CENTRAL SLOPES

CLUSTER REPORT

CLIMATE CHANGE IN AUSTRALIA

PROJECTIONS

FOR AUSTRALIA´S NRM REGIONS

CSIRO

Australian Government
Department of the Environment
Bureau of Meteorology

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CLUSTER REPORT – CENTRAL SLOPES

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PREFACE

Australia's changing climate represents a significant challenge to individuals, communities, governments, businesses and the environment. Australia has already experienced increasing temperatures, shifting rainfall patterns and rising oceans.

The Intergovernmental Panel on Climate Change (IPCC) *Fifth Assessment Report* (IPCC 2013) rigorously assessed the current state and future of the global climate system. The report concluded that:

- greenhouse gas emissions have markedly increased as a result of human activities
- human influence has been detected in warming of the atmosphere and the ocean, in changes in the global water cycle, in reductions in snow and ice, in global mean sea level rise, and in changes in some climate extremes
- it is extremely likely that human influence has been the dominant cause of the observed warming since the mid-20th century
- continued emissions of greenhouse gases will cause further warming and changes in all components of the climate system.

In recognition of the impact of climate change on the management of Australia's natural resources, the Australian Government developed the Regional Natural Resource Management Planning for Climate Change Fund. This fund has enabled significant research into the impact of the future climate on Australia's natural resources, as well as adaptation opportunities for protecting and managing our land, soil, water, plants and animals.

Australia has 54 natural resource management (NRM) regions, which are defined by catchments and bioregions. Many activities of organisations and ecosystem services within the NRM regions are vulnerable to impacts of climate change.

For this report, these NRM regions are grouped into 'clusters', which largely correspond to the broad-scale climate and biophysical regions of Australia (Figure A). The clusters are diverse in their history, population, resource base, geography and climate. Therefore, each cluster has a unique set of priorities for responding to climate change.

CSIRO and the Australian Bureau of Meteorology have prepared tailored climate change projection reports for each NRM cluster. These projections provide guidance on the changes in climate that need to be considered in planning.

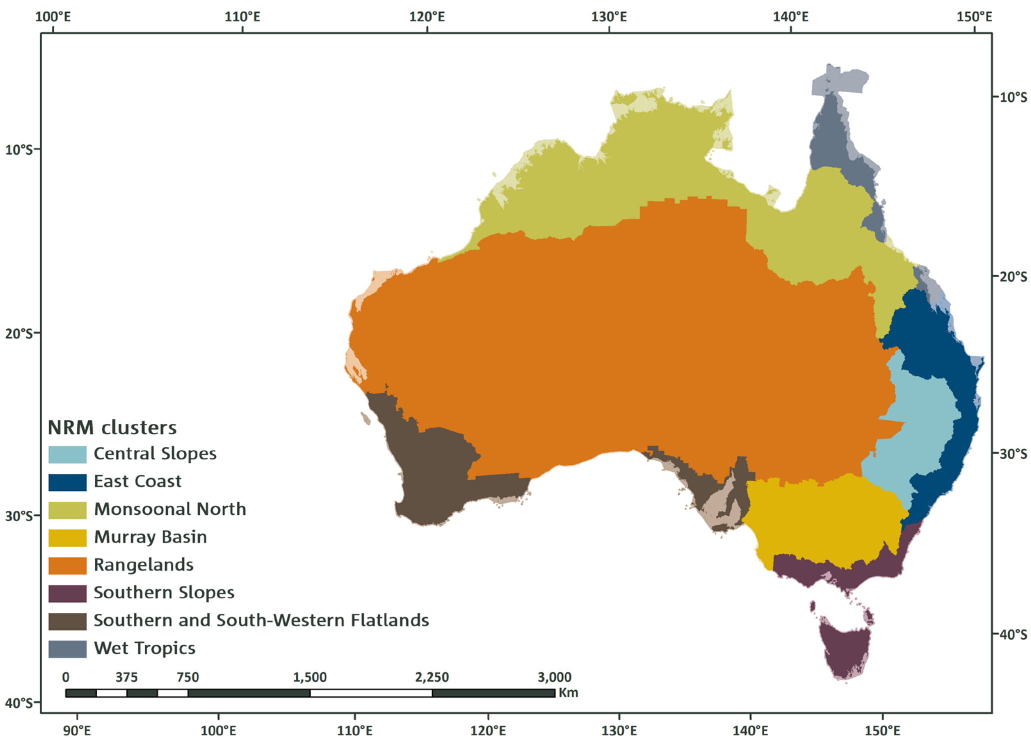

FIGURE A: THE EIGHT NATURAL RESOURCE MANAGEMENT (NRM) CLUSTERS

This is the regional projections report for the Central Slopes cluster. This document provides projections in a straightforward and concise format with information about the cluster as a whole, as well as additional information at finer scales where appropriate.

This cluster report is part of a suite of products. These include a brochure for each cluster that provides the key projection statements in a brief format. There is also the Australian climate change projections Technical Report, which describes the underlying scientific basis for the climate change projections. Box 1 describes all supporting products.

This report provides the most up to date, comprehensive and robust information available for this part of Australia, and draws on both international and national data resources and published peer-reviewed literature.

The projections in this report are based on the outputs of sophisticated global climate models (GCMs). GCMs are based on the laws of physics, and have been developed over many years in numerous centres around the world. These models are rigorously tested for their ability to reproduce past climate. The projections in this report primarily use output from the ensemble of model simulations brought together for the Coupled Model Inter-comparison Project phase 5 (CMIP5) (Taylor *et al.*, 2012), where phase 5 is the most recent comparison of model simulations addressing, amongst other things, projections of future climates. In this report, outputs from GCMs in the CMIP5 archive are complemented by regional climate modelling and statistical downscaling.

BOX 1: CLIMATE CHANGE IN AUSTRALIA – PRODUCTS

This report is part of a suite of Climate Change in Australia (CCIA) products prepared with support from the Australian Government's Regional Natural Resource Management Planning for Climate Change Fund. These products provide information on climate change projections and their application.

CLUSTER BROCHURES

Purpose: key regional messages for everyone

A set of brochures that summarise key climate change projections for each of the eight clusters. The brochures are a useful tool for community engagement.

CLUSTER REPORTS

Purpose: regional detail for planners and decision-makers

The cluster reports are to assist regional decision-makers in understanding the important messages deduced from climate change projection modelling. The cluster reports present a range of emissions scenarios across multiple variables and years. They also include relevant sub-cluster level information in cases where distinct messages are evident in the projections.

TECHNICAL REPORT

Purpose: technical information for researchers and decision-makers

A comprehensive report outlining the key climate change projection messages for Australia across a range of variables. The report underpins all information found in other products. It contains an extensive set of figures and descriptions on recent Australian climate trends, global climate change science, climate model evaluation processes, modelling methodologies and downscaling approaches. The report includes a chapter describing how to use climate change data in risk assessment and adaptation planning.

WEB PORTAL

URL: www.climatechangeinaustralia.gov.au
Purpose: one stop shop for products, data and learning

The CCIA website is for Australians to find comprehensive information about the future climate. This includes some information on the impacts of climate change that communities, including the natural resource management sector, can use as a basis for future adaptation planning. Users can interactively explore a range of variables and their changes to the end of the 21st century. A 'Climate Campus' educational section is also available. This explains the science of climate change and how climate change projections are created.

Information about climate observations can be found on the Bureau of Meteorology website (www.bom.gov.au/climate). Observations of past climate are used as a baseline for climate projections, and also in evaluating model performance.

EXECUTIVE SUMMARY

INTRODUCTION

This report presents projections of future climate for the Central Slopes. These projections are based on our current understanding of the climate system, historical trends and model simulations of the climate response to changing greenhouse gas and aerosol emissions. The simulated climate response is that of the CMIP5 model archive, which also underpins the science of the *Fifth Assessment Report* of the Intergovernmental Panel on Climate Change (IPCC, 2013).

The global climate model (GCM) simulations presented here represent the full range of emission scenarios, as defined by the Representative Concentration Pathways (RCPs) used by the IPCC, with a particular focus on RCP4.5 and RCP8.5. The former represents a pathway consistent with low-level emissions, which stabilise the carbon dioxide concentration at about 540 ppm by the end of the 21st century. The latter is representative of a high-emission scenario, for which the carbon dioxide concentration reaches about 940 ppm by the end of the 21st century.

Projections are generally given for two 20-year time periods: the near future 2020–2039 (herein referred to as 2030) and late in the century 2080–2099 (herein referred to as 2090). The spread of model results are presented as the range between the 10th and 90th percentile in the CMIP5 ensemble output. For each time period, the model spread can be attributed to three sources of uncertainty: the range of future emissions, the climate response of the models, and natural variability. Climate projections do not make a forecast of the exact sequence of natural variability, so they are not 'predictions'. They do however show a plausible range of climate system responses to a given emission scenario and also show the range of natural variability for a given climate. Greenhouse gas concentrations are similar amongst different RCPs for the near future, and for some variables, such as rainfall, the largest range in that period stems from natural variability. Later in the century, the differences between RCPs are more pronounced, and climate responses may be larger than natural variability.

For each variable, the projected change is accompanied by a confidence rating. This rating follows the method used by the IPCC in the *Fifth Assessment Report*, whereby the confidence in a projected change is assessed based on the type, amount, quality and consistency of evidence (which can be process understanding, theory, model output, or expert judgment); as well as the degree of agreement amongst the different lines of evidence (IPCC, 2013). The confidence ratings used here are set as *low, medium, high* or *very high*.

HIGHER TEMPERATURES

Temperatures in the cluster increased by 0.8 °C between 1910 and 2013 (especially since 1960) using a linear trend. For the same period, daytime maximum temperatures have increased by 0.4 °C while overnight minimum temperatures have increased by 1.2 °C using a linear trend.

Continued substantial warming for the Central Slopes cluster for daily mean, maximum and minimum temperature is projected with *very high confidence*, taking into consideration the robust understanding of the driving mechanisms of warming, as well as the strong agreement on direction and magnitude of change amongst GCMs and downscaling results.

For the near future (2030), the mean warming is around 0.6 to 1.5 °C relative to the climate of 1986–2005, with only a minor difference between RCPs. For late in the 21st century (2090) it is 1.4 to 2.7 °C under RCP4.5, and 3 to 5.4 °C under RCP8.5.

HOTTER AND MORE FREQUENT HOT DAYS. LESS FROST

A substantial increase in the temperature reached on the hottest days, the frequency of hot days, and the duration of warm spells, is projected by 2090. Very high model agreement and strong physical understanding lead to *very high confidence* in these projected changes. For example, relative to a 30 year period centred on 1995 the number of days above 35 °C in the town of Dubbo by 2090 doubles under RCP4.5, and the number of days over 40 °C triples. For the same town, but under RCP8.5, the number of days over 35 °C nearly triples and days over 40 °C increases nearly six times. Correspondingly, a substantial decrease in the frequency of frost days is projected by 2090 with *high confidence*. The numbers reported for Dubbo relate to the median projection.

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LESS RAINFALL IN WINTER AND SPRING, BUT CHANGES IN OTHER SEASONS ARE UNCLEAR

The cluster experienced prolonged periods of extensive drying in the early 20th century, but annual rainfall shows no long-term trend throughout the 20th century.

There is *high confidence* that natural climate variability will remain the major driver of rainfall changes in the next few decades (20-year mean changes of +/- 10 % annually, and +/-25 % seasonally), as it has been in the recent past.

Decreases in winter rainfall are projected to become evident by 2090, with *high confidence*. There is strong model agreement and good understanding of the contributing underlying physical mechanisms driving this change (relating to the southward shift of winter storm systems). The magnitude of possible differences from the winter climate of 1986–2005 indicated by GCM results range from around -25 to +10 % under RCP4.5 and -40 to +15 % under RCP8.5. Decreases are also projected for spring, but with *medium confidence* only.

For 2090, changes to rainfall in other seasons, and annually, are possible. The direction of change cannot be reilably projected, due to the complexity of rain producing systems in this cluster, the large spread of model results, and inconsistent results from downscaled models. Overall, the magnitude of possible seasonal changes, as indicated by GCM results, range from around -30 to +25 % under RCP4.5 and -40 to +30 % under RCP8.5. Such contrasting model simulations highlight the potential need to consider the risk of both a drier and wetter climate in impact assessment in this cluster.

INCREASED INTENSITY OF HEAVY RAINFALL EVENTS, CHANGES TO DROUGHT LESS CLEAR

Understanding of physical processes and high model agreement leads to *high confidence* that the intensity of heavy rainfall events will increase. The magnitude of change, and the time when any change may be evident against natural variability, cannot be reliably projected.

On the other hand, there is *low confidence* in projecting how the frequency and duration of extreme meteorological drought may change, although there is *medium confidence* that the time spent in drought will increase over the course of the century under RCP8.5.

SOME DECREASE IN WINTER WIND SPEED, FEWER BUT POSSIBLY MORE INTENSE EAST COAST LOWS

Overall small changes are projected with *high confidence* for mean surface wind speed under all RCPs, particularly by 2030 (*high confidence*). Decreases in winter wind speeds are projected for later in the century with *medium confidence* based on model results and physical understanding (relating to the southward movement of the storm track).

Decreases are also suggested for extreme wind speeds, particularly for the rarer extremes under both RCP4.5 and 8.5. However, low model agreement and limitations to the method suggest only *low confidence* in this projection.

Based on global and regional studies, tropical cyclones are projected to become more intense, but less frequent (*medium confidence*). Changes in their movement or frequency that may be relevant to the Central Slopes cluster cannot be reliably projected. Literature suggests a decline in the number, but an increase in the intensity, of east coast lows which cause damaging winds.

INCREASED SOLAR RADIATION IN WINTER AND REDUCED HUMIDITY THROUGHOUT THE YEAR

With *high confidence*, little change is projected for solar radiation for 2030. For 2090 under RCP4.5 and RCP8.5, there is *medium confidence* in increased winter radiation, which is related to decreases in cloudiness associated with reduced rainfall.

There is *high confidence* in little change in relative humidity for 2030. For 2090 based on model results and physical understanding, there is *medium confidence* in decreases in relative humidity in summer and autumn, and there is *high confidence* in decreases in relative humidity in winter and spring (around -6 to 0 % under RCP4.5 and -10 to 0 % under RCP8.5).

INCREASED EVAPORATION RATES AND REDUCED SOIL MOISTURE. CHANGES TO RUNOFF ARE LESS CLEAR

With *high confidence*, projections for potential evapotranspiration indicate increases in all seasons with the largest changes in summer by 2090. However, despite high model agreement, there is only *medium confidence* in the magnitude of the projections due to shortcomings in the simulation of observed historical changes.

With *medium confidence*, soil moisture projections suggest decreases predominately in winter and spring, with overall annual decreases for later in the century. These changes in soil moisture are strongly influenced by changes in rainfall, but tend to be more negative due to the increase in potential evapotranspiration. For similar reasons, runoff is projected to decrease, but only with *low confidence*. More detailed hydrological modelling is needed to assess changes to runoff confidently.

A HARSHER FIRE-WEATHER CLIMATE IN THE FUTURE

There is *high confidence* that climate change will result in a harsher fire-weather climate in the future. However, there is *low confidence* in the magnitude of the change, as this is strongly dependent on the rainfall projection.

MAKING USE OF THESE PROJECTIONS FOR CLIMATE ADAPTATION PLANNING

These regional projections provide the best available science to support impact assessment and adaptation planning in the Central Slopes cluster. This report provides some guidance on how to use these projections, including the Australian Climate Futures web tool, available from the Climate Change in Australia website. The tool allows users to investigate the range of climate model outcomes for their region across timescales and RCPs of interest, and to select and use data from models that represent a change of particular interest (*e.g.* warmer and drier conditions).

1 THE CENTRAL SLOPES CLUSTER

This report describes climate change projections for the Central Slopes cluster. The cluster is located on the western side of the Great Dividing Range and is dominated by landforms such as tablelands, slopes and plains. The cluster includes NRM regions in Queensland (Border Rivers, Maranoa-Balonne and Condamine) and New South Wales (former Catchment Management Authorities of Border Rivers-Gwydir, the Namoi and the Central West) (Figure 1.1). In January 2014, the Catchment Management Authorities (CMA) regions of NSW were re-organised to form the new Local Land Services (LLS) regions. The North-West, Northern Tablelands, Central-West and Central Tablelands LLS regions all have areas included within the Central Slopes cluster.

The cluster encompasses the cropping land to the west of the Great Dividing Range from the Darling Downs in Queensland to the central-west of NSW. The largest population centres within the cluster are Toowoomba in Queensland and Dubbo in New South Wales. There are also several important regional centres found within the cluster.

The Central Slopes cluster includes a number of important headwater catchments for the Murray-Darling basin, and its many slopes and plains are extensively developed for dryland and irrigated agriculture (cereals, cotton, pulses and oil seeds), livestock grazing and forestry. The cluster further supports horticulture and viticulture industries.

Major natural assets in the cluster include parts of the World Heritage Gondwana Rainforests of Australia, and other important bioregions with extensive representation of native flora and fauna. There are also extensive natural deposits of coal and coal seam gas that are the focus of extraction activities in the cluster.

A range of climate change impacts and adaptation challenges have been identified by NRM organisations across this cluster. These include the management of invasive species; water security; opportunities for improved carbon sequestration; understanding likely changes to agricultural production including changes to the growing conditions and yields for key crops; managing soil erosion and land degradation; and improving the resilience of riparian, aquatic and terrestrial ecosystems.

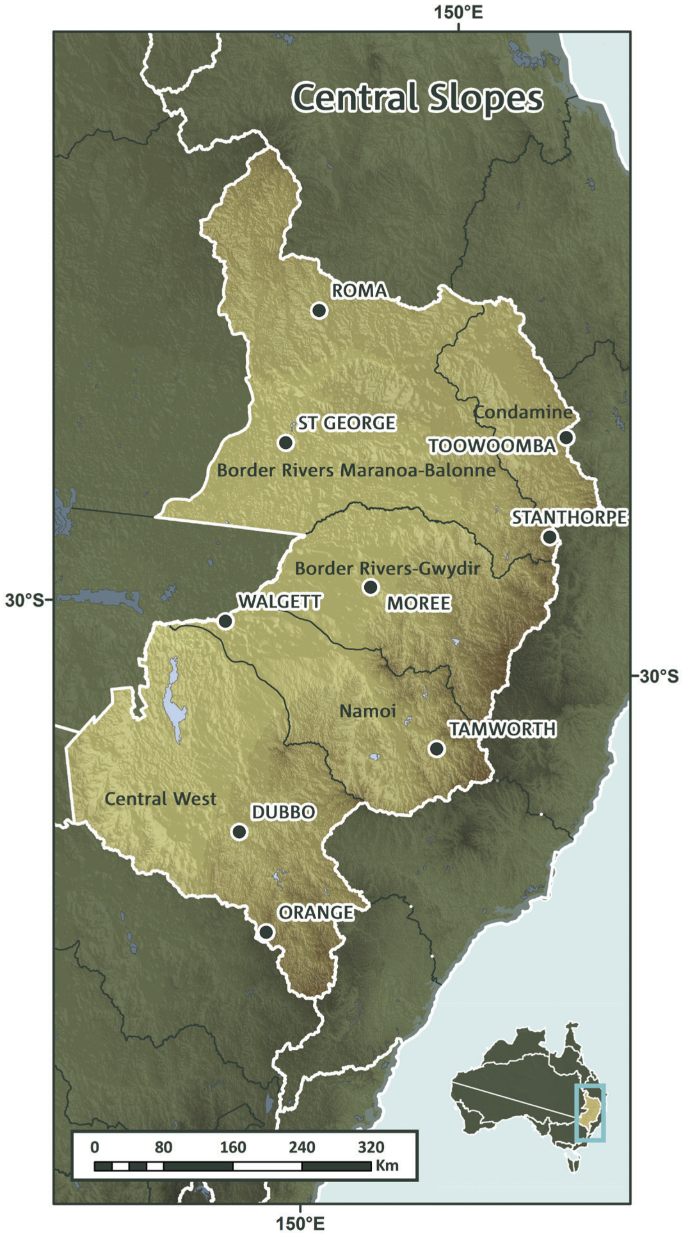


FIGURE 1.1: THE CENTRAL SLOPES CLUSTER AND MAIN LOCALITIES RELATIVE TO THE AUSTRALIAN CONTINENT.

2 CLIMATE OF CENTRAL SLOPES

The Central Slopes cluster straddles the Queensland and NSW border immediately west of the Great Dividing Range. This cluster encompasses a range of climates from subtropical in the north, to temperate in the south, to grasslands towards its western border. This range of climates is caused largely by cooler temperatures towards the south and drier conditions to the west[1]. In the sections below, the current climate of Central Slopes is presented for the period 1986–2005. Box 3.1 presents the observational data sets used in this report.

In summer (December to February), the cluster exhibits the greatest spatial variability in temperature with a clear north-west to south-east decline from the inner rangelands (27 to 30 °C) towards the Great Dividing Range (18 to 24 °C) (Figure 2.1a). In winter (June to August), there is a stronger north-south gradient with 12 to 15 °C in the north and 9 to 12 °C in the south with somewhat lower temperatures in the elevated areas of the Great Dividing Range (Figure 2.1b). The annual average temperature for the entire cluster is 18.5 °C (Figure 2.2).

