WORKING DRAFT - CONFIDENTIAL

SOUTHERN 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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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.

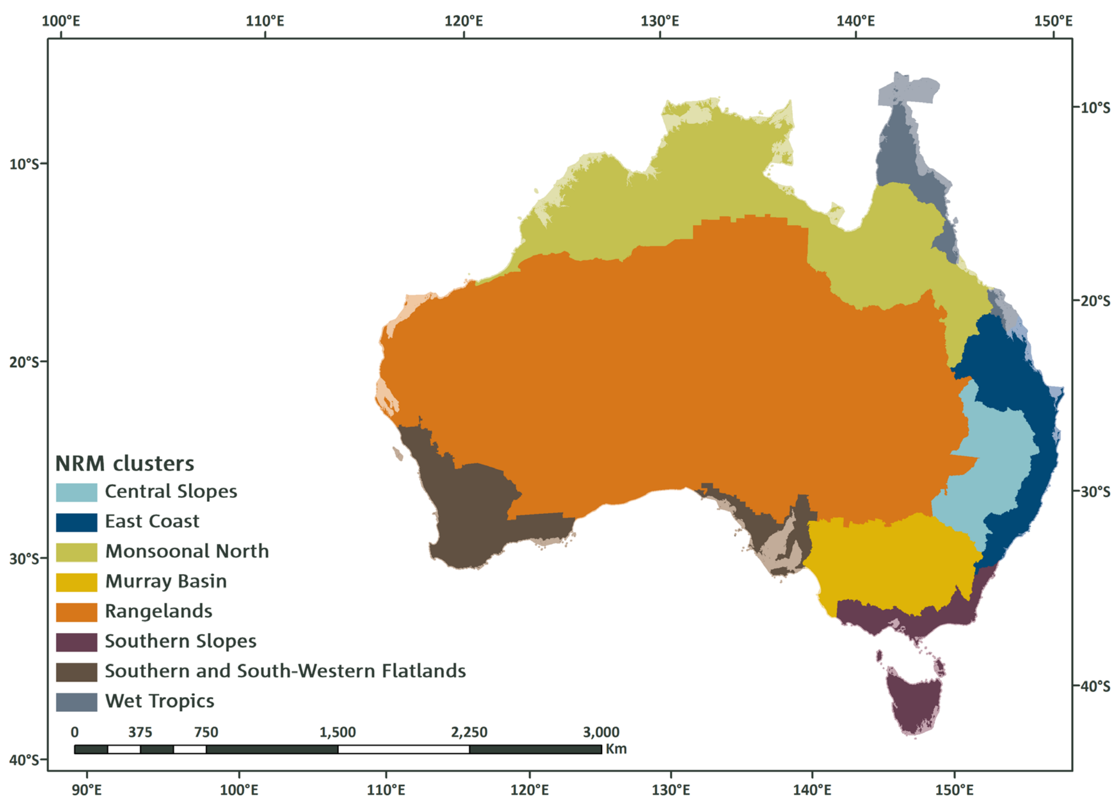

FIGURE A: THE EIGHT NATURAL RESOURCE MANAGEMENT (NRM) CLUSTERS

This is the regional projections report for the Southern 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.

WEBSITE

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 Southern Slopes 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. Sub-clusters will be reported on when their climate differs from the cluster mean. These sub-clusters are western Tasmania, eastern Tasmania, western Victoria and a fourth sub-cluster comprising eastern Victoria and south-east NSW (Figure 1.1). 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). The confidence ratings used here are set as *low*, *medium*, *high* or *very high* (IPCC, 2013).

HIGHER TEMPERATURES

Mean surface air temperatures across the sub-clusters increased in the last century, and particularly since 1960. Between 1910 and 2013, using a linear trend, mean temperature increased by 0.8 to 1.0 °C across all sub-clusters of the Southern Slopes.

Continued increases in mean, daily maximum and daily minimum temperatures are projected for the Southern Slopes cluster with *very high confidence*. There is *high confidence* in these projections as there is robust understanding of the driving mechanisms of warming as well as strong agreement on direction and magnitude of change amongst GCMs and downscaling results.

For the near future (2030), the projected increase of mean annual temperature is around 0.4 to 1.1 °C above the climate of 1986–2005, with only minor differences between RCPs. For late in the century (2090), there is a large difference between scenarios, with projected warming of 1.1 to 2.0 °C for RCP4.5 and 2.5 to 4.0 °C for RCP8.5.

HOTTER AND MORE FREQUENT HOT DAYS, FEWER FROSTS

A substantial increase in the temperature reached on the hottest days, the frequency of hot days and the duration of warm spells is projected with *very high confidence*, based on model results and physical understanding. Correspondingly, a decrease in the frequency of frost-risk days is projected with *high confidence*. For example, in Melbourne the annual average number of days above 35° C is projected to more than double by 2090 under RCP8.5 and median warming. For the same case, frost days in Hobart would reduce from around nine per year to become very rare events.

GENERALLY LESS RAINFALL IN WINTER AND SPRING, BUT WITH REGIONAL DIFFERENCES; LESS SNOW

The cluster experienced wet and dry decades through the 20th century, and shows a drying trend in rainfall since 1960, especially in autumn.

There is *high confidence* that natural climate variability will remain the major driver of rainfall changes by 2030. Changes in 20-year mean rainfall are about -10 to +5 % annually and about -20 to +15 % seasonally.

A good understanding of the driving mechanisms and high agreement between models means there is *high confidence* for rainfall decreases in winter and spring in this cluster under higher emissions (RCP8.5) from 2050 to 2090, but with some differences between sub-clusters and between seasons.

By 2090, spring rainfall is projected to decrease across every sub-cluster by around -25 to +5 % under RCP4.5 and -45 to +5 % under RCP8.5. Most models project a decrease in winter rainfall in Victoria of up to -15 % under RCP4.5 and up to -30 % under RCP8.5. An exception is for little change or an increase in winter in Tasmania (with -5 to +15 % change under RCP4.5 and -10 to +20 % under RCP8.5), given with *medium confidence*. Most models project little change in autumn, however this disagrees with post-1960 trends and there are known deficiencies in the simulation of the current climate in autumn. Therefore the autumn projection of little change is given with *low confidence*, and substantial decreases are also plausible. Statistical downscaling suggests a decrease in autumn rainfall in western Victoria is possible, in line with recent trends. Summer rainfall is projected to decrease in western Tasmania by 2090 by about -20 to +5 % under RCP4.5 and -25 to +5 % under RCP8.5 (*medium confidence*), and increases or decreases are possible in summer rainfall in Victorian sub-clusters.

Snowfall and maximum snow depth have declined significantly since 1960 and are projected to continue to decline for all RCPs with *very high confidence*, particularly under RCP8.5.

INCREASED INTENSITY OF HEAVY RAINFALL EVENTS, MORE TIME IN DROUGHT

Understanding of physical processes and high model agreement gives *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.

There is *medium confidence* that the time spent in meteorological drought will increase over the course of the 21st century in line with changes to mean rainfall, and the frequency and duration of extreme droughts will increase. Projected changes to drought vary by sub-cluster and are greater for RCP8.5 than for RCP4.5.

INCREASE IN MEAN WIND SPEED IN WINTER, FEWER BUT POSSIBLY MORE INTENSE CUT-OFF LOWS

Small changes are projected with *high confidence* for mean surface wind speed under all RCPs, by 2030. Increases in wind speeds in winter, primarily in western Tasmania are possible by 2090, in line with a strengthening winter 'Roaring Forties' circulation, with *medium confidence*. Literature suggests a decline in the number, but an increase in the intensity, of east coast lows, which would have an effect on both mean rainfall and heavy rain events, especially in the eastern districts of the Southern Slopes.

INCREASED SOLAR RADIATION AND REDUCED RELATIVE HUMIDITY IN WINTER AND SPRING

An increase in solar radiation and a decrease in relative humidity are projected in the winter and spring under RCP4.5 and RCP8.5 with *high confidence*. Changes in solar radiation and relative humidity are influenced by changes in rainfall (and associated changes to cloudiness) and temperature in the Southern Slopes. Projected changes in summer and autumn solar radiation and relative humidity are less clear.

INCREASED EVAPORATION RATES, AND REDUCED SOIL MOISTURE AND RUNOFF

There is *high confidence* that potential evapotranspiration will increase in Southern Slopes in all seasons by 2090, with largest absolute rates in summer. This is driven largely by increasing temperatures, but also changes to radiation, humidity and wind speed. However, the magnitude of change is projected with only *medium confidence* due to shortcomings in the simulation of observed historical changes.

Changes to rainfall and evapotranspiration are projected to lead to a decrease in soil moisture and runoff under RCP4.5 and RCP8.5 with *high confidence*. Changes in soil moisture and runoff are strongly influenced by changes in rainfall, but tend to be more negative due to the increase in potential evapotranspiration. More detailed hydrological modelling is needed to assess the magnitude of 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 to fire-weather. This depends on the rainfall projection, particularly its seasonal variation. Relative changes are comparable across all four sub-clusters.

HIGHER SEA LEVELS AND MORE FREQUENT SEA LEVEL EXTREMES

Relative sea level has risen around Australia at an average rate of 1.4 mm per year between 1966 and 2009, and 1.6 mm per year after the influence of the El Niño Southern Oscillation (ENSO) on sea level is removed.

There is *very high confidence* that sea level will continue to rise during the 21st century. In the near future (2030) the projected range of sea level rise for the cluster coastline is 0.07 to 0.19 m above the 1986–2005 level, with only minor differences between RCPs. As the century progresses, projections are sensitive to emissions pathways. By 2090, RCP4.5 gives a rise of 0.27 to 0.66 m, and RCP8.5 gives a rise of 0.39 to 0.89 m. These ranges of sea level rise are considered *likely* (at least 66 % probability). However, if a collapse in the marine based sectors of the Antarctic ice sheet were initiated, these projections could be several tenths of a metre higher by late in the century.

Taking into account the nature of extreme sea level along the Southern Slopes coastlines and the uncertainty in the sea level rise projections, an indicative value of extreme sea level 'allowance' is provided. This allowance is the minimum distance required to raise an asset to maintain current frequency of breaches under the projected sea level rise. For the Southern Slopes in 2030 the vertical allowances along the coastline are in the range of 12 to 15 cm for all RCPs and by 2090 are up to 59 cm for RCP4.5 and up to 83 cm for RCP8.5.

WARMER AND MORE ACIDIC OCEANS IN THE FUTURE

Sea surface temperature (SST) has increased significantly across the globe over recent decades and warming is projected to continue with *very high confidence*. Increases in the range of 1.6 to 5.1 °C by 2090 are projected under RCP8.5.

About 30 % of the anthropogenic carbon dioxide emitted into the atmosphere over the past 200 years has been absorbed by the oceans. This has led to a 0.1 pH fall in the ocean's surface water pH (a 26 % rise in acidity). Continued acidification will compromise the ability of calcifying marine organisms such as corals, oysters and some plankton to form their shells or skeletons. There is *very high confidence* that the ocean around Australia will become more acidic and also *high confidence* that the rate of ocean acidification will be proportional to carbon dioxide emissions. By 2030 pH is projected to fall by up to additional 0.08 units in the coastal waters of the cluster. By 2090, pH is projected to decrease by up to 0.16 under RCP4.5 and by up to 0.3 under RCP8.5.These values would represent a 40 % and 100 % increase in acidity respectively.

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 Southern 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 represents a particular change of interest (*e.g.* warmer and drier conditions).

1 THE SOUTHERN SLOPES CLUSTER

This report describes climate change projections for the Southern Slopes cluster, which is comprised of nine NRM regions in Tasmania, southern Victoria and south-east NSW (Figure 1.1). The cluster includes a range of bioclimatic zones, with sub-clusters being affected by a different set of dominant weather systems and climate drivers. There are also a variety of land uses, vegetation types and hydrology regimes within the cluster.

Given this variety, results are reported for the cluster as a whole and also four sub-clusters (Figure 1.1). These are: Western Victoria (Glenelg Hopkins; Corangamite; Port Philip and Westernport); Eastern Victoria and south-east New South Wales (West Gippsland; East Gippsland; the former NSW region of Southern Rivers), Western Tasmania (containing the North-West Tasmania NRM and the western half of NRM South) and Eastern Tasmania (containing virtually all of NRM North and the eastern half of NRM South). Since January 2014, the NRM regions of NSW have been reorganised into new Local Land Services (LLS) regions – Southern Rivers is now part of the Central Slopes cluster. All analysis for this project was based on the NRM and cluster boundaries set in January 2013.

This cluster includes many of the coolest, high-altitude regions of Australia as well as the extensive basalt plains of western Victoria and lowland coastal regions. Climate challenges for NRM planning activities for this cluster include increasing sea levels and bushfire risk; temperature and rainfall impacts on agriculture and other natural assets; and shifting habitats for terrestrial and marine flora and fauna.

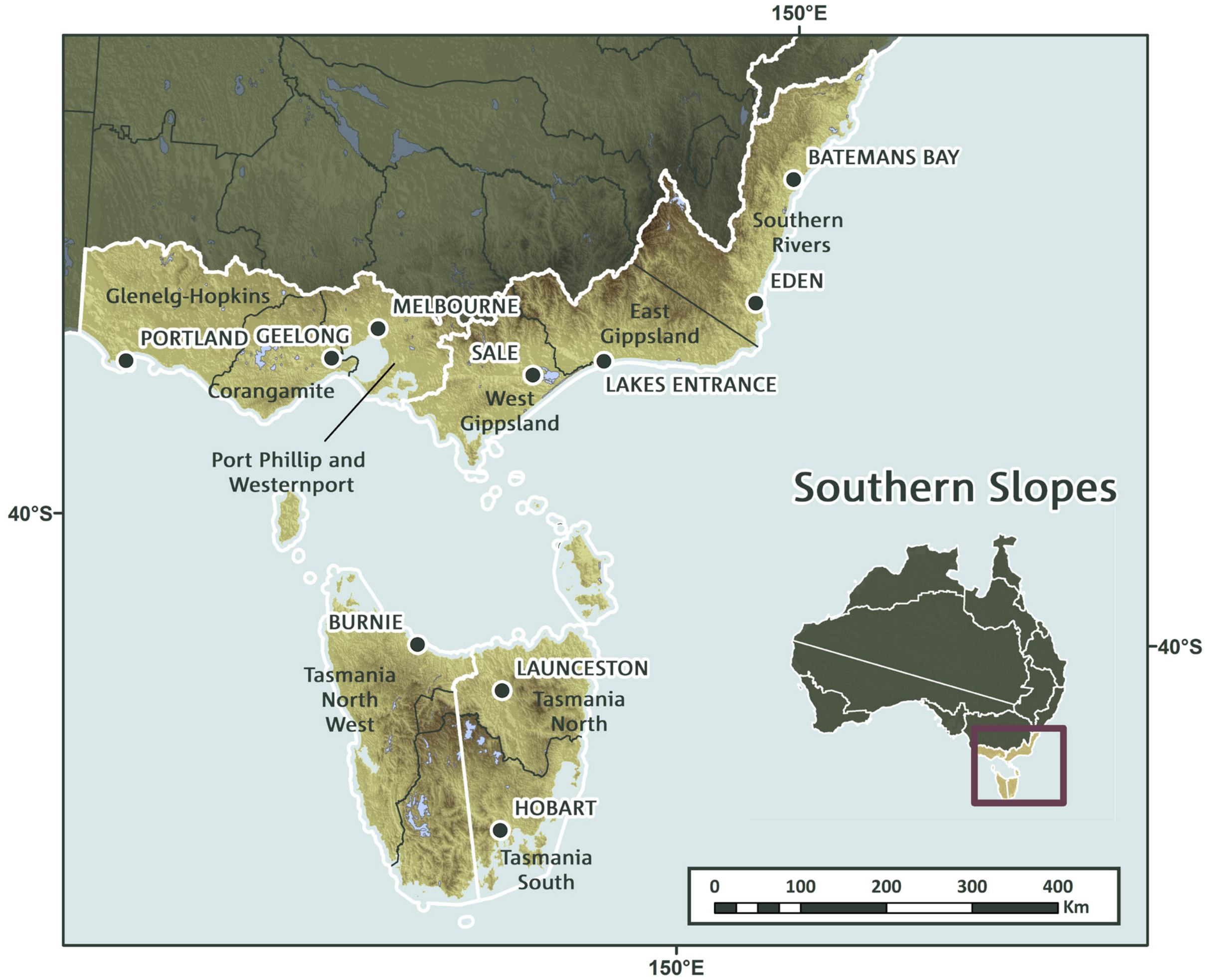

FIGURE 1.1: THE SOUTHERN SLOPES NRM CLUSTER, NRM REGIONS, EXAMPLE TOWN LOCATIONS AND SUB-CLUSTER BOUNDARIES (WHITE LINES), SHOWING SOUTHERN SLOPES VICTORIA WEST (SSVW), SOUTHERN SLOPES VICTORIA EAST AND SOUTH-EAST NSW (SSVE), SOUTHERN SLOPES TASMANIA WEST (SSTW) AND SOUTHERN SLOPES TASMANIA EAST (SSTE).

2 CLIMATE OF SOUTHERN SLOPES

The Southern Slopes cluster includes coastal regions of the south-east Australian mainland and Tasmania. The cluster spans an area stretching from Wollongong (34.4 °S) to the islands off South-east Cape in Tasmania (43.8 °S), and covering Australia's southernmost land areas (excepting sub-Antarctic islands). This cluster is within the 'extra-tropics' or 'mid-latitudes' of the global climate system, generally falling between the subtropical ridge of high pressure at approximately 30 °S (the descending arm of the Hadley Cell), and the northern edge of the so called 'Roaring Forties' of westerly circulation in 40 to 50 °S. As such, the cluster receives regular cold-fronts and troughs embedded in the westerly flow, as well as extra-tropical cyclones (low pressure systems). All NRM regions in the cluster have adjacent coastlines, so they experience relatively temperate, maritime climates. In the sections below, the current climate of Southern Slopes is presented for the period 1986–2005 (Box 3.1 presents the observational data sets used in this report).

The cluster has annual mean temperatures ranging from around 8 °C in the elevated regions of Tasmania and Victoria, to 14 °C in the lowland regions. Maps of mean temperature show the gradients in temperature from north to south and from low elevations to high elevations during winter and summer (Figure 2.1a, b). Highest daily mean temperatures are generally experienced during January in the lowland regions of Victoria and NSW, with a mean daily maximum temperature of over 24 °C (Figure 2.1c). Coldest temperatures are experienced in winter in the highland regions of the Australian Alps and Tasmania, with a mean daily maximum temperature of near 0 °C in July and regular snow above 1500 m (Figure 2.1d). Due to the maritime influence on temperatures, the seasonal cycle is moderate in each sub-cluster and lowest of all in western Tasmania (Figure 2.2).

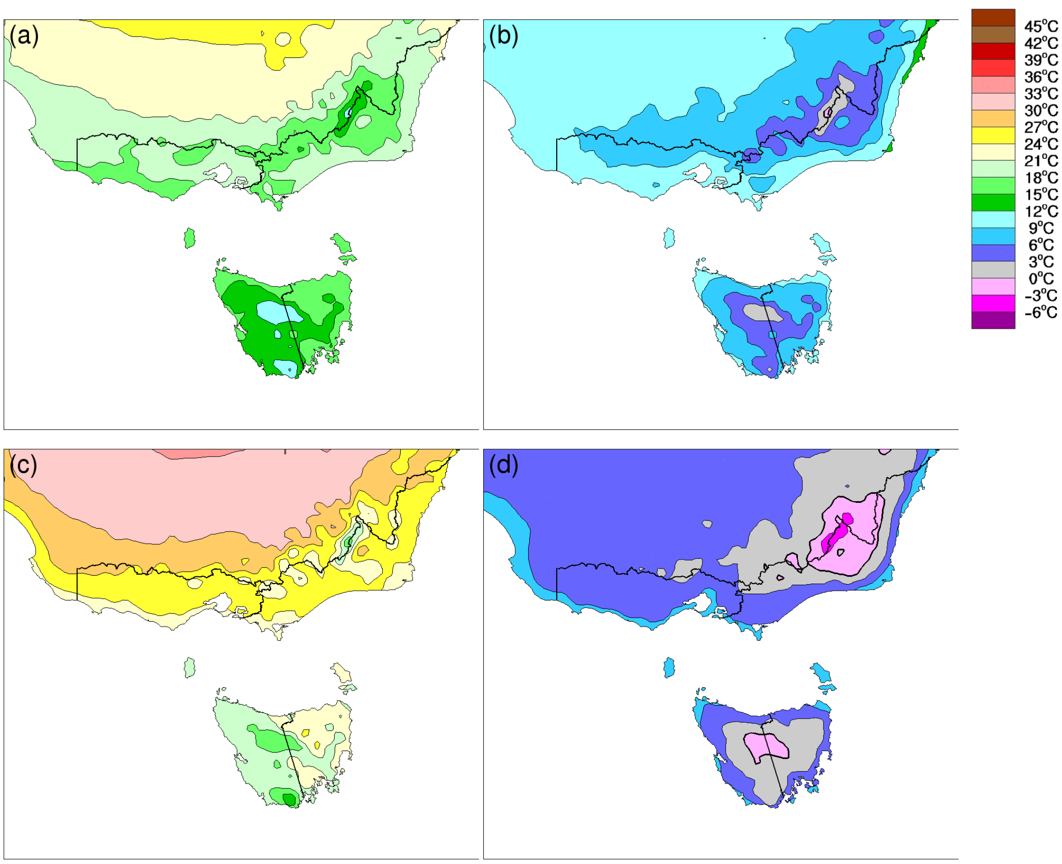

FIGURE 2.1: MAPS OF (A) AVERAGE SUMMER DAILY MEAN TEMPERATURE, (B) AVERAGE WINTER DAILY MEAN TEMPERATURE, (C) AVERAGE JANUARY MAXIMUM DAILY TEMPERATURE AND (D) AVERAGE JULY DAILY MINIMUM TEMPERATURE FOR THE PERIOD 1986–2005.

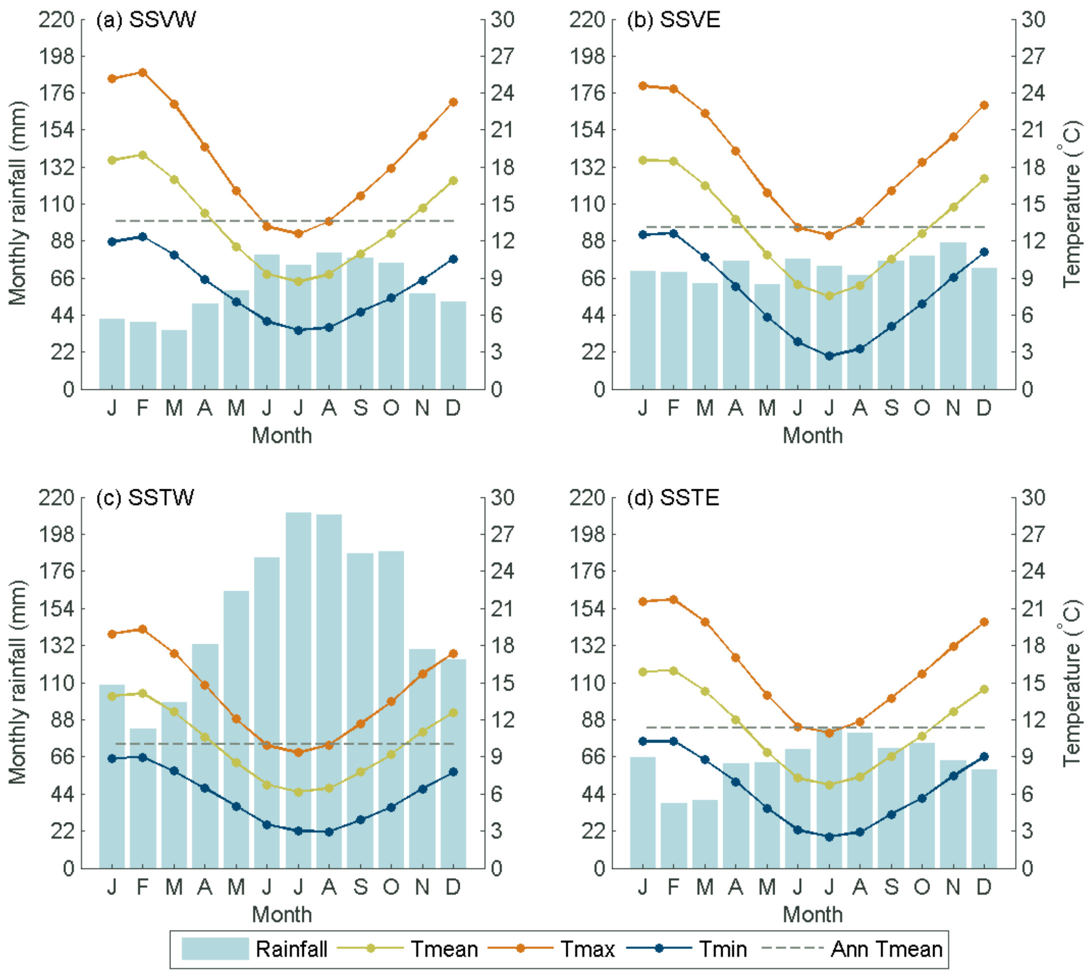

FIGURE 2.2: MONTHLY RAINFALL AND TEMPERATURE CHARACTERISTICS FOR THE SOUTHERN SLOPES CLUSTER (A) VICTORIA WEST, (B) VICTORIA EAST AND SOUTH-EAST NSW, (C) TASMANIA WEST, AND (D) TASMANIA EAST (1986–2005). *TMEAN* IS MONTHLY MEAN TEMPERATURE, *TMAX* IS MONTHLY MEAN DAILY MAXIMUM TEMPERATURE, *TMIN* IS MONTHLY MEAN DAILY MINIMUM TEMPERATURE AND *ANN TMEAN* IS THE ANNUAL AVERAGE OF MEAN TEMPERATURE (13.7 °C FOR SSVW, 13.1 °C FOR SSVE, 10.1 °C FOR SSTW AND 11.2 °C FOR SSTE). TEMPERATURE AND RAINFALL DATA ARE FROM AWAP.

