EAST COAST

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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This version was updated in April 2021 to correct typological errors in Table 3 and text on p.32.

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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.

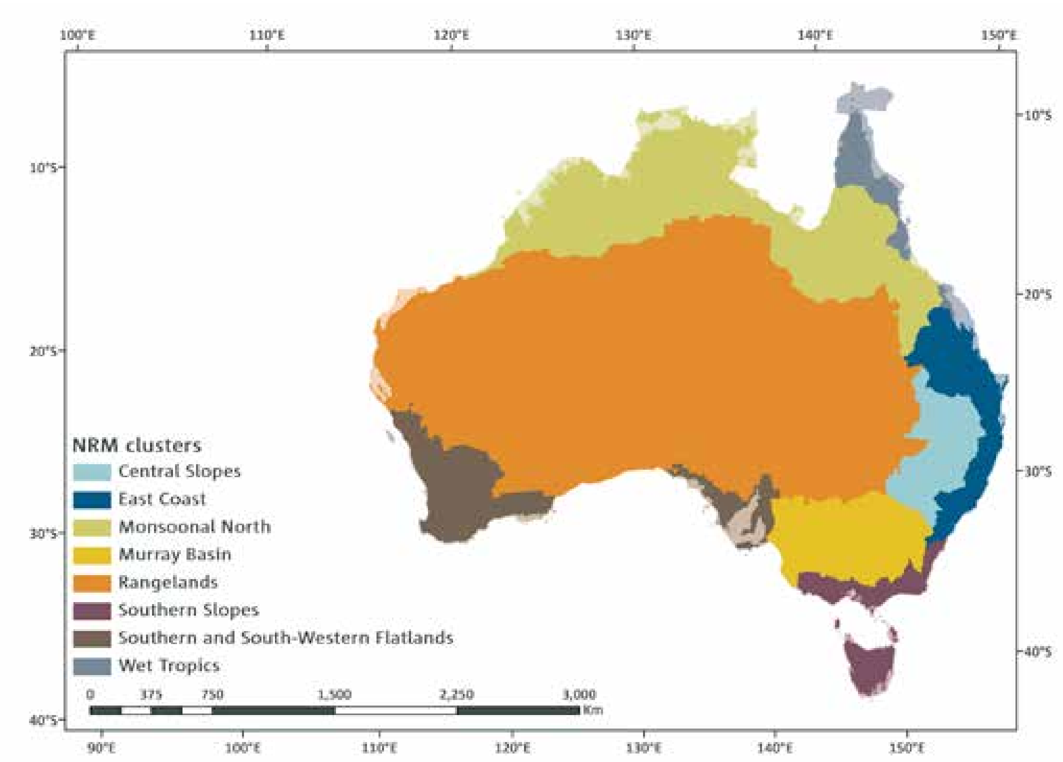


FIGURE A: THE EIGHT NATURAL RESOURCE MANAGEMENT (NRM) CLUSTERS

This is the regional projections report for the East Coast 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 as part of 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 East Coast 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 – East Coast North and East Coast South (Figure 1.1) – will be reported on when their climate differs from the cluster mean. 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) and the degree of agreement amongst the different lines of evidence. The confidence ratings used here are set as *low, medium, high* or *very high* (IPCC, 2013).

HIGHER TEMPERATURES

Between 1910 and 2013 mean surface air temperature has increased by about 1 °C in East Coast North and by about 0.8 °C in East Coast South using a linear trend.

Continued substantial warming for the East Coast cluster for mean, maximum and minimum temperatures are projected with *very high confidence*, taking into consideration the 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 mean warming is around 0.4 to 1.3 °C above the climate of 1986–2005, with only minor difference between RCPs. For late in the century (2090) it is 1.3 to 2.5 °C for RCP4.5 and 2.7 to 4.7 °C for RCP8.5.

HOTTER AND MORE FREQUENT HOT DAYS. LESS FROST

A substantial increase in the temperature reached on the hottest days, the frequency of hot days and the duration of warm spells is projected with *very high confidence*, based on model results and physical understanding. Correspondingly, a substantial decrease in the frequency of frost risk days is projected by 2090 with *high confidence*. For example, in Amberley (near Brisbane) the number of days above 35 °C by late in the century (2090) doubles under RCP4.5 and median model ensemble warming, and the number of days over 40 °C approximately triples. For the same case, the frequency of frost would substantially decrease.