The highest temperatures are experienced in January, with an average daily maximum temperature of 30 to 36 °C for large parts of the Central Slopes cluster (Figure 2.1c). Lowest temperatures occur most commonly in July with average minimum temperatures of 0 to 3 °C in the elevated areas in the south-east and 3 to 6 °C for much of the remaining cluster (Figure 2.1d). The cluster exhibits a clear seasonal pattern in temperature with daily mean temperatures ranging from about 26 °C in summer (January) to about 10 °C in winter (July), with maximum for the cluster about 34 °C in January and a minimum of about 4 °C in July (Figure 2.2).

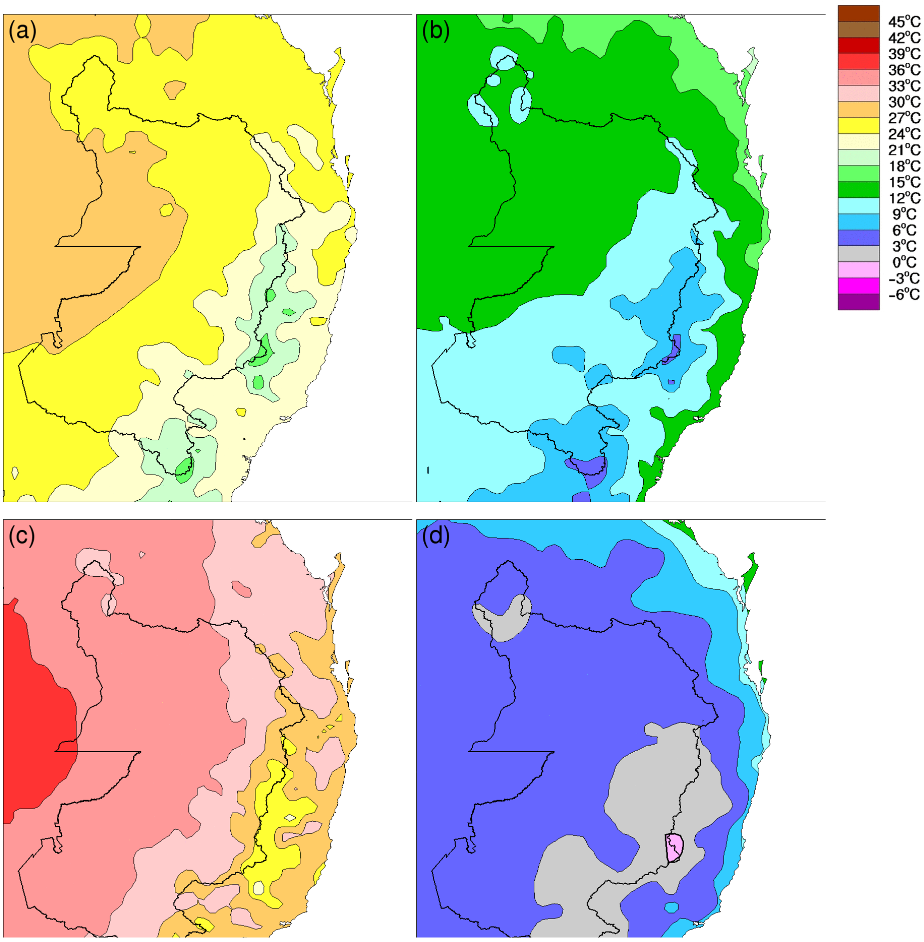


FIGURE 2.1: MAPS OF (A) AVERAGE SUMMER DAILY MEAN TEMPERATURE, (B) AVERAGE WINTER DAILY MEAN TEMPERATURE, (C) AVERAGE JANUARY MAXIMUM DAILY TEMPERATURE AND (D) AVERAGE JULY DAILY MINIMUM TEMPERATURE FOR THE PERIOD 1986–2005.

1 http://www.bom.gov.au/iwk/climate_zones/map_1.shtml

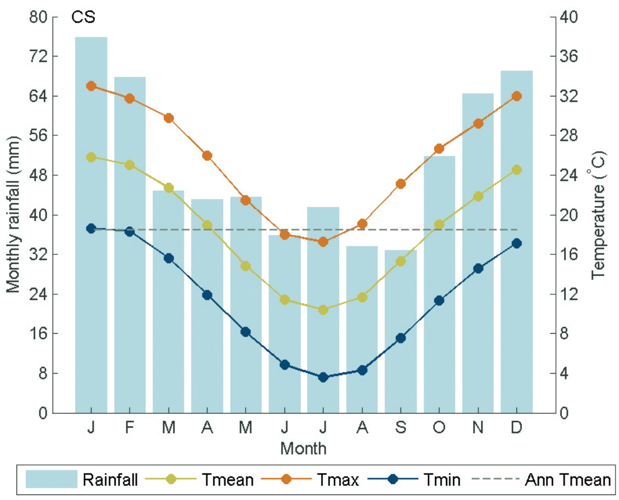


FIGURE 2.2: MONTHLY RAINFALL (BLUE BARS) AND TEMPERATURE CHARACTERISTICS FOR THE CENTRAL SLOPES CLUSTER (1986–2005). *TMEAN* IS MONTHLY MEAN TEMPERATURE (GREEN LINE), *TMAX* IS MONTHLY MEAN MAXIMUM TEMPERATURE (ORANGE LINE), *TMIN* IS MONTHLY MEAN MINIMUM TEMPERATURE (BLUE LINE) AND *ANN TMEAN* IS THE ANNUAL AVERAGE OF MEAN TEMPERATURE (GREY LINE) (18.5 °C). TEMPERATURE AND RAINFALL DATA ARE FROM AWAP.

Rainfall in the Central Slopes cluster varies considerably across space and across seasons with a typical drier winter and a wetter summer (Figure 2.2). The eastern parts see more rainfall with a larger number of rain days. There are less than 40 rain days in the west, compared with more than 50 rain days in the east.

In summer (December to February), rainfall totals range from approximately 100 to 200 mm in the west, to approximately 200 to 300 mm in the east (Figure 2.3a). In the drier winter (June to August), rainfall totals are about 50 to 100 mm in the north and west, with somewhat larger totals of about 100 to 200 mm in the south-eastern parts (Figure 2.3b).

Rainfall in the current climate has experienced low to moderate year to year variability relative to other parts of Australia, most notably in the central and eastern regions. The largest variability occurs in winter, particularly in the north-east regions.

The seasonal rainfall characteristics in the Central Slopes cluster are determined by complex interactions of several rain-bearing weather systems. For example, summer rainfall is strongly influenced by the easterly trough, an elongated zone of low pressure formed as a result of strong surface heating west of the Great Dividing Range. As the trough intensifies during the course of the day, convective storms build in the unstable air causing local showers and thunderstorms. In the winter half of the year, fronts and low-pressure systems, entering either from the south-west (cut-off lows) or from the east (east coast lows), can bring wet conditions to the cluster, particularly its southern areas. Throughout the year, rainfall also occurs as a result of cloud bands linked with the formation of troughs at upper levels in the atmosphere. Regions in the sub-tropical north also experience enhanced rainfall as a result of summer exposure to the trade winds that bring moist, warm air masses onto the northern part of the continent.

The heaviest rainfall events usually occur in summer, with monthly 90th percentile values around 100 to 200 mm for the period 1900–2005. Summer thunderstorms can be hazardous due to accompanying winds, hail, flash floods and potentially damaging lightning strikes. The north-east and southern regions of the Central Slopes cluster experience more than 25 thunder days per year, which is higher than much of western and southern Australia, but much lower than values for northern Australia (Kuleshov *et al.*, 2002).

Year to year rainfall variability in the Central Slopes cluster is related to changes in sea surface temperatures (SSTs) of adjacent ocean basins. For example, SSTs vary as a consequence of the oscillation between El Niño and La Niña type conditions or the variability of SSTs in the Indian Ocean. Rainfall variations are also linked to a mode of variability known as the Southern Annular Mode (SAM), which affects the strength of the summer easterly circulation in the region (Hendon *et al.*, 2007). Rainfall variations are also linked to blocking high pressures systems in the Tasman Sea, which affect variations in autumn and spring rainfall (Risbey *et al.*, 2009). For further details on El Niño Southern Oscillation (ENSO), the Indian Ocean dipole (IOD), or SAM, refer to Chapter 4 in the Technical Report.

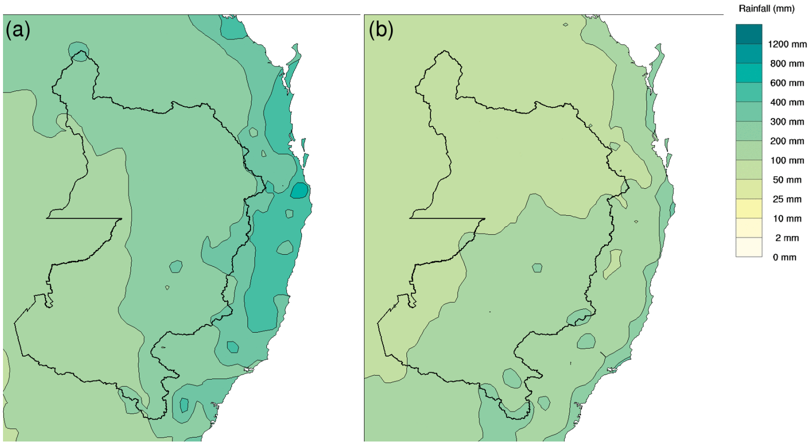


FIGURE 2.3: FOR THE 1986–2005 PERIOD, AVERAGE RAINFALL FOR (A) SUMMER (DECEMBER TO FEBRUARY) AND (B) WINTER (JUNE TO AUGUST).

3 SIMULATING REGIONAL CLIMATE

Researchers use climate models to examine future global and regional climate change. These models have a foundation in well-established physical principles and are closely related to the models used successfully in weather forecasting. Climate modelling groups from around the world produce their own simulations of the future climate, which may be analysed and compared to assess climate change in any region. For this report, projections are based on historical and future climate simulations from the CMIP5 model archive. This archive holds the most recent simulations, as submitted by approximately 20 modelling groups (Taylor *et al.*, 2012). The number of models used in these projections varies by RCP and variable depending on availability, *e.g.* for monthly temperature and rainfall, data are available for 39 models for RCP8.5 but only 28 models for RCP2.6 (see Chapter 3 in the Technical Report).

The skill of a climate model is assessed by comparing model simulations of the current climate with observational data sets (see Box 3.1 for details on the observed data used for model evaluation for the Central Slopes cluster). Accurate simulation of key aspects of the regional climate provides a basis for placing some confidence in the model's projections. However, models are not perfect representations of the real world. Some differences in model output relative to the observations are to be expected. The measure of model skill can also vary depending on the scoring measure used and regions being assessed.

For the Central Slopes cluster, models performed well in simulating the timing and magnitude of the seasonal cycle for temperature (Figure 3.1a). The majority of models simulate the timing of the seasonal rainfall patterns well, although the majority of models overestimate the amount of rainfall in summer. There is about a 20 mm per month discrepancy between the model median and the observed regional mean (Figure 3.1b). In terms of capturing the observed trend in temperature, models perform reasonably well. Over the 1910–2005 period, the multi-model mean overestimates the observed trend in the late spring and summer, and underestimates the trend in winter. In the more recent period of 1960–2005, the models underestimate the observed trend through much of the year (Figure 3.2). To see how the models performed across different parts of Australia, refer to Chapter 5 in the Technical Report.

BOX 3.1: COMPARING MODELS AND OBSERVATIONS: EVALUATION PERIOD, OBSERVED DATA SETS, AND SPATIAL RESOLUTION

Model skill is assessed by running simulations over historical time periods and comparing simulations with observed climate data. Projections presented here are assessed using the 1986–2005 baseline period, which conforms to the IPCC *Fifth Assessment Report*. (IPCC AR5, 2013). The period is also the baseline for projected changes, as presented in bar plots and tabled values in the Appendix. An exception is the time series projection plots, which use a baseline of 1950-2005, as explained in Section 6.2.2 of the Technical Report.

Several data sets are used to evaluate model simulations of the current climate. For assessment of rainfall and temperature, the observed data are derived from the Australian Water Availability Project (AWAP) (Jones *et al.*, 2009) and from the Australian Climate Observations Reference Network – Surface Air Temperature (ACORN-SAT), a data set developed for the study of long-term changes in monthly and seasonal climate (Fawcett *et al.*, 2012).

The spatial resolution of climate model data (around 200 km between the edges of grid cells) is much coarser than observations. For the Central Slopes cluster, approximately half of the CMIP5 models provide coverage by partial grid cells only (*i.e.* partially included within the cluster boundaries). This means that simulation of past and future climates should be interpreted as representative of a region which could include areas of adjacent clusters.

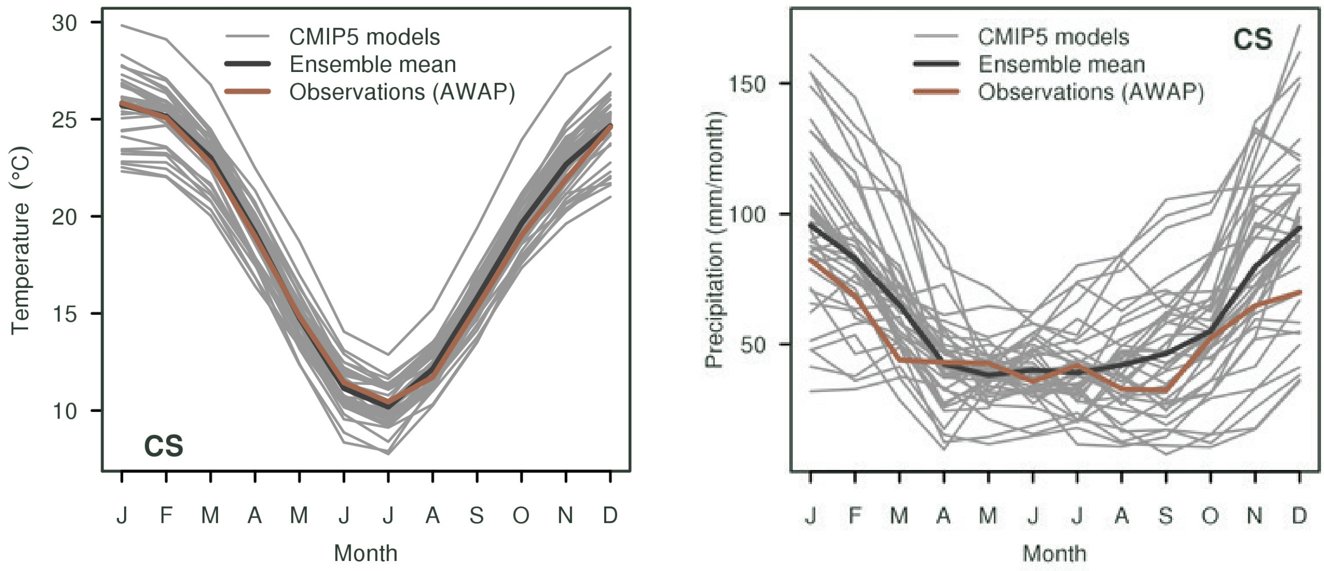


FIGURE 3.1: THE ANNUAL CYCLE OF TEMPERATURE (LEFT PANEL) AND RAINFALL (RIGHT PANEL) IN THE CENTRAL SLOPES CLUSTER SIMULATED BY CMIP5 MODELS (GREY LINES) WITH MODEL ENSEMBLE MEAN (BLACK LINE) AND OBSERVATIONS BASED ON AWAP (BROWN LINE) FOR THE BASELINE PERIOD 1986–2005.

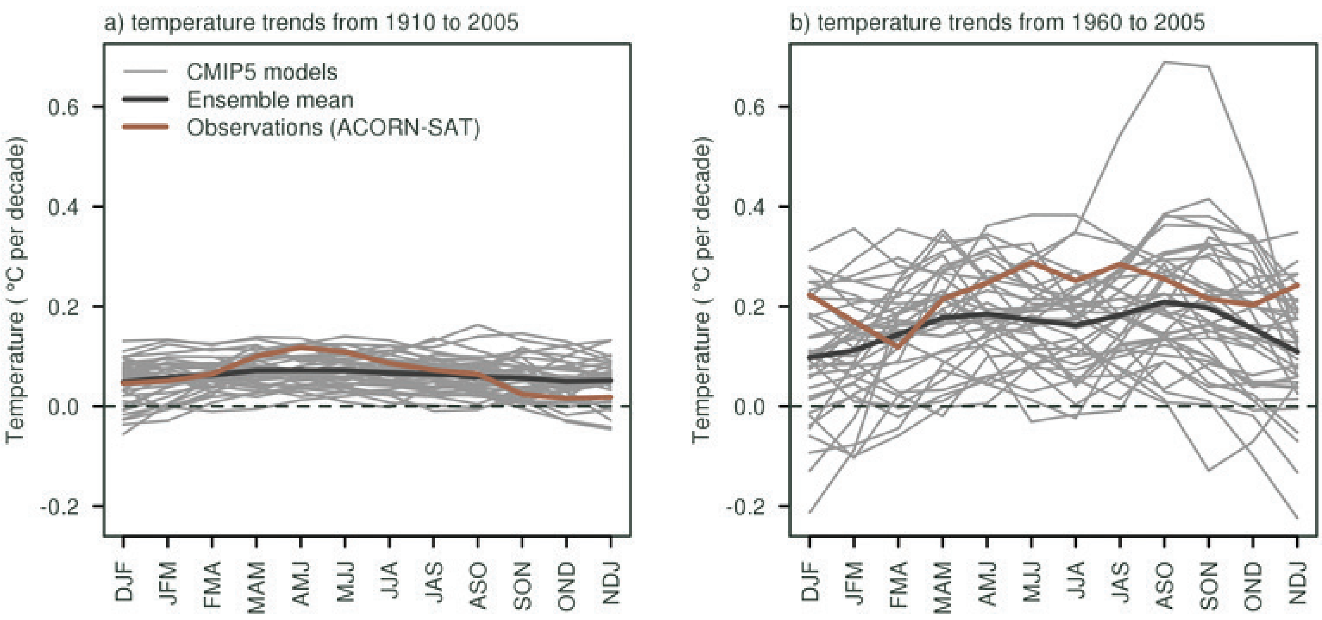


FIGURE 3.2: SIMULATED (GREY) AND OBSERVED (BROWN) SEASONAL TRENDS IN TEMPERATURE FROM (A) 1910–2005 AND (B)1960–2005. THE SOLID BLACK LINE DENOTES THE MULTI-MODEL ENSEMBLE MEAN TREND. THE OBSERVED TREND IS CALCULATED FROM ACORN-SAT DATA.

The ability of CMIP5 models to simulate key modes of climatic variability affecting the region has been assessed. Significantly, the connection between ENSO variations and rainfall is reasonably well simulated and has improved since the previous generation of climate models. Many models also had a reasonably accurate simulation of the relationship between regional rainfall and blocking (the presence of a high pressure centre) over the Tasman Sea. However, all models have at least some significant shortcomings across a range of other tests (more details in Chapter 5 of the Technical Report). Some of these shortcomings are noted in the context of interpreting specific projection results in the chapter that follows. There was no single or small number of models that clearly performed much better than others in the Central Slopes cluster.

In addition to the CMIP5 model results, downscaling can be used to derive finer spatial information in the regional projections, thus potentially capturing processes occurring on a finer scale. While downscaling can provide added value on finer scale processes, it increases the uncertainty in the projections since there is no single best downscaling method, but a range of methods that are more or less appropriate depending on the application. It is advisable to consider more than one technique, as different downscaling techniques have different strengths and weaknesses.

For the regional projections we consider downscaled projections from two techniques: outputs from a dynamical downscaling model, the Conformal Cubic Atmospheric Model (CCAM) (McGregor and Dix, 2008) using six CMIP5 GCMs as input; and the Bureau of Meteorology analogue-based statistical downscaling model with 22 CMIP5 GCMs as input for rainfall and 21 CMIP5 GCMs as input for temperature (Timbal and McAvaney, 2001). Where relevant, projections from these methods are compared to those from GCMs (the primary source of climate change projections in this report). The downscaled results are only emphasised if there are strong reasons for giving the downscaled data more credibility than the GCM data (see Section 6.3 in the Technical Report for further details on downscaling).

4 THE CHANGING CLIMATE OF THE CENTRAL SLOPES

This section presents projections of climate change to the end of the 21st century for a range of climate variables, including average and extreme conditions, of relevance to the Central Slopes cluster. Where there are relevant observational data available, the report shows historical trends.

As outlined in the *Fifth Assessment Report* (IPCC, 2013), greenhouse gases, such as carbon dioxide, have a warming effect on global climate. Greenhouse gases absorb heat that would otherwise be lost to space, and re-radiate it back into the atmosphere and to the Earth's surface. The IPCC concluded that it was *extremely likely* that more than half of the observed increase in global average surface air temperature from 1951–2010 has been caused by the anthropogenic increase in greenhouse gas emissions and other anthropogenic forcings. Further increases in greenhouse gas concentrations, resulting primarily from burning fossil fuel, will lead to further warming, as well as other physical and chemical changes in the atmosphere, ocean and land surface.

The CMIP5 simulations give the climate response to a set of greenhouse gas, aerosol and land-use scenarios that are consistent with socio-economic assumptions of how the future may evolve. These scenarios are known as the Representative Concentration Pathways (RCPs) (Moss *et al*., 2010; van Vuuren *et al.*, 2011). Box 4.1 presents a brief introduction to the RCPs.

In its *Fifth Assessment Report* (IPCC, 2013), the IPCC concluded that global mean surface air temperatures for 2081–2100 relative to 1986–2005 are likely to be in the following ranges: 0.3 to 1.7 °C warmer for RCP2.6 (representing low emissions); 1.1 to 2.6 °C and 1.4 to 3.1 °C warmer for RCP4.5 and RCP6.0 respectively (representing intermediate emissions); and 2.6 to 4.8 °C warmer for RCP8.5 (representing high emissions).