The seasonal cycle of rainfall averaged across the sub-clusters shows that rainfall is typically higher in the cooler months (Figure 2.2). However, there are diverse rainfall regimes across the relatively small cluster of the Southern Slopes. In general, a winter-dominated seasonal cycle occurs in the western districts (May–October peak), with a more uniform seasonal cycle in the eastern districts (Figure 2.2). Perhaps the most distinct region is the extremely wet west coast of Tasmania, which receives over 3000 mm per year from very regular rainfall events. For example, on average at Mount Read there are over 200 rain days per year and more than 10 days of over 1 mm rainfall in every month of the year. There is a rain shadow region from the midlands of Tasmania across to the east coast which receives approximately 600 mm per year from more episodic events with a less distinct seasonal cycle (Figure 2.3). There are a range of rainfall amounts in southern Victoria and south-east NSW, which are also influenced by topography. The western Victoria region around Ararat, Hamilton and Warrnambool receives around 600–700 mm per year, with a distinct winter maximum (Figure 2.3). The coastal regions around Melbourne and Sale also receive around 500–700 mm per year, but with no distinct seasonal cycle. The highland regions receive more rainfall, around 1400 mm of precipitation as rain and snow, with some seasonal cycle in the western part of the Alps (*e.g.* Mount Buller), but a less distinct seasonal cycle further east (*e.g.* Mount Hotham). The eastern districts of Southern Slopes have high inter-annual variability in rainfall compared to some other regions of Australia and the globe, but lower than for the dry interior of Australia.

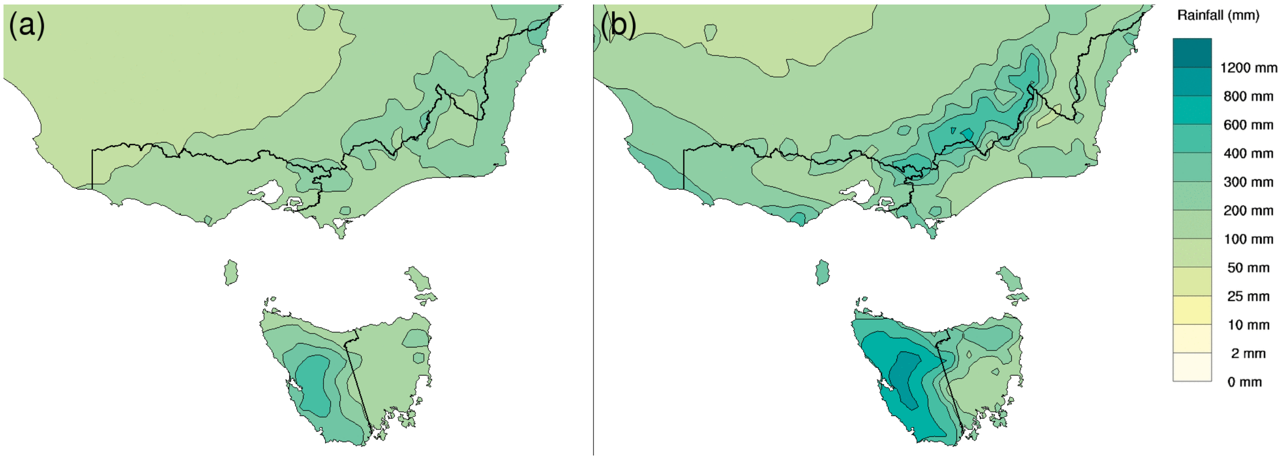

FIGURE 2.3: AVERAGE RAINFALL FOR THE 1986–2005 PERIOD FOR (A) SUMMER (DECEMBER TO FEBRUARY) AND (B) WINTER (JUNE TO AUGUST).

Seasonal rainfall characteristics in the Southern Slopes cluster are determined by complex interactions of several rainfall drivers that influence this region. The term 'driver' is used to signify a system or phenomenon that affects the generation of rainfall, and includes a range of synoptic weather features as well as remote influences on these weather systems. Many of the western districts of Southern Slopes receive rainfall primarily from the interaction between the regular fronts and troughs embedded in the westerly flow and the mountainous topography. The annual cycle of this westerly circulation, peaking in winter, drives the seasonal cycle of rainfall in these areas. The Southern Annular Mode (SAM) influences the rainfall variability in western Tasmania and some parts of western Victoria in winter and spring by affecting the strength and position of the westerly circulation. During winter, a high SAM tends to produce decreased rainfall over south-east Australia. However, during summer a high SAM is often associated with increased rainfall in the southern east coast of Australia but decreased rainfall in western Tasmania (Hendon *et al.*, 2007).

Similarly, atmospheric blocking by high pressure systems in the Tasman Sea also has an influence on the passage of westerly weather systems over the region, and has a negative correlation with rainfall in western Tasmania in spring and autumn (Risbey *et al.*, 2009). There is also a negative correlation between rainfall and the position and strength of the sub-tropical ridge (STR) of high pressure to the north, where a stronger or more southerly ridge is associated with reduced westerly flow and therefore generally lower rainfall, both in terms of year to year variability and long-term trends (Timbal and Drosdowsky, 2013).

Rainfall in eastern Tasmania, as well as many districts in Victoria and south-east NSW, is less influenced by the mid-latitude westerlies. A higher proportion of the rainfall in these regions instead comes from other systems such as extra-tropical cyclones, including cut-off lows (Pook *et al.*, 2013). There is also some influence on rainfall variability from the El Niño Southern Oscillation (ENSO) mainly in winter and spring; and from the Indian Ocean Dipole (IOD) peaking in spring, mainly in the west of Victoria and north-eastern Tasmania. When both the ENSO and IOD are in an extreme phase, the rainfall anomaly can be strongly affected. La Niña combining with a negative IOD phase generally brings wetter than average conditions, while an El Niño combining with a positive IOD phase generally brings drier than average conditions over much of Southern Slopes in the cooler months (Risbey *et al.*, 2009). The ENSO also has some influence on rainfall variability on the eastern seaboard during summer. Blocking is correlated with the incidence of cut-off lows on the east coast. Blocking shows a positive correlation with rainfall anomalies in much of the coastal Victoria, south-east NSW and north-east Tasmania in most seasons (Pook *et al.*, 2006).

Patterns in sea surface temperature (SST) affect the moisture content of the air masses, and hence also influence rainfall. For Southern Slopes, rainfall is influenced by the SST in the adjacent ocean basins, which is in turn affected by the ENSO and the IOD, as outlined above. Temperatures in the Southern Slopes can also be influenced by local SST conditions, including the temperatures in the Great Australian Bight and in the East Australia Current (EAC) running down the east coast of mainland Australia to Tasmania (Fierro and Leslie, 2013). For further details on ENSO, IOD, SAM and other drivers of rainfall variability, see Chapter 4 in the Technical Report.

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 that 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 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 Southern 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 Southern Slopes cluster, models performed well in simulating the timing and magnitude of the seasonal cycle for temperature (Figure 3.1a), with the multi-model mean slightly too warm through all months and a couple of models showing a low bias in summer. The majority of models adequately simulated the timing of the seasonal rainfall patterns, except for a tendency to underestimate winter to spring rainfall (Figure 3.1b). There is a fairly wide spread between rainfall simulations however, and some models show an over-estimation of winter rainfall or some biases in the timing of the annual cycle. The simulation of the annual cycle of mean sea level pressure (MSLP) is similar, with the multi-model mean being similar to observations. To see how the models performed across different parts of Australia, refer to Chapter 5 in the Technical Report.

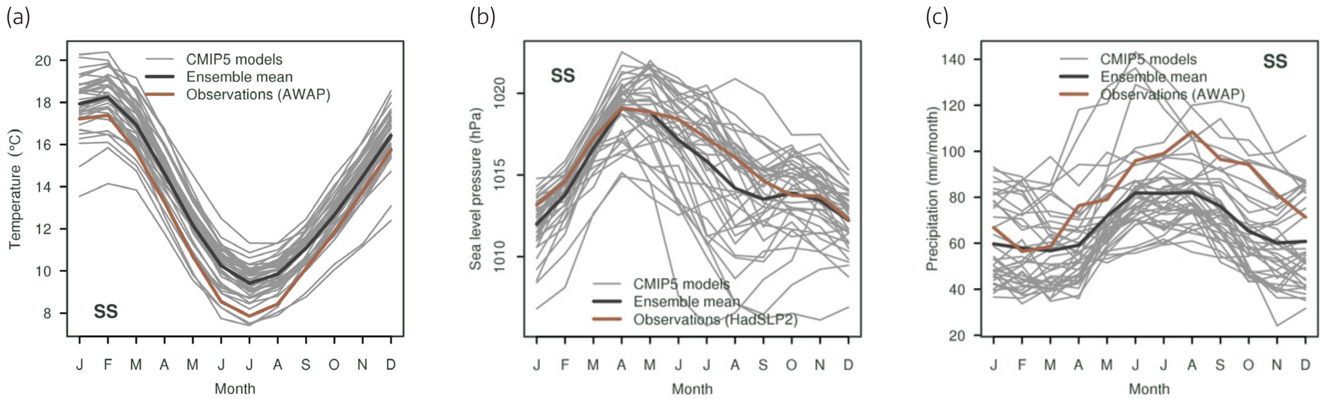

FIGURE 3.1: THE ANNUAL CYCLE OF (A) SURFACE AIR TEMPERATURE, (B) RAINFALL AND (C) MEAN SEA LEVEL PRESSURE IN THE SOUTHERN SLOPES CLUSTER SIMULATED BY CMIP5 MODELS (GREY LINES) WITH MODEL ENSEMBLE MEAN (BLACK LINE) AND OBSERVED CLIMATOLOGY (BASED ON AWAP FOR TEMPERATURE AND RAINFALL, AND HADSLP2 FOR SEA LEVEL PRESSURE) FOR THE BASELINE PERIOD 1986–2005 (BROWN LINE).

BOX 3.1: COMPARING MODELS AND OBSERVATIONS; EVALUATION PERIOD, 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 *Fifth Assessment Report* (IPCC, 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). For mean sea level pressure data, the HadSLP2 is used (Allan and Ansell, 2006).

The spatial resolution of climate model data (around 200 km between the edges of grid cells) is much coarser than observations. For Southern Slopes, approximately half of the CMIP5 models provide coverage only by partial grid cells (*i.e.* only 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.

The ability of the CMIP5 models to simulate key features of atmospheric circulation and modes of climatic variability has also been assessed. Specifically for Southern Slopes, the models adequately simulate the strength, location and seasonal cycle of the subtropical ridge of high pressure as well as the strength and location of the mid-latitude westerly winds. This is reflected in the simulation of MSLP through the year (Figure 3.1). However, both the location and timing of the circulation have biases in some models compared to observations. There are also biases in the relationship of these features to rainfall variability, such as the relationship between rainfall and the STR (Kent *et al.*, 2013). These biases affect the confidence in the regional rainfall projections for Southern Slopes.

The magnitude of the observed temperature trend between 1910 and 2005 is fairly well matched by the multi-model mean, but with a model spread around this mean (Figure 3.2a).

The magnitude of the observed trend between 1960 and 2005 is also matched closely by the multi-model mean (Figure 3.2b), however the distinct seasonal variation in observed temperature trends (high in winter, low in summer) is not present. Similarly, models simulate the increase in annual mean sea level pressure seen in observations, but do not capture the seasonal differences in this trend (Figure 3.3). In particular, models generally do not match the observed increase in MSLP during autumn. Rainfall trends in CMIP5 for 1960–2005 are not different to the equivalent observed trends to a statistically significant degree, except in autumn where the rainfall decline since the mid-1970s is not matched by models (Figure 3.4, J. Bhend, pers. comm. 2014). This discrepancy in MSLP and rainfall trends may indicate an effect of natural variability or a problem with the models, and is an ongoing area of research. For more information about the evaluation of drivers of rainfall variability, see Chapter 7 of the Technical Report.

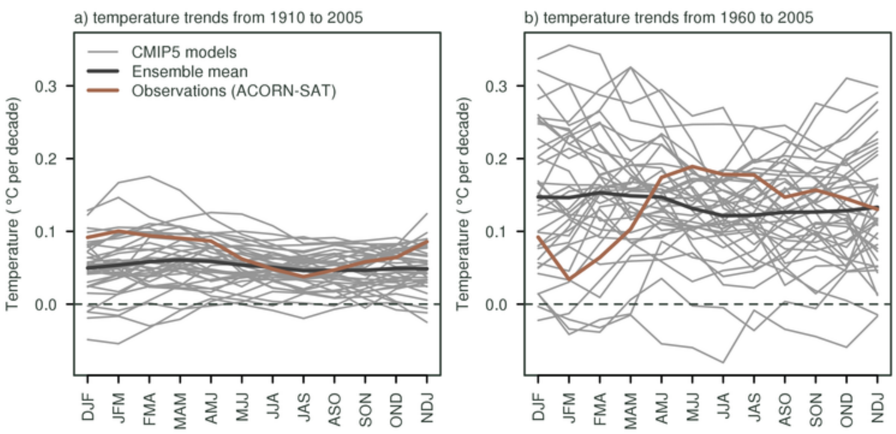

FIGURE 3.2: SIMULATED (GREY) AND OBSERVED (BROWN) SEASONAL TRENDS IN TEMPERATURE FROM 1910–2005 (A) AND 1960–2005 (B). THE SOLID BLACK LINE DENOTES THE MULTI-MODEL ENSEMBLE MEAN TREND. THE OBSERVED TREND IS CALCULATED FROM ACORN-SAT DATA (BROWN LINE). X-AXIS SHOWS THE THREE MONTHLY PERIODS, USING THE FIRST LETTER OF EACH MONTH.

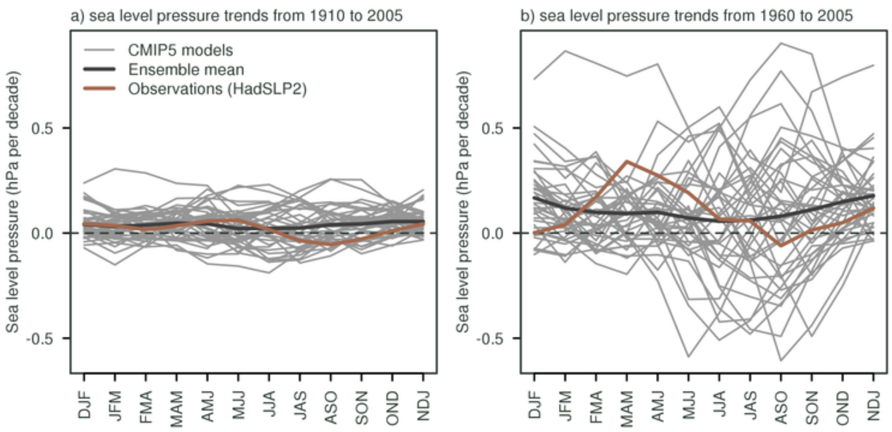

FIGURE 3.3: SIMULATED (GREY) AND OBSERVED (BROWN) SEASONAL TRENDS IN SEA LEVEL PRESSURE FROM 1910–2005 (A) AND 1960–2005 (B). THE SOLID BLACK LINE DENOTES THE MULTI-MODEL ENSEMBLE MEAN TREND. THE OBSERVED TREND IS CALCULATED FROM HADSLP2 DATA (BROWN LINE). X-AXIS SHOWS THE THREE MONTHLY PERIODS, USING THE FIRST LETTER OF EACH MONTH.

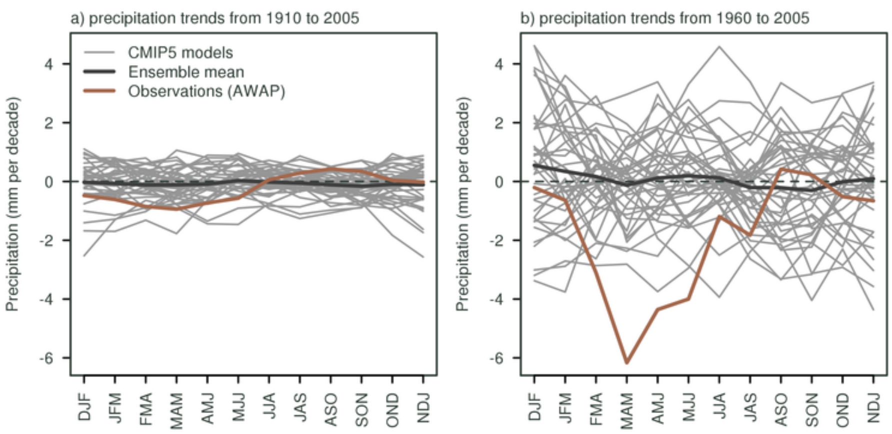

FIGURE 3.4: SIMULATED (GREY) AND OBSERVED (BROWN) SEASONAL TRENDS IN RAINFALL FROM 1910–2005 (A) AND 1960–2005 (B). THE SOLID BLACK LINE DENOTES THE MULTI-MODEL ENSEMBLE MEAN TREND. THE OBSERVED TREND IS CALCULATED FROM AWAP DATA (BROWN LINE). X-AXIS SHOWS THE THREE MONTHLY PERIODS, USING THE FIRST LETTER OF EACH MONTH

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 this report considers 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).

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4 THE CHANGING CLIMATE OF THE SOUTHERN 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 Southern 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. These 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 concentrations and 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 the Southern Slopes cluster, as simulated by the CMIP5 ensemble, should be viewed in the context of the confidence ratings 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)[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) and Table 3 (5th, 50th and 95th, for sea level rise) 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.

1 For sea level rise and sea allowance, the future averaging periods are 2020–2040 and 2080–2100. In the report, these are referred to as 2030 and 2090 respectively.

-20° -10° 0° 10° 20° 30° 40° 50°

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 Southern 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 estimates of the global climate sensitivity are still quite wide. 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 the *Fifth Assessment Report* (IPCC, 2013) Chapter 11 for further discussion of these issues.

The projections presented are accompanied by a confidence rating that follows that used by the IPCC in the *Fifth Assessment Report* (Mastrandrea *et al*., 2010). 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

Surface air temperatures in the cluster have been increasing since national records began in 1910, particularly since 1960 (Figure 4.2.1, Figure 4.2.2). Between 1910 and 2013, the mean temperature across the four sub-clusters rose by between 0.8 °C and 1.0 °C.

There is a difference between western sub-clusters and eastern sub-clusters in trends of daily maximum and daily minimum temperatures. Between 1910 and 2013, daily maximum temperatures increased by 1.0-1.1 °C in the western sub-clusters, but by 0.8-0.9 °C in the eastern sub-clusters. From 1910–2013, daily minimum temperatures increased by 0.6 to 0.7 °C in the west, but by 1.0 °C in the eastern sub-clusters using a linear trend.

Marked decadal variability can be seen when comparing long-term trends in daily minimum and maximum temperatures for the 20th century (Figure 4.2.3). Both records show an increase since the mid 20th century in all sub-clusters, but smaller trends in the early part of the record. Both records showed a negative trend from 1910 to 1950 in some sub-clusters. Periods of more rapid warming and less rapid warming since 1950 are partly related to global-scale changes as well as to regional-scale changes in circulation and rainfall (*e.g.* wet periods in the 1950s and 1970s in some sub-clusters, see Figure 4.3.1).

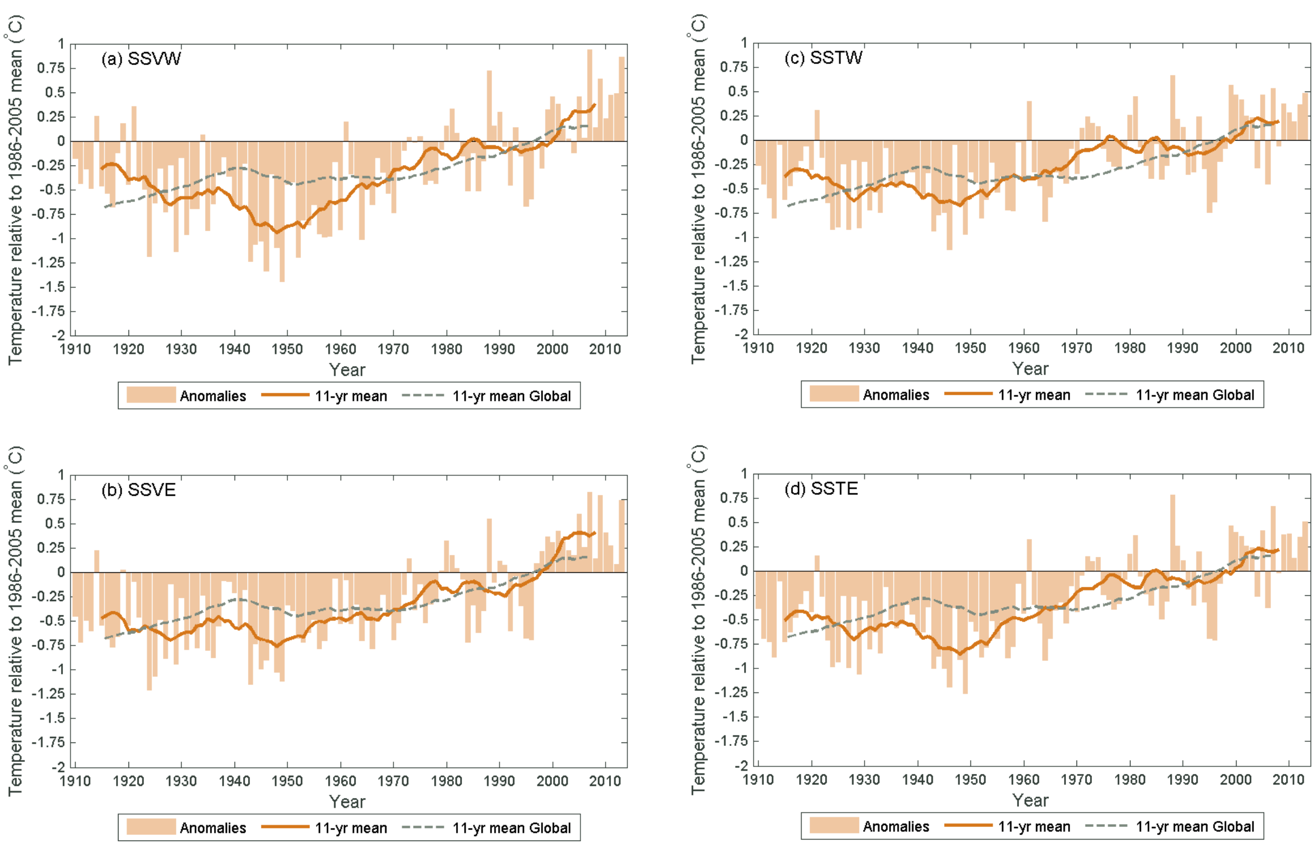


FIGURE 4.2.1: OBSERVED ANNUAL MEAN TEMPERATURE ANOMALIES (°C) FOR 1910–2013 COMPARED TO THE BASELINE 1986–2005 FOR THE SOUTHERN SLOPES CLUSTER VICTORIA WEST, (B) VICTORIA EAST, (C) TASMANIA WEST AND (D) TASMANIA EAST. CLUSTER AVERAGE DATA ARE FROM ACORN-SAT AND GLOBAL DATA ARE FROM HADCRUT3V (BROHAN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

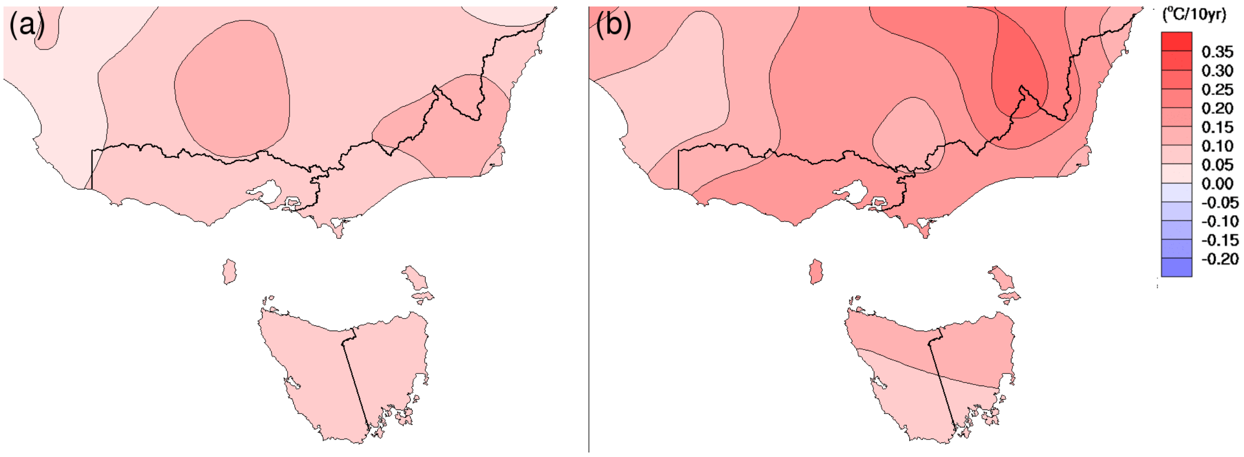


FIGURE 4.2.2: MAPS OF TREND IN MEAN TEMPERATURE (°C/10YEARS) FOR (A) 1910–2013 AND (B) 1960–2013 (ACORN-SAT).

