may hold also for the change around 2030, from both the 2007 and new projections, given that the global warming in 2030 for the various scenarios is approximately 0.8 to 1 °C. However, details may differ, particularly for changes (shown earlier) that are based directly on the CMIP5 simulations. Changes forced by aerosols and ozone are not well represented in these scaled results.

## A.2 TEMPERATURE

The P10, P50 and P90 results for the annual temperature case from both CMIP3 and CMIP5 are shown in Fig. A.1. The percentile values are similar in CMIP3 and CMIP5, although the north-west is notably less warm in CMIP5. Averaged over Australia the best estimate of the warming from CMIP5 is 4.2 °C, 0.2 °C smaller than in CMIP3, in this case. Changes for the four seasonal cases in CMIP3 are also similar to those for CMIP5 shown in Section 7.1.

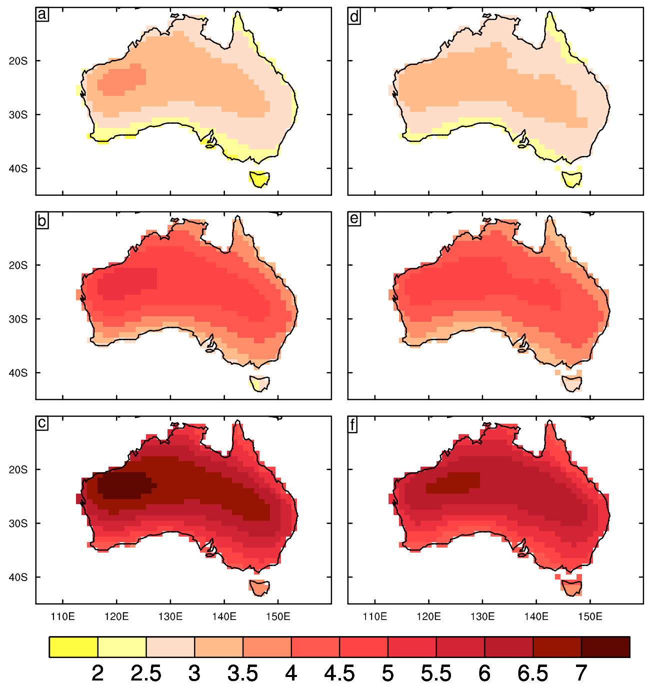



**FIGURE A.1:** CHANGES IN TEMPERATURE (IN °C) FOR THE ANNUAL, STANDARD CASE, FROM CMIP3 (LEFT) AND CMIP5 (RIGHT). THE MIDDLE PANELS (B, E) ARE THE MEDIAN RESULT. THE TOP PANELS (A, D) ARE THE 10TH PERCENTILE RESULT AND BOTTOM PANELS (C, F) ARE THE 90TH PERCENTILE RESULT.

In both ensembles, there is a consistent increase in warming from the coast to the interior. This is partly a result of the maritime influence along the coast, as the warming for model ocean points is slower. In these results, and also for rainfall, only data from model land points are used. In the CMIP5 calculations for temperature, precipitation and land surface variables, values are extrapolated across each model coastline to ensure that the full ensemble of models is used at each (actual) land grid point shown.

## A.3 RAINFALL

The PDFs for rainfall (precipitation) at each point have been calculated using the same method as for CMIP3, using local responses expressed as percentages of the model base climate. Following Watterson (2008), for positive local responses, the global warming factor (centred on 3.7 °C in the standard case) is combined in the usual linear way. However, negative responses are applied in a compounding way, which prevents the net change exceeding an unrealistic −100 %. The changes for the annual case are shown in Figure A.2. Decreases occur for much of the continent in the P50 result, but there is little change in part of the north and also in NSW in the CMIP5 case. In fact, the all-Australia average is now −4.5 %, compared to −11.8 % for CMIP3. Decreases remain large in the south-west. At all points, however, there is a wide range of change, with P90 being positive, except in the far south-west. The percentiles from CMIP5 for changes in each season are shown in Section 7.2. Again, in CMIP5 there are fewer declines, with a slight increase for NSW now extending from summer into autumn.