The projections for the climate of Central Slopes cluster consider model ranges of change, as simulated by the CMIP5 ensemble. However, the projections should be viewed in the context of the confidence ratings that are provided, which consider a broader range of evidence than just the model outputs. The projected change is assessed for two 20-year periods: a near future 2020–2039 (herein referred to as 2030) and a period late in the 21st century, 2080–2099 (herein referred to as 2090) following RCPs 2.6, 4.5 and 8.5 (Box 4.1).

The spread of model results is presented in graphical form (Box 4.2) and provided as tabulated percentiles in Table 1 (10th, 50th and 90th) in the Appendix. CMIP5 results for additional time periods between 2030 and 2090 are provided through the Climate Change in Australia website (Box 1).

Unless otherwise stated, users of these projections should consider the ranges of projected change, as indicated by the different plots and tabulated values, as applicable to each location within the cluster.

BOX 4.1: REPRESENTATIVE CONCENTRATION PATHWAYS (RCPs)

The climate projections presented in this report are based on climate model simulations following a set of greenhouse gas, aerosol and land-use scenarios that are consistent with socio-economic assumptions of how the future may evolve. The well mixed concentrations of greenhouse gases and aerosols in the atmosphere are affected by emissions as well as absorption through land and ocean sinks.

There are four Representative Concentration Pathways (RCPs) underpinned by different emissions. They represent a plausible range of radiative forcing (in W/m^2) during the 21st century relative to pre-industrial levels. Radiative forcing is a measure of the energy absorbed and retained in the lower atmosphere. The RCPs are:

- RCP8.5: high radiative forcing (high emissions)
- RCP4.5 and 6.0: intermediate radiative forcing (intermediate emissions)
- RCP2.6: low radiative forcing (low emissions).

RCP8.5, represents a future with little curbing of emissions, with carbon dioxide concentrations reaching 940 ppm by 2100. The higher of the two intermediate concentration pathways (RCP6.0) assumes implementation of some mitigation strategies, with carbon dioxide reaching 670 ppm by 2100. RCP4.5 describes somewhat higher emissions than RCP6.0 in the early part of the century, with emissions peaking earlier then declining, and stabilisation of the carbon dioxide concentration at about 540 ppm by 2100. RCP2.6 describes emissions that peak around 2020 and then rapidly decline, with the carbon dioxide concentration at about 420 ppm by 2100. It is likely that later in the century active removal of carbon dioxide from the atmosphere would be required for this scenario to be achieved. For further details on all RCPs refer to Section 3.2 and Figure 3.2.2 in the Technical Report.

The previous generation of climate model experiments that underpins the science of the IPCC's *Fourth Assessment Report* used a different set of scenarios. These are described in the IPCC's Special Report on Emissions Scenarios (SRES) (Nakićenović and Swart, 2000). The RCPs and SRES scenarios do not correspond directly to each other, though carbon dioxide concentrations under RCP4.5 and RCP8.5 are similar to those of SRES scenarios B1 and A1FI respectively.

In the Technical and Cluster Reports, RCP6.0 is not included due to a smaller sample of model simulations available compared to the other RCPs. Remaining RCPs are included in most graphical and tabulated material of the Cluster Reports, with the text focusing foremost on results following RCP4.5 and RCP8.5.

4.1 RANGES OF PROJECTED CLIMATE CHANGE AND CONFIDENCE IN PROJECTIONS

Quantitative projections of future climate change in the Central Slopes are presented as ranges. This allows for differences in how future climate may evolve due to three factors – greenhouse gas and aerosol emissions, the climate response and natural variability – that are not known precisely:

- Future emissions cannot be known precisely and are dealt with here by examining several different RCPs described in Box 4.1. There is no 'correct' scenario, so the choice of how many and which scenarios to examine is dependent on the decision-making context.
- The response of the climate system to emissions is well known in some respects, but less well known in others. The thermodynamic response (direct warming) of the atmosphere to greenhouse gases is well understood, although the global climate sensitivity varies. However, changes to atmospheric circulation in a warmer climate are one of the biggest uncertainties regarding the climate response. The range between different climate models (and downscaled models) gives some indication of the possible responses. However, the range of model results is not a systematic or quantitative assessment of the full range of possibilities, and models have some known regional biases that affect confidence.
- Natural variability (or natural 'internal variability' within the climate system) can dominate over the 'forced' climate change in some instances, particularly over shorter time frames and smaller geographic areas. The precise evolution of climate due to natural variability (*e.g.* the sequence of wet years and dry years) cannot be predicted (IPCC, 2013, see Chapter 11). However, the projections presented here allow for a range of outcomes due to natural variability, based on the different evolutions of natural climatic variability contained within each of the climate model simulations.

The relative importance of each of these factors differs for each variable, different timeframes and spatial scale. For some variables with large natural variability, such as rainfall, the predominant reason for differing projections in the early period is likely to be natural variability rather than differences in emission scenarios (the influence of which becomes relatively more important as greenhouse gas concentrations increase). In addition, unpredictable events, such as large volcanic eruptions, and processes not included in models, could influence climate over the century. See IPCC's *Fifth Assessment Report* (IPCC, 2013) Chapter 11 for further discussion of these issues.

The projections presented are accompanied by a confidence rating that follows the system used by the IPCC in the *Fifth Assessment Report* (Mastrandrea *et al.*, 2010), whereby the confidence in a projected change is assessed based on the type, amount, quality and consistency of evidence (which can be process understanding, theory, model output, or expert judgment) and the extent of agreement amongst the different lines of evidence. Hence, this confidence rating does not equate precisely to probabilistic confidence. The levels of confidence used here are set as *low, medium, high* or *very high*. Note that although confidence may be high in the direction of change, in some cases confidence in magnitude of change may be medium or low (*e.g.* due to some known model deficiency). When confidence is low, only qualitative assessments are given. More information on the method used to assess confidence in the projections is provided in Section 6.4 of the Technical Report.

4.2 TEMPERATURE

Since national records began in 1910, surface air temperatures in the cluster have been increasing, especially since 1960 (Figure 4.2.1, 4.2.2). By 2013, mean temperature has risen by 0.8 °C since 1910 using a linear trend. For the same period, daytime maximum temperatures have risen by 0.4 °C while overnight minimum temperatures have increased by 1.2 °C using a linear trend (Figure 4.2.3).

Daily minimum and maximum temperatures have increased since the mid 20th century, but they have different trends in the early part of the record (Figure 4.2.3). The higher anomalies in daily maximum temperature in the early part of the 20th century are most likely explained by the drier than average conditions in Central Slopes during this period (Figure 4.3.1). The reason for this is that when the surface is dry, less energy is consumed by evaporation. Thus proportionally, more energy is felt as heat. This effect will be strongest during the day.

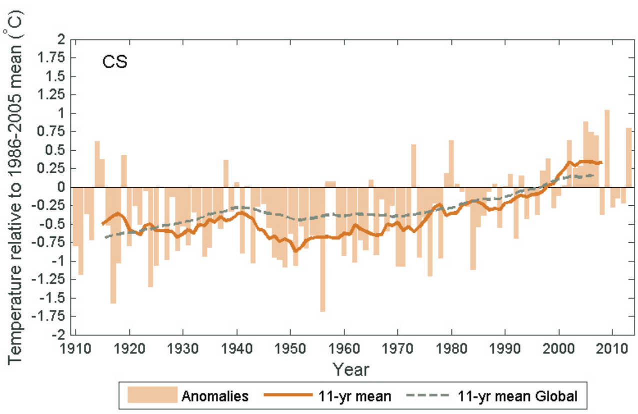


FIGURE 4.2.1: OBSERVED ANNUAL MEAN TEMPERATURE ANOMALIES (°C) FOR 1910–2013 COMPARED TO THE BASELINE 1986–2005 FOR CENTRAL SLOPES. CLUSTER AVERAGE DATA ARE FROM ACORN-SAT AND GLOBAL DATA ARE FROM HADCRUT3V (BROHAN *ET AL.*, 2006).

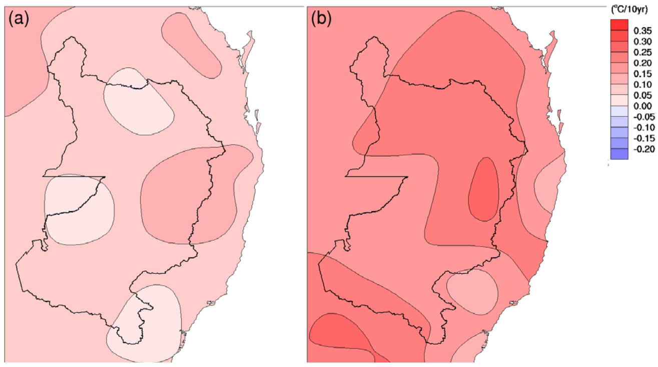


FIGURE 4.2.2: MAPS OF TREND IN MEAN TEMPERATURE (°C/10YEARS) FOR (A) 1910–2013 AND (B) 1960–2013 (ACORN-SAT).

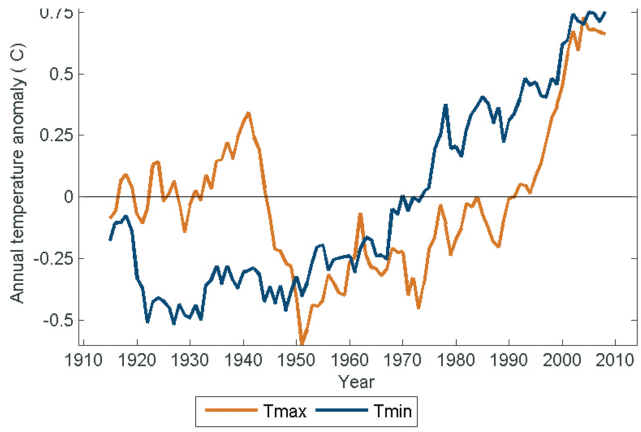
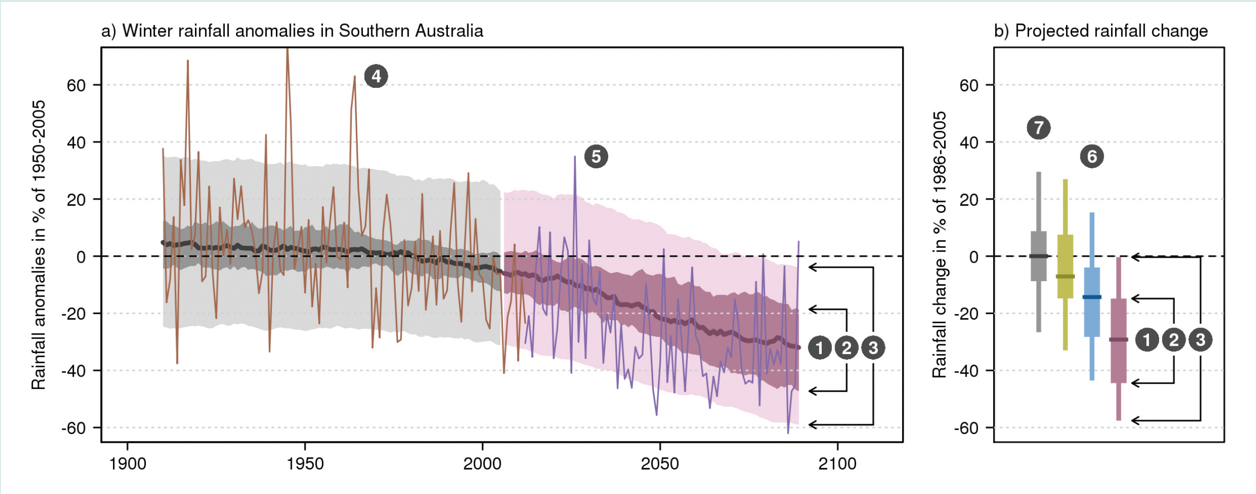


FIGURE 4.2.3: OBSERVED ANNUAL MEAN OF DAILY MAXIMUM (ORANGE LINE) AND MINIMUM (BLUE LINE) TEMPERATURE (°C, 11-YEAR RUNNING MEAN), PRESENTED AS ANOMALIES RELATIVE TO THEIR RESPECTIVE 1910-2013 MEAN VALUE (ACORN-SAT).

BOX 4.2: UNDERSTANDING PROJECTION PLOTS



Projections based on climate model results are illustrated using time series (a) and bar plots (b). The model data are expressed as anomalies from a reference climate. For the time series (a), anomalies are calculated as relative to 1950–2005, and for the bar plots (b) anomalies are calculated as the change between 1986–2005 and 2080–2099 (referred to elsewhere as '2090'). The graphs can be summarised as follows:

1. The middle (bold) line in both (a) and (b) is the median value of the model simulations (20-year moving average); half the model results fall above and half below this line.
2. The bars in (b) and dark shaded areas in (a) show the range (10th to 90th percentile) of model simulations of 20-year average climate.
3. Line segments in (b) and light shaded areas in (a) represent the projected range (10th to 90th percentile) of individual years taking into account year to year variability in addition to the long-term response (20-year moving average).

In the time series (a), where available, an observed time series (4) is overlaid to enable comparison between observed variability and simulated model spread. A time series of the future climate from one model is shown to illustrate what a possible future may look like (5). ACCESS1-0 was used for RCP4.5 and 8.5, and BCC-CSM-1 was used for RCP2.6, as ACCESS1-0 was not available.

In both (a) and (b), different RCPs are shown in different colours (6). Throughout this document, green is used for RCP2.6, blue for RCP4.5 and purple for RCP8.5, with grey bars used in bar plots (b) to illustrate the expected range of change due to natural internal climate variability alone (7).

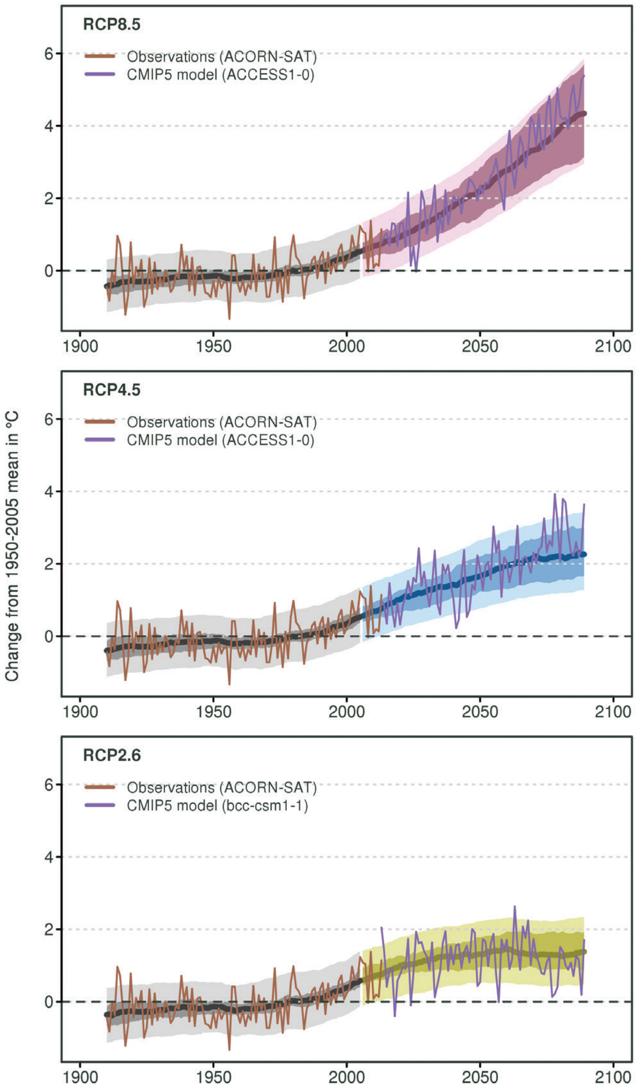


FIGURE 4.2.4: TIME SERIES FOR CENTRAL SLOPES ANNUAL AVERAGE SURFACE AIR TEMPERATURE (°C) FOR 1910–2090, AS SIMULATED IN CMIP5 RELATIVE TO THE 1950–2005 MEAN. THE CENTRAL LINE IS THE MEDIAN VALUE, AND THE SHADING IS THE 10TH AND 90TH PERCENTILE RANGE OF 20-YEAR MEANS (INNER) AND SINGLE YEAR VALUES (OUTER). THE GREY SHADING INDICATES THE PERIOD OF THE HISTORICAL SIMULATION, WHILE THREE FUTURE SCENARIOS ARE SHOWN WITH COLOUR-CODED SHADING: RCP8.5 (PURPLE), RCP4.5 (BLUE) AND RCP2.6 (GREEN). ACORN-SAT OBSERVATIONS AND PROJECTED VALUES FROM A TYPICAL MODEL ARE ALSO SHOWN. TIME SERIES PLOTS ARE EXPLAINED IN BOX 4.2.

Temperatures in the Central Slopes cluster are projected to continue to warm throughout the 21st century, at a rate that strongly follows the increase in global greenhouse gas concentrations (Figure 4.2.4). Tabulated warming for various time slices and RCPs are given in Table 1 in the Appendix.

For 2030, the warming is 0.6 to 1.5 °C (10th to 90th percentile) relative to 1995, with only minor differences between the scenarios. The projected temperature range 2090 shows larger differences with 1.4 to 2.7 °C for RCP4.5, and 3 to 5.4 °C following RCP8.5. Other details that can be deduced from these graphs are:

- Projected warmings are large compared to natural year to year variability in the cluster. For example, cold years become warmer than warm years in the current climate around 2050 under RCP8.5 and warmer than most current warm years under RCP4.5. This is illustrated in Figure 4.2.4 by overlaying the simulated year to year variability in one simulation and comparing this to the historical variability.
- Individual model runs produce temporal variability similar to that of observed temperature, as well as a warming trend (compare example model run with observed time series).
- The model range widens with time (most notable for the 20-year averages, dark shading). This is not due to increase in interannual variability in models. The models warm at different rates, hence the total range widens. As an example, the overlaid model in RCP8.5, simulates warming larger than the ensemble median. Other models simulate warming less than the ensemble median.

Overall the warming rate of the Central Slopes cluster is very much in line with the majority of Australia; with somewhat higher rates being projected for western Australia and somewhat lower overall rates for the south-east and Tasmania (see Figure 7.1.4 in the Technical Report).

Changes to the spatial pattern of temperature in the cluster can be illustrated by applying the projected change in annual mean temperature onto the mapped observed climatology. Figure 4.2.5 gives an example of this for the 2090 period following the high emission scenario RCP8.5 and the median warming from the CMIP5 models. This case, which corresponds to a global warming of 3.7 °C, shows regional temperatures increasing from within the range of about 12 to 22 °C for the current climate up to a range of about 16 to 26 °C for the future climate.

Projected warming is similar across the four seasons in the Central Slopes, and is also broadly similar if daily maximum or minimum temperatures are considered rather than daily mean temperatures (Figure 4.2.6 and Appendix Table 1). However, some models simulate somewhat stronger warming in the daily maximum temperature compared to daily mean temperature in spring, which is likely due to the projected decrease in rainfall in this season.

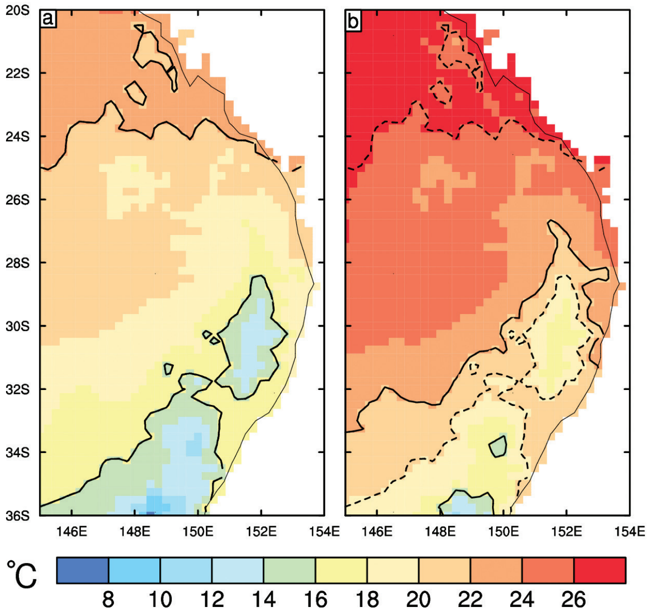


FIGURE 4.2.5: ANNUAL MEAN SURFACE AIR TEMPERATURE (°C), FOR THE PRESENT CLIMATE (A), AND FOR MEDIAN WARMING IN 2090 UNDER RCP8.5 (B). THE PRESENT IS USING AWAP FOR 1986–2005, ON A 0.25 DEGREE GRID. FOR CLARITY, THE 16 AND 22 °C CONTOURS ARE SHOWN WITH SOLID BLACK LINES. IN (B) THE SAME CONTOURS FROM THE ORIGINAL CLIMATE ARE PLOTTED AS DOTTED LINES.