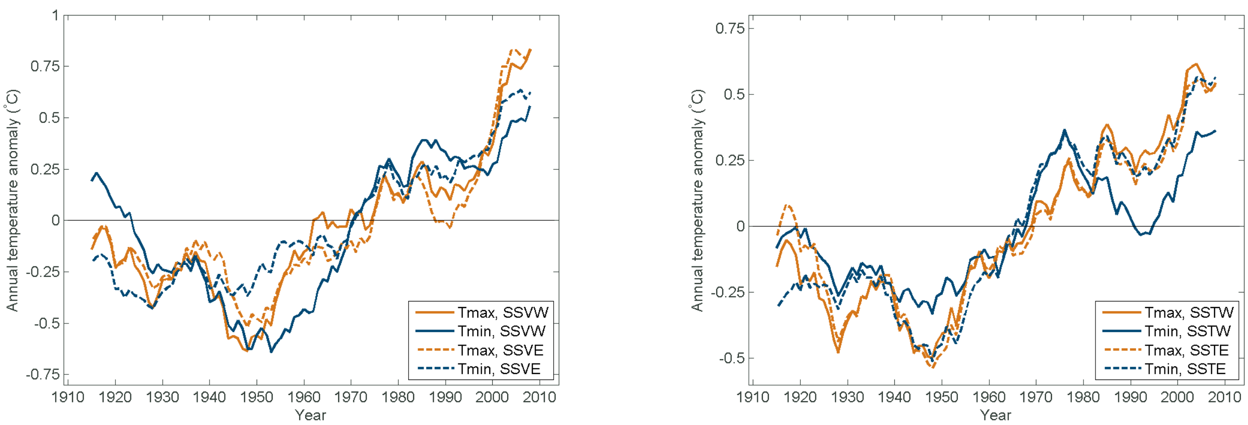
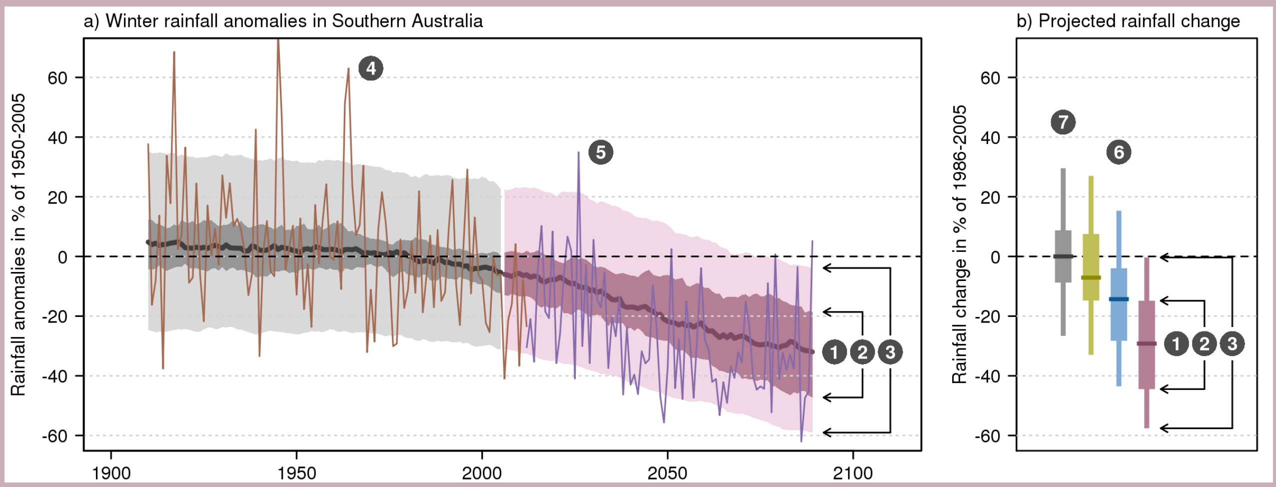


FIGURE 4.2.3: OBSERVED ANNUAL MEAN OF DAILY MAXIMUM (ORANGE LINE) AND MINIMUM (BLUE LINE) TEMPERATURE (°C, 11-YEAR RUNNING MEAN), PRESENTED AS ANOMALIES RELATIVE TO THEIR RESPECTIVE 1910–2013 MEAN VALUE (ACORN-SAT). THE LEFT PANEL SHOWS VICTORIA WEST (SOLID LINE) AND VICTORIA EAST (DASHED LINE). THE RIGHT PANEL SHOWS TASMANIA WEST (SOLID LINE) AND TASMANIA EAST (DASHED LINE).

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).

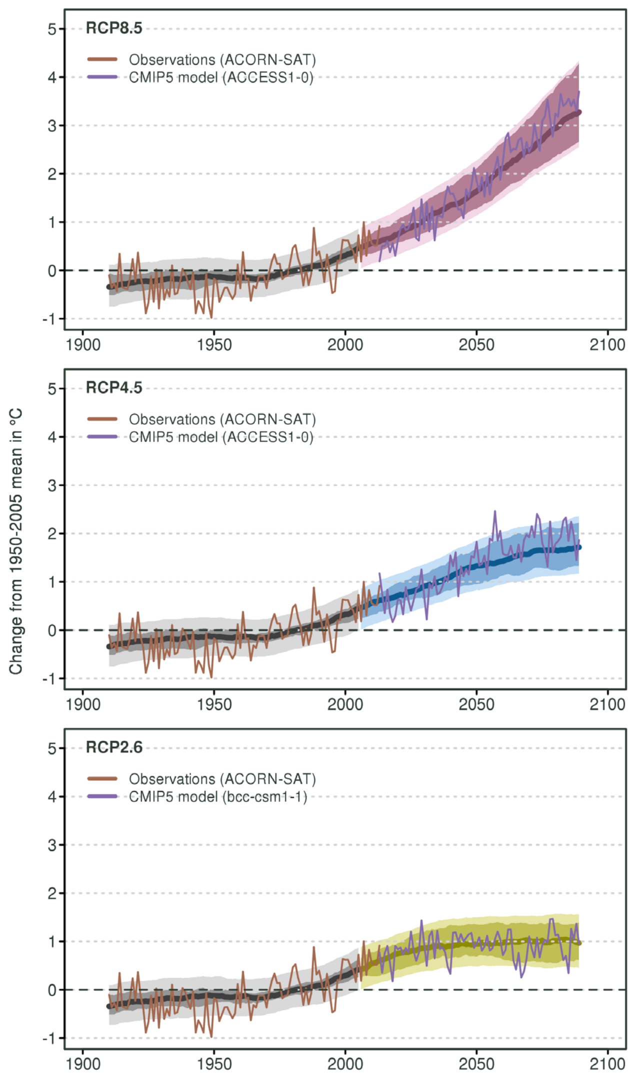


FIGURE 4.2.4: TIME SERIES FOR SOUTHERN SLOPES ANNUAL AVERAGE SURFACE AIR TEMPERATURE (°C) FOR 1910–2090, AS SIMULATED IN CMIP5 RELATIVE TO THE 1950–2005 MEAN. THE CENTRAL LINE IS THE MEDIAN VALUE, AND THE SHADING IS THE 10TH AND 90TH PERCENTILE RANGE OF 20-YEAR MEANS (INNER) AND SINGLE YEAR VALUES (OUTER). 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 SHOWN. TIME SERIES PLOTS ARE EXPLAINED IN BOX 4.2.

The Southern Slopes cluster is projected to warm throughout the 21st century, with a rate that strongly follows the increase in global greenhouse gas concentrations (Figure 4.2.4). A table of the projected range of warming for various time slices and RCPs is given at the end of the report (Table 1 in the Appendix). For 2030, the annual warming across the cluster is 0.4 to 1.1 °C (10th to 90th percentile), with only minor difference between the scenarios. The projected temperature range for 2090 shows larger differences with 1.1 to 2.0 °C for RCP4.5 and 2.5 to 4.0 °C (for RCP8.5).

These 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 by 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. This comparison also illustrates that individual model runs produce temporal variability similar to that of observed temperature, as well as a warming trend. Further, future warming shows inter-annual variability of similar magnitude to that of observed data (*e.g.* the over-laid observational time series stays largely within the lightly shadowed band representing the 10th and 90th year to year variability of the model ensemble). Overall there is good agreement between model and observed data on decadal scales.

Overall, the warming rates of the Southern Slopes cluster are slightly lower than the majority of other clusters of Australia, and particularly lower than the inland regions (see Figure 7.1.4 in the Technical Report). This is consistent with a global pattern of projections, where continental regions are projected to warm more than coastal regions.

Changes to the spatial pattern of temperature in the cluster can be illustrated by adding the projected change in annual mean temperature onto the mapped observed climatology. Figure 4.2.5 gives an example of this for 2090 following the high emission scenario RCP8.5 and the median warming from the CMIP5 models, corresponding to a global warming of 3.7 °C. This shows the increase relative to local mean temperature, such as an increase in coastal Victoria from within the range 11 to 17 °C for the current climate, up to a range of about 15 to 21 °C.

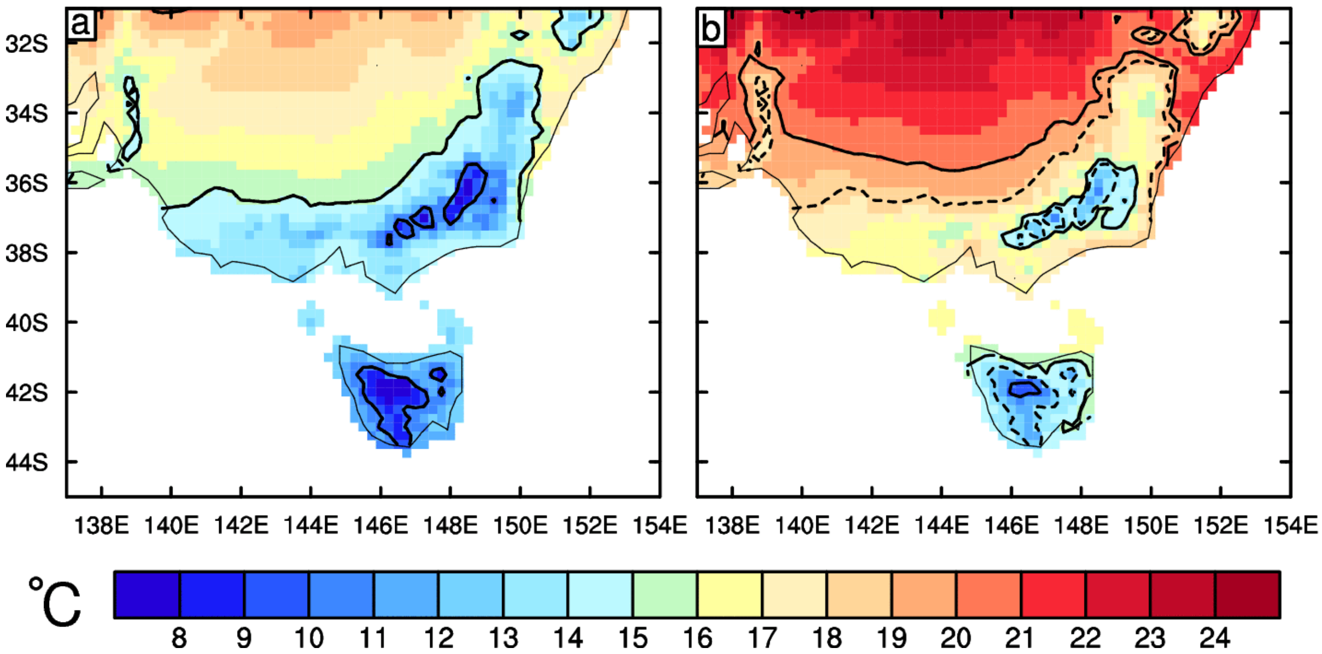


FIGURE 4.2.5: ANNUAL MEAN SURFACE AIR TEMPERATURE (°C), FOR THE PRESENT CLIMATE (A), AND FOR MEDIAN WARMING UNDER RCP8.5 FOR 2090 (B). THE PRESENT IS USING AWAP FOR 1986–2005, BASED ON A 0.25 DEGREE GRID (LATITUDE / LONGITUDE. FOR CLARITY, THE 10, 15 AND 20 °C CONTOURS ARE SHOWN WITH SOLID BLACK LINES. IN (B) THE SAME CONTOURS FROM THE ORIGINAL CLIMATE ARE PLOTTED AS DOTTED LINES.

For the Southern Slopes cluster, projected warming is similar in all seasons, with some models simulating somewhat larger warming in summer and autumn than in other seasons (Figure 4.2.6). Projected changes for both daily maximum and minimum temperature largely follow largely those of the mean temperature; albeit with somewhat lower warming in daily minimum temperatures than daily maxima in autumn, winter and spring (Table 1 in the Appendix and Figure 4.2.6).

The two sets of downscaling results for the cluster indicate generally similar ranges of mean temperature change as the GCMs (Figure 4.2.7). However, the statistical downscaling indicates an enhanced response in daily maximum temperature increase in spring compared to the models used as input (Figure 4.2.7b). This is a plausible projection, and may be the result of the greater resolution of regional climate influences such as local sea surface temperatures in the statistical downscaling compared to GCMs. Projections for the Climate Futures for Tasmania project are broadly consistent with the new CMIP5 results once the difference in emissions scenarios is accounted for.

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

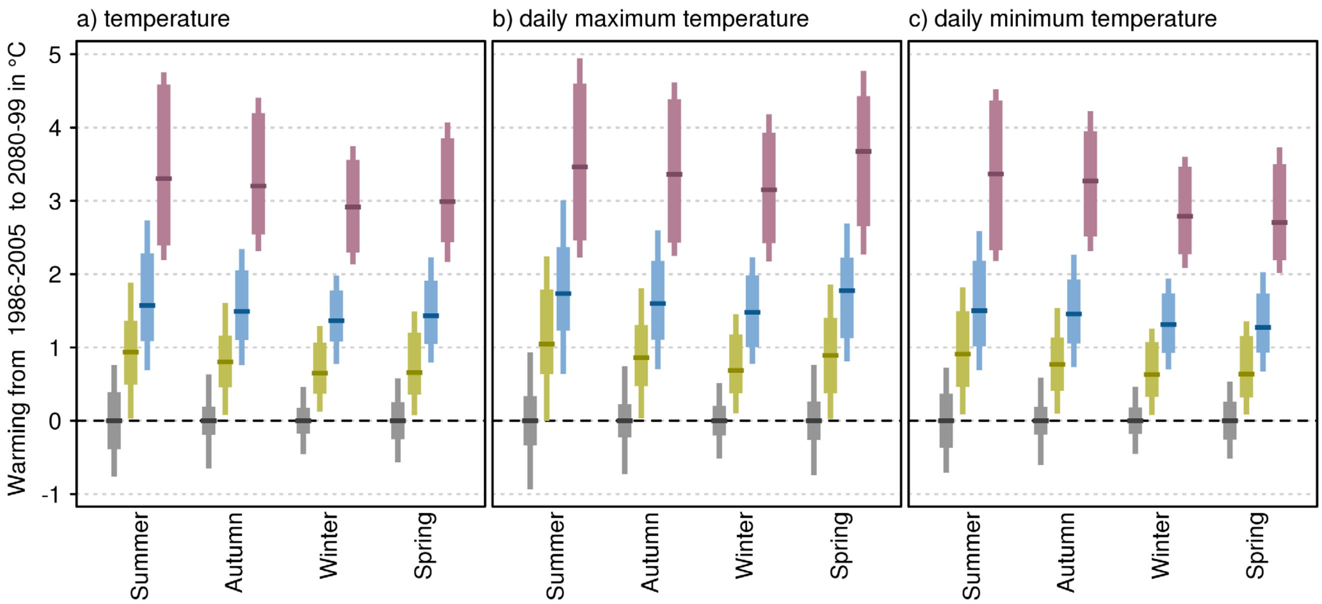


FIGURE 4.2.6: PROJECTED SEASONAL SURFACE AIR TEMPERATURE CHANGES FOR 2090. GRAPHS SHOW CHANGES TO THE (A) MEAN, (B) DAILY MAXIMUM AND (C) DAILY MINIMUM TEMPERATURE. TEMPERATURE ANOMALIES ARE GIVEN IN °C WITH RESPECT TO 1986–2005 MEAN UNDER RCP2.6 (GREEN), RCP4.5 (BLUE) AND RCP8.5 (PURPLE). NATURAL CLIMATE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

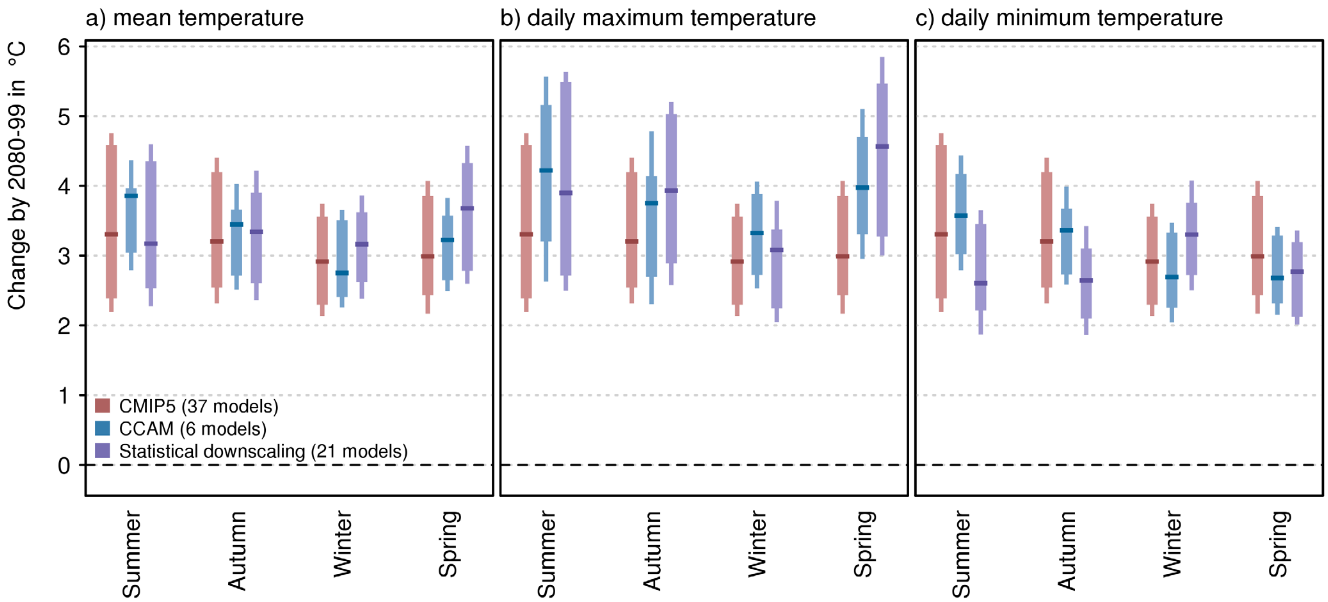


FIGURE 4.2.7: PROJECTED CHANGE IN SOUTHERN SLOPES SEASONAL SURFACE AIR TEMPERATURE FOR 2090 USING CMIP5 GCMS AND TWO DOWNSCALING METHODS (CCAM AND SDM) UNDER RCP8.5 FOR THE (A) MEAN, (B) DAILY MAXIMUM AND (C) DAILY MINIMUM. TEMPERATURE ANOMALIES ARE GIVEN IN °C WITH RESPECT TO THE 1986–2005 MEAN. BAR 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 a similar rate as projected mean temperature with a substantial increase in the number of warm spell days. For late in the century (2090), the 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), is similar to the projected warming of the daily maximum and mean temperatures (discussed in the Section above). The GCM projections also indicate a marked increase in a warm spell index, which is defined as the annual count of days with at least six consecutive days with a cluster average temperature maximum above the 90th percentile (as an example, the 90th percentile in temperature maximum for East Sale, Victoria, is 26.9 °C based on historical data for August 1945 to June 2014).

Given the similarity in projected warming for the mean and annual 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 of maximums for 1981–2010 at selected sites. This is illustrated in Box 4.3, where it can be seen that the number of days above 35 °C in Melbourne doubles by late in the century (2090) under RCP8.5 and median model warming.

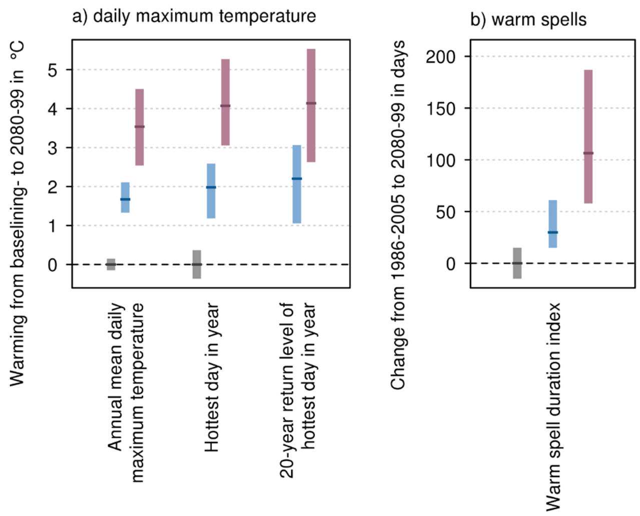


FIGURE 4.2.8: PROJECTED CHANGES IN SURFACE AIR TEMPERATURE EXTREMES BY 2090 IN (A) MEAN DAILY MAXIMUM TEMPERATURE, HOTTEST DAY OF THE YEAR AND THE 20-YEAR RETURN VALUE OF THE HOTTEST DAY OF THE YEAR (°C); AND (B) CHANGE IN THE NUMBER OF DAYS IN WARM SPELLS FOR SOUTHERN SLOPES (SEE TEXT FOR DEFINITION OF VARIABLES). RESULTS ARE SHOWN FOR 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 HOBART AND MELBOURNE?

To illustrate what the CMIP5 projected warming implies for changes to the occurrence of hot days and frost days in Hobart (Tas) and Melbourne (Vic), 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 the 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 °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°C AND BELOW 2 °C (FROSTS) FOR BATTERY POINT (TAS) AND MELBOURNE (VIC) 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	HOBART (TAS EAST)				MELBOURNE (VIC WEST)			
	CURRENT	2030 RCP4.5	2090 RCP4.5	2090 RCP8.5	CURRENT	2030 RCP4.5	2090 RCP4.5	2090 RCP8.5
Over 35 °C	1.6	2.0 (1.9 to 2.1)	2.6 (2.0 to 3.1)	4.2 (3.2 to 6.3)	11	13 (12 to 15)	16 (15 to 20)	24 (19 to 32)
Below 2 °C	9.1	5.8 (6.9 to 3.7)	2.1 (4.1 to 1.1)	0.3 (0.6 to 0.1)	0.9	0.6 (0.8 to 0.4)	0.2 (0.3 to 0.1)	0.0 (0.0 to 0.0)

4.3 MEAN SEA LEVEL PRESSURE

Changes in Mean Sea level Pressure (MSLP) are important to rainfall change in the Southern Slopes cluster, as this represents changes to the mean atmospheric circulation and therefore the incidence of rain-bearing weather systems. Of particular interest are the position and intensity of the sub-tropical ridge (STR) of high pressure. MSLP has been increasing in recent decades (see also Section 3). Analysis of the CMIP5 simulations confirms that most climate models project an increase in the intensity of the STR, dependent on the magnitude of the projected warming. This intensification is 0.24 hPa/ °C in CMIP3 models (Kent *et al.*, 2013). An ongoing intensification and poleward shift of the STR is consistent with the observed trend in the last 30 years as well as the observed global scale changes to circulation. Projections indicate a consensus amongst models toward a further broadening of the mean meridional circulation, of which the STR is a crucial component (IPCC, 2013).

Increases in the intensity of the STR generally imply a reduction in rainfall in many regions of southern Australia in observations. This is to be expected since low pressure systems tend to be associated with rainfall. If there are fewer low pressure systems, while at the same time high pressure systems are more persistent, the local pressures would increase on average and we would expect drier conditions overall. The latitude of this band of high pressure is also important. Thus, a poleward shift in the location of the STR also implies a reduction in rainfall in regions of southern Australia where the STR is currently immediately to the north (Whan *et al.*, 2014). The STR shifts with season, and hence different locations are impacted in different seasons. Rainfall reductions are expected, due to a southward shift in the STR, in regions such as western Victoria in winter and spring, but in western Tasmania during spring and summer.