## A.4 SOLAR RADIATION

For both CMIP3 (20 models) and CMIP5 (38 models) the median estimate for annual solar radiation (downwards at surface) is for little change over Australia (Figure A.3), except for a small increase in the south, particularly Victoria. The changes range typically from −10 W m$^{-2}$ to 10 W m$^{-2}$, with considerable regional variation. For CMIP5, the rise in radiation at P90 is smaller in the north-west than elsewhere, and a decrease is more likely there. Throughout the north a considerable decline is possible at P10. The positive median change in the south is consistent with a general decrease in cloudiness in mid-latitudes. However, the changes in cloud (not shown), like those in rainfall, differ between models.

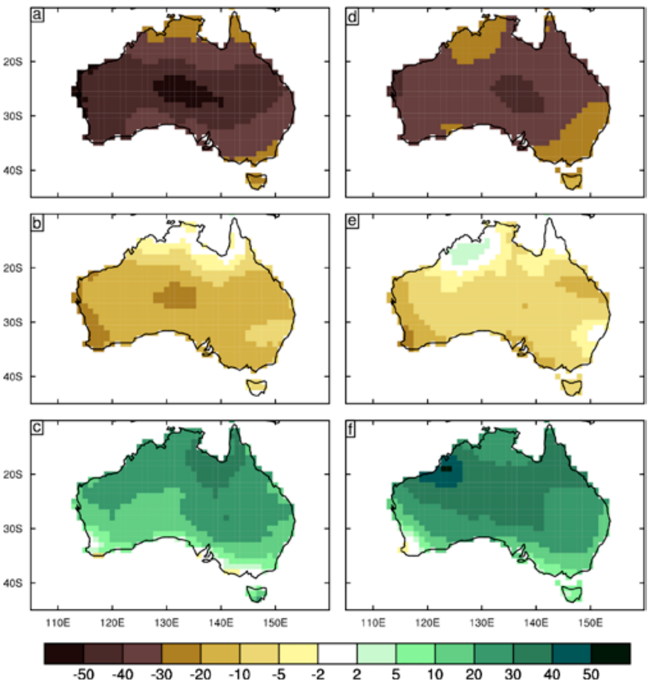



**FIGURE A.2:** CHANGES IN RAINFALL (IN %) FROM CMIP3 (LEFT) AND CMIP5 (RIGHT). THREE PERCENTILES OF THE LOCAL PDFS FOR CHANGE ARE SHOWN: (A, D) 10TH, (B, E) 50TH AND (C, F) 90TH.

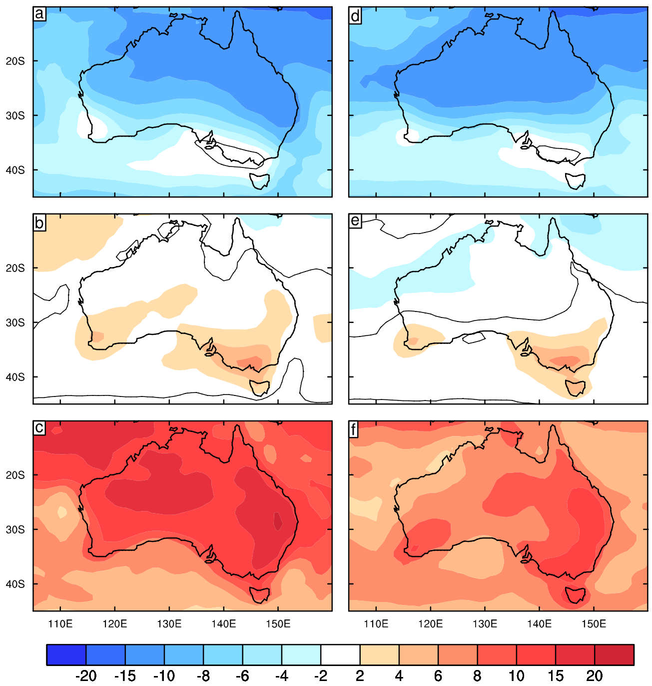



**FIGURE A.3:** CHANGES IN SOLAR RADIATION (IN W M$^{-2}$) FROM CMIP3 (LEFT) AND CMIP5 (RIGHT) FOR THE STANDARD CASE. THREE PERCENTILES OF THE LOCAL PDFS FOR CHANGE, ANNUAL CASE, ARE SHOWN: (A, D) 10TH, (B, E) 50TH AND (C, F) 90TH. THE ZERO LINE IS DRAWN.