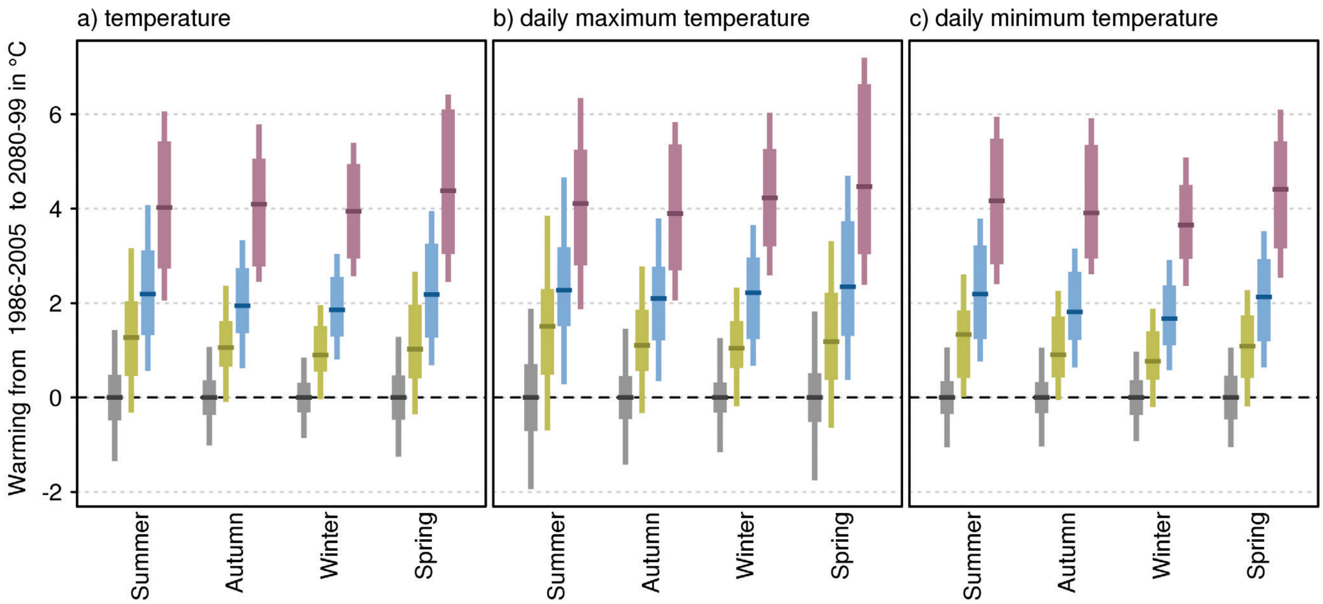


FIGURE 4.2.6: PROJECTED SEASONAL SURFACE AIR TEMPERATURE CHANGES FOR 2090. GRAPHS SHOW CHANGES TO THE (A) MEAN, (B) DAILY MAXIMUM AND (C) DAILY MINIMUM TEMPERATURE. TEMPERATURE ANOMALIES ARE GIVEN IN °C WITH RESPECT TO 1986– 2005 UNDER RCP2.6 (GREEN), RCP4.5 (BLUE) AND RCP8.5 (PURPLE). NATURAL CLIMATE VARIABILITY IS REPRESENTED BY THE GREY BAR. BAR PLOTS ARE EXPLAINED IN BOX 4.2.

For the Central Slopes cluster, projections based on downscaled data generally do not lead to projected warming ranges that differ much from those simulated by the CMIP5 GCM ensemble. An exception is the reduced warming in spring and summer when using the statistical downscaling method (SDM). The close resemblance between the ranges of downscaled and GCM output are illustrated in Figure 4.2.7.

Taking into consideration the strong agreement on the direction and magnitude of change among GCMs and downscaling results, and the robust understanding of the driving mechanisms of warming and its seasonal variation, there is *very high confidence* in substantial warming for the Central Slopes cluster for the annual and seasonal projections for daily mean, maximum and minimum surface air temperature.

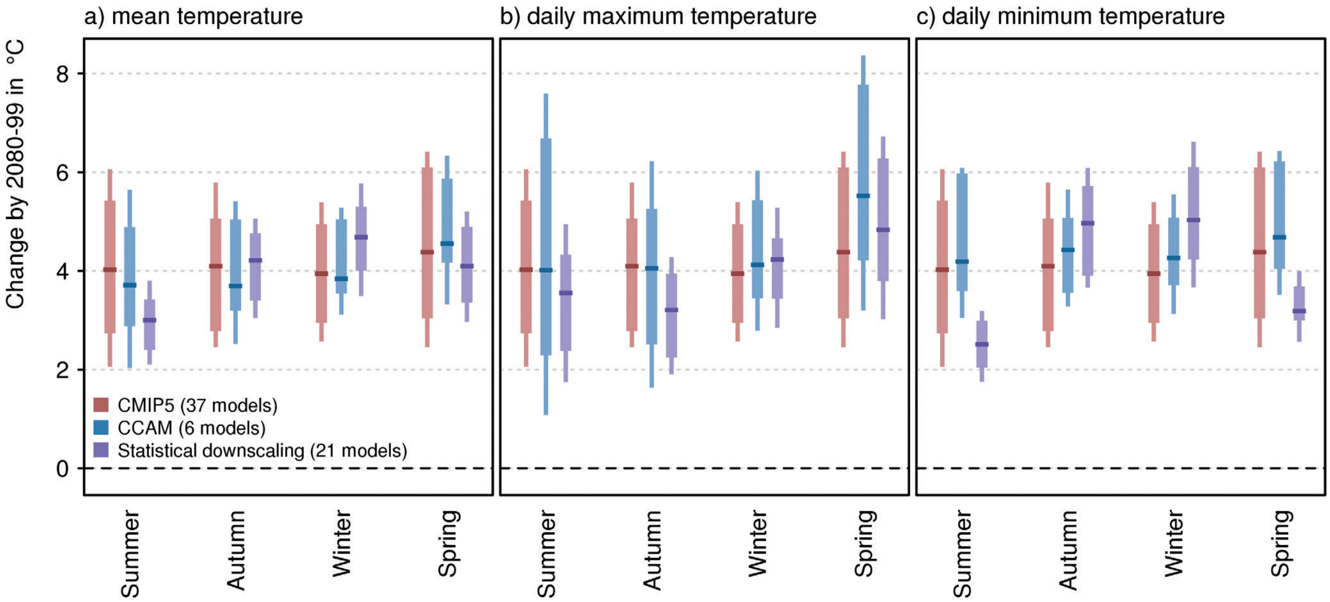


FIGURE 4.2.7: PROJECTED CHANGE IN CENTRAL SLOPES SEASONAL SURFACE AIR TEMPERATURE FOR 2090 USING CMIP5 GCMS AND TWO DOWNSCALING METHODS (CCAM AND SDM). UNDER RCP8.5 FOR THE (A) MEAN, (B) DAILY MAXIMUM AND (C) DAILY MINIMUM. TEMPERATURE ANOMALIES ARE GIVEN IN °C WITH RESPECT TO THE 1986– 2005 MEAN. BAR PLOTS ARE EXPLAINED IN BOX 4.2.

4.2.1 EXTREMES

Changes to temperature extremes often lead to greater impacts than changes to the mean climate. To assess these, researchers examine GCM projected changes to measures such as the warmest day in the year, warm spell duration and frost risk days (see definitions below).

Heat related extremes are projected to increase at the same rate as projected mean temperature with a substantial increase in the number of warm spell days. Figure 4.2.8 (2090 case only) gives the CMIP5 model simulated warming on the hottest day of the year averaged across the cluster, and the corresponding warming for the hottest day in 20 years (20-year return value, equal to a 5 % chance of occurrence within any one year). The rate of warming for these hot days is similar to that for all days (*i.e.* the mean warming in the previous section). The GCM projections also indicate a marked increase in a warm spell index, which is defined as the annual count of days for events with at least six consecutive days where the daily temperature maximum averaged for the cluster is above the 90th percentile. As an example, the 90th percentile for daily temperature maximum in Dubbo is 34 °C based on historical records for January 1921 to June 2014.

Given the similarity in projected warming for the daily mean and the daily maximum temperature, an indication of the change in frequency of hot days locally can be obtained by applying the projected changes for maxima for selected time slices and RCPs to the historical daily record at selected sites. This is illustrated in Box 4.3 for Dubbo and St George, where the number of days above 35 °C by late in the century (2090) for Dubbo nearly doubles under the RCP4.5 and median model warming, and the corresponding number of days over 40 °C triples. Under RCP8.5, days over 35 °C triple and days over 40 °C show a sixfold increase. Changes for St George are somewhat lower, particularly under RCP8.5.

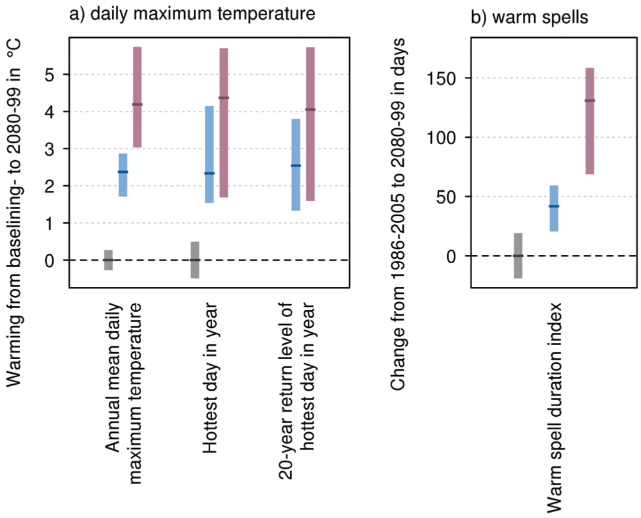


FIGURE 4.2.8: PROJECTED CHANGES IN SURFACE AIR TEMPERATURE EXTREMES BY 2090 IN (A) MEAN DAILY MAXIMUM TEMPERATURE, HOTTEST DAY OF THE YEAR AND THE 20-YEAR RETURN VALUE OF THE HOTTEST DAY OF THE YEAR (°C); AND (B) CHANGE IN THE NUMBER OF DAYS IN WARM SPELLS FOR CENTRAL SLOPES (SEE TEXT FOR DEFINITION OF VARIABLES). RESULTS ARE SHOWN FOR EMISSION SCENARIOS RCP4.5 (BLUE) AND RCP8.5 (PURPLE) RELATIVE TO THE 1986–2005 MEAN. NATURAL CLIMATE VARIABILITY IS REPRESENTED BY THE GREY BAR. BAR PLOTS ARE EXPLAINED IN BOX 4.2.

BOX 4.3: HOW WILL THE FREQUENCY OF HOT DAYS AND FROST RISK DAYS CHANGE IN DUBBO AND ST GEORGE?

To illustrate what the CMIP5 projected warming implies for changes to the occurrence of hot days and frost days in Dubbo and St George, a simple downscaling example was conducted.

The type of downscaling used here is commonly referred to as 'change factor approach' (see Section 6.3.1 in the Technical Report), whereby a change (calculated from the simulated model change) is applied to an observed time series. In doing so, it is possible to estimate the frequency of extreme days under different emission scenarios.

In Table B4.3, days with maximum temperature above 35 and 40 °C, and frost risk days (minimum temperature less than 2 °C) are provided for a number of locations for a 30-year period (1981-2010), and for downscaled data using seasonal change factors for maximum or minimum temperature for 2030 and 2090 under different RCPs.

TABLE B4.3: CURRENT AVERAGE ANNUAL NUMBER OF DAYS (FOR THE 30-YEAR PERIOD 1981–2010) ABOVE 35 AND 40 °C AND BELOW 2 °C (FROSTS) FOR DUBBO AIRPORT (NSW) AND ST GEORGE AIRPORT (QLD) BASED ON ACORN-SAT. ESTIMATES FOR THE FUTURE ARE CALCULATED USING THE MEDIAN CMIP5 WARMING FOR 2030 AND 2090, AND WITHIN BRACKETS THE 10TH AND 90TH PERCENTILE CMIP5 WARMING FOR THESE PERIODS, APPLIED TO THE 30-YEAR ACORN-SAT STATION SERIES. NUMBERS ARE TAKEN FROM TABLE 7.1.2 AND TABLE 7.1.3 IN THE TECHNICAL REPORT.

THRESHOLD	DUBBO				ST GEORGE			
	CURRENT	2030 RCP4.5	2090 RCP4.5	2090 RCP8.5	CURRENT	2030 RCP4.5	2090 RCP4.5	2090 RCP8.5
Over 35 °C	22	31 (26 to 37)	44 (36 to 54)	65 (49 to 85)	40	54 (48 to 62)	70 (59 to 87)	101 (79 to 127)
Over 40 °C	2.5	3.9 (3.2 to 5.6)	7.8 (5.1 to 12)	17 (9.9 to 26)	5.1	8.2 (6.3 to 11)	15 (11 to 23)	31 (20 to 49)
Below 2 °C	39	30 (34 to 27)	21 (26 to 13)	6.0 (10 to 2.4)	17	12 (15 to 11)	8.3 (11 to 5.5)	1.5 (3.5 to 0.5)

The coldest night of the year is expected to warm by about one degree for the near future under all scenarios. Higher warming is simulated for late in the 21st century. The model median is about 2 °C under RCP4.5 and around 4.5 °C following RCP8.5. Changes in the frequency of surface frost (defined here as days with minimum temperature less than 2 °C) are important to the environment as well as to sectors such as agriculture and energy. Assessing frost occurrence directly from global model output is not reliable, in part because of varying biases in land surface temperatures. However, it is possible to evaluate what CMIP5 models say about changes to frost occurrences by superimposing the projected change in temperature on to the minimum daily temperature record. Statistical downscaling may also be used, with similar results (see Technical Report section 7.1). A seasonal assessment of frost is conducted for the Murray Basin cluster (see Murray Basin Cluster Report) using statistically downscaled temperatures, which indicates that spring frosts decline less rapidly than autumn frosts. This seasonal discrepancy in change together with advancement of plant phenology due to a warmer climate, suggests that risks associated with late frost occurrences may not decline as much as otherwise may be expected.

Box 4.3 illustrates the change in frost days using the simple change factor approach for Dubbo and St George, as was done for hot days – noting that actual occurrence of frost will depend on many local factors not represented by this method. Results show that for the near future (2030) under RCP4.5 there is only a minor reduction in frost days (from 39 days to an ensemble model median of 30 days for Dubbo, and a reduction from 17 days to an ensemble model median of 12 days for St George. For late in the 21st century, however, substantial reductions occur in frost days under RCP4.5 and 8.5. Models simulate a reduction from 40 to 21 days under RCP4.5, and from 40 to 6 days under RCP8.5 for Dubbo. St George has a reduction from 17 days to 8.3 days following RCP4.5 and 1.5 days under RCP8.5.

Strong model agreement and understanding of physical mechanisms of warming lead to *very high confidence* in a substantial increase in temperature of the hottest days, the frequency of hot days and the duration of warm spells; and to *high confidence* in a substantial decrease in the frequency of frost.

-20° -10° 0° 10° 20° 30° 40° 50°

4.3 RAINFALL

Rainfall in the cluster has not shown any long-term trend over the 20th century, but has demonstrated intermittent periods of wetter and drier conditions (Figure 4.3.1). During much of the early part of the century, the cluster experienced extensive drying, including the Australia-wide Federation drought, and the World War II drought in the 1930s and 1940s (Figure 4.3.1). The latter part of the 20th century has seen more variable conditions with individual years of very high rainfall, and sequences of years with below average rainfall; notably in the early 1990s and 2000s.

The influence of the sub-tropical ridge on rainfall in south-east Australia, including the southernmost part of this cluster, has been described in some detail by Timbal and Drosdowsky (2013). The authors showed that the 1997 to 2009 decrease in autumn–spring rainfall could be linked to a weakening of the westerly flow south of Australia, which is in agreement with a strengthening of its northern-lying high pressure areas, such as the sub-tropical ridge (STR). The main mechanism for the 1997–2009 drought in south-east Australia, appears to be the intensification of the STR rather than a shift in its location (Timbal and Drosdowsky, 2013). It is also noteworthy that whilst dry conditions characterised much of the cluster around the turn of the century, recent years have seen extreme flooding in summer as a consequence of extraordinary La Niña conditions, possibly in combination with a return to cold phase Interdecadal Pacific Oscillation (IPO) conditions (Cai and van Rensch, 2012).

For all RCPs, simulated annual rainfall changes are small compared to natural variability for the near future (2030), with 20-year mean changes of about +/- 10 % annually, but changes become evident in some models (about +/- 20 % annually) under RCP8.5 by 2090 (Figure 4.3.2, Appendix Table 1).

Changes to the spatial distribution of rainfall in the cluster can be illustrated by applying the CMIP5 projected change in annual mean rainfall onto the observed climatology. Figure 4.3.3 gives an example of this for late in the century (2090) under RCP8.5 and the simulated rainfall change from the CMIP5 models. The figure displays the dry (10th percentile) and wet (90th percentile) case of the simulated model range relative to the observed climatology. For the dry case, characteristic rainfall rates decrease from about 1 to 2.5 mm/day to 0.7 to 2 mm/day, whilst for the wet case, rates increase to about 1.5 to 3 mm/day.

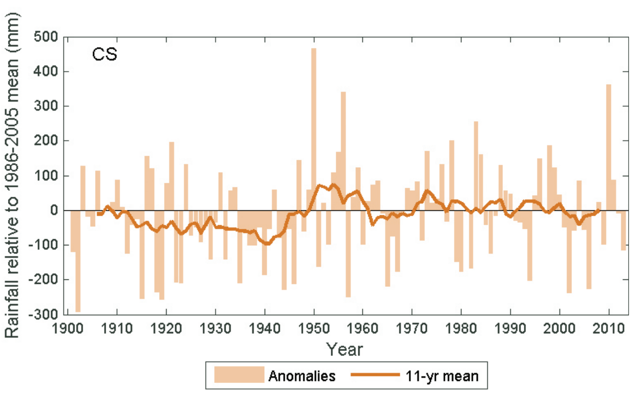


FIGURE 4.3.1: OBSERVED ANNUAL RAINFALL ANOMALIES (MM) FOR 1901-2013, COMPARED TO THE BASELINE1986–2005 FOR CENTRAL SLOPES (AWAP).

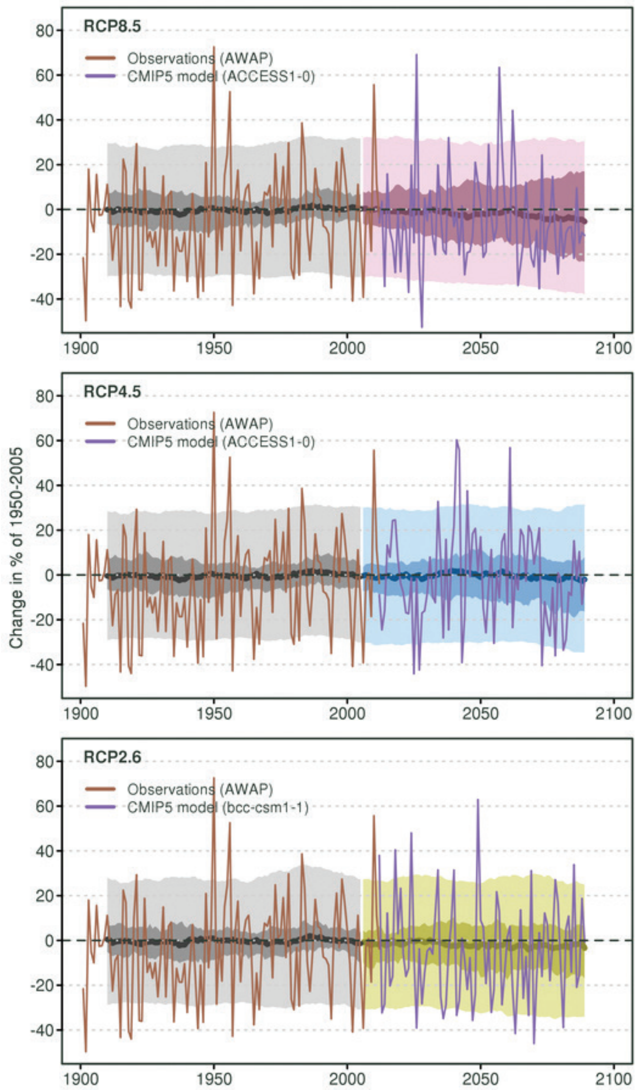


FIGURE 4.3.2: TIME SERIES FOR CENTRAL SLOPES ANNUAL RAINFALL FOR 1910–2090, AS SIMULATED IN CMIP5 EXPRESSED AS A PERCENTAGE RELATIVE TO THE 1950–2005 MEAN. THE CENTRAL LINE IS THE MEDIAN VALUE, AND THE SHADING IS THE 10TH AND 90TH PERCENTILE RANGE OF 20-YEAR MEANS (INNER) AND SINGLE YEAR VALUES (OUTER). THE GREY SHADING INDICATES THE PERIOD OF THE HISTORICAL SIMULATION, WHILE THREE FUTURE SCENARIOS ARE SHOWN WITH COLOUR-CODED SHADING: RCP8.5 (PURPLE), RCP4.5 (BLUE) AND RCP2.6 (GREEN). AWAP OBSERVATIONS (BEGINNING 1901) AND PROJECTED VALUES FROM A TYPICAL MODEL ARE SHOWN. TIME SERIES PLOTS ARE EXPLAINED IN BOX 4.2.