Mean sea level pressure is projected to increase over southern Australia, including a small increase during summer, but a much larger increase during winter and spring, which is the time of the year where the relationship between the STR intensity and rainfall in much of southern Australia is most important. In Southern Slopes specifically, the projected increase is greatest in winter and spring, with model mean changes of over 1 hPa under RCP8.5 by 2090 (Figure 4.3.1, see also Table 1 in the Appendix). Since these projections are consistent with theory and recent trends, there is *high confidence* about the increase in MSLP, and that the magnitude is proportional to warming. These MSLP future projections are expected to translate into a rainfall decrease in winter and spring. However, the confidence in the regional rainfall projections in response to these pressure changes is reduced because the relationship between inter-annual variability in STR and rainfall anomalies is poor in many CMIP3 models (Kent *et al.*, 2013). Preliminary work shows that this is also the case in many CMIP5 models.

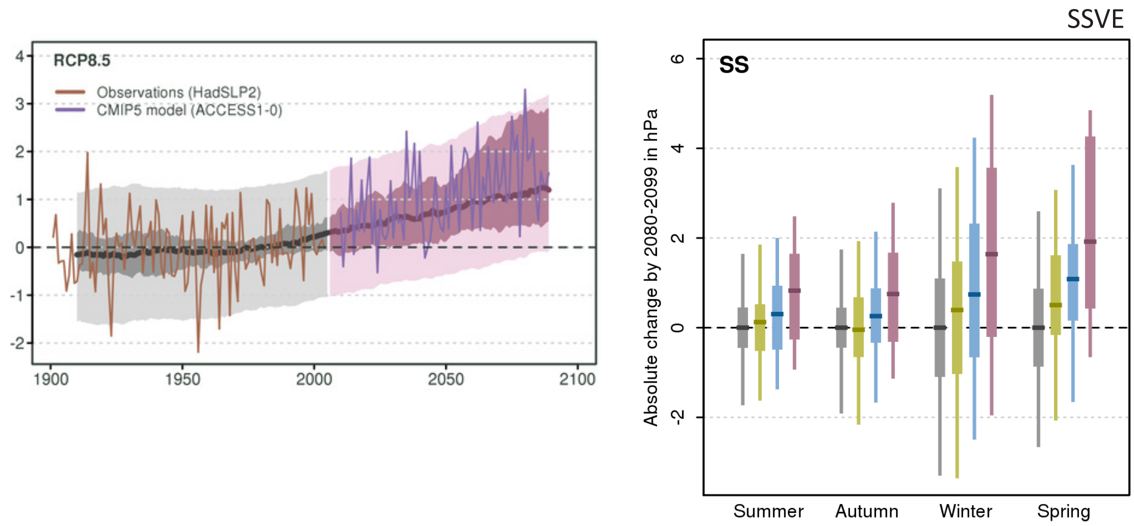


FIGURE 4.3.1: ON THE LEFT IS A TIME SERIES ANOMALY FOR ANNUAL MEAN SEA LEVEL PRESSURE (HPA) ACROSS THE SOUTHERN SLOPES FOR 1910–2100, FROM HADSLP2 OBSERVATIONS AND CMIP5 MODELS, RELATIVE TO THE 1950–2005 MEAN. THE CENTRAL LINE IS THE MEDIAN VALUE, AND THE SHADING IS THE 10TH AND 90TH PERCENTILE RANGE OF 20-YEAR MEANS (INNER) AND SINGLE YEAR VALUES (OUTER). THE GREY SHADING INDICATES THE PERIOD OF THE HISTORICAL SIMULATION. SIMULATED VALUES FROM A TYPICAL MODEL ARE SHOWN INTO THE FUTURE (PURPLE LINE). ON THE RIGHT IS A BAR PLOT OF MSLP CHANGE (HPA) FOR 2090 UNDER RCP2.6 (GREEN), RCP4.5 (BLUE) AND RCP8.5 (PURPLE), FOR EACH SEASON, WITH GREY BARS SHOWING NATURAL CLIMATE VARIABILITY. BAR PLOTS ARE EXPLAINED IN BOX 4.2.

4.4 RAINFALL

In Southern Slopes there were wet years during the 1950s and 1970s, and a very dry period in the late 1990s and 2000s known as the Millennium drought (Figure 4.4.1). Overall, there has been a generally negative trend in mean annual rainfall since the mid-1970s (Figure 4.4.1). There are also differences between sub-clusters during some periods. For example, the wet period seen in the late 1980s and early 1990s, and the dry periods observed during the late 1930s and early 1940s (the World War II drought), are more pronounced in the northern sub-clusters compared to Tasmania.

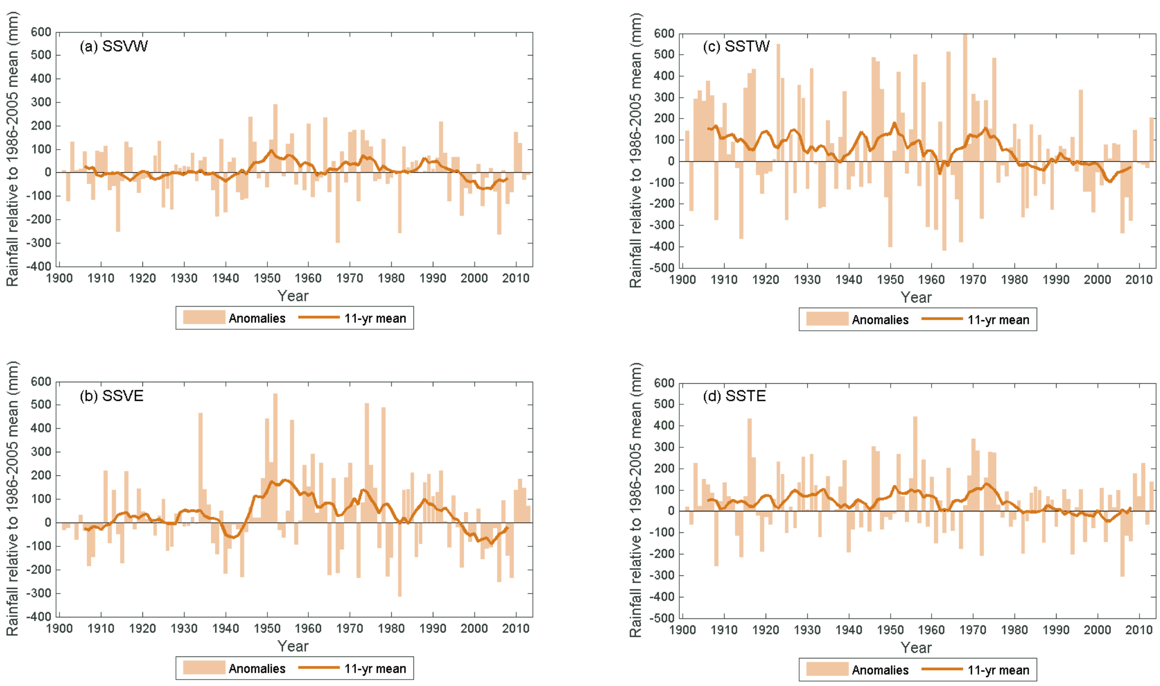


FIGURE 4.4.1: OBSERVED ANNUAL RAINFALL ANOMALIES (MM) FOR 1901–2013 COMPARED TO THE BASELINE 1986–2005 FOR SOUTHERN SLOPES CLUSTER (A) VICTORIA WEST, (B) VICTORIA EAST, (C) TASMANIA WEST AND (D) TASMANIA EAST DATA ARE FROM AWAP.

Seasonal rainfall trends across the Southern Slopes also vary by region. For the full duration of the rainfall record (1901–2012), the trends were generally small (less than 5 mm/decade). These trends included an increase during winter, spring and summer in the northern districts (Figure 4.4.2 (a), (c), (d)) and a decrease in all areas in autumn (Figure 4.4.2(b)). In many cases, trends during the shorter 1960–2012 period showed a similar spatial pattern but were greater in magnitude than for the longer period, such as the consistent decrease in autumn (Figure 4.4.2 (f)). However, during winter and spring there was a consistent decrease across most of the northern districts in this period (Figure 4.4.2 (g), (h)).

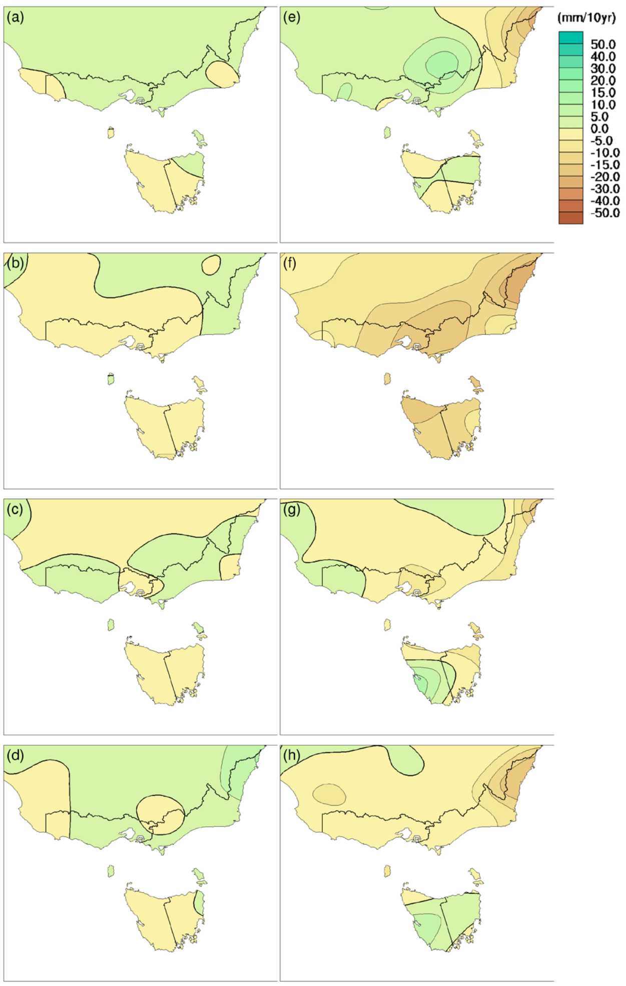


FIGURE 4.4.2: MAPS OF SEASONAL RAINFALL TRENDS (MM/DECADE). THE LEFT COLUMN OF MAPS SHOWS TRENDS FOR (A) SUMMER, (B) AUTUMN, (C) WINTER AND (D) SPRING FOR 1901–2013. THE RIGHT COLUMN SHOWS TRENDS FOR (E) SUMMER, (F) AUTUMN, (G) WINTER AND (H) SPRING FOR 1960–2013.

The influence of the sub tropical ridge (STR) on rainfall trends in south-east Australia has been described in some detail by Timbal and Drosdowsky (2013). The authors show that the 1997 to 2009 decrease in autumn-spring rainfall could be linked to a weakening of the westerly flow, which is in agreement with a strengthening of a high pressure belt to the north, such as the 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 while dry conditions characterised much of the region around the turn of the century, recent years have seen some average and wet years during some seasons in the Southern Slopes. This occurred along with extreme flooding during summer in some other Australian regions as a consequence of extraordinary La Niña conditions, and possibly in combination with a return to cold phase Interdecadal Pacific Oscillation (IPO) conditions (Cai and van Rensch, 2012).

Projections from CMIP5 show a reduction of mean annual rainfall across the Southern Slopes in almost all models. The magnitude of this reduction is proportional to the RCP (Figure 4.4.3), and is substantial compared to natural variability by 2050 under the higher RCPs (not shown). Changes in 20-year annual mean rainfall by 2030 are about - 10 to +5 % annually and about -20 to +15 % seasonally, primarily due to natural variability (see Table 1 in the Appendix).

Under RCP8.5 by 2090, the trend is marked, but smaller than the full range of inter-annual variability, and also comparable to decadal variability. The mean annual rainfall that results from the projected changes can be seen by overlaying the rainfall climatology in the current climate with a change factor from the model results (Figure 4.4.4). This shows the spatial pattern of mean annual rainfall in the current climate (centre) and the equivalent annual rainfall in each end of the range of models. The 10th percentile of the model range on the left and the 90th percentile case on the right of projected rainfall for 2090 following the high emission scenario (for a global warming of 3.7 °C). The plots show a general shift in mean rainfall over the entire region, but with some regional differences in the changes.

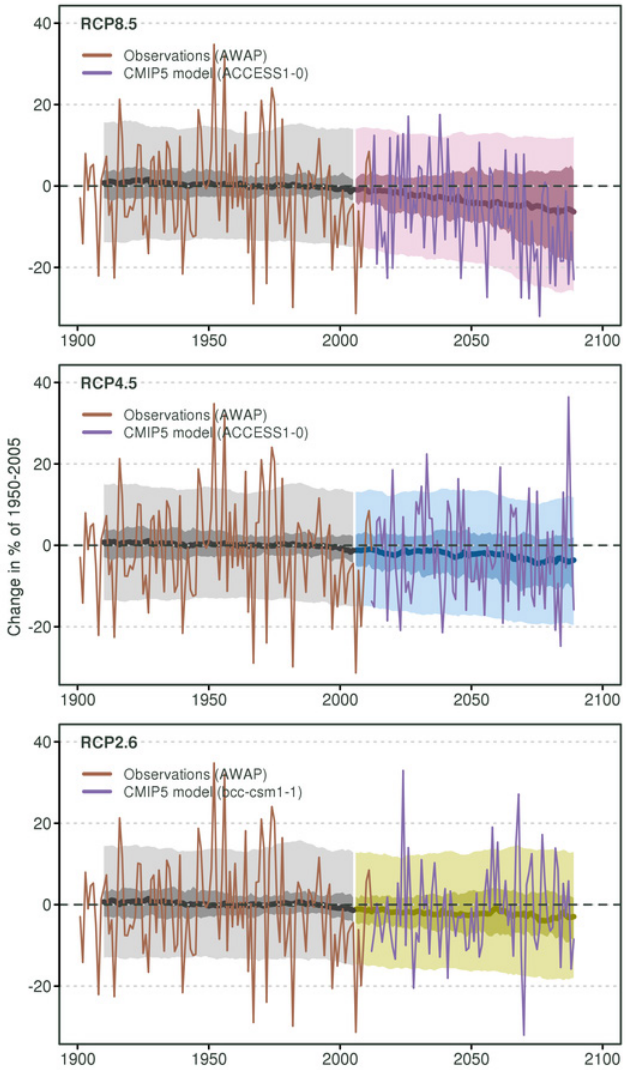


FIGURE 4.4.3: TIME SERIES FOR THE SOUTHERN SLOPES ANNUAL RAINFALL FOR 1910–2090, AS SIMULATED IN CMIP5 EXPRESSED AS A PERCENTAGE RELATIVE TO THE 1950–2005 MEAN. THE CENTRAL LINE IS THE MEDIAN VALUE, AND THE SHADING IS THE 10TH AND 90TH PERCENTILE RANGE OF 20-YEAR MEANS (INNER) AND SINGLE YEAR VALUES (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.

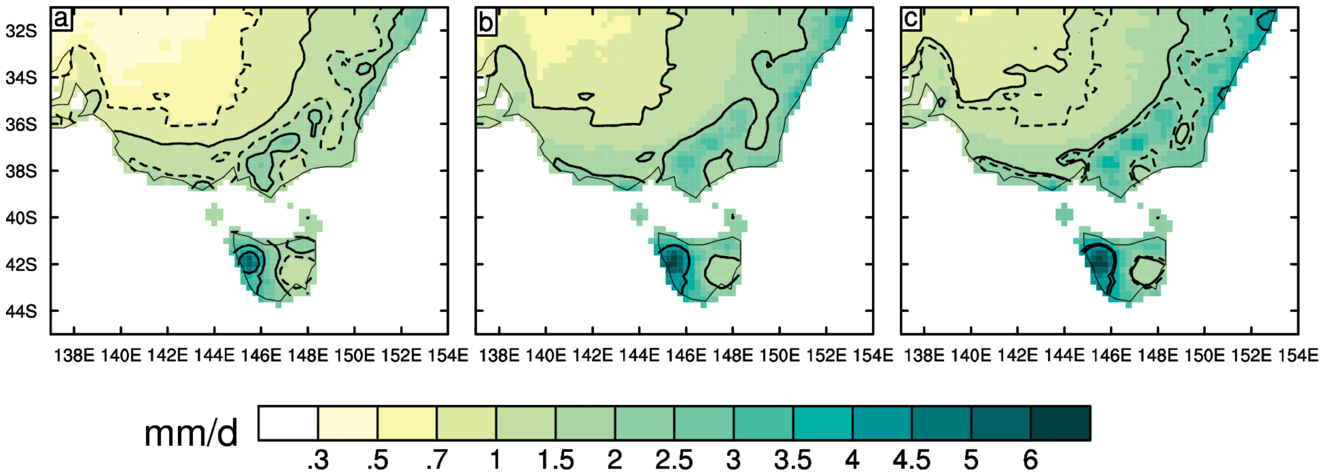


FIGURE 4.4.4: ANNUAL MEAN RAINFALL (MM/DAY), FOR THE PRESENT CLIMATE (B), AND THE DRIER END OF THE PROJECTED MODEL RANGE (A) AND WETTER END OF THE PROJECTED MODEL RANGE (C). THE PRESENT CLIMATE USES THE AWAP DATASET FOR 1986–2005, BASED ON A 0.25 DEGREE LATITUDE / LONGITUDE GRID). THE DRIER AND WETTER CASES USE THE 10TH AND 90TH PERCENTILE CHANGE AT 2090 FOR RCP8.5. FOR CLARITY, THE 0.5, 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.

-20° -10° 0° 10° 20° 30° 40° 50°

While mean annual rainfall is projected to decrease, there are some different changes in each sub-cluster and in each season, illustrated by bar plots for RCP8.5 by 2090 for each sub-cluster (Figure 4.4.5). There are some important differences in the direction of change, such as the decrease in summer rainfall in Tasmania in many models compared to the small change in the two northern sub-clusters. In contrast, winter rainfall is projected to stay the same or decrease in the northern sub-clusters, but is projected to increase in Tasmania. Some trends in the western districts appear slightly different from the equivalent eastern district. Further differences have been revealed through downscaling of climate models (see below).

Rainfall declines are strongest in winter and spring. By 2090 most models project a decrease in winter rainfall in Victoria of -15 to +5 % under RCP4.5 and -30 to +5 % under RCP8.5; but an increase in Tasmania of -5 to +15 % under RCP4.5 and -5 to +20 % under RCP8.5. In particular, spring rainfall is projected to decrease across every sub-cluster, with the strongest decline projected for western Victoria with a model range of -25 to -5 % under RCP4.5 and -45 to -5 % under RCP8.5 by 2090. Summer rainfall is projected to decrease in western Tasmania by 2090 by about -20 to +5 % under RCP4.5 and -25 to +5 % under RCP8.5, while either increases or decreases in summer rainfall are possible in Victorian sub-clusters. There is little change projected for autumn in all the sub-clusters. The changes in spring and autumn are the reverse of those observed in recent decades, where autumn declines have been more significant than spring changes. This 'seasonal paradox' between past trends and projected changes is an area of ongoing research.

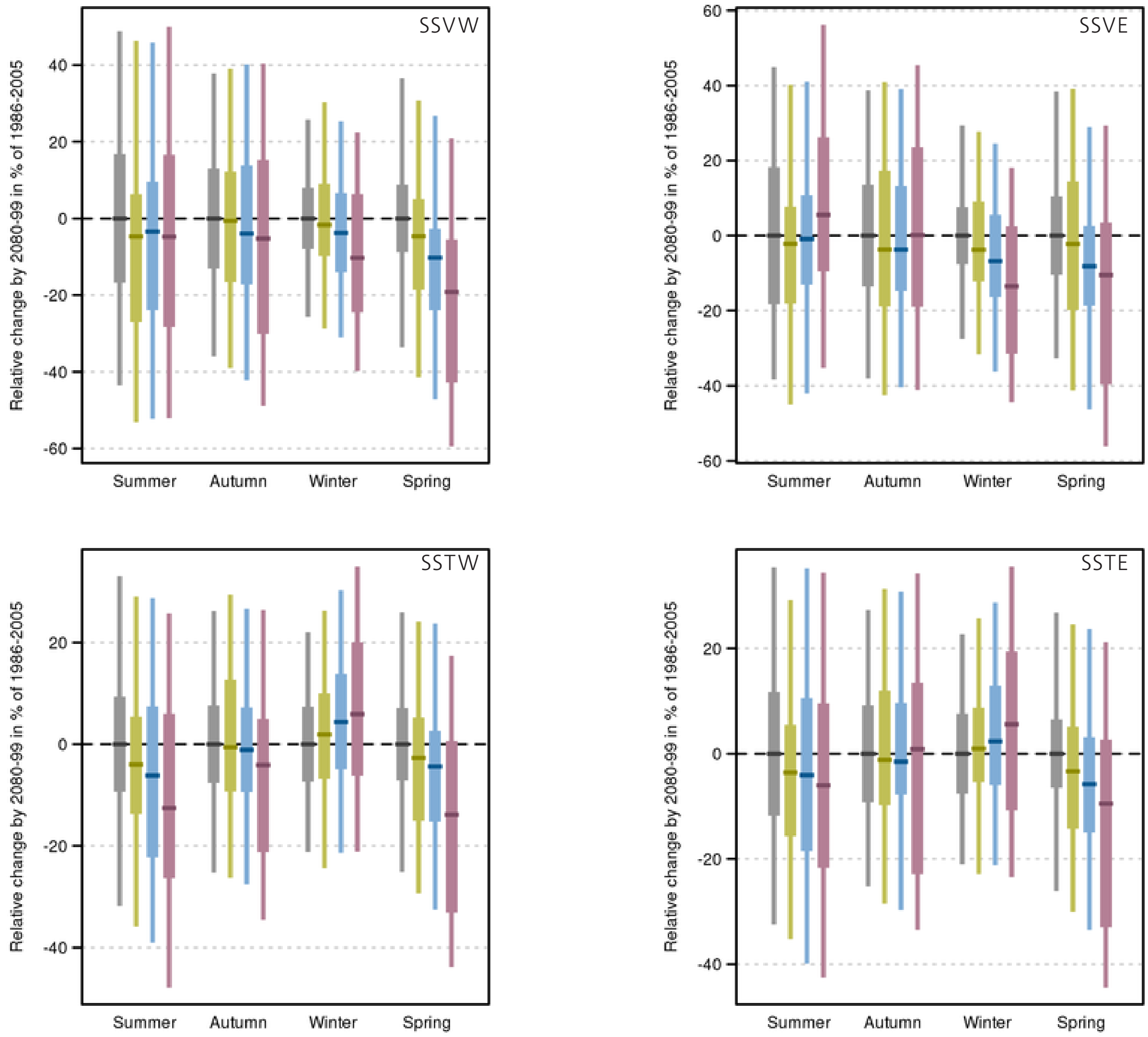


FIGURE 4.4.5: PROJECTED SEASONAL RAINFALL CHANGES FOR THE SOUTHERN SLOPES SUB-CLUSTERS FOR 2090. RAINFALL ANOMALIES ARE GIVEN IN PER CENT WITH RESPECT TO THE 1986–2005 MEAN UNDER RCP2.6 (GREEN), RCP4.5 (BLUE) AND RCP8.5 (PURPLE) FOR 2090. NATURAL CLIMATE VARIABILITY IS REPRESENTED BY THE GREY BAR. TOP LEFT IS VICTORIA WEST, TOP RIGHT IS VICTORIA EAST AND SOUTH-EAST NSW, BOTTOM LEFT IS TASMANIA WEST, AND BOTTOM RIGHT IS TASMANIA EAST. BAR PLOTS ARE EXPLAINED FURTHER IN BOX 4.2.

The circulation changes in the cooler months that include a strengthening and southerly movement of the STR are part of a broader trend for poleward expansion of the tropics. This means that in Victoria the cooler six months are projected to get drier and a greater proportion of the annual rainfall coming from the warmer half-year (November to April) (Figure 4.4.6). In contrast, the seasonal cycle is projected to be enhanced over Tasmania, with a lesser proportion of rain falling in the already drier warmer half-year and more in the already wetter cooler half-year. However, the interpretation of this result is complicated by the presence of a bias in the location of this boundary in the current climate in the models compared to observations. See Figure 4.4.6 (a) and (b).

Due to the varied nature of the cluster, downscaling has the potential to be of benefit in revealing detail in the projected climate change signal. Statistical downscaling results show a greater rainfall decline in autumn in western Victoria than the GCMs, which is more in line with recent trends (see above regarding the 'seasonal paradox' issue). Downscaling for the Climate Futures for Tasmania project found a plausible difference in projected change between western and eastern Tasmania in summer and autumn (decreases in the west but not along the east coast) and to some extent in winter (increases over much of Tasmania, except for the east coast). This is consistent with a difference in the influence of western circulation that is present in these regions (Grose *et al*., 2013). The dynamical and statistical downscaling done for this NRM project confirms that some difference between eastern and western Tasmania is plausible in many cases. However, Climate Futures for Tasmania results show little trend in spring rainfall across all of Tasmania, which is in contrast with a decrease projected by CMIP3 models, CMIP5 models, and new downscaling (including a newer version of the CCAM model that was used in Climate Futures for Tasmania). This appears to be related to the pressure response of this particular configuration of CCAM (Grose *et al*., Submitted). Thus the Climate Futures for Tasmania results are at the wetter end of the plausible range of spring rainfall projections.