LESS RAINFALL IN WINTER IN THE SOUTH, BUT OTHERWISE RAINFALL CHANGES ARE UNCLEAR

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

There is *high confidence* that natural climate variability will remain the major driver of rainfall changes in the next few decades in this cluster with 20-year mean changes of -15 to +10 % annually, and -30 to +20 % seasonally, relative to the climate of 1986–2005.

By 2090 under RCP4.5 and RCP8.5 in East Coast North, models show a broad range of results, with the median generally indicating little change or decrease, particularly in winter and spring. However, uncertainty over driving processes and some inconsistent results from downscaling indicate that the direction of change cannot be reliably projected. The magnitude of possible seasonal differences from the climate of 1986–2005 indicated by GCM results range from around -35 to +20 % under RCP4.5 and -55 to +30 % under RCP8.5.

By 2090 under RCP4.5 and RCP8.5 in East Coast South, a decrease in winter rainfall is projected, with *medium confidence* based on strong model agreement and good understanding of the contributing underlying physical mechanisms driving this change (relating to a southward shift of winter storm systems). A range of changes are projected in the other seasons, with a tendency for increase in summer, but uncertainty over driving processes. Some inconsistent results from downscaling mean that the direction of change cannot be reliably projected. The magnitude of possible seasonal differences from the climate of 1986–2005 indicated by GCM results is around -25 to +20 % under RCP4.5 and -30 to +25 % under RCP8.5.

Contrasting model simulations highlight the potential need to consider the risk of both a drier and wetter climate in impact assessment in this cluster.

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

Understanding of physical processes and high model agreement provide *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.

Greater time spent in meteorological drought is projected with *medium confidence* by late in the 21st century under RCP8.5. An increase in the frequency and duration of extreme drought is projected with *low confidence*.

SOME DECREASE IN WINTER WIND SPEED. FEWER EAST COAST LOWS

Little change in mean surface wind speed is projected with *high confidence* under all RCPs, particularly by 2030, and with *medium confidence* by 2090. However, under RCP8.5 in East Coast South, winter decreases (associated with southward shift of storms) are projected with *medium confidence*, and spring increases are projected in East Coast North with *low confidence*.

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

Based on global and regional studies, tropical cyclones are projected to become less frequent but with increases in the proportion of the most intense storms (*medium confidence*). A larger proportion of storms may decay south of 25°S although this projection is made with *low confidence*.

Scientific literature suggests a decline in the number of east coast lows.

LITTLE CHANGE IN SOLAR RADIATION AND REDUCED HUMIDITY THROUGHOUT THE YEAR

With *high confidence*, little change is projected for solar radiation for the near future (2030). For the late in the century (2090) under RCP8.5, little change is projected with *low confidence*, except for winter and spring increases.

There is *high confidence* in little change in relative humidity for the near future (2030), but *medium confidence* in a decrease (-3.5 to 0.5 % under RCP4.5 and -3.5 to 1.9 % under RCP8.5) for late in the century (2090) given model agreement and understanding of physical processes.

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

Projections for potential evapotranspiration indicate increases with *high confidence* in all seasons by late in the 21st century. However, despite high model agreement, and good physical understanding, there is only *medium confidence* in the magnitude of these projections due to shortcomings in the simulation of observed historical changes.

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

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 that change because of the significant uncertainties in the rainfall projection.

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 from 1966–2009, 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 0.08 to 0.18 m above the 1986–2005 level, with only minor differences between RCPs. As the century progresses, projections are sensitive to RCPs. By 2090, RCP4.5 gives a rise of 0.30 to 0.65 m and RCP8.5 gives a rise of 0.44 to 0.88 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 East Coast coastlines and the uncertainty in the sea level rise projections, an indicative extreme sea level 'allowance' is provided. The allowance being the minimum distance required to raise an asset to maintain current frequency of breaches under projected sea level rise. For the East Coast in 2030, the vertical allowances along the cluster coastline are in the range of 13 to 15 cm for all RCPs. By 2090 they are 55 to 63 cm for RCP4.5 and 78 to 89 cm for RCP8.5.

WARMER AND MORE ACIDIC OCEANS IN THE FUTURE

Sea surface temperature (SST) has risen significantly across the globe over recent decades and warming is projected to continue with *very high confidence*.

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, decreases in pH of up to 0.1 are projected under RCP4.5 and up to 0.14 under RCP8.5. These values would represent a 25 % and 40 % 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 East Coast 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 a model that represents a particular change of interest (*e.g.* warmer and drier conditions).