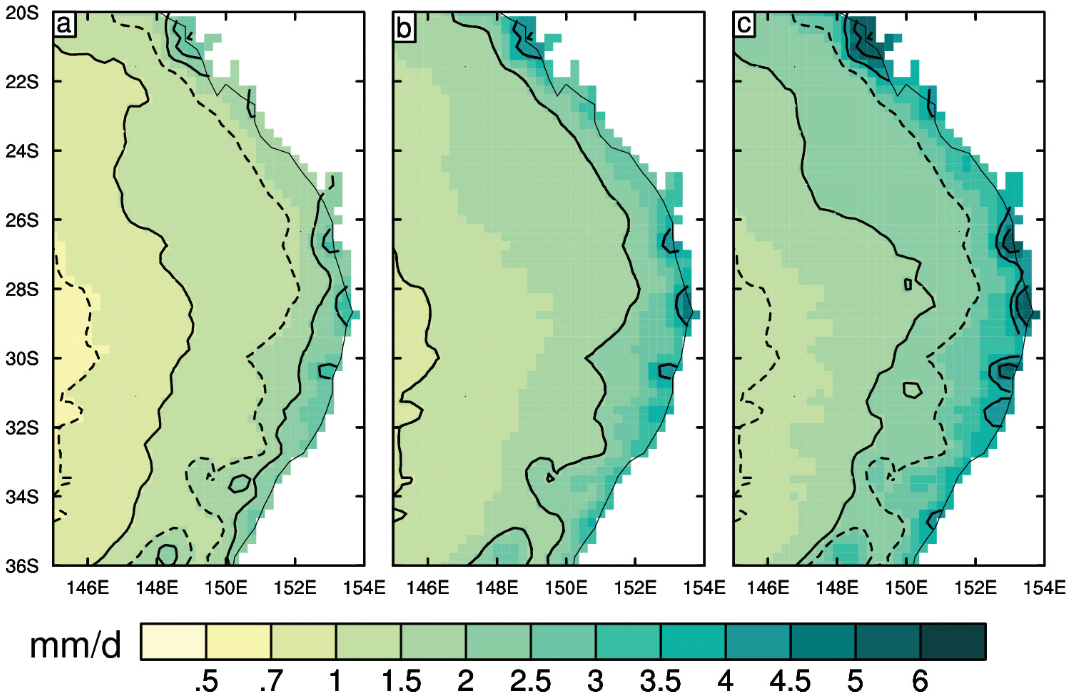


FIGURE 4.3.3: ANNUAL MEAN RAINFALL (MM/DAY), FOR THE PRESENT CLIMATE (B), AND THE DRIER END OF THE PROJECTED MODEL RANGE (A) OR WETTER END OF THE PROJECTED RANGE (C). THE PRESENT IS USING THE AWAP DATA SET FOR 1986–2005 (BASED ON A 0.25 DEGREE LATITUDE-LONGITUDE GRID). THE DRIER AND WETTER CASES USE THE 10TH AND 90TH PERCENTILES CHANGES AT 2090 FOR RCP8.5. FOR CLARITY, THE 1, 2 AND 4 MM/DAY CONTOURS ARE PLOTTED WITH SOLID BLACK LINES. IN (A) AND (C) THE SAME CONTOURS FROM THE ORIGINAL CLIMATE (B) ARE PLOTTED AS DOTTED LINES.

Decreases in winter rainfall are projected to become evident later in the century, with *high confidence*. There is strong model agreement and good understanding of the contributing underlying physical mechanisms driving this change (relating to the southward shift of winter storm systems). The magnitude of possible differences from the winter climate of 1986–2005 indicated by GCM results range from around -25 to +10 % under RCP4.5 and -40 to +15 % under RCP8.5 for 2090 (Appendix Table 1). Decreases are also projected for spring, but with *medium confidence* only.

In summer and autumn most (but not all) models show changes that would not be clearly evident against natural variability, even under RCP8.5 at 2090 (Figure 4.3.4 and Appendix Table 1). The magnitude of possible seasonal (summer and autumn) changes indicated by GCM results range from around -30 to +25 % under RCP4.5 and -35 to +30 % under RCP8.5 at 2090. These contrasting model simulations highlight the potential need to consider the risk of both a drier and wetter climate in impact assessment in this cluster. However, by late in the century (2090) there is general agreement amongst models on decrease in winter and spring rainfall under RCP8.5; the model ensemble median being -17 % and -14 % respectively (Appendix Table 1).

The changes from downscaled rainfall projections for the Central Slopes cluster (Figure 4.3.5) are broadly similar to those of the GCMs, although the dynamical method (CCAM based on six models only) shows a notable difference in winter. During this season, the GCM and SDM outputs mainly indicate decreasing rainfall (negative ensemble medians) while the CCAM ensemble median indicates that increases or decreases are equally plausible in the cluster.

Decreases in winter and spring may be partly explained by projected reductions in the number of winter storm systems entering the region due to a simulated southward shift in winter storm tracks (Grose *et al.*, 2012, Dowdy *et al.*, 2013a). As described in the Technical Report, confidence in spring changes for the broader Eastern Australia region is low. This is due to the greater complexity of rainfall-bearing mechanisms in spring relative to winter, as reflected in the mixed messages amongst GCMs and downscaling techniques. For Central Slopes, however, the messages from GCMs and downscaling techniques are largely in agreement, hence there is *medium confidence* in a spring rainfall decline for Central Slopes.

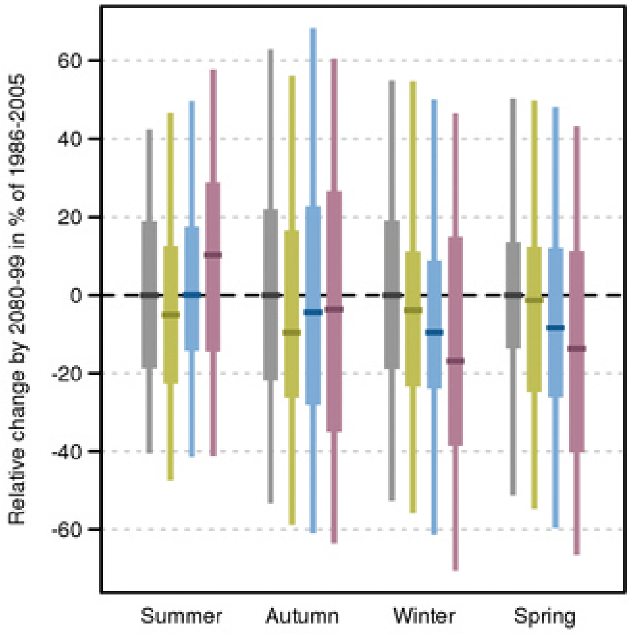


FIGURE 4.3.4: PROJECTED SEASONAL RAINFALL CHANGES FOR CENTRAL SLOPES FOR 2090. RAINFALL ANOMALIES ARE GIVEN IN PER CENT WITH RESPECT TO THE 1986–2005 MEAN FOR RCP2.6 (GREEN), RCP4.5 (BLUE) AND RCP8.5 (PURPLE) SCENARIOS. NATURAL CLIMATE VARIABILITY IS REPRESENTED BY THE GREY BAR. BAR PLOTS ARE EXPLAINED IN BOX 4.2.

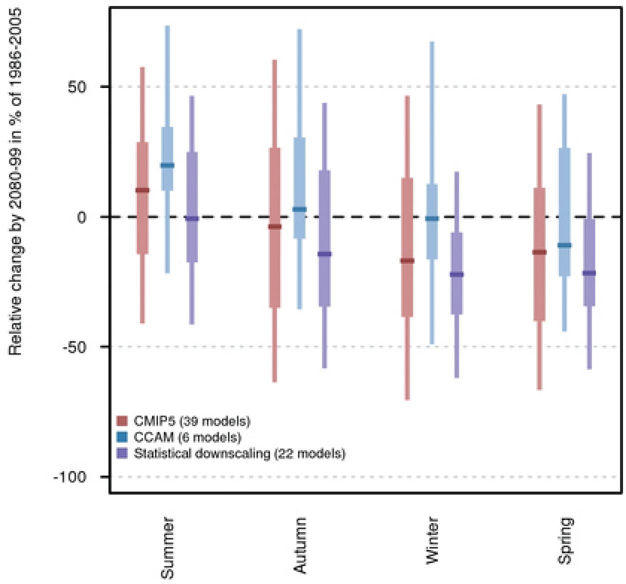


FIGURE 4.3.5: PROJECTED CHANGE IN CENTRAL SLOPES SEASONAL RAINFALL FOR 2090 USING CMIP5 GCMS AND TWO DOWNSCALING METHODS (CCAM AND SDM) UNDER RCP8.5. RAINFALL ANOMALIES ARE GIVEN IN PER CENT WITH RESPECT TO 1986–2005. BAR PLOTS ARE EXPLAINED IN BOX 4.2.

In summary, we have *high confidence* that natural climate variability will remain the major driver of rainfall changes by 2030 in this cluster (20-year mean changes of about +/- 10 % annually, and about +/-25 % seasonally relative to the climate of 1986–2005). Decreases in winter rainfall are projected to become evident for later in the 21st century with *high confidence*. There is strong model agreement and good understanding of contributing underlying physical mechanisms driving this change (relating to the southward shift of winter storm systems). Decreases are indicated for spring rainfall with *medium confidence*, with medium model agreement on substantial change. Changes to rainfall in other seasons, and annually, for later in the century are possible, but the direction of change cannot be reliably projected, due to the complexity of rain producing systems in this region, the large spread of model results, and the inconsistent results from downscaled models.

4.3.1 HEAVY RAINFALL EVENTS

In a warming climate, heavy rainfall events are expected to increase in magnitude mainly due to a warmer atmosphere being able to hold more moisture (Sherwood *et al.*, 2010). Studies of rainfall extremes typically make use of extreme indices to define the frequency of events (occurrence over a certain percentile), intensity of events (amount within a period) and contribution by extremes (proportion of extreme rainfall relative to the total rainfall); specifics such as values of thresholds may differ between individual studies.

Historical trends in extreme rainfall for Central Slopes can be gleaned from Australia wide studies of trends in extreme rainfall indices. For example, Gallant *et al.,* (2007) note a decrease in the spring extreme proportion indices and an increase in winter extreme proportions for the period 1910–2005 for the Western Tablelands region, which includes the southern part of Central Slopes. For a more recent period, authors note a significant increase in the autumn, winter and annual extreme proportion indices, and a decrease in the annual extreme frequency. For a similar time period (1907–2009), but based on only a couple of locations, King *et al.,* (2013) show significant increase in annual extreme frequency and annual extreme intensity, but a decrease in the annual extreme contribution, throughout the 20th century. A similar analysis was performed by the authors on a seasonal basis, showing a significant summer increase in extreme frequency in the observed AWAP dataset.

Projections show an increase in the annual maximum 1-day value and the 20-year return value (equivalent to a 5 % chance of occurrence within any one year) for the period 2080 to 2099 relative to the baseline period 1986 to 2005 (Figure 4.3.6 for RCP8.5). Indeed, while the projections for mean rainfall are tending towards a decrease in the cluster, the extremes are projected to increase (and more so for the rare extremes). This pattern (change in mean relative to extremes) is found in all other clusters, and is also supported by results from other studies (see Technical Report Section 7.2.2).

The magnitudes of the simulated changes in extreme rainfall indices are strongly dependent on the emission scenario and time into the future. Furthermore, the magnitude of the change simulated by GCMs is less certain because many of the smaller scale systems that generate extreme rainfall are not well resolved by GCMs (Fowler and Ekstroem, 2009). In summary, there is *high confidence* that the intensity of heavy rainfall events will increase in the cluster, but there is *low confidence* in the magnitude of change, and thus the time when any change may be evident against natural fluctuations, cannot be reliably projected.

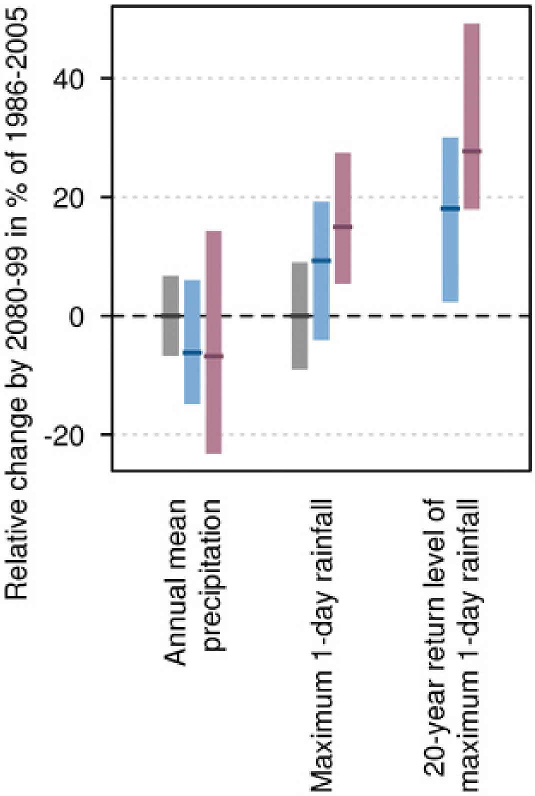


FIGURE 4.3.6: PROJECTED CHANGES IN CENTRAL SLOPES MEAN RAINFALL, MAGNITUDE OF ANNUAL MAXIMUM 1-DAY RAINFALL AND MAGNITUDE OF THE 20-YEAR RETURN VALUE FOR THE 1-DAY RAINFALL FOR 2090 (SEE TEXT FOR DEFINITION OF VARIABLES). CHANGES ARE GIVEN IN PERCENTAGE WITH RESPECT TO THE 1986 –2005 MEAN FOR RCP4.5 (BLUE) AND RCP8.5 (PURPLE). NATURAL CLIMATE VARIABILITY IS REPRESENTED BY THE GREY BAR. BAR PLOTS ARE EXPLAINED IN BOX 4.2.

4.3.2 DROUGHT

Historically, the Central Slopes cluster was affected by the Federation drought and the World War II drought in the early part of the 20th century (Figure 4.3.1). However, the Millennium drought was not as pronounced in the Central Slopes cluster as it was in clusters further south and east. These clusters display positive trends for both drought events and duration, but negative trends in intensity for the 1960 to 2009 period (Gallant *et al.*, 2007).

To assess the implications of projected climate change for drought occurrence, the Standardised Precipitation Index (SPI) was selected as a measure of meteorological drought. Duration of time spent in drought and changes to the duration and frequency of droughts were calculated for different levels of severity (mild, moderate, severe and extreme). Section 7.2.3 in the Technical Report presents details on the calculation of the SPI, and further information on drought.

Projected changes to meteorological drought share much of the uncertainty of mean rainfall change, and there is no clear indication on changes to drought conditions in the cluster (Figure 4.3.7). Under RCP8.5, there is an increase in the proportion of time spent in drought through the century. However the picture is less clear for RCP4.5. The 90th percentiles of the model range under RCP8.5 suggest that extreme droughts could become more frequent in some models and the duration could increase, but other models (see 10th percentile) show change in the opposite direction. Any increase in drought duration is likely to be related to the reduction in winter mean rainfall.

Meteorological drought will continue to be a regular feature of regional climate. It may change its characteristics as the climate warms, but there is *low confidence* in projecting how the frequency and duration of extreme drought may change, although there is *medium confidence* that the time spent in drought will increase over the course of the century under RCP8.5. Given the importance of the ENSO for rainfall in the Central Slopes cluster and some indication that these events will intensify under global warming, there is potential for an intensification of El Niño driven drying in this cluster (Power *et al.*, 2013).

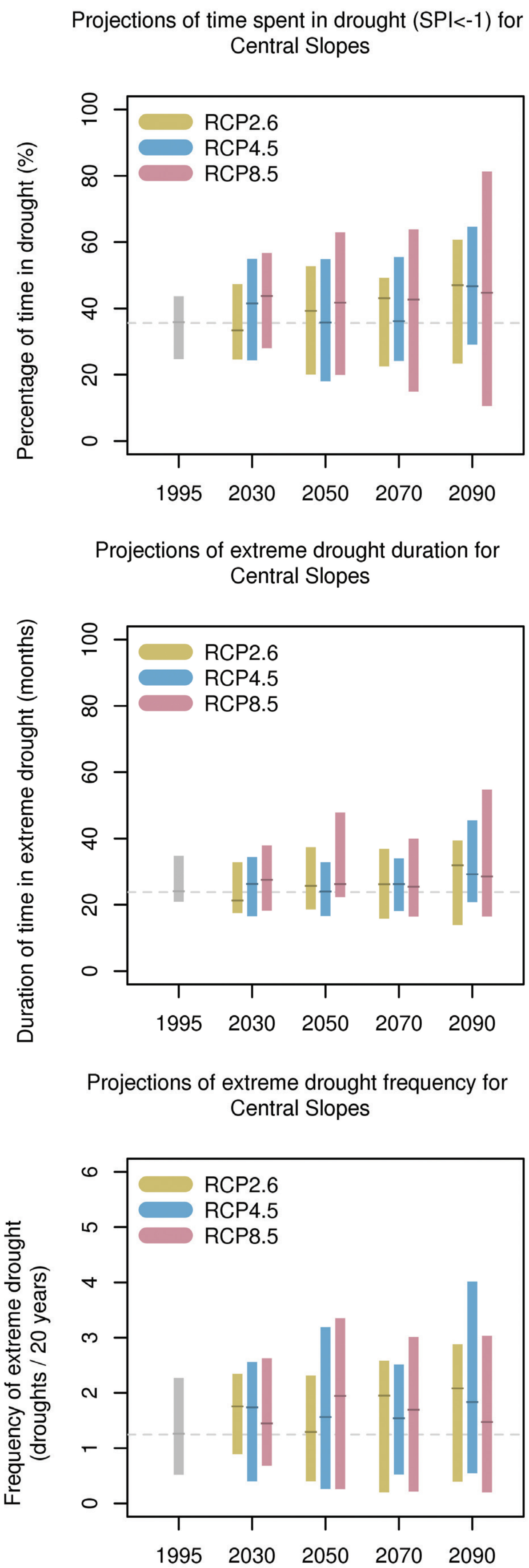


FIGURE 4.3.7: SIMULATED CHANGES IN DROUGHT BASED ON THE STANDARDISED PRECIPITATION INDEX (SPI). THE MULTI-MODEL ENSEMBLE RESULTS FOR CENTRAL SLOPES SHOW THE PERCENTAGE OF TIME IN DROUGHT (SPI LESS THAN -1) (TOP), DURATION OF EXTREME DROUGHT (MIDDLE) AND FREQUENCY OF EXTREME DROUGHT (BOTTOM) FOR EACH 20-YEAR PERIOD CENTRED ON 1995, 2030, 2050, 2070 AND 2090 UNDER RCP2.6 (GREEN), RCP4.5 (BLUE) AND RCP8.5 (PURPLE). NATURAL CLIMATE VARIABILITY IS REPRESENTED BY THE GREY BAR. SEE TECHNICAL REPORT CHAPTER 7.2.3 FOR DEFINITION OF DROUGHT INDICES. BAR PLOTS ARE EXPLAINED IN BOX 4.2.

4.4 WINDS, STORMS AND WEATHER SYSTEMS

4.4.1 MEAN WINDS

The surface wind climate is driven by the large-scale circulation pattern of the atmosphere: when pressure gradients are strong, winds are strong. For Central Slopes, summer surface winds are largely dominated by easterly to north-easterly winds associated with the south-east trade winds. In winter, the surface wind climate is strongly influenced by the more northerly position of the subtropical high with consequential weak wind patterns of predominately south to south-easterly origin. Any trends in observed winds are difficult to establish due to sparse coverage of wind observations and difficulties with instruments and the changing circumstances of anemometer sites (Jakob, 2010). McVicar *et al.*, (2012) and Troccoli *et al.*, (2012) have reported weak and conflicting trends across Australia (although they considered winds at different levels).

Projected changes to seasonal surface winds for Central Slopes are overall small (less than 5 % seasonally) for the near future period (2030) under both RCP4.5 and 8.5 (Appendix Table 1). For late in the century (2090), changes are still small under RCP4.5 with medium to high agreement amongst models on little change. For RCP8.5 there is high agreement amongst models on increase in spring (about -2 to 10 %) and while there is medium agreement on little change in winter, some models suggest potential for substantial decrease (Figure 4.4.1). Possible winter reductions in wind speed are likely related to the southward movement of the storm track, which leads to a weakening of westerly winds in the Central Slopes cluster. The increases during spring are more difficult to understand, as this is a season during which large-scale circulation moves from more established patterns during summer and winter.

Taking this into account, we have *high confidence* in little change for the near future (2030) in all seasons. For late in the century, there is *medium confidence* in some decrease during the winter supported by model agreement and our understanding of the physical mechanisms. While the model agreement is high for increase in spring, the unclear mechanisms for increase in wind speed indicate a *low confidence* in increase during this season.

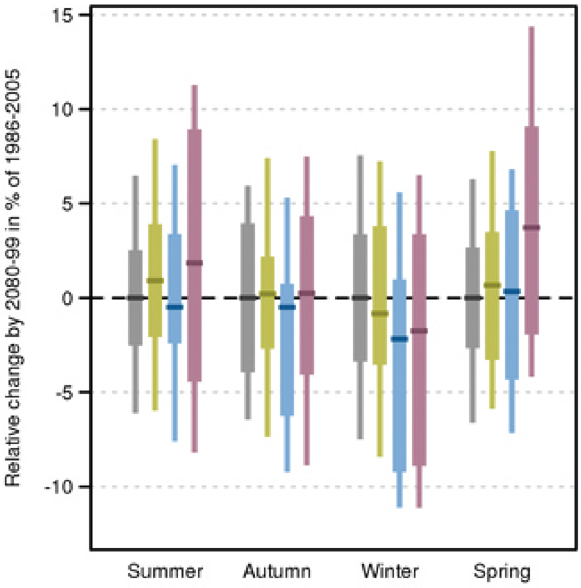


FIGURE 4.4.1: PROJECTED NEAR-SURFACE WIND SPEED CHANGES FOR 2090 FOR CENTRAL SLOPES. ANOMALIES ARE GIVEN IN PERCENT WITH RESPECT TO THE 1986–2005 MEAN FOR RCP2.6 (GREEN), RCP4.5 (BLUE) AND RCP8.5 (PURPLE), WITH GREY BARS SHOWING THE EXTENT OF NATURAL CLIMATE VARIABILITY. BAR PLOTS ARE EXPLAINED IN BOX 4.2.