Regarding confidence in these projections, there is a range of considerations. Firstly, there is *high confidence* that natural climate variability will remain a major driver of rainfall changes by 2030 even as anthropogenic changes become apparent. The high model agreement and understanding of the circulation changes involved means that a general decrease in winter and spring rainfall in western Victoria by 2090 is given with *high confidence*, and an increase in western Tasmania in winter is given with *medium confidence*. However, the magnitude and spatial pattern of change is less certain due to the effect of model bias, and the disagreement with past trends in autumn and spring, and this reduces our confidence in the seasonal expression of changes. GCMs project little change or a chance of substantial decrease in western Victoria in autumn, however statistical downscaling projects a substantial decline in line with recent trends, so a decrease is projected with *medium confidence*. A decrease in summer rainfall is also projected for Tasmania with *medium confidence*, and downscaling suggests this may be restricted to the western half of Tasmania with other influences important in the east. The rainfall changes on the eastern coasts are more complex since there are other influences involved and coarse GCMs do not adequately resolve the local rainfall regime. Downscaling offers the possibility of 'added value' in these regions, however the results of downscaling are not unanimous. Therefore the changes in the east coast (see Figure 4.4.5) are presented with *low confidence*.

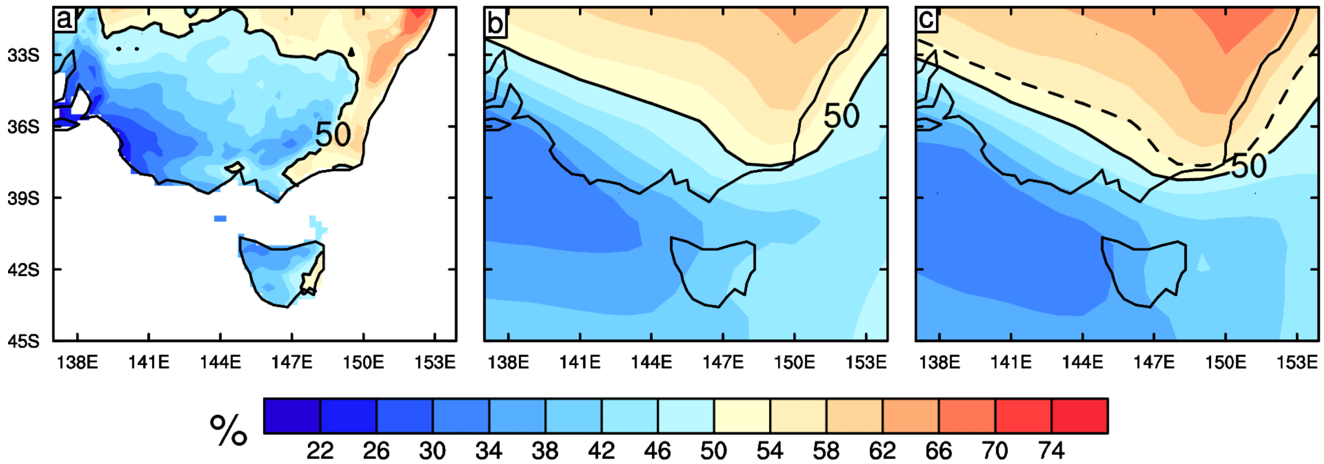


FIGURE 4.4.6: PERCENTAGE OF ANNUAL RAIN THAT FALLS IN THE WARMER SIX MONTHS (NOVEMBER TO APRIL): (A) OBSERVED 1986–2005 (AWAP); (B) FROM CMIP5 40 MODEL MEAN FOR 1986–2005; AND FOR (C) CMIP5 26 MODEL MEAN FOR 2080–2099. THE 50 PER CENT CONTOUR LINE, WHICH INDICATES THE BOUNDARY BETWEEN THE SUMMER AND WINTER DOMINATED ZONES, IS SHOWN (SOLID). THE DASHED LINE IN (C) REFERS TO THE 50 PER CENT LINE SHOWN IN THE MODEL SIMULATED CURRENT CLIMATE (B).

4.4.1 HEAVY RAINFALL EVENTS

The frequency of heavy rainfall events and associated flooding is projected to increase in many regions of Southern Slopes, even where projected changes to average rainfall are small or negative. 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).

The CMIP5 models simulate an increase in the magnitude of the annual maximum 1-day value and the magnitude of the 20-year return value for the period 2080–2099 relative to the baseline period 1986–2005 (Figure 4.4.7 for RCP8.5) where a 20-year return value is equivalent to a 5 % chance of occurrence within any one year. Comparing the trend in the two extreme indices with that of the annual mean rainfall (Figure 4.4.7) clearly shows that while the projection for mean rainfall is tending towards decrease in the cluster, the extremes are projected to increase. The magnitude of this increase in heavy rainfall events is more clearly differentiated from natural variability than average rainfall. This pattern (change in mean relative to extremes) is found in all other NRM clusters, and is also supported by results from other studies (see Technical Report Section 7.2.2). The results support the findings of the Climate Futures for Tasmania project, once the difference in emission scenarios is accounted for. An additional finding from this project was that the east coast of Tasmania may experience particularly strong increases in daily and sub-daily extremes during late summer and autumn (White *et al*., 2013).

The magnitudes of the changes in extreme rainfall are strongly dependent on the emission scenario and time into the future. Furthermore, the magnitude of the changes 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 magnitude of change, and thus the time when any change may be evident against natural fluctuations, cannot be reliably projected.

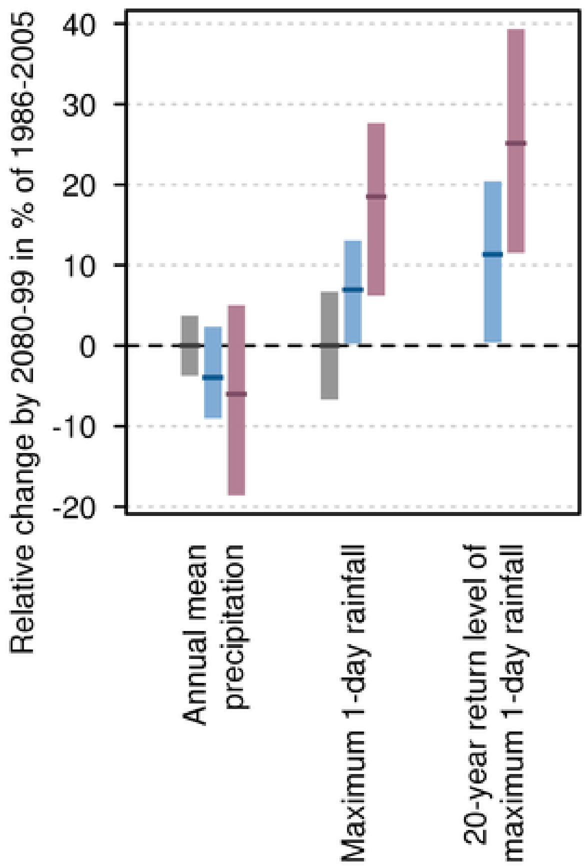


FIGURE 4.4.7: PROJECTED CHANGES IN SOUTHERN SLOPES MEAN RAINFALL, MAGNITUDE OF ANNUAL MAXIMUM 1-DAY RAINFALL AND MAGNITUDE OF THE 20-YEAR RETURN VALUE FOR THE 1-DAY RAINFALL FOR 2090 (SEE TEXT FOR DEFINITION OF VARIABLES). CHANGES ARE GIVEN IN PERCENTAGE WITH RESPECT TO THE 1986–2005 MEAN FOR RCP4.5 (BLUE) AND RCP8.5 (PURPLE). NATURAL CLIMATE VARIABILITY IS REPRESENTED BY THE GREY BAR. BAR PLOTS ARE EXPLAINED IN BOX 4.2.

4.4.2 DROUGHT

Parts of the Southern Slopes cluster were affected by the Federation drought and the World War II drought in the early part of the 20th century, and the entire cluster was strongly affected by the Millennium drought (Figure 4.4.1). The proportion of time in drought as well as the length, duration and intensity of meteorological droughts all increased in some parts of south-east Australia over the period 1911–2009 (Gallant *et al.*, 2013), with regional differences also evident across the Southern Slopes. Positive trends were seen particularly in the duration of droughts over the second half of the 20th century (Gallant *et al.*, 2013).

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

The proportion of time spent in any category of drought (from mild to extreme) is projected to increase through the century, especially by 2090 under RCP8.5 (Figure 4.4.8). The duration and frequency of droughts in the extreme category are also projected to increase, with smaller changes in lower categories (Figure 4.4.8).

Because the projections of meteorological drought depend on projections of mean rainfall, the direction of any changes in drought is typically the same as that of the mean annual rainfall. Additionally, the confidence in changes to the SPI can only be as high as for the rainfall projections, and are generally less than mean rainfall change. This is because changes in meteorological drought result from changes in rainfall variability as well as in the mean state. Therefore, the direction of change in SPI is given with *medium confidence*, but the magnitude of change can only be given *low confidence*. Rainfall in some regions within the Southern Slopes is also influenced by the ENSO, and there is some indication that these events will intensify under global warming, leading to an intensification of El Niño driven drying over much of Australia (Power *et al.*, 2013).

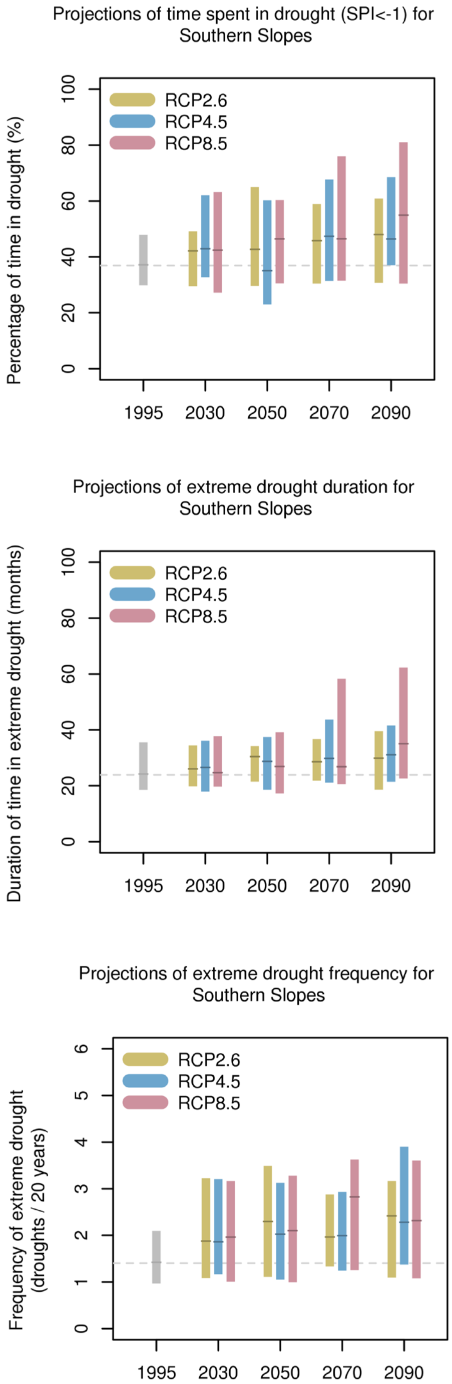


FIGURE 4.4.8: SIMULATED CHANGES IN DROUGHT BASED ON THE STANDARDISED PRECIPITATION INDEX (SPI). THE MULTI-MODEL ENSEMBLE RESULTS FOR SOUTHERN SLOPES SHOW THE PERCENTAGE OF TIME IN DROUGHT (SPI LESS THAN -1) (TOP), DURATION OF EXTREME DROUGHT (MIDDLE) AND FREQUENCY OF EXTREME DROUGHT (BOTTOM) FOR EACH 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.

4.4.3 SNOW

Snow cover is strongly affected by precipitation and temperature. Snow accumulation in mainland Australia has shown considerable inter-annual and decadal variability, but snow depths at many sites have shown ongoing long-term decline in recent decades (Davis, 2013; Nicholls, 2005; Hennessy *et al.*, 2003; Bhend *et al.*, 2012).

Declines in snow depth, duration and covered area are projected in the future for mainland alpine areas, with little difference between scenarios in 2020, though larger differences are found amongst scenarios later in the century (Hennessy *et al.*, 2007; Hendrikx *et al.*, 2013). Projections based on 18 CMIP3 simulations for Victoria concluded that lower maximum snow depths and an earlier end to the snow season are projected, along with a slightly later start to the snow season and a decrease in the area covered in snow (Bhend *et al.*, 2012). For example, in Victoria by 2050, the area averaging at least 1 day of snow-cover decreases by 25 to 55 % for the low scenario (SRES B1) and 35 to 75 % for the high scenario (SRES A1FI). By 2050, the average snow season becomes 20 to 55 days shorter for the low scenario and 30 to 80 days shorter for the high scenario. There have been fewer published studies about snow cover in Tasmania compared to mainland Australia. However, it is expected that broadly similar patterns will apply, including a general reduction in snow accumulation with a strong dependence on emission scenario towards the end of the century. See also Section 7.2.4 of the Technical Report.

In summary, there is *high confidence* in lower maximum snow depths, a shorter snow season and a decrease in the area covered in snow. There is *medium confidence* in the magnitude of change, although these estimates need to be updated with projections based on CMIP5 models.

4.5 WINDS, STORMS AND WEATHER SYSTEMS

4.5.1 MEAN WINDS

The surface wind climate is driven by the large-scale circulation pattern of the atmosphere. The Southern Slopes is at the northern edge of the 'Roaring Forties' belt of westerly circulation, and so receives predominantly westerly winds. For the eastern and north-eastern regions of the Southern Slopes, there is a greater influence from easterly synoptic systems and circulation contributing to the overall wind climatology. Local winds are then also affected by surface topography and other small scale influences. Any trends in observed winds are difficult to establish due to sparse coverage of wind observations, 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).

For the southern and western regions of the Southern Slopes cluster, projected changes to surface winds follow the projected changes to pressure and westerly circulation. In the near future (2030), these changes are mostly small and are not shown. However, late in the century (2090), changes include stronger average wind speeds during winter in western Tasmania, though not in Victoria (Figure 4.5.1). Decreases in summer mean wind speeds in Tasmania are seen under RCP8.5, and are reflected in the projected decrease in rainfall in western Tasmania during summer. The projected changes in other seasons are smaller.

There is *high confidence* in little change by 2030 throughout the cluster. Since there is high model agreement and driving mechanisms are well understood, the increase in winter wind speeds by 2090 in Tasmania is given *medium confidence*. However, there is *low confidence* in the projected direction of change in winter wind speeds for Victoria. There is *medium confidence* in small projected change for the other seasons and other sub-clusters.

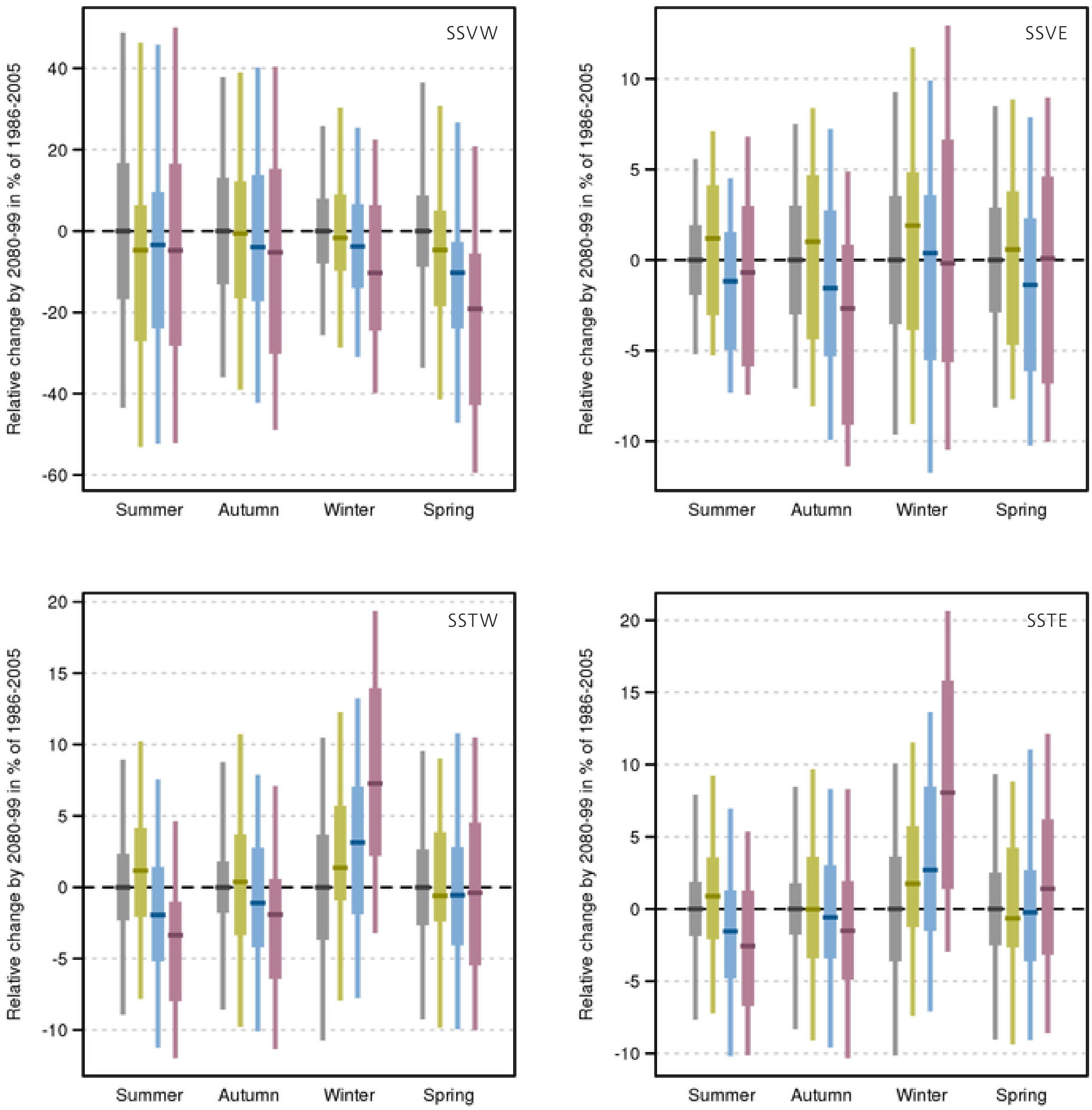


FIGURE 4.5.1: PROJECTED NEAR-SURFACE WIND SPEED CHANGES FOR 2090 FOR THE SOUTHERN SLOPES SUB-CLUSTERS. TOP LEFT IS WESTERN VICTORIA TOP RIGHT IS EASTERN VICTORIA AND SOUTH-EAST NSW, BOTTOM LEFT IS WESTERN TASMANIA, AND BOTTOM RIGHT IS EASTERN TASMANIA. ANOMALIES ARE GIVEN IN PERCENT WITH RESPECT TO THE 1986–2005 MEAN FOR 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.

4.5.2 EXTREME WINDS

The projections of extreme winds are less certain than for other variables since there is a limited number of GCMs that provide wind data, and maximum wind speed needs to be estimated using indirect means. Furthermore, the intensity of observed extreme wind speeds across land is strongly modified by surrounding terrain (including vegetation and other 'obstacles'). These topographical effects, as well as many other meteorological systems capable of generating extreme winds, are not resolved at the relevant scale in GCMs. For these reasons, confidence in model estimated changes for the Southern Slopes cluster are lowered and the results are only given for direction of change rather than magnitudes of change. For further details see the Technical Report Chapter 7.4.

The annual maximum 1-day wind speed and the 20-year return value for 1-day wind speed are projected to increase in Tasmania by 2090 under RCP8.5, in line with an increase in mean wind speed (where a 20-year return value is equivalent to a 5 % chance occurrence within any one year). This projected increase is given with *medium confidence*. Changes are not as clear for RCP4.5 or for Victoria, and extreme winds could increase or decrease.

4.5.3 EXTRA-TROPICAL CYCLONES

Cut-off lows provide a large proportion of the rainfall to the eastern districts of the Southern Slopes (Pook *et al.*, 2013). Cut-off lows and their extreme form, East Coast Lows, can bring both extreme rainfall and winds to these regions. Studies in the literature suggest a continuation of the observed decreasing trend in 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.*, 2013). While the number of cut-off lows may reduce, there is some indication that the average intensity of cut-off lows may increase (Grose *et al.*, 2012), providing a mechanism to explain the projected increase in extreme rainfall on the east coast of Tasmania (White *et al.*, 2013).

4.6 SOLAR RADIATION

By 2030, the CMIP5 models simulate little change in radiation (less than 3 %). By 2090, solar radiation is projected to increase in all seasons. There is high model agreement for a substantial increase of up to 10 % in winter and spring associated with a decrease in cloudiness and rainfall. Projected changes in summer and autumn are smaller (generally less than 5 %) and there is less model agreement on this change (Table 1 in the Appendix, Figure 4.6.1). 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, there is *high confidence* in little change for 2030. For 2090, there is *high confidence* in increased winter and spring radiation, but *low confidence* in change in the other seasons.

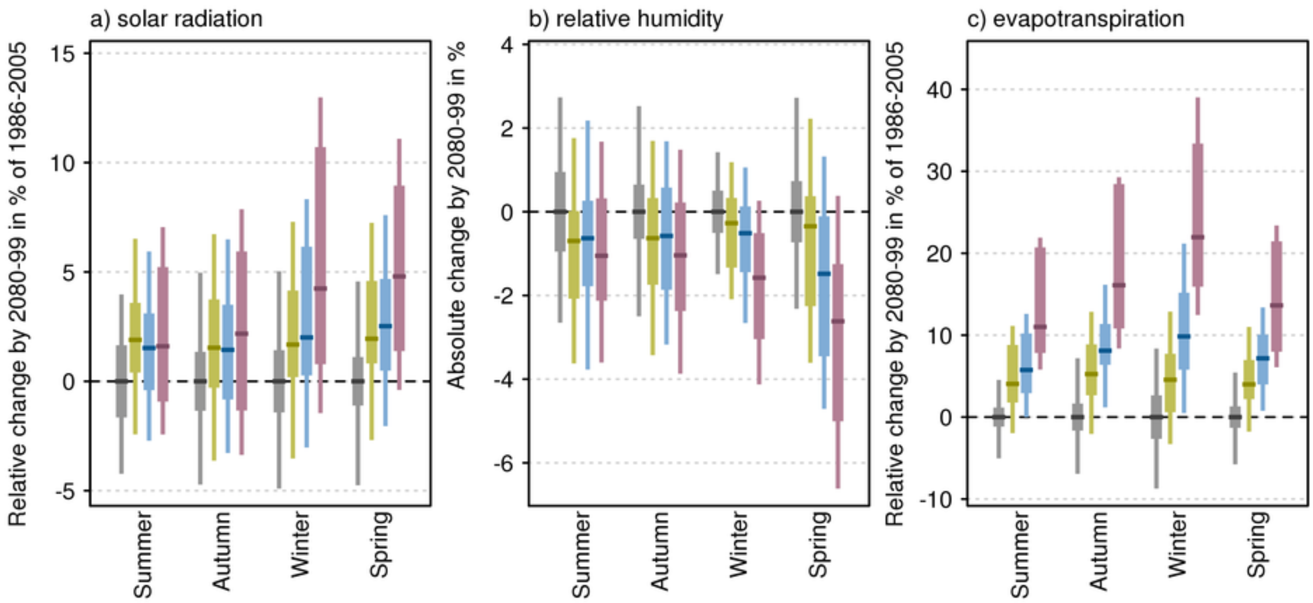


FIGURE 4.6.1: PROJECTED CHANGES IN (A) SOLAR RADIATION (%), (B) HUMIDITY (%, ABSOLUTE) AND (C) WET-ENVIRONMENTAL POTENTIAL EVAPOTRANSPIRATION (%) FOR SOUTHERN SLOPES IN 2090. THE BAR PLOTS SHOW SEASONAL PROJECTIONS WITH RESPECT TO THE 1986–2005 MEAN UNDER RCP2.6 (GREEN), RCP4.5 (BLUE) AND RCP8.5 (PURPLE), AND THE EXTENT OF NATURAL CLIMATE VARIABILITY IS SHOWN IN GREY BAR. BAR CHARTS ARE EXPLAINED IN BOX 4.2.

4.7 RELATIVE HUMIDITY

CMIP5 projections of relative humidity in the Southern Slopes indicate an overall tendency to decrease in all seasons (Figure 4.6.1b, Table 1 in the Appendix). Projected changes by 2030 are smaller than 2 % in all seasons for both RCP4.5 and 8.5. However, there are marked reductions projected for 2090, particularly in spring (up to -5 % under RCP8.5) and also winter (up to -3 % under RCP8.5), with smaller decreases in summer and autumn.

There are also regional differences in these projected changes, as there are for rainfall. For example, there is greater agreement for a substantial decrease in relative humidity during summer in the Tasmanian sub-clusters than in Victoria.

A decrease in relative humidity away from coasts is expected because of the increased moisture holding capacity in a warming atmosphere. The greater warming of land compared to sea leads to increases in relative humidity over ocean and to decreases over continents. This general tendency to decrease can be counteracted by a strong rainfall increase. Taking this and the CMIP5 projections into account, there is *high confidence* in little change for 2030. By 2090, there is *medium confidence* in decrease for summer and autumn, while for winter and spring there is *high confidence* in decrease.