## A.5 RELATIVE HUMIDITY

Changes in (near-surface) relative humidity also differ much more across the percentiles than between CMIP3 (14 models) and CMIP5 (29 models), as seen in Figure A.4. In both ensembles, the median change is for a small decline, around 2 to 3 % (of the saturation value), in humidity except over Tasmania and some mainland coasts. Over most of the regional ocean, there is some chance of a small increase, except to the south-east of Australia. In Climate Change in Australia (CSIRO and BOM, 2007), it was stated that humidity changes were broadly consistent with rainfall. In CMIP5 for P50, declines are more widespread in humidity than in rainfall, however. This difference may be associated with the representation of land surface characteristics. As in evident in the maps, changes over the ocean in relative humidity are smaller.

## A.6 SURFACE WIND SPEED

Most models in CMIP5 have provided data for the true mean speed (at the 10 m height), averaged from speeds during the model simulation (which was not available from CMIP3). Changes calculated using the PDF method for the annual case are shown in Figure A.5, using change per degree data from 19 models. Note that the changes in speed have been converted to a percentage using the 1986-2005 multi-model mean. The range over the PDF is from substantial decreases to increases, over nearly all of Australia. The pattern of change for P50 is quite similar to the results presented in 2007, despite those being calculated using speeds from monthly mean wind components. However, for P90 the changes over the surrounding ocean seem more moderate in CMIP5, and with fewer areas with an increase.

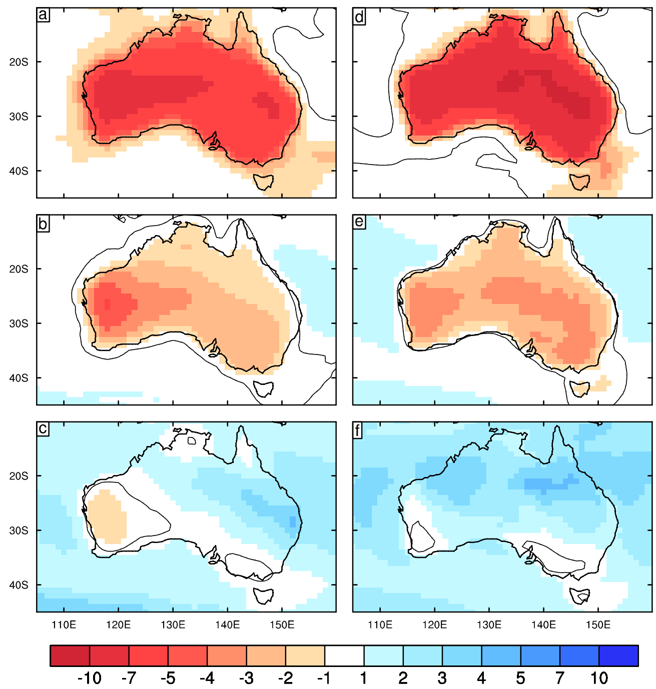



**FIGURE A.4:** CHANGES IN HUMIDITY (IN % OF SATURATION) FROM CMIP3 (LEFT) AND CMIP5 (RIGHT) FOR THE STANDARD CASE. THREE PERCENTILES OF THE LOCAL PDFS FOR CHANGE, ANNUAL CASE, ARE SHOWN: (A, D) 10TH, (B, E) 50TH AND (C, F) 90TH. THE ZERO LINE IS DRAWN.