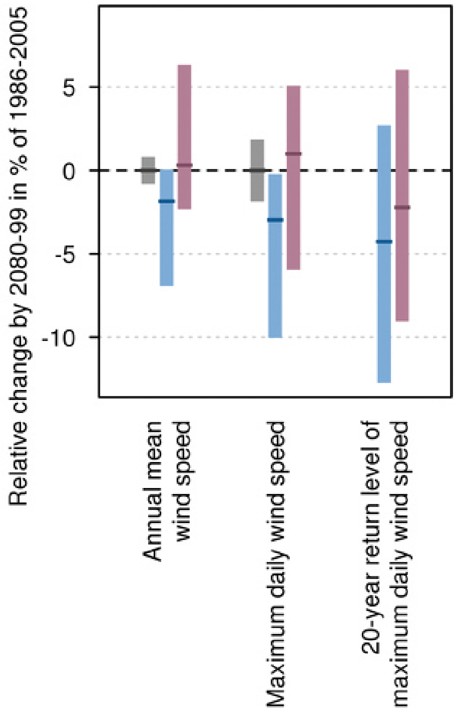


FIGURE 4.4.2: PROJECTED NEAR-SURFACE ANNUAL MEAN WIND SPEED, ANNUAL MAXIMUM DAILY WIND SPEED AND THE 20-YEAR RETURN VALUE FOR THE ANNUAL MAXIMUM DAILY WIND SPEED FOR 2090 FOR CENTRAL SLOPES. ANOMALIES ARE GIVEN IN PER CENT WITH RESPECT TO THE 1986–2005 MEAN FOR RCP2.6 (GREEN), RCP4.5 (BLUE) AND RCP8.5 (PURPLE) WITH GREY BARS SHOWING THE EXTENT OF NATURAL CLIMATE VARIABILITY. BAR PLOTS ARE EXPLAINED IN BOX 4.2.

4.4.2 EXTREME WINDS

The projections of extreme wind (1-day annual maximum speed) presented here need to be considered in light of several limitations imposed on this variable. These include the limited number of GCMs that provide wind data, and the need to estimate wind speed from daily direction component data. Furthermore, the intensity of observed extreme wind speeds across land is strongly modified by surrounding terrain (including vegetation and other 'obstacles') that are not resolved at the relevant scale in GCMs. Many meteorological systems generating extreme winds are not resolved either. For these reasons, confidence in model estimated changes for the Central Slopes cluster are lowered and their value lies foremost in the direction of change rather than the projected changes in magnitude. See further details in the Technical Report Chapter 7.3.

In light of the limitations mentioned above, the projected ranges for 2090 in maximum daily wind speed and the 20-year return value of the daily maximum following RCP4.5 and 8.5 suggest that both increases and decreases are possible, though more models suggest decrease for the more extreme winds (Figure 4.4.2), where a 20-year return value is equivalent to a 5 % chance occurrence within any one year. For Australia as a whole, there is generally *medium confidence* in a decrease in mid-latitudes since such changes resonate with changes to the broad scale changes to circulation and mean wind speed at these latitudes. For Central Slopes, there is *low confidence* due to the low model agreement on the direction of change.

4.4.3 TROPICAL AND EXTRA-TROPICAL CYCLONES

The Central Slopes cluster is not often directly affected by tropical cyclones, with only one occurrence during the baseline period (1986–2005) considered here; tropical cyclone Gertie passed through the Australian interior from 17–24 December 1995. However, even though tropical cyclones are rare in this cluster, they are capable of causing heavy rainfall much further south than their geographical location due to their impact on the regional circulation.

Projected changes in tropical cyclone frequency have been assessed in the current generation of GCMs over the north-east Australian region, from both the large-scale environmental conditions that promote cyclones and from direct simulation of cyclone-like synoptic features (see Section 7.3.3 of the Technical Report). Results in this region generally indicate a decrease in the formation of tropical cyclones. These results are broadly consistent with current projections of cyclones over the globe (IPCC, 2013, Section 14.6.1), which indicate little change through to substantial decrease in frequency.

It is also anticipated that the proportion of the most intense cyclones will increase over the century while the intensity of associated rainfall may increase further, as can be anticipated from Section 4.3.1 here. The projection of a larger proportion of storms decaying south of 25°S in the late 21st century may impact the Central Slopes – although this projection is made with *low confidence*.

In summary, based on global and regional studies, tropical cyclones are projected with *medium confidence* to become less frequent with increases in the proportion of the most intense storms.

With regard to extra-tropical cyclones, the literature suggests a continuation of the observed decreasing trend of east coast lows since the 1970s (Speer, 2008) with a reduction of about 30% of east coast low formation in the late 21st century compared to the late 20th century (Dowdy *et al.*, 2013b). However, whilst the number of cut-off lows may decrease, there is some indication that the most severe east coast lows could increase in their severity (Grose *et al.*, 2012).

4.5 SOLAR RADIATION

By 2030, the CMIP5 models simulate little change in radiation (about -1 to +2 %) for both RCP4.5 and RCP8.5. For 2090, projected seasonal changes are generally less than +/- 5 %, with the exception for winter where there is some indication of increase in both RCP4.5 (about 0 to 7 %) and RCP8.5 (about 0 to 10 %) (Appendix Table 1, Figure 4.7.1).

Projected increases in winter are likely to be related to decreases in cloudiness associated with reduced rainfall. However, an Australian model evaluation suggested that some models are not able to adequately reproduce the climatology of solar radiation (Watterson *et al.*, 2013). Globally, CMIP3 and CMIP5 models appear to underestimate the observed trends in some regions due to underestimation of aerosol direct radiative forcing and/or deficient aerosol emission inventories (Allen *et al.*, 2013). Taking this into account, we have *high confidence* in little change for 2030. For 2090, there is *medium confidence* in increased winter radiation, and *low confidence* for the small changes projected for the other seasons.

4.6 RELATIVE HUMIDITY

CMIP5 projections of relative humidity in Central Slopes indicate an overall decrease (Figure 4.7.1). For 2030, seasonal reductions for both RCP4.5 and RCP8.5 are generally smaller than -5% and projected increases less than 2 %, for both scenarios and there is medium or high model agreement on little change. For 2090, reductions are more marked, particularly in winter and spring with projected ranges of about -6 to 0 % under RCP4.5 and about -10 to 0 % under RCP8.5 (Appendix Table 1). A decrease in relative humidity away from coasts is expected because of an increase in the moisture holding capacity of a warming atmosphere and the greater warming of land compared to sea, leading to increases in relative humidity over ocean and decreases over land. This general tendency for decrease over land can be counteracted by a strong rainfall increase. Taking this and the CMIP5 projections into account, we have *high confidence* in little change for 2030; and *medium confidence* in decrease for summer and autumn by 2090, while for winter and spring there is *high confidence* in decrease.

4.7 POTENTIAL EVAPOTRANSPIRATION

Projected changes for potential evapotranspiration using Morton's wet-environmental potential evapotranspiration (McMahon *et al.,* (2013) and Technical Report section 7.5.3) suggest increases for all seasons in Central Slopes (Figure 4.7.1). In relative terms, increases are similar amongst the four seasons, with somewhat smaller increases in spring. Projected changes for summer, autumn and winter are around -1 to 8 % (about 1 to 5 % for spring) in 2030 and about 5 to 15 % (about 0 to 10% for spring) and 10 to 25 % (about 5 to 15 % for spring) respectively for RCP4.5 and RCP8.5 in 2090 (Appendix Table 1). In absolute terms, changes are largest in summer, particularly for RCP8.5 (not shown).

Overall, models generally show high agreement by 2030, and very high agreement by 2090, on substantial increases in evapotranspiration. Despite having *high confidence* in an increase, there is only *medium confidence* in the magnitude of the increase. The method is able to reproduce the spatial pattern and the annual cycle of the observed climatology and there is theoretical understanding around increases in evapotranspiration as a response to increasing temperatures and an intensified hydrological cycle (Huntington, 2006), which adds to confidence. However, there has been no clear increase in observed Pan Evaporation across Australia from data available since 1970 (see Technical Report Chapter 4.2.11). Also, earlier GCMs were not able to reproduce the historical linear trends found in Morton's potential evapotranspiration (Kirono and Kent, 2011).

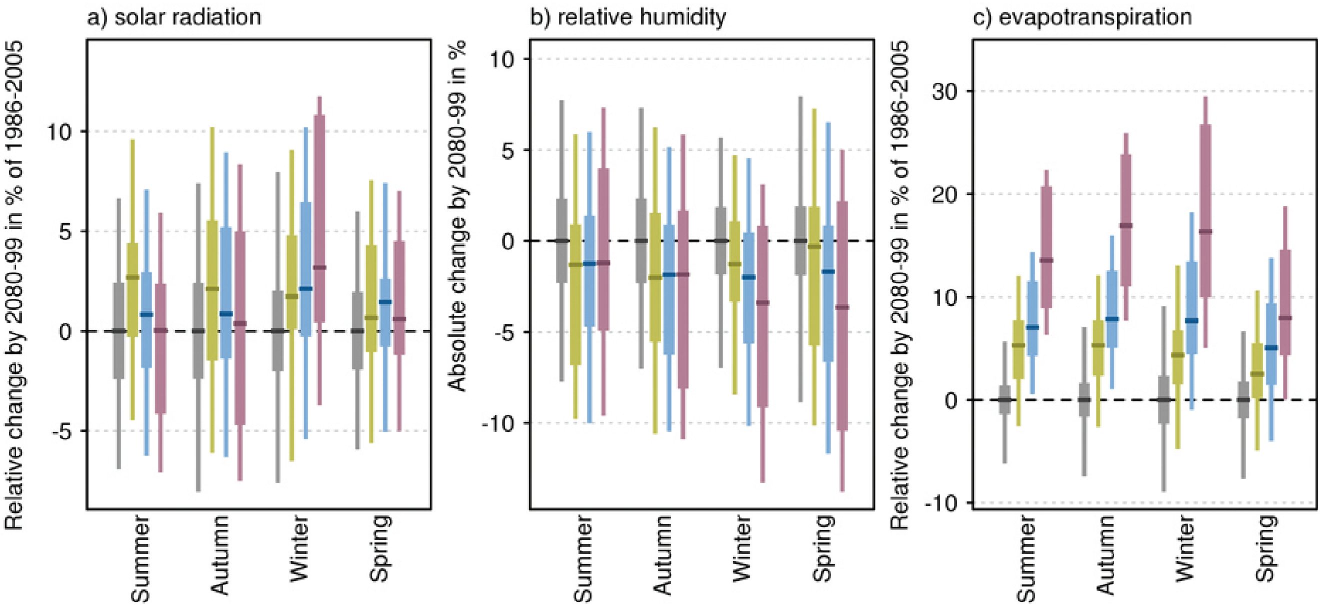


FIGURE 4.7.1: PROJECTED CHANGES IN (A) SOLAR RADIATION (%), (B) RELATIVE HUMIDITY (%, ABSOLUTE CHANGE) AND (C) WET-ENVIRONMENTAL POTENTIAL EVAPOTRANSPIRATION (%) FOR CENTRAL SLOPES IN 2090. THE BAR PLOTS SHOW SEASONAL PROJECTIONS WITH RESPECT TO THE 1986–2005 MEAN FOR RCP2.6 (GREEN), RCP4.5 (BLUE) AND RCP8.5 (PURPLE), AND THE EXTENT OF NATURAL CLIMATE VARIABILITY IS SHOWN IN GREY. BAR CHARTS ARE EXPLAINED IN BOX 4.2.

4.8 SOIL MOISTURE AND RUNOFF

Increases in potential evapotranspiration rates (Figure 4.7.1) combined with a decrease (less certain) in rainfall (Figure 4.3.1) have implications for soil moisture and runoff. However, soil moisture and runoff are difficult to simulate. This is particularly true in GCMs where, due to their relatively coarse resolution, the models cannot simulate much of the rainfall detail that is important to many hydrological processes, such as the intensity of rainfall. For these reasons, and in line with many previous studies, we do not present runoff and soil moisture as directly-simulated by the GCMs. Instead, the results of hydrological models forced by CMIP5 simulated rainfall and potential evapotranspiration are presented. Soil moisture is estimated using a dynamic hydrological model based on an extension of the Budyko framework (Zhang *et al.*, 2008), and runoff is estimated by the long-term annual water and energy balance using the Budyko framework (Teng *et al.*, 2012). Runoff is presented as change in 20-year averages, derived from output of a water balance model. The latter uses input from CMIP5 models as smoothed time series (30-year running means). The reason for this is that 30 years is the minimum for dynamic water balance to attain equilibrium using the Budyko framework. For further details on methods (including limitations) see Section 7.7 of the Technical Report.

Decreases in soil moisture are projected, particularly in winter and spring (Figure 4.8.1). The annual changes for RCP8.5 by 2090 range from around -15 % to +2 % with medium model agreement on substantial decrease (Appendix Table 1). The percentage changes in soil moisture are strongly influenced by those in rainfall, but tend to be more negative due to the strong increase in potential evapotranspiration. Given the potential limitations of this method, there is only *medium confidence* that soil moisture will decline.

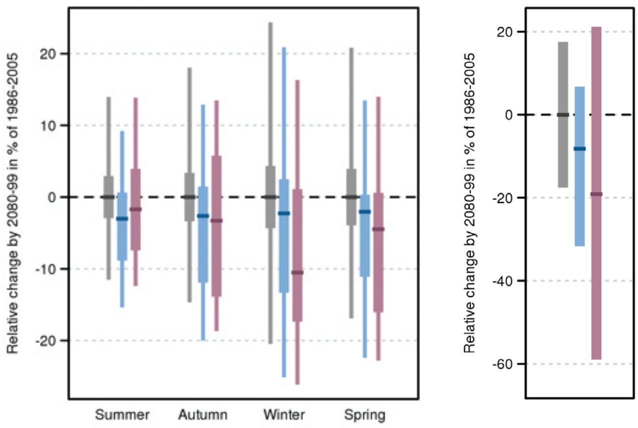


FIGURE 4.8.1: PROJECTED CHANGE IN SEASONAL SOIL MOISTURE (LEFT) AND ANNUAL RUNOFF (RIGHT) (BUDYKO METHOD – SEE TEXT) IN CENTRAL SLOPES FOR 2090. ANOMALIES ARE GIVEN IN PER CENT WITH RESPECT TO THE 1986–2005 MEAN FOR RCP4.5 (BLUE) AND RCP8.5 (PURPLE) WITH GREY BARS SHOWING THE EXTENT OF NATURAL VARIABILITY. BAR CHARTS ARE EXPLAINED IN BOX 4.2.

For Central Slopes, runoff could increase or decrease following RCP4.5 and RCP8.5 for 2080–2099 relative to 1986–2005, though the majority of models suggest decrease, as indicated by the negative multi-model ensemble median (Figure 4.8.1). There is *low confidence* in these projections because, in addition to low agreement on direction of change by the models, the method used is not able to consider changes to rainfall intensity, seasonality and changes in vegetation characteristics.

Further hydrological modelling with appropriate climate scenarios (*e.g.* Chiew *et al.*, 2009) could provide insights into impacts on future runoff and soil moisture characteristics that may be needed in detailed climate change impact assessment studies.

4.9 FIRE WEATHER

Bushfire occurrence at a given place depends on four 'switches': 1) ignition, either human-caused or from natural sources such as lightning; 2) fuel abundance or load (a sufficient amount of fuel must be present); 3) fuel dryness, where lower moisture contents are required for fire, and 4) suitable weather conditions for fire spread – generally hot, dry and windy (Bradstock, 2010). The settings of the switches depend on meteorological conditions across a variety of time scales, particularly the fuel conditions. Given this strong dependency on the weather, climate change will have a significant impact on future fire weather (*e.g.* Hennessy *et al.*, 2005; Lucas *et al.*, 2007; Williams *et al.*, 2009; Clarke *et al.*, 2011; Grose *et al.*, 2014). The study of Clarke *et al.*, (2013) suggests moderate increasing, but not significant trends over 1973 to 2010 in observed fire weather across Central Slopes.

Fire weather is estimated here using the McArthur Forest Fire Danger Index (FFDI; McArthur, 1967), which captures two of the four switches (note that it excludes ignition). The fuel dryness is summarised by the drought factor (DF) component of FFDI, which depends on both long-term and short-term rainfall. The FFDI also estimates the ability of a fire to spread, as the temperature, relative humidity and wind speed are direct inputs into the calculation. Fuel abundance is not measured by FFDI, but does depend largely on rainfall, with higher rainfall totals generally resulting in a larger fuel load, particularly in regions dominated by grasslands. However, the relationship between fuel abundance and climate change in Australia is complex and only poorly understood. Fire weather is considered 'severe' when FFDI exceeds 50; bushfires have potentially greater human impacts at this level (Blanchi *et al.*, 2010).

Here, estimates of future fire weather using FFDI are derived from three CMIP5 models (GFDL-ESM2M, MIROC5 and CESM-CAM5), chosen to provide a spread of results across all clusters. Using a method similar to that of Hennessy *et al.,* (2005), monthly mean changes to maximum temperature, rainfall, relative humidity and wind speed from these models are applied to observation-based high-quality historical fire weather records (Lucas, 2010).

A period centred on 1995 (*i.e.* 1981–2010) serves as the baseline. These records are modified using the changes from the three models for four 30-year time slices (centred on 2030, 2050, 2070 and 2090) and the RCP4.5 and RCP8.5 emission scenarios. In Southern and Eastern Australia, significant fire activity occurs primarily in areas characterised by forests and woodlands – fuel is abundant and the 'weather switch', well-characterised by FFDI, is key to fire occurrence. Two stations are used in the analysis for this cluster: Moree and Dubbo.

Focusing on the 2030 and 2090 time slices, the results indicate a tendency towards increased fire weather risk in the future (Table 4.9.1). Increased temperature combined with lower rainfall results in a higher drought factor. Across the cluster, the sum of all daily FFDI values over a year (∑FFDI from July to June) is broadly indicative of general fire weather risk and increases by 9 to 15 % by 2030 and around 20 % under RCP4.5, or 40 % under RCP8.5, by 2090. The number of days with a 'severe' fire danger rating increases by 35 to 70 % by 2030, to 85 % under RCP4.5 by 2090, and to 220 % under RCP8.5 by 2090.

Results from the individual stations and models (Table 2 in the Appendix) indicate small variability in the changes to fire weather across the cluster. Rainfall at Dubbo, further south, tends to increase less or decline more compared to Moree. However, the actual variability of fire weather in this cluster may be underestimated as the baseline fire climate is poorly sampled due to the small number of stations.

The choice of models for this analysis also introduces variability into the projections. The GFDL-ESM2M model generally simulates a decline in rainfall that is particularly strong in the 2090 RCP8.5 scenario. The other two models show mixed results, with the CESM-CAM simulation showing near neutral changes or slight declines in rainfall, while the MIROC5 simulated rainfall is highly dependent on the scenario and location. The 2090 RCP8.5 scenario shows a general increase in rainfall, while slight declines are indicated in other areas (*e.g.* Dubbo 2030 RCP8.5). Projections of fire weather are particularly sensitive to rainfall. While most models project similar warming, changes to the fire weather variables are smaller where the rainfall shows an increase or smaller decline. This reflects the interplay between the variables influencing fire danger. Increased temperatures by themselves result in some level of increased fire weather danger, generally slightly lower than the average values presented in Table 4.9.1. This temperature effect is modulated by rainfall, as significant reductions in rainfall leads to more severe fire weather for a given amount of temperature change. Mean changes to relative humidity and wind speed are small in all models and do not appear to play a significant role in the mean changes for fire weather.

There is *high confidence* that climate change will result in a harsher fire weather in the future. This is seen in the mean changes (Table 4.9.1) and when examining individual models and scenarios (Table 2 in Appendix). However, there is *low confidence* in the magnitude of the change, as this is strongly dependent on the rainfall projection.

TABLE 4.9.1: CLUSTER MEAN ANNUAL VALUES OF MAXIMUM TEMPERATURE (T; °C), RAINFALL (R; MM), DROUGHT FACTOR (DF; NO UNITS), THE NUMBER OF SEVERE FIRE DANGER DAYS (SEV; FFDI GREATER THAN 50 DAYS PER YEAR) AND CUMULATIVE FFDI (∑FFDI; NO UNITS) FOR THE 1995 BASELINE AND PROJECTIONS FOR 2030 AND 2090 UNDER RCP4.5 AND RCP8.5. AVERAGES ARE COMPUTED ACROSS ALL STATIONS AND MODELS IN EACH SCENARIO. TWO STATIONS ARE USED IN THE AVERAGING: MOREE AND DUBBO.