4.8 POTENTIAL EVAPOTRANSPIRATION

Morton's wet-environmental potential evapotranspiration (McMahon *et al*., 2013 and Technical Report section 7.5.3) is projected to increase substantially in all seasons in the Southern Slopes, with the largest relative increases in winter and spring (Figure 4.6.1c). Projected changes for 2030 are less than 10 % in all scenarios, but by 2090 under RCP8.5 increases of about 10 to 20 % are projected in summer and spring, and about 10 to 30 % in autumn and winter (Figure 4.6.1c and Table 1 in the Appendix). In absolute terms, changes are largest in summer, particularly for RCP8.5 (not shown).

Overall, the models generally show high agreement on a substantial increase in evapotranspiration by 2030 or very high agreement by 2090. Despite there being *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 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 in data available since 1970 (see Technical Report, Chapter 4). Also, earlier GCMs were not able to reproduce the historical linear trends found in Morton's potential evapotranspiration (Kirono and Kent 2011).

4.9 SOIL MOISTURE AND RUNOFF

Increases in potential evapotranspiration rates (Figure 4.6.1) combined with decreases (though less certain) in rainfall (Figure 4.4.5) 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, this report does 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 being that 30 years is the minimum required 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 in all seasons (Figure 4.9.1). There are some differences in the projected changes between sub-clusters, with a greater decline in soil moisture during winter and spring than in the other seasons in the northern regions, but a greater decline during summer and autumn than in the other seasons in Tasmania. For the Southern Slopes as a whole, the annual changes for RCP8.5 by 2090 range from around -14 to -3 % with very high model agreement on substantial decrease (Table 1 in the Appendix). Given that reduced rainfall and increased evapotranspiration both contribute to a decrease in soil moisture, and given the *high confidence* in the direction of change for rainfall and evapotranspiration, the projected decrease in soil moisture is also given *high confidence*. However, due to the potential limitations of this method, there is only *medium confidence* in the magnitude of change indicated here.

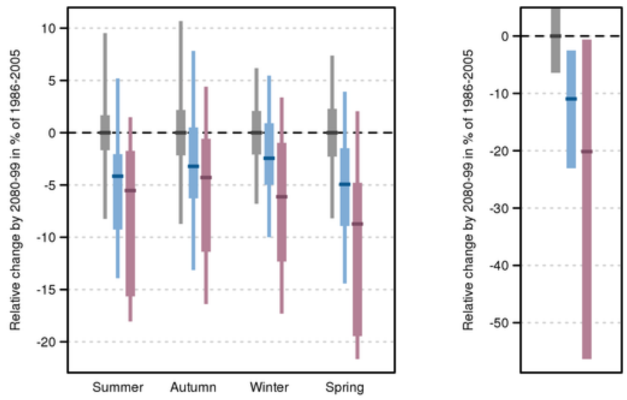


FIGURE 4.9.1: PROJECTED CHANGE IN SEASONAL SOIL MOISTURE (LEFT) AND ANNUAL RUNOFF (RIGHT) (BUDYKO METHOD – SEE TEXT) IN SOUTHERN SLOPES FOR 2090. ANOMALIES ARE GIVEN IN PER CENT WITH RESPECT TO THE 1986–2005 MEAN FOR RCP4.5 (BLUE) AND RCP8.5 (PURPLE) WITH GREY BARS SHOWING THE EXTENT OF NATURAL VARIABILITY. BAR CHARTS ARE EXPLAINED IN BOX 4.2.

Similar to the results for soil moisture, runoff in the Southern Slopes is calculated by the Budyko relationship and is projected to decrease under RCP4.5 and RCP8.5 by 2090 (Figure 4.9.1). However, the method used is not able to consider changes to rainfall intensity, seasonality or changes in vegetation characteristics – factors that each could impact future runoff. Therefore, there is *high confidence* in the direction of change, but due to the limitations in the methods the magnitudes of change cannot be reliably projected. Further hydrological modelling with appropriate climate scenarios *(e.g.* Chiew *et al*., 2009) could provide further insights into impacts on future runoff and soil moisture characteristics that would be needed in detailed climate change impact assessment studies. Detailed runoff projections using sophisticated methods are available for Tasmania (Bennett *et al*., 2012) as part of the Climate Futures for Tasmania project. They are a useful resource and are mindful of the context of rainfall projections, particularly in spring, from this work (see Chapter 4.4). Work on the South East Australian Climate Initiative (SEACI) includes more detailed analysis and projections for the hydro-climate of south-east mainland Australia (CSIRO, 2012).

4.10 FIRE WEATHER

Bushfire occurrence depends on four 'switches': 1) ignition, either human-caused or from natural sources such as lightning; 2) fuel abundance or load; 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). In the study of Clarke *et al.,* (2013), significant trends in observed fire weather for the period 1973 to 2010 are observed over most of the Southern Slopes cluster. These trends are largest in the East and West sub-clusters.

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 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 the Southern Slopes cluster, significant fire activity occurs primarily in areas characterised by forests and woodlands; fuel is abundant. Six stations are used in the analysis for this cluster: Melbourne Airport (AP), Laverton, Hobart, Launceston AP, East Sale and Nowra.

Focusing on the 2030 and 2090 time slices, the results indicate a tendency towards increased fire weather risk in the future (Table 4.10.1). 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. This index increases by roughly 7 % by 2030, and around 10 % under RCP4.5 by 2090, and 30 % under RCP8.5 by 2090. The number of days with a 'severe' fire danger rating increases by 20 % by 2030, and about 40 % under RCP4.5 by 2090, and 100 % under RCP8.5 by 2090.

If considering indices on an individual station and model basis, there is considerable variability from the mean cluster values (Table 2 of Appendix). The baseline fire climate varies, with Nowra being considerably wetter with a lower fire climate than other stations. Tasmanian stations are cooler and have few 'severe' days in the baseline dataset (see Fox-Hughes, 2011). The harshest fire climates in this cluster are found in SSVW (Melbourne AP and Laverton), with higher ∑FFDI values and more 'severe' days. Relative changes are comparable across the entire cluster for ∑FFDI, with largest changes occurring in SSVE. Across the cluster, 'severe' days may become 2 to 3 times more frequent by 2090 in the worst scenario. The range of projected fire weather presented here is generally comparable to earlier work (Hennessy *et al*., 2005; Lucas *et al*., 2007). However, consistent increases in fire weather are projected for Tasmania.

Considerable variability in the projections is driven by the choice of models for this analysis. On average, model projections for this cluster are reasonably consistent amongst themselves, projecting similar warming and a decline in rainfall of 10 to 40 %. Quite often, the GFDL-ESM2M model simulates the strongest decline in annual rainfall. For a given temperature change, it would be expected that less rainfall results in higher fire weather risk. This can be clearly observed in some scenarios (*e.g.* Melbourne AP 2030 RCP4.5). However, in some cases the GFDL model has the lowest rainfall, but not the greatest fire weather change (*e.g.* Hobart 2090 RCP8.5). In these cases, the timing of the rainfall changes is also important. Here, the differences are linked to summer rainfall (not shown). The CESM simulation shows a decline, while the GFDL simulation indicates an increase. A summer increase in rainfall will generally lower the DF and correspondingly eliminate some of the more extreme fire weather days, despite the strong winter rainfall decline. Mean changes to relative humidity and wind speed are generally small in all models and do not appear to play a significant role in predicting changes for fire weather.

There is *high confidence* that climate change will result in harsher fire weather in the future. This is seen in the mean changes (Table 2 of Appendix) and when examining individual models and scenarios (Table 4.10.1). Rainfall and temperature projections across the models are robust in an annual average sense. However, there is *low confidence* in the magnitude of the change to fire weather. This depends on the rainfall projection, particularly its seasonal variation. The models used here give the range of what changes may be expected. However, with only three models, it is not possible to identify the most probable outcome within this range. If future rainfall is at the low end of this range, changes will be larger and vice versa.

TABLE 4.10.1: 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 (S 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. SIX STATIONS ARE USED IN THE AVERAGING: MELBOURNE AP, LAVERTON, HOBART, LAUNCESTON, EAST SALE AND NOWRA.

VARIABLE	1995 BASELINE	2030 RCP4.5	2030 RCP8.5	2090 RCP4.5	2090 RCP8.5
T	19.1	20.2	20.2	21.1	22.6
R	691	555	565	566	540
DF	5.9	6.1	6.0	6.2	6.7
SEV	1.0	1.2	1.2	1.4	2.1
SFFDI	1891	2018	2027	2102	2473

4.11 MARINE PROJECTIONS

Changes in mean sea levels and their extremes, as well as sea surface temperatures (SSTs) and ocean pH (acidity) have the potential to affect the coastal, terrestrial and marine environments. This is discussed at length in Chapter 8 of the Technical Report. Of particular significance for the terrestrial environment of the lower Southern Slopes is the impact of sea level rise and changes to the frequency of extreme sea levels. Impacts will be felt through coastal flooding and erosion. For the adjacent marine environment, increases in ocean temperatures and acidity may alter the distribution and composition of marine ecosystems, and affect vegetation (*e.g.* sea grass and kelp forests) and coastal fisheries.

4.11.1 SEA LEVEL

Changes in sea level are caused primarily by changes in ocean density (*e.g.* 'thermal expansion') and changes in ocean mass due to the exchange of water with the terrestrial environment (*e.g.* Church *et al.*, 2013) or including from glaciers and ice sheets (*e.g.* Church *et al.*, 2014; also see Technical Report, Section 8.1 for details). Over 1966–2009, the average of the relative tide gauge trends around Australia is a rise of 1.4 ± 0.2 mm/yr. After the influence of the El Niño Southern Oscillation (ENSO) on sea level is removed, the average trend is 1.6 ± 0.2 mm/yr. After accounting for and removing the effects of vertical land movements due to glacial rebound and the effects of natural climate variability and changes in atmospheric pressure, sea levels have risen around the Australian coastline at an average rate of 2.1 mm/yr over 1966–2009 and 3.1 mm/yr over 1993–2009. These observed rates of rise for Australia are consistent with global average values (White *et al.*, 2014).

Projections of future sea level changes are shown for Stony Point in Victoria (Figure 4.11.1). Values for this and other locations are provided for the 2030 and 2090 periods relative to the 1986–2005 period in Table 3 in the Appendix.

Continued increase in sea level for the Southern Slopes is projected with *very high confidence.* The rate of sea level rise during the 21st century will be larger than the average rate during the 20th century as radiative forcing from greenhouse gas emissions continues to grow (Figure 4.11.1). For the first decades of the 21st century the projections are almost independent of the emission scenario, but they begin to separate significantly from about 2050. For higher greenhouse gas emissions, particularly for RCP8.5, the rate of rise continues to increase through the 21st century, and results in sea level rise about 30 % higher than the RCP4.5 level by 2100. Significant inter-annual variability will continue through the 21st century. An indication of its magnitude is given by the dotted lines in Figure 4.11.1. In the near future (2030), the projected range of sea level rise for the Southern Slopes cluster coastline is 0.07 to 0.19 m above 1986–2005, with only minor differences between RCPs. For late in the century (2090) the projected range of sea level rise increases to 0.27 to 0.66 m for RCP4.5 and 0.39 to 0.89 m for RCP8.5. There are some differences in the projected change for the sites for which values are provided (Table 3 in Appendix). These ranges of sea level rise are considered *likely* (at least 66% probability), however, if a collapse in the marine based sectors of the Antarctic ice sheet were initiated, these projections could be several tenths of a metre higher by late in the century (Church *et al.*, 2014).

Extreme coastal sea levels are exacerbated by rising sea levels and caused by a combination of factors including astronomical tides, storm surges and wind-waves. Along the south coast of Australia, the majority of storm surges occur in conjunction with the passage of cold fronts during the winter months (*e.g.* McInnes and Hubbert, 2003).

Using the method of Hunter (2012), an allowance has been calculated based on the mean sea level rise, the uncertainty around the rise, and taking into account the nature of extreme sea levels along the Southern Slopes coastline (Haigh *et al.*, 2014). The allowance is the minimum distance required to raise an asset to maintain current frequency of breaches under projected sea level rise. When uncertainty in mean sea level rise is high (*e.g.* in 2090), this allowance approaches the upper end of the range of projected mean sea level rise. For the Southern Slopes in 2030 the vertical allowances along the cluster coastline are in the range 0.12 to 0.15 m for all RCPs, and up to 0.59 m for RCP4.5 by 2090 and 0.83 m for RCP8.5 by 2090 . These estimates also vary by region, with larger vertical distances indicated for Spring Bay, Tasmania (Table 3 in Appendix). Detailed analysis of tide and storm surge from downscaled climate projections (McInnes *et al.*, 2011; Colberg and McInnes, 2012) reported that changes to storm surge is a minor component of change to extreme sea levels compared to sea level rise in Tasmania.

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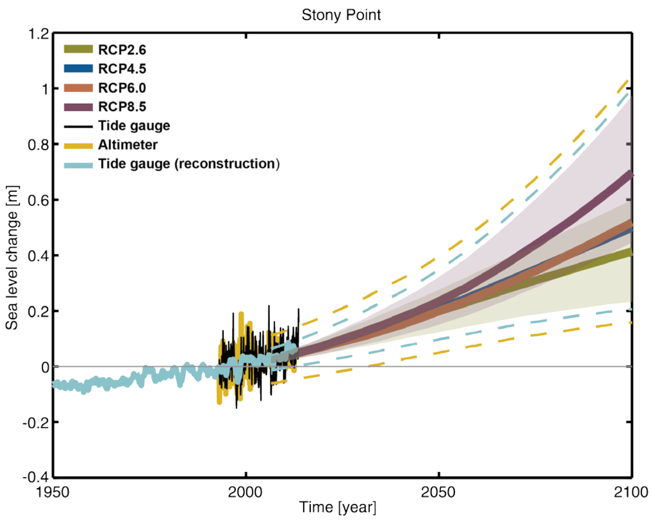

FIGURE 4.11.1: OBSERVED AND PROJECTED RELATIVE SEA LEVEL CHANGE (METRES) FOR STONY POINT, VICTORIA (WHICH HAS CONTINUOUS RECORDS AVAILABLE FOR THE PERIOD 1993–2010). THE OBSERVED TIDE GAUGE RELATIVE SEA LEVEL RECORDS ARE INDICATED IN BLACK, WITH THE SATELLITE RECORD (SINCE 1993) IN MUSTARD AND TIDE GAUGE RECONSTRUCTION (WHICH HAS LOWER VARIABILITY) IN CYAN. MULTI-MODEL MEAN PROJECTIONS (THICK PURPLE AND OLIVE LINES) FOR THE RCP8.5 AND RCP2.6 SCENARIOS WITH UNCERTAINTY RANGES SHOWN BY THE PURPLE AND OLIVE SHADED REGIONS FROM 2006–2100. THE MUSTARD AND CYAN DASHED LINES ARE ESTIMATES OF INTERANNUAL VARIABILITY IN SEA LEVEL (LIKELY UNCERTAINTY RANGE ABOUT THE PROJECTIONS) AND INDICATE THAT INDIVIDUAL MONTHLY AVERAGES OF SEA LEVEL CAN BE ABOVE OR BELOW LONGER TERM AVERAGES. NOTE THAT THE RANGES OF SEA LEVEL RISE SHOULD BE CONSIDERED *LIKELY* (AT LEAST 66 % PROBABILITY) AND THAT IF A COLLAPSE IN THE MARINE BASED SECTORS OF THE ANTARCTIC ICE SHEET WERE INITIATED, THESE PROJECTIONS COULD BE SEVERAL TENTHS OF A METRE HIGHER BY LATE IN THE CENTURY.

4.11.2 SEA SURFACE TEMPERATURE, SALINITY AND ACIDIFICATION

Sea surface temperature (SST) has increased significantly across the globe over recent decades (IPCC, 2013). Increases in SST pose a significant threat to the marine environment through biological changes in marine species, including local abundance and community structure. In the Southern Slopes cluster, the projected warming is largest off the Tasmanian East Coast and smallest on the south-west coast of Victoria. For example, for 2030 under RCP8.5, the range of projected SST increase for Portland (Victoria) is 0.3 to 0.8 °C while for Spring Bay (Tasmania) it is 0.7 to 1.4 °C. For 2090, under RCP2.6 the range of warming at Portland is 0.3 to 0.9 °C and for Spring Bay it is 0.1 to 1.2 °C. For 2090 under RCP8.5, it is 1.6 to 3.4 °C at Portland and 2.1 to 5.1 °C at Spring Bay (see Table 3 in the Appendix).

Ocean salinity in coastal waters will be affected by changes to rainfall and evaporation and may impact on upwelling and mixing, and potentially nutrient supply. Changes to salinity across the coastal waters of the Southern Slopes span a large range that includes both possible increases and decreases, particularly over the longer term and higher emission scenarios as indicated in Table 3 (in the Appendix). Locally, salinity can also be affected by riverine input.

About 30% of the anthropogenic carbon dioxide emitted into the atmosphere over the past 200 years has been absorbed by the oceans (Ciais *et al.*, 2013) and this has led to a 0.1 unit decrease in the ocean's surface water pH, which represents a 26 % increase in the concentration of hydrogen ions in seawater (Raven *et al.*, 2005). As carbon dioxide enters the ocean it reacts with the seawater to cause a decrease in pH and carbonate concentration, collectively known as ocean acidification. Carbonate is used in conjunction with calcium as aragonite by many marine organisms such as corals, oysters, clams and some plankton such as foraminifera and pteropods, to form their hard skeletons or shells. A reduction in shell mass has already been detected in foraminifera and pteropods in the Southern Ocean (Moy *et al.,* 2009; Bednaršek *et al.*, 2012). Ocean acidification lowers the temperature at which corals bleach, reducing resilience to natural variability. Ocean acidification can affect fin and shellfish fisheries, aquaculture, tourism and coastal protection. In the cluster by 2030, pH change is projected to be another 0.08 units lower. Under RCP4.5 by 2090 pH is projected to be up to 0.16 units lower and up to 0.3 units lower for RCP8.5. This represents an additional increase in hydrogen ion concentration of 40 % and 100 % respectively. These changes are also accompanied by reductions in aragonite saturation state (see Table 3 in the Appendix) and together with SST changes will affect all levels of the marine food web, and make it harder for calcifying marine organisms to build their hard shells, potentially affecting resilience and viability of marine ecosystems.

In summary, there is *very high confidence* that sea surface temperatures will continue to rise along the Southern Slopes coastline, with the magnitude of the warming dependent on emission scenarios. Changes in salinity are related to changes in the hydrological cycle and are of *low confidence*. There is *very high confidence* that the ocean will become more acidic, showing a nett reduction in pH. There is also *high confidence* that the rate of ocean acidification will be proportional to carbon dioxide emissions.

4.12 OTHER PROJECTION MATERIAL FOR THE CLUSTER

For the Southern Slopes cluster, previous climate change projection information includes the nationwide *Climate Change in Australia* projections, produced by the CSIRO and Bureau of Meteorology (CSIRO and BOM, 2007); regional projections for Tasmania under the *Climate Futures for Tasmania* project[2]; and regional projections for south-east mainland Australia focussing primarily on hydroclimate in the South East Australian Climate Initiative (SEACI)[3]. In addition to these projections, a new set of regional projections by the New South Wales Office of Environment and Heritage have been produced through the NSW/ACT Regional Climate Modelling project, also known as NARCliM[4] will be available in the near future.

These previous projections (including NARCliM) build on climate change information derived from the previous generation of GCMs included in the CMIP3 archive. These 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.acecrc.org.au/Research/Climate%20Futures

3 http://www.seaci.org

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 climates may respond to increasing greenhouse gas concentrations. This Section 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 representative of futures 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, 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, as simulated by CMIP5 models, in temperature and rainfall in the Southern Slopes Victoria West sub-cluster for 2060 (years 2050–2069) under the RCP4.5 scenario with regard to temperature and rainfall. The table organises the models into groupings according to their simulated changes to winter rainfall (rows) and winter temperature (columns). Regarding rainfall, models simulate increases and decreases from *much drier* (less than -15 %) to *much wetter* (greater than 15 %), with 16 of 34 models showing *little change* (-5 to 5 %), ten models showing *drier* conditions (-15 to -5 %), 3 models showing *much drier* conditions (less than -15 %) and five models showing *wetter* or *much wetter* conditions. There is high consistency in temperature, with 30 of 34 models projecting *warmer* conditions (0.5 to 1.5 °C warmer) and the other four models showing *hotter* conditions (1.5 to 3 °C warmer).

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 *warmer* and *much wetter* climate and the worst case the *warmer* and *much drier* scenario.

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 populate 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 (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.

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 Southern 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, as well as to compare scenarios developed using downscaled and GCM results.

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		1 of 34 models		
	Wetter +5.0 to +15.0		3 of 34 models	1 of 34 models	
	Little change -5.0 to +5.0		15 of 34 models	1 of 34 models	
	Drier -15.0 to -5.0		8 of 34 models	2 of 34 models	
	Much drier < -15.0		3 of 34 models		

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

BOX 5.2: INDICATIVE CLIMATE SCENARIOS FOR THE SOUTHERN 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 Southern 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 (with other potential scenarios excluded as less likely than the selected cases or lying within the range of climates specified by the selected cases). For each case, when available, the current climate analogue for the future climates of Melbourne and Hobart are 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). Note that other potentially important aspects of local climate are not matched, such as rainfall seasonality, and thus the analogues should not be used directly in adaptation planning without considering more detailed information.

- *Warmer* (0.5 to 1.5 °C warming) with *little change in rainfall* (-5 to +5 %). This may occur by 2030 under any emission scenario, but may persist through to late in the 21st century under RCP2.6 or RCP4.5. In this case, Melbourne's future climate would be more like the current climate of Wangaratta (VIC), and Hobart's future climate would be more like the current climate of Geelong (VIC).
- *Hotter* (1.5 to 3.0 °C warming), and *little change in rainfall* (-5 to +5 %). This is possible mid-century under an RCP8.5 emission scenario, or late in the century under RCP4.5. In this case, Melbourne's future climate would be more like Cowra (NSW), and Hobart's future climate would be more like the current climate of Victor Harbor (SA).
- *Much hotter* (greater than 3.0 °C warming), but *drier* (5 to 15 % reduction). This is possible by late in the 21st century under RCP8.5. In this case Melbourne's future climate would be more like that of Dubbo (NSW), and Hobart's future climate would be more like the current climate of Adelaide (SA).
- *Warmer* (0.5 to 1.5 °C warming) and *drier* (5 to 15 % reduction). This may occur by 2030 under any emission scenario, but may persist through to late in the century under RCP2.6 or RCP4.5. In this case, Melbourne's future climate would be more like that currently in Clare (SA).
- *Warmer* (0.5 to 1.5 °C warming) and *wetter* (5 to 15 % increase). This may be possible in the eastern Tasmanian sub-cluster by mid-century under all emission scenarios (not shown in figure), though less likely in other sub-clusters. In this case Hobart's future climate would be more like the current climate of Ararat (VIC).

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FIGURE B5.2: A TABLE BASED ON OUTPUT FROM CLIMATE FUTURES SHOWING CATEGORIES OF FUTURE CLIMATE PROJECTIONS FOR THE SOUTHERN 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 Southern Slopes cluster

Annual Rainfall (%)	RCP	Slightly Warmer 0 to +0.5: 2030	2050	2090	Warmer +0.5 to +1.5: 2030	2050	2090	Hotter +1.5 to +3.0: 2030	2050	2090	Much Hotter > +3.0: 2030	2050	2090
Much Wetter > +15.0	2.6												
	4.5												
	8.5												
Wetter +5.0 to +15.0	2.6												
	4.5												
	8.5					1				2			
Little Change −5.0 to +5.0	2.6		1		14	10	8			1			
	4.5	1			19	14	5		3	10			
	8.5	1			17	7			10	2			5
Drier −15.0 to −5.0	2.6	2			2	6	9		1				
	4.5				7	9	5		1	7			
	8.5				10	6		1	5	4			10
Much Drier < −15.0	2.6												
	4.5												
	8.5									1			5

Annual Surface Temperature (°C)

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% | 66-90%

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

REFERENCES

ALLAN, R. & ANSELL, T. 2006. A new globally complete monthly historical gridded mean sea level pressure dataset (HadSLP2): 1850-2004. Journal of Climate, 19**,** 5816-5842.

ALLEN, R. J., NORRIS, J. R. & WILD, M. 2013. Evaluation of multidecadal variability in CMIP5 surface solar radiation and inferred underestimation of aerosol direct effects over Europe, China, Japan, and India. Journal of Geophysical Research-Atmospheres, 118**,** 6311-6336.

BEDNARŠEK, N., TARLING, G., BAKKER, D., FIELDING, S., JONES, E., VENABLES, H., WARD, P., KUZIRIAN, A., LEZE, B. & FEELY, R. 2012. Extensive dissolution of live pteropods in the Southern Ocean. Nature Geoscience, 5**,** 881-885.

BENNETT, J., LING, F., POST, D., GROSE, M., CORNEY, S., GRAHAM, B., HOLZ, G., KATZFEY, J. & BINDOFF, N. 2012. High-resolution projections of surface water availability for Tasmania, Australia. Hydrology and Earth System Sciences Discussions, 9**,** 1783-1825.

BHEND, J., BATHOLS, J. & HENNESSY, K. 2012. Climate change impacts on snow in Victoria. Aspendale, Australia: CSIRO report for the Victorian Department of Sustainability and Environment 42.URL: http://www.climatechange.vic.gov.au/__data/assets/pdf_file/0005/200795/cawcr_report_on_climate_change_and_Victorian_snow_final-dec12_web.pdf (Accessed 18/8/2014)

BLANCHI, R., LUCAS, C., LEONARD, J. & FINKELE, K. 2010. Meteorological conditions and wildfire-related house loss in Australia. International Journal of Wildland Fire, 19**,** 914-926.