1 THE EAST COAST CLUSTER

This report describes climate change projections for the East Coast cluster comprising six coastal NRM regions from Queensland (Fitzroy, Burnett Mary and South East Queensland) and New South Wales (formerly Northern Rivers, Hunter-Central Rivers and Hawkesbury-Nepean) (Figure 1.1). Since January 2014, the previous Catchment Management Authority regions of NSW have been re-organised into new Local Land Services (LLS) regions. The North West, Northern Tablelands, North Coast, Hunter, Central Tablelands, Greater Sydney and South East LLS regions all have areas included within the East Coast cluster.

Because of the large north-south extent of the cluster, and the diversity of the region, climate change projections are presented for two sub-clusters: the Queensland side (East Coast North) and the New South Wales side (East Coast South) (Figure 1.1).

The East Coast cluster forms the central part of the eastern seaboard of Australia, encompassing the drainage basins of a number of major rivers that flow from important head-water catchments within sub-tropical mountain ranges through the coastal zone and into the Pacific Ocean. The cluster includes five of the ten largest urban areas in Australia (Sydney, Brisbane, Gold Coast, Newcastle and Sunshine Coast).

Dominant land uses of the cluster include extensive urban and peri-urban development, large-scale dryland grazing, large mining centres, and valuable agriculture. Internationally significant natural features in the cluster include the southern end of the Great Barrier Reef, biodiversity world heritage rainforest, unique islands and important coastal ecosystems. Considering the climate change impacts and the adaptation challenge for these land uses and natural features, are high priorities for the region's natural resource management planning community.

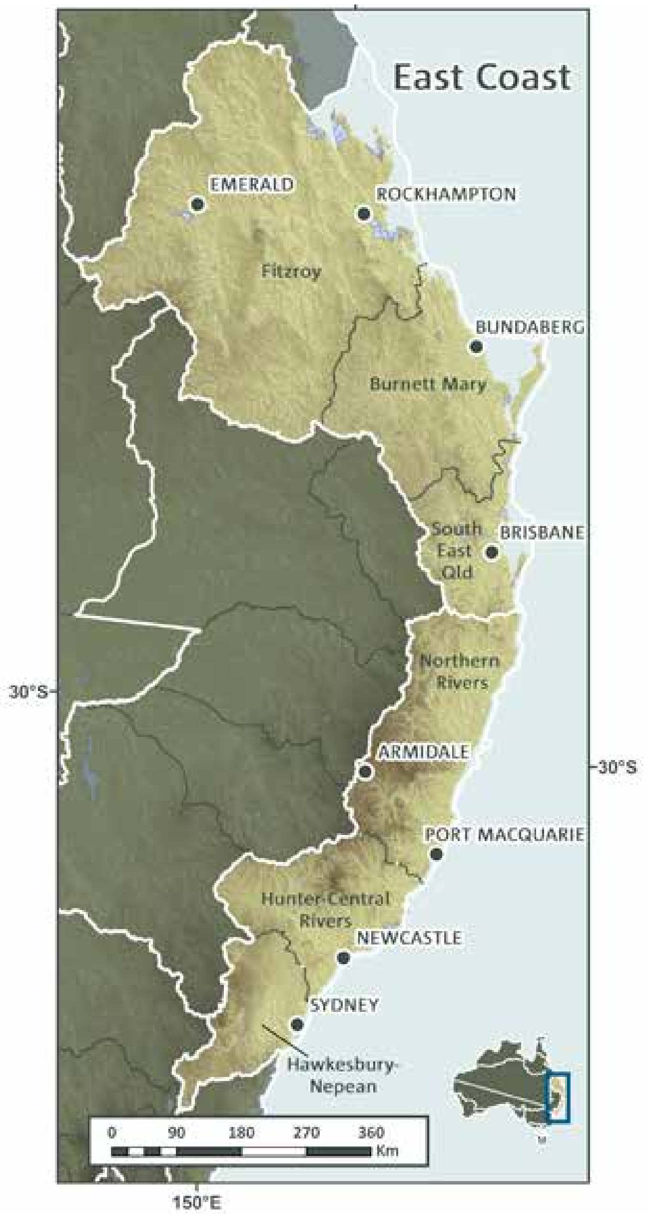


FIGURE 1.1: THE EAST COAST CLUSTER AND MAIN LOCALITIES WITH RESPECT TO THE AUSTRALIAN CONTINENT. THE STATE BOUNDARY BETWEEN QUEENSLAND AND NEW SOUTH WALES IS ALSO THE SEPARATION BETWEEN THE NORTHERN AND SOUTHERN SUB-CLUSTERS.