VARIABLE	1995 BASELINE	2030, RCP4.5	2030, RCP8.5	2090, RCP4.5	2090, RCP8.5
T	25.2	26.5	26.8	27.8	29.6
R	586	541	526	519	504
DF	6.8	7.2	7.3	7.5	7.8
SEV	2.2	3.0	3.7	4.1	7.2
∑FFDI	3857	4183	4446	4600	5357

4.10 OTHER PROJECTION MATERIAL FOR THE CLUSTER

For the Central Slopes area, previous projection products comprise the nationwide *Climate Change in Australia* projections (CSIRO and BOM, 2007); regional projections derived for New South Wales by its Government's department for Environment and Heritage[2] (*NSW Climate Impact Profile*); and projections presented in the *Climate Q* document[3], delivered as part of the Queensland state Government's Climate Smart Strategy are based on the CSIRO and BOM 2007 projections. In addition, a new set of regional projections, the NSW/ACT Regional Climate Modelling project (NARCliM)[4], is currently under production by the New South Wales Office for Environment and Heritage. These previous projections (as well as the upcoming NARCliM work) build on climate change information derived from the previous generation of GCMs included in the CMIP3 archive. A very brief comparison of these regional projections with regard to temperature and rainfall follow below.

In comparison to the 2007 projections (that also underpin projections presented in the Climate Q document for Queensland) the warming patterns suggested by the CMIP5 models are somewhat more uniform, with a somewhat less pronounced west-east gradient in warming (Figure A.1 of the Technical Report). With regard to rainfall, the CMIP5 projections appear to give a slightly wetter projection for the Central Slopes cluster (Figure A.2 of the Technical Report).

The 2010 projections from the New South Wales Office for Environment and Heritage are based on the A2 SRES scenario for 2050 using only four CMIP3 climate models, which makes a like-for-like comparison difficult. There is no equivalent to the SRES A2 emission scenario amongst the RCPs, as A2 falls between RCP6 and RCP8.5 in terms of CO_2 concentration, though around 2050 it is somewhat closer to RCP8.5. Nevertheless, a broad comparison can be made to give an idea of where the 2010 NSW projections sit relative to the projections presented here.

Looking at the New England/North-West region, which overlaps significantly with the southern parts of the Central Slopes cluster, the warming rate is 1 to 3 °C (Department of the Environment, Climate Change and Water NSW Government, 2010). This range is similar to that projected by RCP8.5 for annual temperature and somewhat higher than that of RCP4.5 (Figure 4.2.4). For rainfall for the same region, the 2010 NSW projections suggest increases in all seasons except for winter in 2050. This is a wetter projection than what is presented here for Central Slopes, where all seasons show a mixed response, with more models showing decreases rather than increases in autumn, winter and spring (Figure 4.2.5). In summer, more models simulate increases, particularly following RCP8.5 (for 2090). Hence, unlike the 2010 NSW projections, the CMIP5 projections do not indicate a clear directional change in rainfall.

Despite the use of previous generation models, these other projections are still relevant, particularly if placed in the context of the latest modelling results (see Appendix A in the Technical Report for a discussion on CMIP3 and CMIP5 model-based projections).

2 http://www.environment.nsw.gov.au/climatechange/RegionalImpactsOfClimateChange.htm

3 http://www.agdf.org.au/information/sustainable-development/climate-q

4 http://www.ccrc.unsw.edu.au/NARCliM/

5 APPLYING THE REGIONAL PROJECTIONS IN ADAPTATION PLANNING

The fundamental role of adaptation is to reduce the adverse impacts of climate change on vulnerable systems, using a wide range of actions directed by the needs of the vulnerable system. Adaptation also identifies and incorporates new opportunities that become feasible under climate change. For adaptation actions to be effective, all stakeholders need to be engaged, resources must be available and planners must have information on 'what to adapt to' and 'how to adapt' (Füssel and Klein, 2006).

This report presents information about 'what to adapt to' by describing how future climate may change. This chapter gives guidance on how climate projections can be framed in the context of climate scenarios (Section 5.1) using tools such as the Climate Futures web tool, available on the Climate Change in Australia website (Box 5.1). The examples of its use presented here are not exhaustive, but rather an illustration of what can be done.

BOX 5.1: USER RESOURCES ON THE CLIMATE CHANGE IN AUSTRALIA WEBSITE

The Climate Change in Australia website provides information on the science of climate change in a global and Australian context with material supporting regional planning activities. For example, whilst this report focuses on a selected set of emission scenarios, time horizons and variables, the website enables generation of graphs tailored to specific needs, such as a different time period or emission scenario.

The website includes a decision tree yielding application-relevant information, report-ready projected change information and the web tool Climate Futures (Whetton *et al.*, 2012). The web tool facilitates the visualisation and categorisation of model results and selection of data sets that are of interest to the user. These products are described in detail in Chapter 9 of the Technical Report.

www.climatechangeinaustralia.gov.au

5.1 IDENTIFYING FUTURE CLIMATE SCENARIOS

In Chapter 4 of this report, projected changes are expressed as a range of plausible change for individual variables as simulated by CMIP5 models or derived from their outputs. However, many practitioners are interested in information on how the climate may change, not just changes in one climate variable. To consider how several climate variables may change in the future, data from individual models should be considered because each model simulates changes that are internally consistent across many variables. For example, one should not combine the projected rainfall from one model with projected temperature from another, as these would represent the climate responses of unrelated simulations.

The challenge for practitioners lies in selecting which models to look at. This is an important decision, since models can vary in their simulated climate response to increasing greenhouse gas emissions. Climate models can be organised according to their simulated climate response to assist with this selection. For example, sorting according to rainfall and temperature responses would give an immediate feel for how models fall into a set of discrete climate scenarios framed in terms such as: *much drier and slightly warmer, much wetter and slightly warmer, much drier and much hotter,* and *much wetter and much hotter.*

The Climate Futures web tool described in Box 9.1 of the Technical Report presents a scenario approach to investigating the range of climate model simulations for projected future periods. The following Section describes how this tool can be used to facilitate the use of model output in impact and adaptation assessment.

5.2 DEVELOPING CLIMATE SCENARIOS USING THE CLIMATE FUTURES TOOL

The example presented in Figure 5.1 represents the changes in temperature and rainfall in Central Slopes for 2060 (years 2050–2069) under the RCP4.5 scenario as simulated by CMIP5 models. The table organises the models into groupings according to their simulated changes to annual rainfall (rows) and temperatures (columns). Regarding rainfall, models simulate increases and decreases from *much drier* (less than -15 %) to *much wetter* (greater than 15 %), with 17 of 34 models showing drying conditions (less than -5 %) compared to 12 models showing rainfall increases (greater than 5 %) and five models showing little change (-5 to 5 % change). With regard to temperature, models show results ranging from *warmer* (0.5 to 1.5 °C warmer) to *hotter* (1.5 to 3.0 °C warmer), with no models falling into the lowest category *slightly warmer* (0 to 0.5 °C warmer) nor the highest category *much hotter* (greater than 3.0 °C warming). The largest number of models falls in the *hotter* category (25 of 34 models). When considering the two variables together, we see that the most commonly simulated climate for 2060 under RCP4.5 is for a *'hotter and much drier'* climate (9 of 34 models).

In viewing the projection data in this way, the user can gain an overview of what responses are possible when considering the CMIP5 model archive for a given set of constraints. In a risk assessment context, a user may want to consider not only the maximum consensus climate (simulated by most models), but also the best case and worst case scenarios. Their nature will depend on the application. A water-supply manager, for example, is likely to determine from Figure 5.1 that the best case scenario would be a *wetter and warmer* climate and the worst case the *hotter and much drier* scenario, which in this case coincides with the maximum consensus climate.

Assuming that the user has identified what futures are likely to be of most relevance to the system of interest, Climate Futures allows exploration of the numerical values for each of the models that populates the scenarios. Further, it provides a function for choosing a single model that most closely represents the particular future climate of interest, but also taking into account models that have been identified as sub-optimal for particular regions based on model evaluation information (as described in Chapter 5 of the Technical Report). Through this approach, users can select a small set of models to provide scenarios for their application, taking into consideration model spread and the sensitivity of their application to climate change.

CONSENSUS	PROPORTION OF MODELS
Not projected	No models
Very low	< 10 %
Low	10 to 33 %
Moderate	33 to 66 %
High	66 - 90 %
Very high	> 90 %

		June - Aug temperature (°C)			
		Slightly warmer 0 to +0.5	Warmer +0.5 to 1.5	Hotter +1.5 to +3.0	Much hotter > +3.0
June - Aug rainfall (%)	Much wetter > +15.0			2 of 34 models	
	Wetter +5.0 to +15.0		5 of 34 models	5 of 34 models	
	Little change -5.0 to +5.0		2 of 34 models	3 of 34 models	
	Drier -15.0 to -5.0		1 of 34 models	6 of 34 models	
	Much drier < -15.0		1 of 34 models	9 of 34 models	

FIGURE 5.1: AN EXAMPLE TABLE BASED ON OUTPUT FROM THE CLIMATE FUTURES WEB TOOL SHOWING RESULTS FOR CENTRAL SLOPES WHEN ASSESSING PLAUSIBLE CLIMATE FUTURES FOR 2060 UNDER RCP4.5, AS DEFINED BY GCM SIMULATED ANNUAL RAINFALL (% CHANGE) AND TEMPERATURE (°C WARMING).

Alternatively, the user may wish to consider a small set of scenarios defined irrespective of emission scenario or date (but with their likelihood of occurrence being time and emission scenario sensitive). This may be in circumstances where the focus is on critical climate change thresholds. This strategy is illustrated for the Central Slopes cluster in Box 5.2, where results are produced in Climate Futures by comparing model simulations from separate time slices and emission scenarios. This box also illustrates each of these scenarios with current climate analogues (comparable climates) for selected sites.

Another user case could be the desire to compare simulations from different climate model ensembles (such as the earlier CMIP3 ensemble, or ensembles of downscaled results such as the NARCliM results for NSW). Comparing model spread simulated by different generations of GCMs in Climate Futures allows an assessment of the ongoing relevance of existing impact studies based on selected CMIP3 models, and to compare scenarios developed using downscaled and GCM results.

BOX 5.2: INDICATIVE CLIMATE SCENARIOS FOR THE CENTRAL SLOPES AND ANALOGUE FUTURE CLIMATES

Users may wish to consider the future climate of their region in terms of a small set of scenarios defined irrespective of emission scenario or date (but with their likelihood of occurrence being time and emission scenario sensitive). An example of using this strategy for the Central Slopes cluster is illustrated here. Combining the results in Climate Futures for 2030, 2050, and 2090, under RCP2.6, RCP4.5, and RCP8.5, gives a set of future climate scenarios (see Figure B5.2). From these, five highlighted scenarios are considered representative of the spread of results. Other potential scenarios are excluded as generally less likely than the selected cases or because they lie within the range of climates specified by the selected cases. For each case, when available, the current climate analogue for the future climate of Dubbo is given as an example. These were generated using the method described in Chapter 9.3.5 of the Technical Report and are based on matching annual average rainfall (within +/- 5 %) and maximum temperature (within +/- 1 °C). Other potentially important aspects of local climate, such as rainfall seasonality, are not matched. Thus the analogues should not be used directly for adaptation planning without considering more detailed information.

- *Warmer* (0.5 to 1.5 °C warmer) with *little change in rainfall* (-5 to +5 %). This could occur by 2030 under any emission scenario, but may persist through to late in the 21st century under RCP2.6. In this case, Dubbo's future climate would be more like the current climate of Muswellbrook or Scone (NSW).
- *Hotter* (1.5 to 3.0 °C warming), but *drier* (5 to 15 % reduction). This is also possible by 2030 under RCP4.5 or RCP8.5, or later in the century under RCP2.6. In this case Dubbo's climate would be more like that of Coonamble or St George (QLD).
- *Much hotter* (greater than 3.0 °C warming), and *much drier* (greater than 15 % reduction). This is possible late in the century and especially under RCP8.5. In this case, Dubbo's future climate would be more like Walgett or Lightning Ridge (NSW).
- *Warmer* (0.5 to 1.5 °C warmer) and *wetter* (5 to 15 % increase). This could occur by 2030 under any emission scenario, but may persist through to late in the 21st century under RCP2.6. However, this future is considerably less likely than the drier case above. In this case, the Dubbo's future climate would be more like that of Gayndah or Rockhampton (QLD).
- *Hotter* (1.5 to 3.0 °C warming) with *little change in rainfall* (-5 to +5 %). This may occur by 2050 under RCP4.5 or RCP8.5. In this case, Dubbo's future climate would be more like that currently in Moree (NSW) or Miles (QLD).

FIGURE B5.2: A TABLE BASED ON OUTPUT FROM CLIMATE FUTURES SHOWING CATEGORIES OF FUTURE CLIMATE PROJECTIONS FOR THE CENTRAL SLOPES CLUSTER, AS DEFINED BY CHANGE IN ANNUAL TEMPERATURE (COLUMN) AND CHANGE IN RAINFALL (ROWS). WITHIN EACH FUTURE CLIMATE CATEGORY, MODEL SIMULATIONS ARE SORTED ACCORDING TO TIME (2030, 2050 AND 2090) AND CONCENTRATION PATHWAY (RCP2.6, RCP4.5 AND RCP8.5); THE NUMBER INDICATING HOW MANY MODEL SIMULATIONS OF THAT PARTICULAR SUB-CATEGORY FALL INTO THE CLIMATE CATEGORY OF THE TABLE (THE NUMBER OF MODELS USED IN THIS EXAMPLE VARIES FOR DIFFERENT CONCENTRATION PATHWAYS). A COLOUR CODE INDICATES HOW OFTEN A PARTICULAR CLIMATE IS SIMULATED AMONGST THE CONSIDERED MODELS (PER CENT OCCURRENCE). THE SCENARIOS DESCRIBED IN THE TEXT ARE HIGHLIGHTED IN BOLD.

Future Realisations for the Central Slopes cluster

Annual Rainfall (%)		Annual Surface Temperature (°C)											
		Slightly Warmer 0 to+0.5			Warmer +0.5 to +1.5			Hotter +1.5 to +3.0			Much Hotter > +3.0		
	RCP	2030	2050	2090	2030	2050	2090	2030	2050	2090	2030	2050	2090
Much Wetter > +15.0	2.6												
	4.5												
	8.5				1					1			1
Wetter +5.0 to +15.0	2.6				1	1	1						
	4.5				3	3				2			
	8.5				3	1			3				2
Little Change −5.0 to +5.0	2.6	1			11	5	6			1			
	4.5				13	6			7	9			
	8.5				13	2		1	9				6
Drier −15.0 to −5.0	2.6				4	7	4		2	1			
	4.5				7		1	2	8	8			
	8.5				3			4	9	1			8
Much Drier < −15.0	2.6				1				3	5			
	4.5				1	1		1	2	5			2
	8.5				1			3	5				10

By when and under what greenhouse gas pathway could this occur (colour code=% of models for that period/RCP)?

Not projected | <10% | 10-33% | 33-66%

RCP2.6-18 models
RCP4.5-27 models
RCP8.5-29 models

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APPENDIX

TABLE 1A: GCM SIMULATED CHANGES IN A RANGE OF CLIMATE VARIABLES FOR THE 2020–2039 (2030) AND 2080–2099 (2090) PERIODS RELATIVE TO THE 1986–2005 PERIOD FOR THE CENTRAL SLOPES CLUSTER. THE TABLE GIVES THE MEDIAN (50TH PERCENTILE) CHANGE, AS PROJECTED BY THE CMIP5 MODEL ARCHIVE, WITH 10TH TO 90TH PERCENTILE RANGE GIVEN WITHIN BRACKETS. RESULTS ARE GIVEN FOR RCP2.6, RCP4.5, AND RCP8.5 FOR ANNUAL AND SEASONAL AVERAGES. 'DJF' REFERS TO SUMMER (DECEMBER TO FEBRUARY), 'MAM' TO AUTUMN (MARCH TO MAY), 'JJA' TO WINTER (JUNE TO AUGUST) AND 'SON' TO SPRING (SEPTEMBER TO NOVEMBER). THE PROJECTIONS ARE PRESENTED AS EITHER PERCENTAGE OR ABSOLUTE CHANGES. THE COLOURING (SEE LEGEND) INDICATES CMIP5 MODEL AGREEMENT, WITH 'MEDIUM' BEING MORE THAN 60 % OF MODELS, 'HIGH' MORE THAN 75 %, 'VERY HIGH' MORE THAN 90 %, AND 'SUBSTANTIAL' AGREEMENT ON A CHANGE OUTSIDE THE 10TH TO 90TH PERCENTILE RANGE OF MODEL NATURAL VARIABILITY. NOTE THAT 'VERY HIGH AGREEMENT' CATEGORIES ARE RARELY OCCUPIED EXCEPT FOR 'VERY HIGH AGREEMENT ON SUBSTANTIAL INCREASE', AND SO TO REDUCE COMPLEXITY THE OTHER CASES ARE INCLUDED WITHIN THE RELEVANT 'HIGH AGREEMENT' CATEGORY.

VARIABLE	SEASON	2030, RCP2.6	2030, RCP4.5	2030, RCP8.5	2090, RCP2.6	2090, RCP4.5	2090, RCP8.5
Temperature mean (°C)	Annual	**0.9 (0.6 to 1.2)**	**1 (0.6 to 1.3)**	**1.1 (0.7 to 1.5)**	**1.1 (0.6 to 1.8)**	**2.1 (1.4 to 2.7)**	**4.2 (3 to 5.4)**
	DJF	0.8 (0.5 to 1.5)	1 (0.5 to 1.5)	1 (0.4 to 1.7)	1.3 (0.5 to 2)	2.2 (1.3 to 3.1)	4 (2.7 to 5.4)
	MAM	0.9 (0.5 to 1.2)	0.9 (0.6 to 1.3)	1 (0.5 to 1.5)	1.1 (0.7 to 1.6)	1.9 (1.4 to 2.7)	4.1 (2.8 to 5.1)
	JJA	0.8 (0.5 to 1.2)	0.9 (0.5 to 1.2)	1 (0.7 to 1.4)	0.9 (0.6 to 1.5)	1.9 (1.3 to 2.6)	3.9 (2.9 to 4.9)
	SON	0.9 (0.4 to 1.5)	1 (0.5 to 1.4)	1.1 (0.6 to 1.9)	1 (0.4 to 2)	2.2 (1.3 to 3.3)	4.4 (3 to 6.1)
Temperature maximum (°C)	Annual	**0.9 (0.7 to 1.3)**	**1.1 (0.6 to 1.4)**	**1.2 (0.5 to 1.6)**	**1.3 (0.6 to 1.9)**	**2.2 (1.5 to 3)**	**4.2 (3.2 to 5.5)**
	DJF	0.9 (0.6 to 1.6)	0.9 (0.5 to 1.7)	1.1 (0.4 to 1.8)	1.5 (0.5 to 2.3)	2.3 (1.5 to 3.2)	4.1 (2.8 to 5.3)
	MAM	0.9 (0.3 to 1.3)	1 (0.5 to 1.4)	1.1 (0.4 to 1.5)	1.1 (0.6 to 1.9)	2.1 (1.2 to 2.8)	3.9 (2.7 to 5.4)
	JJA	0.9 (0.5-1.3)	1.1 (0.6 to 1.5)	1.1 (0.6 to 1.7)	1 (0.6 to 1.6)	2.2 (1.2 to 3)	4.2 (3.2 to 5.3)
	SON	1 (0.4 to 1.8)	1.1 (0.5 to 1.7)	1.2 (0.5 to 2.1)	1.2 (0.4 to 2.2)	2.3 (1.3 to 3.7)	4.5 (3 to 6.6)
Temperature minimum (°C)	Annual	**0.9 (0.5 to 1.1)**	**1 (0.6 to 1.1)**	**1 (0.7 to 1.4)**	**1 (0.6 to 1.6)**	**1.9 (1.3 to 2.7)**	**4.1 (3 to 5.3)**
	DJF	0.9 (0.5 to 1.3)	1 (0.7 to 1.4)	1 (0.6 to 1.6)	1.3 (0.4 to 1.8)	2.2 (1.2 to 3.2)	4.2 (2.8 to 5.5)
	MAM	0.8 (0.4 to 1.1)	0.9 (0.6 to 1.3)	1 (0.5 to 1.5)	0.9 (0.4 to 1.7)	1.8 (1.2 to 2.7)	3.9 (2.9 to 5.4)
	JJA	0.6 (0.3 to 1)	0.8 (0.3 to 1.1)	0.9 (0.6 to 1.3)	0.8 (0.4 to 1.4)	1.7 (1.1 to 2.4)	3.7 (2.9 to 4.5)
	SON	0.8 (0.4 to 1.4)	1 (0.6 to 1.3)	1.1 (0.6 to 1.6)	1.1 (0.4 to 1.7)	2.1 (1.2 to 2.9)	4.4 (3.2 to 5.4)
Rainfall (%)	Annual	**-1 (-11 to 8)**	**-2 (-11 to 7)**	**-1 (-13 to 8)**	**-3 (-18 to 8)**	**-4 (-16 to 6)**	**-6 (-23 to 18)**
	DJF	2 (-13 to 17)	1 (-9 to 16)	2 (-12 to 23)	-5 (-23 to 13)	0 (-14 to 17)	10 (-14 to 29)
	MAM	-2 (-25 to 19)	-5 (-22 to 19)	-2 (-17 to 14)	-10 (-26 to 17)	-4 (-28 to 23)	-4 (-35 to 27)
	JJA	-3 (-18 to 14)	-3 (-20 to 11)	-2 (-27 to 15)	-4 (-24 to 11)	-10 (-24 to 9)	-17 (-39 to 15)
	SON	-2 (-21 to 19)	-2 (-18 to 12)	-1 (-23 to 12)	-1 (-25 to 12)	-8 (-26 to 12)	-14 (-40 to 11)
Solar radiation (%)	Annual	**1 (-0.3 to 2.3)**	**0.5 (-0.7 to 1.8)**	**0.6 (-0.7 to 2.1)**	**1.7 (0.3 to 3.9)**	**1.3 (-0.3 to 2.6)**	**0.9 (-1.7 to 3.3)**
	DJF	0.8 (-1 to 2.4)	0 (-1.6 to 2.4)	0 (-2 to 2.1)	2.7 (-0.3 to 4.4)	0.8 (-1.8 to 3)	0 (-4.2 to 2.4)
	MAM	0.9 (-2.1 to 5.6)	0.4 (-1.4 to 3.4)	0.5 (-1.8 to 3.5)	2.1 (-1.5 to 5.6)	0.9 (-1.4 to 5.2)	0.4 (-4.7 to 5)
	JJA	1.4 (-0.6 to 3.8)	1.2 (-0.5 to 4.1)	1.4 (-0.8 to 4.6)	1.7 (0.1 to 4.8)	2.1 (-0.3 to 6.5)	3.2 (0.4 to 10.8)
	SON	1 (-1.5 to 2.9)	0.6 (-1.1 to 1.7)	0.2 (-1.7 to 3)	0.7 (-1.1 to 4.3)	1.4 (-0.8 to 2.6)	0.6 (-1.2 to 4.5)
Relative humidity (%, absolute)	Annual	**-0.4 (-2.5 to 0.9)**	**-0.6 (-2.5 to 0.9)**	**-0.8 (-2.8 to 1.6)**	**-1.2 (-4.2 to 0.7)**	**-1.6 (-4.1 to -0.3)**	**-2.4 (-7.4 to 1.1)**
	DJF	-0.3 (-2.4 to 1.7)	-0.4 (-2.7 to 1.7)	-0.1 (-3 to 1.3)	-1.3 (-6.8 to 0.9)	-1.2 (-4.7 to 1.4)	-1.2 (-4.9 to 4)
	MAM	-0.7 (-4.3 to 1.9)	-0.5 (-4.1 to 1.5)	-0.6 (-2.8 to 1.8)	-2 (-5.5 to 1.5)	-1.9 (-6.3 to 0.9)	-1.8 (-8.1 to 1.7)
	JJA	-0.7 (-2.8 to 0.5)	-0.7 (-2.9 to 0.7)	-1 (-3.7 to 1.6)	-1.3 (-3.3 to 1.1)	-2 (-5.6 to 0.5)	-3.4 (-9.1 to 0.8)
	SON	-0.8 (-4 to 2.3)	-0.6 (-4 to 1.5)	-0.7 (-4.4 to 1.9)	-0.3 (-5.8 to 1.9)	-1.7 (-6.7 to 0.8)	-3.6 (-10.4 to 2.2)