BRADSTOCK, R. A. 2010. A biogeographic model of fire regimes in Australia: current and future implications. Global Ecology and Biogeography, 19**,** 145-158.

BROHAN, P., KENNEDY, J. J., HARRIS, I., TETT, S. F. & JONES, P. D. 2006. Uncertainty estimates in regional and global observed temperature changes: A new data set from 1850. Journal of Geophysical Research: Atmospheres (1984–2012), 111**,** D12, 1-21.

CAI, W. & VAN RENSCH, P. 2012. The 2011 southeast Queensland extreme summer rainfall: A confirmation of a negative Pacific Decadal Oscillation phase? Geophysical Research Letters, 39**,** 8702.

CHIEW, F., KIRONO, D., KENT, D. & VAZE, J. 2009. Assessment of rainfall simulations from global climate models and implications for climate change impact on runoff studies. *18th World Imacs Congress and Modsim09 International Congress on Modelling and Simulation: Interfacing Modelling and Simulation with Mathematical and Computational Sciences*. 3907-3913

CHURCH, J. A., CLARK, P. U., CAZENAVE, A., GREGORY, J. M., JEVREJEVA, S., LEVERMANN, A., MERRIFIELD, M. A., MILNE, G. A., NEREM, R. S., NUNN, P. D., PAYNE, A. J., PFEFFER, W. T., STAMMER, D. & UNNIKRISHNAN, A. S. 2014. Sea Level Change. *In:* STOCKER, T. F., D. QIN, G.-K. PLATTNER, M. TIGNOR, S. K. ALLEN, J. BOSCHUNG, A. NAUELS, Y. XIA, V. BEX AND P. M. MIDGLEY (ed.) *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.*

CIAIS, P., SABINE, C., BALA, G., BOPP, L., BROVKIN, V., CANADELL, J., CHHABRA, A., DEFRIES, R., GALLOWAY, J., HEIMANN, M., JONES, C., LE QUÉRÉ, C., MYNENI, R. B., PIAO, S. & THORNTON, P. 2013. Carbon and Other Biogeochemical Cycles. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. *In:* STOCKER, T. F., D. QIN, G.-K. PLATTNER, M. TIGNOR, S.K. ALLEN, J. BOSCHUNG, A. NAUELS, Y. XIA, BEX, V. & MIDGLEY, P. M. (eds.) *Climate Change 2013: The Physical Science Basis.* Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press.

CLARKE, H., LUCAS, C. & SMITH, P. 2013. Changes in Australian fire weather between 1973 and 2010. International Journal of Climatology, 33**,** 931-944.

CLARKE, H. G., SMITH, P. L. & PITMAN, A. J. 2011. Regional signatures of future fire weather over eastern Australia from global climate models. International Journal of Wildland Fire, 20**,** 550-562.

COLBERG, F. & MCINNES, K. L. 2012. The impact of future changes in weather patterns on extreme sea levels over southern Australia. Journal of Geophysical Research: Oceans (1978–2012), 117**,** C08001.

CSIRO 2012. Climate and water availability in south-eastern Australia – A synthesis of findings from Phase 2 of the South Eastern Australian Climate Initiative (SEACI). Melbourne, Australia: CSIRO 41 pp. URL: http://www.seaci.org/research/phase2.html Accessed 19/8/2014

CSIRO AND BOM 2007. Climate change in Australia: Technical Report. Aspendale, Australia: CSIRO Marine and Atmospheric Research. URL http://www.climatechangeinaustralia.gov.au/technical_report.php Accessed 19/8/2014

DAVIS, C. 2013. Towards the development of long term winter records for the Snowy Mountains. Australian Meteorological Magazine, 63**,** 303-313.

DOWDY, A. J., MILLS, G. A., TIMBAL, B. & WANG, Y. 2013. Changes in the risk of extratropical cyclones in eastern Australia. Journal of Climate, 26**,** 1403-1417.

FAWCETT, R., DAY, K. A., TREWIN, B., BRAGANZA, K., SMALLEY, R., JOVANOVIC, B. & JONES, D. 2012. On the sensitivity of Australian temperature trends and variability to analysis methods and observation networks, Centre for Australian Weather and Climate Research Technical Report No.050.

FIERRO, A. O. & LESLIE, L. M. 2014. Relationships between Southeast Australian Temperature Anomalies and Large-Scale Climate Drivers. Journal of Climate, 27**,** 1395-1412.

FOWLER, H. & EKSTRÖM, M. 2009. Multi-model ensemble estimates of climate change impacts on UK seasonal precipitation extremes. International Journal of Climatology, 29**,** 385-416.

FOX-HUGHES, P. 2011. Impact of more frequent observations on the understanding of Tasmanian fire danger. Journal of Applied Meteorology and Climatology, 50**,** 1617-1626.

FÜSSEL, H.-M. & KLEIN, R. J. 2006. Climate change vulnerability assessments: an evolution of conceptual thinking. Climatic Change, 75**,** 301-329.

GALLANT, A. J. E., REEDER, M. J., RISBEY, J. S. & HENNESSY, K. J. 2013. The characteristics of seasonal-scale droughts in Australia, 1911-2009. International Journal of Climatology, 33**,** 1658-1672.

GROSE, M., CORNEY, S., KATZFEY, J., BENNETT, J., HOLZ, G., WHITE, C. & BINDOFF, N. 2013. A regional response in mean westerly circulation and rainfall to projected climate warming over Tasmania, Australia. Climate Dynamics, 40**,** 2035-2048.

GROSE, M. R., FOX-HUGHES, P., HARRIS, R. M. & BINDOFF, N. L. 2014. Changes to the drivers of fire weather with a warming climate–a case study of southeast Tasmania. Climatic Change, 124**,** 255-269.

GROSE, M. R., MOISE, A. F., TIMBAL, B., KATZFEY, J. J., EKSTROM, M. & WHETTON, P. In Review. Climate projections for southern Australia cool season rainfall: insights from a downscaling comparison. Climate Research.

GROSE, M. R., POOK, M. J., MCINTOSH, P. C., RISBEY, J. S. & BINDOFF, N. L. 2012. The simulation of cutoff lows in a regional climate model: reliability and future trends. Climate Dynamics, 39**,** 445-459.

HAIGH, I. D., WIJERATNE, E., MACPHERSON, L. R., PATTIARATCHI, C. B., MASON, M. S., CROMPTON, R. P. & GEORGE, S. 2014. Estimating present day extreme water level exceedance probabilities around the coastline of Australia: tides, extra-tropical storm surges and mean sea level. Climate Dynamics, 42**,** 121-138.

HENDON, H., THOMPSON, D. & WHEELER, M. 2007. Australian rainfall and surface temperature variations associated with the Southern Hemisphere annular mode. Journal of Climate, 20**,** 2452-2467.

HENNESSY, K., LUCAS, C., NICHOLLS, N., BATHOLS, J., SUPPIAH, R. & RICKETTS, J. 2005. Climate change impacts on fire-weather in south-east Australia. Melbourne, Australia: Consultancy report for the New South Wales Greenhouse Office, Victorian Department of Sustainability and Environment, Tasmanian Department of Primary Industries, Water and Environment, and the Australian Greenhouse Office. CSIRO Atmospheric Research and Australian Government Bureau of Meteorology 78pp. URL http://laptop.deh.gov.au/soe/2006/publications/drs/pubs/334/lnd/ld_24_climate_change_impacts_on_fire_weather.pdf Accessed 18/8/2014

HENNESSY, K., WHETTON, P., WALSH, K., SMITH, I., BATHOLS, J., HUTCHINSON, M. & SHARPLES, J. 2007. Climate change effects on snow conditions in mainland Australia and adaptation at ski resorts through snowmaking. Climate Research, 35**,** 255-270.

HENNESSY, K. J., WHETTON, P., SMITH, I., BATHOLS, J., HUTCHINSON, M. & SHARPLES, J. 2003. The impact of climate change on snow conditions in mainland Australia. A report by CSIRO and ANU for the Victorian Department of Sustainability and Environment, Victorian Greenhouse Office, Parks Victoria, New South Wales National Parks and Wildlife Service, New South Wales Department of Infrastructure, Planning and Natural Resources, Australian Greenhouse Office and Australian Ski Areas Association. URL http://www.climatechange.vic.gov.au/__data/assets/pdf_file/0015/73212/TheImpactofClimateChangeonSnowConditions2003.pdf Accessed 18/8/2014

HUNTER, J. 2012. A simple technique for estimating an allowance for uncertain sea-level rise. Climatic Change, 113**,** 239-252.

HUNTINGTON, T. G. 2006. Evidence for intensification of the global water cycle: Review and synthesis. Journal of Hydrology, 319**,** 83-95.

IPCC 2013. Climate Change 2013: The Physical Science Basis. *In:* STOCKER, T. F., D. QIN, G.-K. PLATTNER, M. TIGNOR, S. K. ALLEN, J. BOSCHUNG, A. NAUELS, Y. XIA, V. BEX & P. M. MIDGLEY (eds.) *Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.* Cambridge, UK, and New York, NY, USA: Cambridge University Press.

JAKOB, D. 2010. Challenges in developing a high-quality surface wind-speed data-set for Australia. Australian Meteorological Magazine, 60**,** 227-236.

JONES, D. A., WANG, W. & FAWCETT, R. 2009. High-quality spatial climate data-sets for Australia. Australian Meteorological and Oceanographic Journal, 58**,** 233-248.

KENT, D. M., KIRONO, D. G., TIMBAL, B. & CHIEW, F. H. 2013. Representation of the Australian sub-tropical ridge in the CMIP3 models. International Journal of Climatology, 33**,** 48-57.

KIRONO, D. G. & KENT, D. M. 2011. Assessment of rainfall and potential evaporation from global climate models and its implications for Australian regional drought projection. International Journal of Climatology, 31**,** 1295-1308.

LEVITUS, S., ANTONOV, J. I., BOYER, T. P. & STEPHENS, C. 2000. Warming of the world ocean. Science, 287**,** 2225-2229.

LUCAS, C. 2010. On developing a historical fire weather data-set for Australia. Australian Meteorological Magazine, 60**,** 1-13.

LUCAS, C., HENNESSY, K., MILLS, G. & BATHOLS, J. 2007. Bushfire Weather in Southeast Australia: Recent Trends and Projected Climate Change Impacts. Consultancy Report prepared for The Climate Institute of Australia. Bushfire CRC and Australian Bureau of Meteorology CSIRO Marine and Atmospheric Research. URL http://www.royalcommission.vic.gov.au/getdoc/c71b6858-c387-41c0-8a89-b351460eba68/TEN.056.001.0001.pdf Accessed 18/8/2014

MASTRANDREA, M. D., FIELD, C. B., STOCKER, T. F., EDENHOFER, O., EBI, K. L., FRAME, D. J., HELD, H., KRIEGLER, E., MACH, K. J. & MATSCHOSS, P. R. 2010. Guidance note for lead authors of the IPCC fifth assessment report on consistent treatment of uncertainties. *Intergovernmental Panel on Climate Change (IPCC)*. URL http://www.ipcc.ch/pdf/supporting-material/uncertainty-guidance-note.pdf Accessed 18/8/2014

MCARTHUR, A. G. 1967. Fire behaviour in Eucalypt forests. Leaflet. Forestry Timber Bureau Australia**,** 35-35.

MCGREGOR, J. & DIX, M. 2008. An updated description of the conformal-cubic atmospheric model. *In:* HAMILTON, K. & OHFUCHI, W. (eds.) *High Resolution Numerical Modelling of the Atmosphere and Ocean.* Springer New York.

MCINNES, K., O'GRADY, J., HEMER, M., MACADAM, I., ABBS, D., WHITE, C., BENNETT, J., CORNEY, S., HOLZ, G. & GROSE, M. 2011. Climate Futures for Tasmania: extreme tide and sea-level events technical report. Antarctic Climate and Ecosystems Cooperative Research Centre, Hobart, Tasmania 44pp. URL http://www.dpac.tas.gov.au/__data/assets/pdf_file/0009/184797/ACE_CFT_-_Extreme_Tides_and_Sea-Level_Events_final.pdf Accessed 18/8/2014

MCINNES, K. L. & HUBBERT, G. D. 2003. A numerical modeling study of storm surges in Bass Strait. Australian Meterological Magazine, 52**,** 143-156.

MCMAHON, T. A., PEEL, M. C., LOWE, L., SRIKANTHAN, R. & MCVICAR, T. R. 2013. Estimating actual, potential, reference crop and pan evaporation using standard meteorological data: a pragmatic synthesis. Hydrology and Earth System Sciences, 17**,** 1331-1363.

MCVICAR, T. R., RODERICK, M. L., DONOHUE, R. J., LI, L. T., VAN NIEL, T. G., THOMAS, A., GRIESER, J., JHAJHARIA, D., HIMRI, Y. & MAHOWALD, N. M. 2012. Global review and synthesis of trends in observed terrestrial near-surface wind speeds: Implications for evaporation. Journal of Hydrology, 416**,** 182-205.

MOSS, R. H., EDMONDS, J. A., HIBBARD, K. A., MANNING, M. R., ROSE, S. K., VAN VUUREN, D. P., CARTER, T. R., EMORI, S., KAINUMA, M., KRAM, T., MEEHL, G. A., MITCHELL, J. F. B., NAKICENOVIC, N., RIAHI, K., SMITH, S. J., STOUFFER, R. J., THOMSON, A. M., WEYANT, J. P. & WILBANKS, T. J. 2010. The next generation of scenarios for climate change research and assessment. Nature, 463**,** 747-756.

MOY, A. D., HOWARD, W. R., BRAY, S. G. & TRULL, T. W. 2009. Reduced calcification in modern Southern Ocean planktonic foraminifera. Nature Geoscience, 2**,** 276-280.

NAKIĆENOVIĆ, N. & SWART, R. (eds.) 2000. *Special Report on Emissions Scenarios. A Special Report of Working Group III of the Intergovernmental Panel on Climate Change*, Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press.

NICHOLLS, N. 2005. Climate variability, climate change and the Australian snow season. Australian Meteorological Magazine, 54**,** 177-185.

POOK, M. J., MCINTOSH, P. C. & MEYERS, G. A. 2006. The synoptic decomposition of cool-season rainfall in the southeastern Australian cropping region. Journal of Applied Meteorology and Climatology, 45**,** 1156-1170.

POOK, M. J., RISBEY, J. S. & MCINTOSH, P. C. 2013. A comparative synoptic climatology of cool-season rainfall in major grain-growing regions of southern Australia. Theoretical and Applied Climatology**,** 1-13.

POWER, S., DELAGE, F., CHUNG, C., KOCIUBA, G. & KEAY, K. 2013. Robust twenty-first-century projections of El Nino and related precipitation variability. Nature, 502**,** 541-545.

RAVEN, J., CALDEIRA, K., ELDERFIELD, H., HOEGH-GULDBERG, O., LISS, P., RIEBESELL, U., SHEPHERD, J., TURLEY, C. & WATSON, A. 2005. Ocean acidification due to increasing atmospheric carbon dioxide. The Royal Society 68pp.

RISBEY, J. S., POOK, M. J., MCINTOSH, P. C., WHEELER, M. C. & HENDON, H. H. 2009. On the remote drivers of rainfall variability in Australia. Monthly Weather Review, 137**,** 3233-3253.

SHERWOOD, S. C., ROCA, R., WECKWERTH, T. M. & ANDRONOVA, N. G. 2010. Tropospheric water vapor, convection, and climate. Reviews of Geophysics, 48**,** RG2001.

SPEER, M. S. 2008. On the late twentieth century decrease in Australian east coast rainfall extremes. Atmospheric Science Letters, 9**,** 160-170.

TAYLOR, K. E., STOUFFER, R. J. & MEEHL, G. A. 2012. An overview of CMIP5 and the experiment design. Bulletin of the American Meteorological Society, 93**,** 485-498.

TENG, J., CHIEW, F., VAZE, J., MARVANEK, S. & KIRONO, D. 2012. Estimation of climate change impact on mean annual runoff across continental Australia using Budyko and Fu equations and hydrological models. Journal of Hydrometeorology, 13**,** 1094-1106.

TIMBAL, B. & DROSDOWSKY, W. 2013. The relationship between the decline of South Eastern Australia rainfall and the strengthening of the sub-tropical ridge. International Journal of Climatology, 33**,** 1021-1034.

TIMBAL, B. & MCAVANEY, B. J. 2001. An analogue-based method to downscale surface air temperature: Application for Australia. Climate Dynamics, 17**,** 947-963.

TROCCOLI, A., MULLER, K., COPPIN, P., DAVY, R., RUSSELL, C. & HIRSCH, A. L. 2012. Long-term wind speed trends over Australia. Journal of Climate, 25**,** 170-183.

VAN VUUREN, D. P., EDMONDS, J., KAINUMA, M., RIAHI, K., THOMSON, A., HIBBARD, K., HURTT, G. C., KRAM, T., KREY, V. & LAMARQUE, J.-F. 2011. The representative concentration pathways: an overview. Climatic Change, 109**,** 5-31.

WATTERSON, I. G., HIRST, A. C. & ROTSTAYN, L. D. 2013. A skill score based evaluation of simulated Australian climate. Australian Meteorological and Oceanographic Journal, 63**,** 181-190.

WHAN, K., TIMBAL, B. & LINDESAY, J. 2014. Linear and nonlinear statistical analysis of the impact of sub-tropical ridge intensity and position on south-east Australian rainfall. International Journal of Climatology, 34, 326-342.

WHETTON, P., HENNESSY, K., CLARKE, J., MCINNES, K. & KENT, D. 2012. Use of Representative Climate Futures in impact and adaptation assessment. Climatic Change, 115**,** 433-442.

WHITE, C. J., MCINNES, K. L., CECHET, R. P., CORNEY, S. P., GROSE, M. R., HOLZ, G. K., KATZFEY, J. J. & BINDOFF, N. L. 2013. On regional dynamical downscaling for the assessment and projection of temperature and precipitation extremes across Tasmania, Australia. Climate Dynamics, 41**,** 3145-3165.

WHITE, N. J., HAIGH, I. D., CHURCH, J. A., KEON, T., WATSON, C. S., PRITCHARD, T., WATSON, P. J., BURGETTE, R. J., ELIOT, M., MCINNES, K. L., YOU, B., ZHANG, X. & TREGONING, P. 2014. Australian Sea Levels - Trends, regional variability and Influencing factors. Earth-Science Reviews, 136**,** 155-174.

WILLIAMS, R. J., BRADSTOCK, R. A., CARY, G. J., ENRIGHT, N., GILL, A., LIEDLOFF, A., LUCAS, C., WHELAN, R., ANDERSEN, A. & BOWMAN, D. 2009. Interactions between climate change, fire regimes and biodiversity in Australia- A preliminary assessment. Canberra: Department of Climate Change and Department of the Environment, Water, Heritage and the Arts. URL http://climatechange.gov.au/sites/climatechange/files/documents/04_2013/20100630-climate-fire-biodiversity-PDF.pdf Accessed 18/8/2014

ZHANG, L., POTTER, N., HICKEL, K., ZHANG, Y. & SHAO, Q. 2008. Water balance modeling over variable time scales based on the Budyko framework – Model development and testing. Journal of Hydrology 360**,** 117-131.

-20° -10° 0° 10° 20° 30° 40° 50°

APPENDIX

TABLE 1: 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 SOUTHERN SLOPES CLUSTER (AND FOR THE FOUR SOUTHERN SLOPES SUB-CLUSTERS FOR RAINFALL CHANGES). 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. SSVW IS SOUTHERN SLOPES VICTORIA WEST, SSVE IS SOUTHERN SLOPES VICTORIA EAST, SSTW IS SOUTHERN SLOPES TASMANIA WEST AND SSTE IS SOUTHERN SLOPES TASMANIA EAST.

VARIABLE	SEASON	2030, RCP2.6	2030, RCP4.5	2030, RCP8.5	2090, RCP2.6	2090, RCP4.5	2090, RCP8.5
Temperature (°C)	Annual	**0.7 (0.4 to 0.9)**	**0.6 (0.5 to 0.9)**	**0.8 (0.5 to 1.1)**	**0.8 (0.4 to 1.3)**	**1.5 (1.1 to 2)**	**3.1 (2.5 to 4)**
	DJF	0.8 (0.4 to 1.2)	0.8 (0.5 to 1.2)	0.9 (0.5 to 1.4)	0.9 (0.5 to 1.4)	1.6 (1.1 to 2.3)	3.3 (2.4 to 4.6)
	MAM	0.7 (0.5 to 0.9)	0.7 (0.4 to 0.9)	0.8 (0.5 to 1.2)	0.8 (0.5 to 1.2)	1.5 (1.1 to 2.1)	3.2 (2.5 to 4.2)
	JJA	0.6 (0.4 to 0.8)	0.6 (0.4 to 0.8)	0.7 (0.5 to 1)	0.6 (0.4 to 1.1)	1.4 (1.1 to 1.8)	2.9 (2.3 to 3.6)
	SON	0.6 (0.3 to 1)	0.7 (0.3 to 0.9)	0.8 (0.4 to 1.2)	0.7 (0.4 to 1.2)	1.4 (1 to 1.9)	3 (2.4 to 3.9)
Temperature maximum (°C)	Annual	**0.7 (0.5 to 1)**	**0.7 (0.5 to 1)**	**0.8 (0.6 to 1.2)**	**0.8 (0.5 to 1.4)**	**1.6 (1.1 to 2.1)**	**3.5 (2.5 to 4.3)**
	DJF	0.9 (0.5 to 1.3)	0.8 (0.5 to 1.3)	0.9 (0.6 to 1.3)	1 (0.6 to 1.8)	1.7 (1.2 to 2.4)	3.5 (2.5 to 4.6)
	MAM	0.7 (0.5 to 1)	0.7 (0.4 to 1.1)	0.8 (0.5 to 1.4)	0.9 (0.5 to 1.3)	1.6 (1.1 to 2.2)	3.4 (2.4 to 4.4)
	JJA	0.6 (0.4 to 0.8)	0.7 (0.4 to 1)	0.8 (0.6 to 1.1)	0.7 (0.4 to 1.2)	1.5 (1 to 2)	3.1 (2.4 to 3.9)
	SON	0.7 (0.4 to 1.1)	0.8 (0.4 to 1.1)	0.8 (0.5 to 1.3)	0.9 (0.4 to 1.4)	1.8 (1.1 to 2.2)	3.7 (2.7 to 4.4)
Temperature minimum (°C)	Annual	**0.6 (0.3 to 0.9)**	**0.6 (0.4 to 0.9)**	**0.8 (0.5 to 1.1)**	**0.7 (0.4 to 1.2)**	**1.4 (1 to 1.8)**	**2.9 (2.4 to 3.8)**
	DJF	0.7 (0.3 to 1.1)	0.7 (0.4 to 1.1)	0.9 (0.5 to 1.2)	0.9 (0.5 to 1.5)	1.5 (1 to 2.2)	3.4 (2.3 to 4.4)
	MAM	0.6 (0.4 to 0.8)	0.7 (0.5 to 1)	0.8 (0.5 to 1.1)	0.8 (0.4 to 1.1)	1.5 (1.1 to 1.9)	3.3 (2.5 to 4)
	JJA	0.5 (0.2 to 0.7)	0.6 (0.3 to 0.8)	0.7 (0.5 to 1)	0.6 (0.3 to 1.1)	1.3 (0.9 to 1.7)	2.8 (2.3 to 3.5)
	SON	0.5 (0.3 to 0.9)	0.6 (0.3 to 0.8)	0.7 (0.4 to 1)	0.6 (0.3 to 1.2)	1.3 (0.9 to 1.7)	2.7 (2.2 to 3.5)
Rainfall (%)	Annual	**-1 (-6 to 3)**	**-1 (-7 to 4)**	**-1 (-7 to 2)**	**-2 (-8 to 2)**	**-3 (-10 to 3)**	**-5 (-19 to 5)**
	DJF	-5 (-11 to 9)	-2 (-16 to 8)	-2 (-12 to 10)	-3 (-18 to 5)	-4 (-17 to 7)	-3 (-19 to 13)
	MAM	0 (-10 to 10)	0 (-11 to 9)	-2 (-9 to 9)	-2 (-12 to 8)	-2 (-11 to 8)	-2 (-19 to 13)
	JJA	0 (-4 to 7)	-1 (-6 to 6)	-1 (-6 to 6)	0 (-6 to 8)	0 (-9 to 6)	-3 (-14 to 11)
	SON	-3 (-12 to 3)	-4 (-11 to 5)	-5 (-11 to 4)	-4 (-14 to 4)	-9 (-17 to 1)	-14 (-34 to -1)
SSVW Rainfall (%)	Annual	**-3 (-9 to 2)**	**-2 (-8 to 3)**	**-3 (-10 to 2)**	**-3 (-13 to 3)**	**-7 (-15 to 3)**	**-9 (-27 to 4)**
	DJF	-6 (-13 to 6)	-2 (-20 to 16)	-1 (-16 to 13)	-5 (-27 to 6)	-3 (-24 to 10)	-5 (-28 to 17)
	MAM	-1 (-15 to 15)	0 (-20 to 14)	-4 (-15 to 14)	-1 (-17 to 12)	-4 (-17 to 14)	-5 (-30 to 15)
	JJA	-1 (-9 to 7)	-3 (-10 to 7)	-2 (-11 to 6)	-2 (-10 to 9)	-4 (-14 to 7)	-10 (-25 to 6)
	SON	-5 (-15 to 4)	-5 (-14 to 6)	-7 (-20 to 1)	-5 (-19 to 5)	-10 (-24 to -3)	-19 (-43 to -5)
SSVE Rainfall (%)	Annual	**-1 (-6 to 5)**	**-2 (-9 to 6)**	**-1 (-8 to 5)**	**-4 (-15 to 5)**	**-5 (-14 to 3)**	**-5 (-20 to 9)**
	DJF	-2 (-10 to 14)	-1 (-12 to 16)	0 (-11 to 14)	-2 (-18 to 8)	-1 (-13 to 11)	6 (-10 to 26)
	MAM	0 (-14 to 15)	-2 (-18 to 12)	0 (-10 to 9)	-4 (-19 to 17)	-4 (-15 to 13)	0 (-19 to 24)
	JJA	-1 (-7 to 5)	-2 (-11 to 6)	-3 (-13 to 9)	-4 (-12 to 9)	-7 (-16 to 6)	-14 (-31 to 2)
	SON	0 (-11 to 6)	-3 (-12 to 7)	-4 (-15 to 10)	-2 (-20 to 14)	-8 (-19 to 3)	-10 (-40 to 3)