2 CLIMATE OF EAST COAST

The East Coast cluster straddles the Queensland and NSW border immediately east of the ridge-line of the Great Dividing Range. The cluster spans a large range of latitude and altitude, resulting in a large range of climatic conditions. Its climate is predominantly sub-tropical, with regional variations such as tropical influences in the north and temperate influences in the south. In the sections below, the current climate of East Coast is presented for the period 1986–2005 (Box 3.1 presents the observational data sets used in this report).

Maps of the average daily mean temperature show considerable variability in summer, with temperatures ranging from 27–30 °C in the northern parts of the Fitzroy region in Queensland to 15–18 °C in the southern elevated regions of New South Wales (Figure 2.1a). In winter, mean temperatures range from 15–18 °C in the north to 3–6 °C in the southern elevated regions (Figure 2.1b). The average daily maximum temperature during January ranges from 33–36 °C in the north to 21–24 °C in the south (Figure 2.1c), while the average daily minimum temperature during July ranges from 12–15 °C in the north to -3–0 °C in the south (Figure 2.1d). The cluster generally experiences fewer hot days on average than locations elsewhere in Australia at similar latitudes, due to its close proximity to the ocean, which has a moderating influence on temperatures. The coldest minimum temperatures tend to follow the ridge line of the Great Dividing Range, noting some regional variations, such as the Hunter Valley experiencing fewer cold days than surrounding regions because its altitude is lower than other nearby parts of the Great Dividing Range.

As a whole, the East Coast North sub-cluster exhibits a clear seasonal variation in temperature with daily mean temperatures ranging from about 26 °C in summer (January) to about 15 °C in winter (July), with a maximum for the sub-cluster of about 33 °C in January and a minimum of about 8 °C in July (Figure 2.2). Similarly for the East Coast South sub-cluster, daily mean temperatures range from about 22 °C degrees in summer (January) to about 10 °C in winter (July), with a maximum for the sub-cluster of about 28 °C in January and a minimum of about 4 °C in July. The annual average temperature is 21.3 °C for East Coast North and 16.4 °C for East Coast South (Figure 2.2).

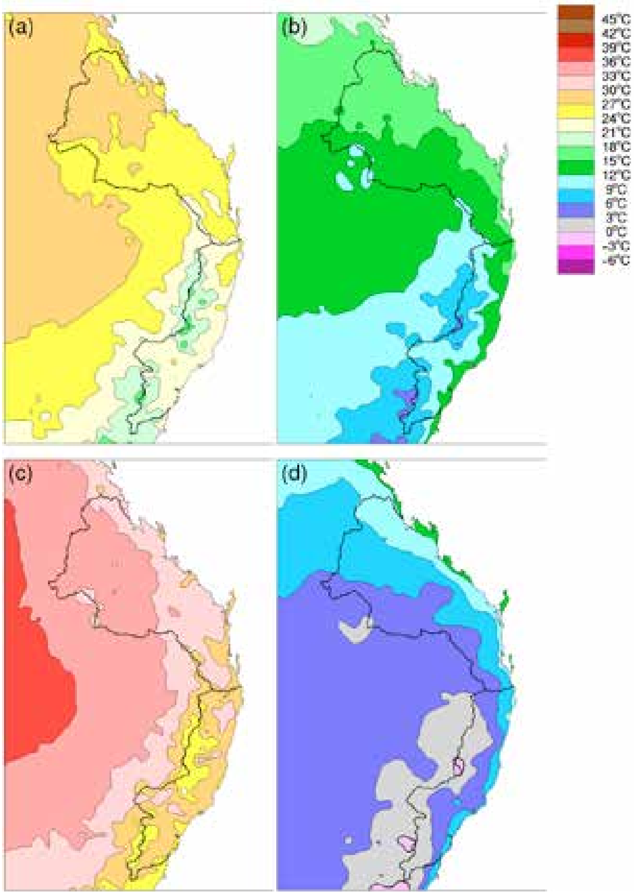


FIGURE 2.1: MAPS OF (A) AVERAGE SUMMER DAILY MEAN TEMPERATURE, (B) AVERAGE WINTER DAILY MEAN TEMPERATURE, (C) AVERAGE JANUARY MAXIMUM DAILY TEMPERATURE AND (D) AVERAGE JULY MINIMUM DAILY TEMPERATURE FOR THE PERIOD 1986–2005.