VARIABLE	SEASON	2030, RCP2.6	2030, RCP4.5	2030, RCP8.5	2090, RCP2.6	2090, RCP4.5	2090, RCP8.5
Evapo-transpiration (%)	Annual	3.6 (2.5 to 4.8)	3.3 (1.6 to 4.8)	3.6 (1.8 to 5.8)	4.2 (2.3 to 6.9)	6.8 (4.2 to 10.8)	12.5 (9.8 to 18.1)
	DJF	3.9 (1.7 to 5.1)	2.8 (1.3 to 6.2)	3.1 (1.2 to 6.6)	5.3 (2 to 7.7)	7.1 (4.3 to 11.5)	13.5 (8.9 to 20.8)
	MAM	4.6 (-0.9 to 6.6)	3.2 (1 to 7.2)	4.7 (2.3 to 7.2)	5.3 (2.3 to 7.7)	7.8 (5 to 12.5)	16.9 (11 to 23.8)
	JJA	4 (1.5 to 8.2)	3.7 (0.5 to 8)	4.5 (1.1 to 7.4)	4.3 (1.5 to 6.8)	7.7 (4.4 to 13.5)	16.3 (9.9 to 26.8)
	SON	3.3 (0.5 to 5.6)	3 (0.8 to 4.6)	2.2 (0.5 to 4.9)	2.5 (0.2 to 5.5)	5.1 (1.5 to 9.4)	8 (4.3 to 14.6)
Soil moisture (Budyko) (%)	Annual	NA	-1.3 (-7.6 to 1.2)	-1.5 (-7.8 to 3.2)	NA	-3.2 (-11.2 to 0.5)	-4.1 (-14.5 to 2.4)
	DJF	NA	-0.6 (-5.5 to 4)	-1.5 (-6.2 to 3.2)	NA	-3 (-8.9 to 0.6)	-1.7 (-7.4 to 3.9)
	MAM	NA	+0.1 (-10.7 to 3.7)	-1.1 (-10.7 to 4.9)	NA	-2.6 (-11.9 to 1.5)	-3.3 (-13.9 to 5.8)
	JJA	NA	-1.8 (-8.5 to 3.7)	-3.2 (-14.8 to 2.3)	NA	-2.3 (-13.3 to 2.5)	-10.5 (-17.4 to 1.1)
	SON	NA	-0.8 (-9.8 to 1.7)	-1.6 (-10 to 3.7)	NA	-2 (-11.1 to 0.3)	-4.5 (-16.1 to 0.6)
Wind speed (%)	Annual	0 (-1.9 to 1.7)	-1 (-5.3 to 1.5)	0.2 (-1.9 to 3.5)	0.1 (-1.2 to 2.6)	-0.7 (-5.3 to 1.7)	1.4 (-3.5 to 6.8)
	DJF	0.1 (-1.6 to 2.2)	-0.7 (-3.2 to 1.6)	0.9 (-2.2 to 3.1)	0.9 (-2.1 to 3.9)	-0.5 (-2.4 to 3.4)	1.8 (-4.5 to 8.9)
	MAM	0.2 (-3 to 1.7)	-0.3 (-3.9 to 1.7)	-0.6 (-2.4 to 3)	0.2 (-2.7 to 2.2)	-0.5 (-6.3 to 0.8)	0.2 (-4.1 to 4.3)
	JJA	0.3 (-4.7 to 2.4)	-1.5 (-5.8 to 1.4)	-0.2 (-5.1 to 2.8)	-0.8 (-3.5 to 3.8)	-2.2 (-9.2 to 1)	-1.7 (-8.9 to 3.4)
	SON	0.1 (-1.4 to 2.7)	-0.2 (-4.1 to 3.7)	0.9 (-1.1 to 5.4)	0.7 (-3.3 to 3.5)	0.3 (-4.3 to 4.6)	3.7 (-1.9 to 9.1)

LEGEND TO TABLE 1

	Very high model agreement on substantial increase
	High model agreement on substantial increase
	Medium model agreement on substantial increase
	High model agreement on increase
	Medium model agreement on increase
	High model agreement on little change
	Medium model agreement on little change
	High model agreement on substantial decrease
	Medium model agreement on substantial decrease
	High model agreement on decrease
	Medium model agreement on decrease

TABLE 2: ANNUAL VALUES OF MAXIMUM TEMPERATURE (T; °C), RAINFALL (R; MM), DROUGHT FACTOR (DF; NO UNITS), THE NUMBER OF SEVERE FIRE DANGER DAYS (SEV: FFDI GREATER THAN 50 DAYS PER YEAR) AND CUMULATIVE FFDI (ΣFFDI; NO UNITS) FOR THE 1995 BASELINE AND PROJECTIONS FOR 2030 AND 2090 UNDER RCP4.5 AND RCP8.5. VALUES WERE CALCULATED FROM THREE CLIMATE MODELS AND FOR SEVEN STATIONS.

STATION	VARIABLE	1995 BASELINE	2030, RCP4.5			2030, RCP8.5			2090, RCP4.5			2090, RCP8.5		
			CESM	GFDL	MIROC	CESM	GFDL	MIROC	CESM	GFDL	MIROC	CESM	GFDL	MIROC
Moree	T	26.2	27.2	28.1	27.3	27.7	28.2	27.6	29.1	29.2	28.2	31.3	31.4	29.4
	R	585.5	582.9	486.7	618.7	583.8	459.5	588.2	565.0	458.2	590.7	555.8	343.0	684.5
	DF	7.0	7.2	7.9	7.0	7.2	7.9	7.3	7.5	8.1	7.3	7.8	8.7	7.2
	SEV	2.4	2.5	4.3	2.7	3.1	5.4	3.3	4.2	5.9	3.4	7.7	12.3	3.4
	ΣFFDI	4247	4334	5183	4265	4653	5393	4555	4933	5588	4588	5718	7235	4464
Dubbo	T	24.1	25.1	26.0	25.1	25.6	26.0	25.5	27.0	27.0	26.1	29.1	29.3	27.2
	R	586.5	550.3	439.4	573.1	564.6	425.9	536.9	535.7	413.9	551.5	513.7	300.8	627.3
	DF	6.6	6.8	7.6	6.7	6.8	7.6	6.9	7.1	7.9	6.9	7.5	8.8	6.8
	SEV	2.0	2.2	3.9	2.2	3.1	4.5	2.7	3.7	4.8	2.9	6.5	10.1	3.0
	ΣFFDI	3467	3539	4305	3475	3830	4506	3739	4042	4694	3757	4809	6281	3634

ABBREVIATIONS

ACORN-SAT	Australian Climate Observations Reference Network – Surface Air Temperature
AR5	The IPCC *Fifth Assessment Report*
AWAP	Australian Water Availability Project
BOM	Australian Bureau of Meteorology
CCAM	Conformal Cubic Atmospheric Model
CCIA	Climate Change in Australia
CMIP5	Coupled Model Intercomparison Project (Phase 5)
CS	Central Slopes cluster
CSIRO	Commonwealth Scientific and Industrial Research Organisation
ENSO	El Niño Southern Oscillation
FFDI	Forest Fire Danger Index
GCMs	General Circulation Models or Global Climate Models
IOD	Indian Ocean Dipole
IPCC	Intergovernmental Panel on Climate Change
IPO	Interdecadal Pacific Oscillation
LLS	Local Land Service
MSLP	Mean Sea level Pressure
NARCliM	NSW/ACT Regional Climate Modelling project
NRM	Natural Resource Management
RCP	Representative Concentration Pathway
SAM	Southern Annular Mode
SPI	Standardised Precipitation Index
SRES	Special Report on Emissions Scenarios
SST	Sea Surface Temperature
STR	Sub-tropical Ridge
SRES	Special Report on Emissions Scenarios
SST	Sea Surface Temperature
STR	Sub-tropical Ridge

NRM GLOSSARY OF TERMS

Adaptation	The process of adjustment to actual or expected climate and its effects. Adaptation can be autonomous or planned. *Incremental adaptation* Adaptation actions where the central aim is to maintain the essence and integrity of a system or process at a given scale. *Transformational adaptation* Adaptation that changes the fundamental attributes of a system in response to climate and its effects.
Aerosol	A suspension of very small solid or liquid particles in the air, residing in the atmosphere for at least several hours.
Aragonite saturation state	The saturation state of seawater with respect to aragonite (Ω) is the product of the concentrations of dissolved calcium and carbonate ions in seawater divided by their product at equilibrium: $([Ca^{2+}] \times [CO^{3}_{2-}]) / [CaCO^{3}] = \Omega$
Atmosphere	The gaseous envelope surrounding the Earth. The dry atmosphere consists almost entirely of nitrogen and oxygen, together with a number of trace gases (*e.g.* argon, helium) and greenhouse gases (*e.g.* carbon dioxide, methane, nitrous oxide). The atmosphere also contains aerosols and clouds.
Carbon dioxide	A naturally occurring gas, also a by-product of burning fossil fuels from fossil carbon deposits, such as oil, gas and coal, of burning biomass, of land use changes and of industrial processes (*e.g.* cement production). It is the principle anthropogenic greenhouse gas that affects the Earth's radiative balance.
Climate	The average weather experienced at a site or region over a period of many years, ranging from months to many thousands of years. The relevant measured quantities are most often surface variables such as temperature, rainfall and wind.
Climate change	A change in the state of the climate that can be identified (*e.g.* by statistical tests) by changes in the mean and/or variability of its properties, and that persists for an extended period of time, typically decades or longer.
Climate feedback	An interaction in which a perturbation in one climate quantity causes a change in a second, and that change ultimately leads to an additional (positive or negative) change in the first.
Climate projection	A climate projection is the simulated response of the climate system to a scenario of future emission or concentration of greenhouse gases and aerosols, generally derived using climate models. Climate projections are distinguished from climate predictions by their dependence on the emission/concentration/radiative forcing scenario used, which in turn is based on assumptions concerning, for example, future socioeconomic and technological developments that may or may not be realised.
Climate scenario	A plausible and often simplified representation of the future climate, based on an internally consistent set of climatological relationships that has been constructed for explicit use in investigating the potential consequences of anthropogenic climate change, often serving as input to impact models.
Climate sensitivity	The effective climate sensitivity (units; °C) is an estimate of the global mean surface temperature response to doubled carbon dioxide concentration that is evaluated from model output or observations for evolving non-equilibrium conditions.
Climate variability	Climate variability refers to variations in the mean state and other statistics (such as standard deviations, the occurrence of extremes, etc.) of the climate on all spatial and temporal scales beyond that of individual weather events. Variability may be due to natural internal processes within the climate system (internal variability), or to variations in natural or anthropogenic external forcing (external variability).
Cloud condensation nuclei	Airborne particles that serve as an initial site for the condensation of liquid water, which can lead to the formation of cloud droplets. A subset of aerosols that are of a particular size.

CMIP3 and CMIP5	Phases three and five of the Coupled Model Intercomparison Project (CMIP3 and CMIP5), which coordinated and archived climate model simulations based on shared model inputs by modelling groups from around the world. The CMIP3 multi-model dataset includes projections using SRES emission scenarios. The CMIP5 dataset includes projections using the Representative Concentration Pathways (RCPs).
Confidence	The validity of a finding based on the type, amount, quality, and consistency of evidence (*e.g.* mechanistic understanding, theory, data, models, expert judgment) and on the degree of agreement.
Decadal variability	Fluctuations, or ups-and-downs of a climate feature or variable at the scale of approximately a decade (typically taken as longer than a few years such as ENSO, but shorter than the 20–30 years of the IPO).
Detection and attribution	Detection of change is defined as the process of demonstrating that climate or a system affected by climate has changed in some defined statistical sense, without providing a reason for that change. An identified change is detected in observations if its likelihood of occurrence by chance due to internal variability alone is determined to be small, for example, less than 10 per cent. Attribution is defined as the process of evaluating the relative contributions of multiple causal factors to a change or event with an assignment of statistical confidence.
Downscaling	Downscaling is a method that derives local to regional-scale information from larger-scale models or data analyses. Different methods exist *e.g.* dynamical, statistical and empirical downscaling.
El Niño Southern Oscillation (ENSO)	A fluctuation in global scale tropical and subtropical surface pressure, wind, sea surface temperature, and rainfall, and an exchange of air between the south-east Pacific subtropical high and the Indonesian equatorial low. Often measured by the surface pressure anomaly difference between Tahiti and Darwin or the sea surface temperatures in the central and eastern equatorial Pacific. There are three phases: neutral, El Niño and La Niña. During an El Niño event the prevailing trade winds weaken, reducing upwelling and altering ocean currents such that the eastern tropical surface temperatures warm, further weakening the trade winds. The opposite occurs during a La Niña event.
Emissions scenario	A plausible representation of the future development of emissions of substances that are potentially radiatively active (*e.g.* greenhouse gases, aerosols) based on a coherent and internally consistent set of assumptions about driving forces (such as demographic and socioeconomic development, technological change) and their key relationships.
Extreme weather	An extreme weather event is an event that is rare at a particular place and time of year. Definitions of rare vary, but an extreme weather event would normally be as rare as or rarer than the 10th or 90th percentile of a probability density function estimated from observations.
Fire weather	Weather conditions conducive to triggering and sustaining wild fires, usually based on a set of indicators and combinations of indicators including temperature, soil moisture, humidity, and wind. Fire weather does not include the presence or absence of fuel load.
Global Climate Model or General Circulation Model (GCM)	A numerical representation of the climate system that is based on the physical, chemical and biological properties of its components, their interactions and feedback processes. The climate system can be represented by models of varying complexity and differ in such aspects as the spatial resolution (size of grid-cells), the extent to which physical, chemical, or biological processes are explicitly represented, or the level at which empirical parameterisations are involved.
Greenhouse gas	Greenhouse gases are those gaseous constituents of the atmosphere, both natural and anthropogenic, that absorb and emit radiation at specific wavelengths within the spectrum of terrestrial radiation emitted by the Earth's surface, the atmosphere itself, and by clouds. Water vapour (H_2O), carbon dioxide (CO_2), nitrous oxide (N_2O), methane (CH_4) and ozone (O_3) are the primary greenhouse gases in the Earth's atmosphere.

Hadley Cell/Circulation	A direct, thermally driven circulation in the atmosphere consisting of poleward flow in the upper troposphere, descending air into the subtropical high-pressure cells, return flow as part of the trade winds near the surface, and with rising air near the equator in the so-called Inter-Tropical Convergence zone.
Indian Ocean Dipole (IOD)	Large-scale mode of interannual variability of sea surface temperature in the Indian Ocean. This pattern manifests through a zonal gradient of tropical sea surface temperature, which in its positive phase in September to November shows cooling off Sumatra and warming off Somalia in the west, combined with anomalous easterlies along the equator.
Inter-decadal Pacific Oscillation	A fluctuation in the sea surface temperature (SST) and mean sea level pressure (MSLP) of both the north and south Pacific Ocean with a cycle of 15–30 years. Unlike ENSO, the IPO may not be a single physical 'mode' of variability, but be the result of a few processes with different origins. The IPO interacts with the ENSO to affect the climate variability over Australia. A related phenomena, the Pacific Decadal Oscillation (PDO), is also an oscillation of SST that primarily affects the northern Pacific.
Jet stream	A narrow and fast-moving westerly air current that circles the globe near the top of the troposphere. The jet streams are related to the global Hadley circulation. In the southern hemisphere the two main jet streams are the polar jet that circles Antarctica at around 60 °S and 7–12 km above sea level, and the subtropical jet that passes through the mid-latitudes at around 30 °S and 10–16 km above sea level.
Madden Julian Oscillation (MJO)	The largest single component of tropical atmospheric intra-seasonal variability (periods from 30 to 90 days). The MJO propagates eastwards at around 5 m s^{-1} in the form of a large-scale coupling between atmospheric circulation and deep convection. As it progresses, it is associated with large regions of both enhanced and suppressed rainfall, mainly over the Indian and western Pacific Oceans.
Monsoon	A monsoon is a tropical and subtropical seasonal reversal in both the surface winds and associated rainfall, caused by differential heating between a continental-scale land mass and the adjacent ocean. Monsoon rains occur mainly over land in summer.
Percentile	A percentile is a value on a scale of one hundred that indicates the percentage of the data set values that is equal to, or below it. The percentile is often used to estimate the extremes of a distribution. For example, the 90th (or 10th) percentile may be used to refer to the threshold for the upper (or lower) extremes.
Radiative forcing	Radiative forcing is the change in the net, downward minus upward, radiative flux (expressed in W m^{-2}) at the tropopause or top of atmosphere due to a change in an external driver of climate change, such as a change in the concentration of carbon dioxide or the output of the Sun.
Representative Concentration Pathways (RCPs)	Representative Concentration Pathways follow a set of greenhouse gas, air pollution (*e.g.* aerosols) and land-use scenarios that are consistent with certain socio-economic assumptions of how the future may evolve over time. The well mixed concentrations of greenhouse gases and aerosols in the atmosphere are affected by emissions as well as absorption through land and ocean sinks. There are four Representative Concentration Pathways (RCPs) that represent the range of plausible futures from the published literature.
Return period	An estimate of the average time interval between occurrences of an event (*e.g.* flood or extreme rainfall) of a defined size or intensity.
Risk	The potential for consequences where something of value is at stake and where the outcome is uncertain. Risk is often represented as a probability of occurrence of hazardous events or trends multiplied by the consequences if these events occur.
Risk assessment	The qualitative and/or quantitative scientific estimation of risks.
Risk management	The plans, actions, or policies implemented to reduce the likelihood and/or consequences of risks or to respond to consequences.

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Sub-tropical ridge (STR)	The sub-tropical ridge runs across a belt of high pressure that encircles the globe in the middle latitudes. It is part of the global circulation of the atmosphere. The position of the sub-tropical ridge plays an important part in the way the weather in Australia varies from season to season.
Southern Annular Mode (SAM)	The leading mode of variability of Southern Hemisphere geopotential height, which is associated with shifts in the latitude of the mid-latitude jet.
SAM index	The SAM Index, otherwise known as the Antarctic Oscillation Index (AOI) is a measure of the strength of SAM. The index is based on mean sea level pressure (MSLP) around the whole hemisphere at 40 °S compared to 65 °S. A positive index means a positive or high phase of the SAM, while a negative index means a negative or low SAM. This index shows a relationship to rainfall variability in some parts of Australia in some seasons.
SRES scenarios	SRES scenarios are emissions scenarios developed by Nakićenović and Swart (2000) and used, among others, as a basis for some of the climate projections shown in Chapters 9 to 11 of IPCC (2001) and Chapters 10 and 11 of IPCC (2007).
Uncertainty	A state of incomplete knowledge that can result from a lack of information or from disagreement about what is known or even knowable. It may have many types of sources, from imprecision in the data to ambiguously defined concepts or terminology, or uncertain projections of human behaviour. Uncertainty can therefore be represented by quantitative measures (*e.g.* a probability density function) or by qualitative statements (*e.g.* reflecting the judgment of a team of experts).
Walker Circulation	An east-west circulation of the atmosphere above the tropical Pacific, with air rising above warmer ocean regions (normally in the west), and descending over the cooler ocean areas (normally in the east). Its strength fluctuates with that of the Southern Oscillation.

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