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VARIABLE	SEASON	2030, RCP2.6	2030, RCP4.5	2030, RCP8.5	2090, RCP2.6	2090, RCP4.5	2090, RCP8.5
SSTW Rainfall (%)	Annual	-2 (-7 to 3)	0 (-6 to 3)	-2 (-6 to 2)	-1 (-7 to 4)	-2 (-7 to 4)	-5 (-17 to 4)
	DJF	-6 (-18 to 5)	-4 (-18 to 8)	-5 (-16 to 6)	-4 (-14 to 5)	-6 (-22 to 7)	-13 (-26 to 6)
	MAM	-1 (-8 to 10)	-2 (-8 to 9)	-3 (-9 to 8)	-1 (-9 to 13)	-1 (-9 to 7)	-4 (-21 to 5)
	JJA	2 (-4 to 8)	1 (-5 to 10)	1 (-4 to 9)	2 (-7 to 10)	4 (-5 to 14)	6 (-6 to 20)
	SON	-5 (-12 to 3)	-3 (-13 to 3)	-5 (-13 to 4)	-3 (-15 to 5)	-4 (-15 to 3)	-14 (-33 to 1)
SSTE Rainfall (%)	Annual	-1 (-7 to 4)	1 (-6 to 4)	-1 (-7 to 4)	-2 (-7 to 3)	-1 (-8 to 5)	-2 (-18 to 9)
	DJF	-5 (-15 to 6)	-3 (-16 to 9)	-3 (-15 to 11)	-4 (-16 to 5)	-4 (-18 to 11)	-6 (-22 to 10)
	MAM	1 (-7 to 10)	0 (-7 to 11)	0 (-9 to 9)	-1 (-10 to 12)	-2 (-8 to 10)	1 (-23 to 13)
	JJA	3 (-5 to 9)	1 (-6 to 10)	1 (-4 to 8)	1 (-5 to 9)	2 (-6 to 13)	6 (-11 to 19)
	SON	-4 (-11 to 4)	-3 (-11 to 5)	-4 (-13 to 5)	-3 (-14 to 5)	-6 (-15 to 3)	-9 (-33 to 3)
Sea level pressure (hPa)	Annual	0.3 (-0.1 to 0.8)	0.3 (-0.1 to 0.7)	0.5 (-0.1 to 0.9)	0.3 (-0.3 to 0.9)	0.6 (-0.1 to 1.4)	1 (0.3 to 2.7)
	DJF	0.4 (-0.5 to 0.7)	0.1 (-0.3 to 0.7)	0.3 (-0.3 to 0.8)	0.1 (-0.5 to 0.5)	0.3 (-0.5 to 0.9)	0.8 (-0.3 to 1.6)
	MAM	0.1 (-0.3 to 0.5)	0.1 (-0.4 to 0.7)	0.2 (-0.4 to 0.8)	0 (-0.7 to 0.7)	0.3 (-0.3 to 0.9)	0.8 (-0.3 to 1.7)
	JJA	0.4 (-0.7 to 1.4)	0.4 (-0.8 to 1.4)	0.6 (-0.6 to 1.3)	0.4 (-1 to 1.5)	0.7 (-0.7 to 2.3)	1.6 (-0.2 to 3.6)
	SON	0.6 (-0.1 to 1.9)	0.4 (-0.2 to 1.5)	0.6 (0 to 1.6)	0.5 (-0.2 to 1.6)	1.1 (0.2 to 1.9)	1.9 (0.4 to 4.3)
Solar radiation (%)	Annual	1.7 (0.7 to 3)	0.7 (-0.1 to 2)	1.3 (0.1 to 2.4)	2 (0.9 to 3)	1.9 (0.1 to 3.5)	3.1 (0.3 to 6.8)
	DJF	1.9 (0 to 3.4)	0.4 (-0.5 to 2.2)	0.9 (-0.4 to 2.8)	1.9 (0.4 to 3.6)	1.5 (-0.4 to 3.1)	1.6 (-0.9 to 5.2)
	MAM	1.1 (-0.3 to 3.1)	0.5 (-1.1 to 2.4)	0.6 (-0.6 to 3)	1.5 (-0.3 to 3.7)	1.4 (-0.8 to 3.5)	2.2 (-1.3 to 5.9)
	JJA	1.5 (-0.2 to 3.3)	1.3 (-0.7 to 3.3)	1.7 (0 to 4.3)	1.7 (0.2 to 4.2)	2 (0.3 to 6.2)	4.2 (0.8 to 10.7)
	SON	1.8 (0 to 3.9)	1.2 (-0.1 to 2.5)	1.8 (-0.2 to 3.3)	1.9 (0.8 to 4.6)	2.5 (0.5 to 4.7)	4.8 (1.4 to 8.9)
Relative humidity (%, absolute)	Annual	-0.5 (-1.2 to 0.2)	-0.4 (-0.9 to 0.1)	-0.5 (-1.1 to 0)	-0.5 (-2.1 to 0)	-0.9 (-1.7 to -0.1)	-1.3 (-2.9 to -0.8)
	DJF	-0.5 (-1.4 to 0.3)	-0.4 (-1 to 0.7)	-0.4 (-1.4 to 0.3)	-0.7 (-2.1 to 0)	-0.6 (-1.8 to 0.3)	-1.1 (-2.1 to 0.3)
	MAM	-0.5 (-1.5 to 0.3)	-0.1 (-1.5 to 0.6)	-0.4 (-1.2 to 0.3)	-0.6 (-1.7 to 0.3)	-0.6 (-1.9 to 0.6)	-1 (-2.4 to 0.2)
	JJA	-0.2 (-1.1 to 0.3)	-0.3 (-1 to 0.2)	-0.4 (-1.3 to 0.2)	-0.3 (-1.3 to 0.3)	-0.5 (-1.4 to 0.1)	-1.6 (-3 to -0.5)
	SON	-0.4 (-1.3 to 0.2)	-0.6 (-1.5 to 0.2)	-0.6 (-1.6 to 0.2)	-0.3 (-2.3 to 0.4)	-1.5 (-3.5 to -0.1)	-2.6 (-5 to -1.3)
Evapotranspi-ration (%)	Annual	4.1 (3.1 to 5.6)	3 (1.9 to 4.4)	4.3 (2.2 to 6.1)	4.3 (2.6 to 7.2)	6.9 (4.3 to 10.1)	14.4 (9.5 to 22.2)
	DJF	3.7 (2.1 to 6.5)	2.2 (1.2 to 4.7)	3.7 (2 to 6.7)	4.1 (1.8 to 8.8)	5.8 (2.9 to 10.2)	11 (7.8 to 20.7)
	MAM	4.5 (2.6 to 6.2)	3.3 (0.9 to 6.8)	4.7 (2.1 to 7)	5.3 (2.7 to 8.9)	8.1 (6.4 to 11.4)	16.1 (10.8 to 28.4)
	JJA	4.5 (2.1 to 7.9)	4.2 (0.8 to 8.7)	5 (2 to 8.8)	4.6 (0.6 to 7.7)	9.8 (5.8 to 15.2)	22 (15.9 to 33.4)
	SON	4.1 (2.1 to 6.4)	3.3 (2.3 to 5.2)	4.2 (2.1 to 6.6)	4 (2.2 to 7)	7.2 (4 to 10.1)	13.6 (8 to 21.5)
Wind speed (%)	Annual	0.5 (-0.6 to 2.2)	0.4 (-2 to 1.3)	0.4 (-2.1 to 2.4)	1.1 (-1 to 2.8)	-0.6 (-2.1 to 1.5)	0.3 (-2.5 to 2.9)
	DJF	0.4 (-2.6 to 2.6)	-0.7 (-3.3 to 0.8)	-0.1 (-2 to 1.9)	1.5 (-1.1 to 4)	-1.2 (-4.5 to 0.5)	-1.6 (-4.7 to 0.5)
	MAM	0.3 (-1.2 to 3.5)	-0.1 (-3.1 to 3.6)	-0.2 (-3.1 to 3.2)	0.8 (-3.6 to 3.6)	-1.3 (-4.6 to 1.4)	-2.5 (-7 to 0.2)
	JJA	1.4 (-1.6 to 5.5)	1.7 (-1.5 to 4.6)	1.6 (-0.4 to 5.6)	1.8 (-1.8 to 4.7)	1.6 (-3.3 to 5.2)	4.5 (-1.1 to 10.6)
	SON	0.1 (-2.7 to 2.2)	-1.1 (-3.2 to 1.6)	-0.2 (-4 to 3.5)	0.1 (-3 to 3.8)	-1.3 (-5 to 2.6)	-0.1 (-4.9 to 3.8)
Soil moisture (Budyko) (%)	Annual	NA	-2.3 (-4.2 to -0.4)	-2.9 (-4.9 to -0.5)	NA	-3.6 (-5.9 to -0.7)	-6.8 (-13.7 to -3.4)
	DJF	NA	-2.9 (-5.3 to -1.1)	-4.3 (-7.5 to -1.4)	NA	-4.2 (-9.3 to -2)	-5.5 (-15.7 to -1.7)
	MAM	NA	-1.6 (-6 to 0.6)	-2.1 (-6.4 to 0)	NA	-3.2 (-6.3 to 0.5)	-4.3 (-11.4 to -0.6)
	JJA	NA	-0.9 (-4.1 to 1.5)	-1.9 (-3.9 to 1)	NA	-2.4 (-5 to 0.9)	-6.1 (-12.3 to -1)
	SON	NA	-2.6 (-5 to -0.8)	-3 (-6 to -0.6)	NA	-4.9 (-8.9 to -1.5)	-8.7 (-19.5 to -4.8)

LEGEND TO TABLE 1

Dark red	Very high model agreement on substantial increase
Pink	High model agreement on substantial increase
Light pink	Medium model agreement on substantial increase
Orange	High model agreement on increase
Light orange	Medium model agreement on increase
Grey	High model agreement on little change
Light grey	Medium model agreement on little change
White	Low model agreement on the direction of change
Blue	High model agreement on substantial decrease
Light blue	Medium model agreement on substantial decrease
Green	High model agreement on decrease
Light green	Medium model agreement on decrease

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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
Hobart (TAS EAST)	T	17.2	18.2	18.2	18.1	18.4	18.0	17.9	19.7	18.6	18.8	21.5	19.8	20.0
	R	620	526	502	541	542	526	541	567	565	537	531	509	541
	DF	5.4	5.5	5.6	5.5	5.6	5.5	5.5	5.7	5.5	5.6	6.2	5.9	5.9
	SEV	0.2	0.2	0.2	0.1	0.2	0.1	0.2	0.3	0.1	0.2	0.5	0.2	0.3
	ΣFFDI	1395	1437	1520	1423	1501	1473	1459	1578	1447	1526	1888	1669	1638
Launces-ton (TAS EAST)	T	17.1	18.1	18.1	18.0	18.3	17.9	17.8	19.6	18.5	18.7	21.4	19.7	19.9
	R	683	558	541	577	575	565	581	603	600	582	570	548	590
	DF	5.2	5.3	5.4	5.2	5.3	5.3	5.3	5.4	5.2	5.4	5.8	5.7	5.6
	SEV	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.1	0.1	0.1
	ΣFFDI	1434	1472	1561	1449	1536	1504	1498	1609	1473	1564	1909	1704	1669
East Sale (NSW/VIC EAST)	T	19.8	20.8	21.0	21.0	21.2	20.8	20.9	22.5	21.7	21.8	24.6	23.2	23.0
	R	611	540	481	543	531	511	512	515	487	511	501	403	570
	DF	6.0	6.0	6.4	6.0	6.2	6.1	6.2	6.5	6.4	6.4	7.1	7.3	6.4
	SEV	0.5	0.5	0.8	0.5	0.8	0.8	0.6	0.9	0.8	0.7	1.9	1.6	0.8
	ΣFFDI	1849	1878	2114	1874	2053	1999	1991	2174	2113	2070	2712	2737	2048
Nowra (NSW/VIC EAST)	T	21.5	22.5	22.8	22.7	22.9	22.5	22.7	24.2	23.4	23.6	26.4	24.9	24.7
	R	1135	888	806	912	868	855	859	859	810	844	834	677	960
	DF	6.2	6.0	6.3	6.1	6.1	6.1	6.1	6.4	6.3	6.3	6.7	6.8	6.3
	SEV	0.9	0.9	1.0	0.8	1.2	1.1	1.0	1.4	1.1	1.1	2.6	2.5	1.4
	ΣFFDI	1905	1820	2026	1849	1968	1954	1935	2090	2044	1984	2555	2568	2015
Melbourne (VIC WEST)	T	19.6	20.6	20.9	20.6	20.9	20.6	20.3	22.2	21.3	21.0	24.0	22.9	22.2
	R	544	477	366	492	493	419	490	491	428	482	450	322	516
	DF	6.2	6.5	7.1	6.4	6.6	6.7	6.3	6.8	6.8	6.5	7.4	8.1	6.6
	SEV	2.7	3.2	4.2	3.0	3.4	3.5	2.8	3.9	3.6	3.5	5.4	5.8	3.7
	ΣFFDI	2553	2678	3227	2646	2862	2935	2619	2988	2949	2772	3624	3966	2806
Laverton (VIC WEST)	T	19.6	20.6	20.9	20.6	20.9	20.6	20.3	22.2	21.3	21.0	24.0	22.9	22.2
	R	557	449	344	463	464	393	462	463	404	455	423	301	484
	DF	6.3	6.5	7.2	6.4	6.5	6.7	6.3	6.8	6.8	6.5	7.5	8.1	6.6
	SEV	1.7	1.8	3.0	1.6	2.2	2.2	1.6	2.7	2.3	1.8	4.1	4.6	2.2
	ΣFFDI	2208	2280	2809	2253	2439	2534	2222	2557	2545	2358	3130	3480	2394

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TABLE 3: PROJECTED ANNUAL CHANGE IN SIMULATED MARINE CLIMATE VARIABLES FOR THE 2020–2039 (2030) AND 2080–2099 (2090) PERIODS RELATIVE TO THE 1986–2005 PERIOD FOR SOUTHERN SLOPES, WHERE SEA ALLOWANCE IS THE MINIMUM DISTANCE REQUIRED TO RAISE AN ASSET TO MAINTAIN CURRENT FREQUENCY OF BREACHES UNDER PROJECTED SEA LEVEL RISE. FOR SEA LEVEL RISE, THE RANGE WITHIN THE BRACKETS REPRESENTS THE 5TH AND 95TH PERCENTILE CHANGE, AS PROJECTED BY THE CMIP5 MODEL ARCHIVE WHEREAS FOR SEA SURFACE TEMPERATURE, SALINITY, OCEAN PH AND ARAGONITE CONCENTRATION THE RANGE REPRESENTS THE 10TH TO 90TH PERCENTILE RANGE. ANNUAL RESULTS ARE GIVEN FOR RCP2.6, RCP4.5, AND RCP8.5. NOTE THAT THE RANGES OF SEA LEVEL RISE SHOULD BE CONSIDERED *LIKELY* (AT LEAST 66 % PROBABILITY), AND THAT IF A COLLAPSE IN THE MARINE BASED SECTORS OF THE ANTARCTIC ICE SHEET WERE INITIATED, THESE PROJECTIONS COULD BE SEVERAL TENTHS OF A METRE HIGHER BY LATE IN THE CENTURY.

VARIABLE	LOCATION (°E, °S)	2030, RCP2.6	2030, RCP4.5	2030, RCP8.5	2090, RCP2.6	2090, RCP4.5	2090, RCP8.5
Sea level rise (m)	Portland (141.613E, 38.343S)	0.12 (0.08-0.17)	0.12 (0.08-0.16)	0.13 (0.08-0.18)	0.39 (0.23-0.55)	0.46 (0.29-0.64)	0.61 (0.39-0.84)
	Stony Point (145.225E, 38.372S)	0.11 (0.07-0.16)	0.11 (0.07-0.16)	0.12 (0.08-0.17)	0.37 (0.22-0.53)	0.44 (0.27-0.62)	0.59 (0.38-0.81)
	Burnie (145.915E, 41.055S)	0.12 (0.08-0.17)	0.12 (0.08-0.16)	0.13 (0.08-0.18)	0.38 (0.23-0.54)	0.46 (0.29-0.63)	0.61 (0.41-0.83)
	Spring Bay (147.933E, 42.546S)	0.13 (0.08-0.18)	0.13 (0.09-0.18)	0.14 (0.09-0.19)	0.40 (0.24-0.56)	0.48 (0.31-0.66)	0.66 (0.45-0.89)
Sea allowance (m)	Portland (141.613E, 38.343S)	0.12	0.12	0.13	0.46	0.54	0.74
	Stony Point (145.225E, 38.372S)	0.12	0.12	0.13	0.43	0.51	0.70
	Burnie (145.915E, 41.055S)	0.13	0.13	0.14	0.44	0.53	0.72
	Spring Bay (147.933E, 42.546S)	0.14	0.14	0.15	0.49	0.59	0.83
Sea surface temperature (°C)	Portland (141.61, -38.34)	0.5 (0.2 to 0.7)	0.5 (0.3 to 0.7)	0.5 (0.3 to 0.8)	0.6 (0.3 to 0.9)	1.1 (0.7 to 1.6)	2.2 (1.6 to 3.4)
	Stony Point (145.23, -38.37)	0.5 (0.3 to 0.8)	0.5 (0.4 to 0.7)	0.6 (0.3 to 0.9)	0.5 (0.3 to 0.9)	1.1 (0.8 to 1.7)	2.3 (1.9 to 3.8)
	Burnie (145.92, -41.05)	0.5 (0.3 to 0.8)	0.5 (0.4 to 0.8)	0.6 (0.4 to 0.9)	0.5 (0.3 to 0.9)	1.1 (0.9 to 1.7)	2.8 (1.9 to 4.0)
	Spring Bay (147.93, -42.55)	0.7 (0.4 to 1.0)	0.7 (0.5 to 1.2)	0.8 (0.7 to 1.4)	0.6 (0.1 to 1.2)	1.3 (1.0 to 2.1)	3.6 (2.1 to 5.1)
Sea surface salinity	Portland (141.61, -38.34)	-0.03 (-0.08 to 0.11)	-0.03 (-0.09 to 0.13)	-0.04 (-0.11 to 0.08)	-0.05 (-0.10 to 0.07)	-0.05 (-0.16 to 0.18)	-0.0 (-0.3 to 0.4)
	Stony Point (145.23, -38.37)	-0.03 (-0.08 to 0.12)	-0.02 (-0.09 to 0.16)	-0.03 (-0.11 to 0.08)	-0.04 (-0.10 to 0.07)	-0.01 (-0.18 to 0.20)	0.1 (-0.3 to 0.4)
	Burnie (145.92, -41.05)	-0.02 (-0.08 to 0.12)	-0.01 (-0.08 to 0.16)	-0.02 (-0.11 to 0.09)	-0.03 (-0.10 to 0.07)	0.01 (-0.17 to 0.19)	0.2 (-0.3 to 0.4)
	Spring Bay (147.93, -42.55)	0.02 (-0.04 to 0.23)	0.03 (-0.04 to 0.56)	0.05 (-0.07 to 0.39)	-0.02 (-0.12 to 0.19)	0.00 (-0.11 to 0.42)	0.2 (0.0 to 1.2)
Ocean pH	Portland (141.61, -38.34)	-0.07 (-0.07 to -0.06)	-0.07 (-0.08 to -0.07)	-0.08 (-0.09 to -0.08)	-0.07 (-0.07 to -0.06)	-0.15 (-0.15 to -0.14)	-0.3 (-0.3 to -0.3)
	Stony Point (145.23, -38.37)	-0.07 (-0.07 to -0.06)	-0.07 (-0.08 to -0.07)	-0.08 (-0.09 to -0.08)	-0.07 (-0.07 to -0.06)	-0.16 (-0.16 to -0.14)	-0.3 (-0.3 to -0.3)
	Burnie (145.92, -41.05)	-0.07 (-0.07 to -0.06)	-0.07 (-0.08 to -0.07)	-0.08 (-0.09 to -0.08)	-0.07 (-0.07 to -0.06)	-0.16 (-0.16 to -0.14)	-0.3 (-0.3 to -0.3)
	Spring Bay (147.93, -42.55)	-0.07 (-0.07 to -0.06)	-0.07 (-0.08 to -0.06)	-0.08 (-0.09 to -0.07)	-0.07 (-0.08 to -0.07)	-0.15 (-0.16 to -0.15)	-0.3 (-0.3 to -0.3)

Aragonite saturation	Portland (141.61, -38.34)	-0.29 (-0.29 to -0.25)	-0.29 (-0.31 to -0.28)	-0.35 (-0.36 to -0.30)	-0.27 (-0.29 to -0.24)	-0.60 (-0.65 to -0.53)	-1.1 (-1.3 to -1.1)
	Stony Point (145.23, -38.37)	-0.28 (-0.29 to -0.25)	-0.30 (-0.30 to -0.27)	-0.34 (-0.36 to -0.26)	-0.28 (-0.29 to -0.21)	-0.59 (-0.62 to -0.46)	-1.1 (-1.2 to -1.0)
	Burnie (145.92, -41.05)	-0.28 (-0.29 to -0.24)	-0.30 (-0.31 to -0.25)	-0.35 (-0.35 to -0.24)	-0.28 (-0.29 to -0.20)	-0.58 (-0.62 to -0.42)	-1.1 (-1.2 to -1.0)
	Spring Bay (147.93, -42.55)	-0.24 (-0.30 to -0.17)	-0.26 (-0.31 to -0.18)	-0.28 (-0.30 to -0.26)	-0.27 (-0.47 to -0.21)	-0.56 (-0.68 to -0.45)	-1.1 (-1.2 to -0.9)

For sea level rise and sea allowance, the future averaging periods are 2020–2040 and 2080–2100. In the report, these are referred to as 2030 and 2090 respectively.

ABBREVIATIONS

ACORN-SAT	Australian Climate Observations Reference Network – Surface Air Temperature
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)
CSIRO	Commonwealth Scientific and Industrial Research Organisation
EAC	East Australian Current
ENSO	El Niño Southern Oscillation
FFDI	Forest Fire Danger Index
GCMs	General Circulation Models or Global Climate Models
IOD	Indian Ocean Dipole
IPO	Interdecadal Pacific Oscillation
IPCC	Intergovernmental Panel on Climate Change
MSLP	Mean Sea level Pressure
NARCliM	NSW/ACT Regional Climate Modelling project
NRM	Natural Resource Management
RCP	Representative Concentration Pathway
SAM	Southern Annular Mode
SEACI	South East Australian Climate Initiative
SPI	Standardised Precipitation Index
SRES	Special Report on Emissions Scenarios
SS	Southern Slopes cluster
SSVE	Southern Slopes sub-cluster Eastern Victoria (and southern New South Wales)
SSVW	Southern Slopes sub-cluster Western Victoria
SSTE	Southern Slopes sub-cluster Eastern Tasmania
SSTW	Southern Slopes sub-cluster Eastern Tasmania
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.

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.

GLOSSARY REFERENCES

AUSTRALIAN BUREAU OF METEOROLOGY - http://www.bom.gov.au/watl/about-weather-and-climate/australian-climate-influences.shtml (cited August 2014)

INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE - http://www.ipcc.ch/pdf/glossary/ar4-wg1.pdf (cited August 2014)

INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE - http://ipcc-wg2.gov/AR5/images/uploads/WGIIAR5-Glossary_FGD.pdf (cited August 2014)

MUCCI, A. 1983. The solubility of calcite and aragonite in seawater at various salinities, temperatures, and one atmosphere total pressure *American Journal of Science*, 283 (7), 780-799.

NAKIĆENOVIĆ, N. & SWART, R. (eds.) 2000. *Special Report on Emissions Scenarios. A Special Report of Working Group III of the Intergovernmental Panel on Climate Change*, Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press.

STURMAN, A.P. & TAPPER, N.J. 2006. *The Weather and Climate of Australia and New Zealand*, 2nd ed., Melbourne, Oxford University Press.

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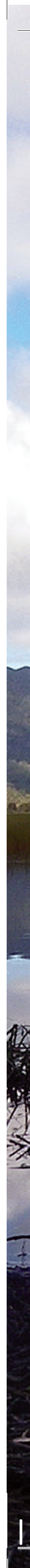

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