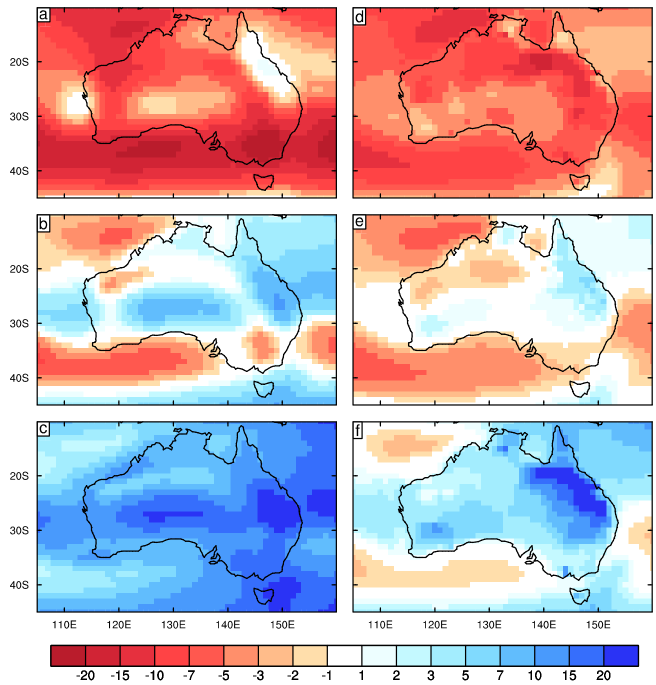



**FIGURE A.5:** CHANGES IN WIND SPEED (IN % OF THE BASE PERIOD MULTI-MODEL MEAN) FROM CMIP3 (LEFT) AND CMIP5 (RIGHT) FOR THE STANDARD CASE. THREE PERCENTILES OF THE LOCAL PDFS FOR CHANGE, ANNUAL CASE, ARE SHOWN: (A, D) 10TH, (B, E) 50TH AND (C, F) 90TH.

## A.7 POTENTIAL EVAPOTRANSPIRATION

The potential evapotranspiration’ has been evaluated for CMIP5 (using 22 models), similarly to CMIP3 (14 models) – see Section 7.6. The fields calculated using the scaling approach also very similar over Australian land (Figure A.6). All changes in the P10, P50 and P90 fields are increases. The mean P50 for the standard case is 11 % for each ensemble.

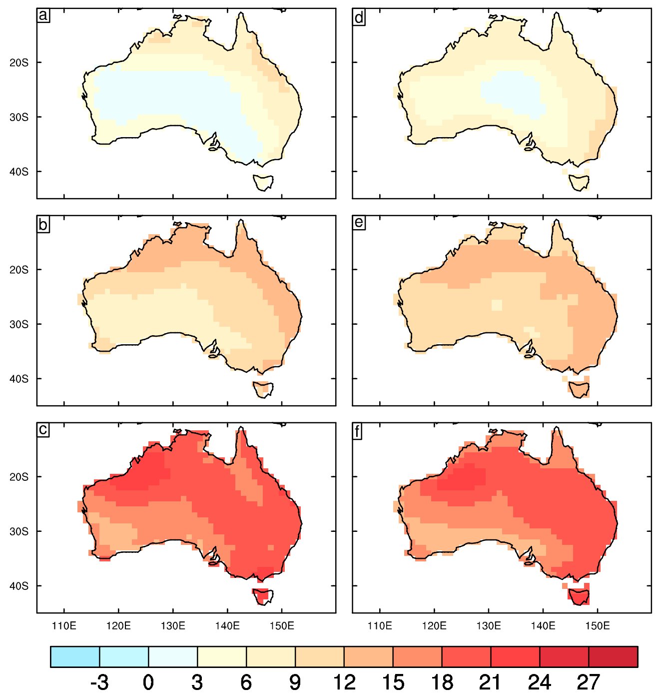



**FIGURE A.6:** CHANGES IN POTENTIAL EVAPOTRANSPIRATION (IN % OF THE BASE PERIOD MULTI-MODEL MEAN) FROM CMIP3 (LEFT) AND CMIP5 (RIGHT) FOR THE STANDARD CASE. THREE PERCENTILES OF THE LOCAL PDFS FOR CHANGE, ANNUAL CASE, ARE SHOWN: (A, D) 10TH, (B, E) 50TH AND (C, F) 90TH.

## A.8 SUMMARY

In conclusion, the comparisons show that for a scenario with a large global warming towards the end of the century, the pattern of simulated change in these six surface variables is generally similar in the CMIP3 and CMIP5 ensembles. This applies to both the median estimate of change and to the range of changes, as estimated using the pattern scaling approach. However, there are some differences, attributable to small differences in local response to global warming. Scaled to the standard case, with a median estimate for global warming of 3.7 °C, the mean warming over Australia is typically 5 % less in CMIP5. The reduction is consistent with a less negative rainfall change in the median change field for CMIP5, although the P50 rainfall change remains near-zero in the north. Humidity and solar radiation decrease slightly in the south in both ensembles. The best estimate for wind speed is still for little change. However, all these variables still have a considerable range of change as depicted in the 10th and 90th percentile fields. At many locations, the range spans both signs, except for temperature and potential evaporatranspiration.