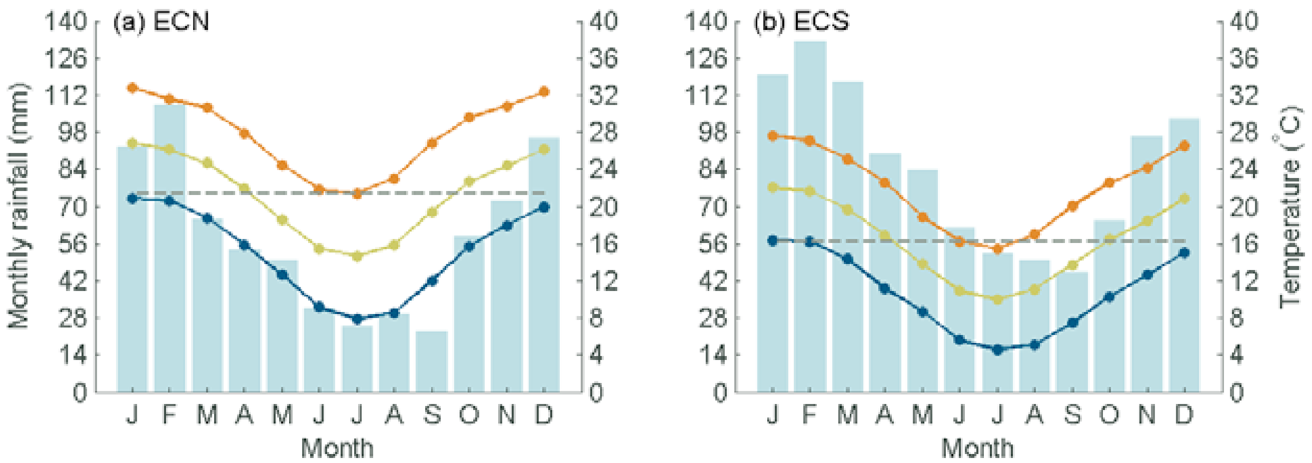


FIGURE 2.2: SEASONAL RAINFALL (BLUE BARS) AND TEMPERATURE CHARACTERISTICS FOR THE EAST COAST CLUSTER NORTH (A) AND SOUTH (B) (1986–2005). *TMEAN* IS MONTHLY MEAN TEMPERATURE (GREEN LINE), *TMAX* IS MONTHLY MEAN MAXIMUM TEMPERATURE (ORANGE LINE), *TMIN* IS MONTHLY MEAN MINIMUM TEMPERATURE (BLUE LINE) AND *ANN TMEAN* IS THE ANNUAL AVERAGE OF MEAN TEMPERATURE (GREY LINE) (21.4 °C FOR ECN AND 16.3 °C FOR ECS). TEMPERATURE AND RAINFALL DATA ARE FROM AWAP.

There is a clear variation in rainfall throughout the year in both the East Coast North and East Coast South sub-clusters: for both regions February is the wettest month, followed by a drier period during the cooler months (*e.g.* from June to September; Figure 2.2). However, in contrast to the East Coast South sub-cluster, the East Coast North sub-cluster has a more pronounced difference between the wetter and the drier months of the year, relating to stronger tropical influences (such as the monsoon as well as tropical cyclones and tropical depressions) and weaker temperate influences (such as rainfall associated with fronts during the cooler months).

Across the cluster, there is a spatial gradient in rainfall (Figure 2.3), where locations near the coast generally experience more rainfall than locations further inland. During the baseline period 1986–2005, rainfall in the East Coast cluster has experienced year to year variability similar in magnitude to many other parts of Australia.

The seasonal rainfall characteristics in the East Coast cluster are determined by the complex interactions of several rain-bearing weather systems. The sub-tropical northern regions can experience enhanced rainfall, as a result of the summer exposure to the trade winds that bring moist, warm air-masses onto the northern part of the continent. Extreme rainfall in northern areas can also be associated with tropical cyclones during the warmer months of the year, typically from about November to April. During the cooler months of the year, fronts and low-pressure systems (*e.g.* East Coast Lows) can bring wet conditions to the cluster, particularly in southern areas. Throughout the year, rainfall is also associated with cloud bands relating to the formation of troughs at upper levels of the atmosphere.

Thunderstorms can be hazardous due to accompanying winds, hail, tornados, flash floods and lightning strikes. A strong annual cycle of thunderstorm activity occurs throughout the East Coast cluster, with a maximum during the warmer months and a minimum during the cooler months (Dowdy and Kuleshov 2014). The East Coast cluster experiences thunderstorms on about 20–50 days a year, depending on location, which is higher than most other regions in other parts of Australia at similar latitude to the East Coast cluster (Kuleshov *et al*. 2006).

Year to year rainfall variability in the East Coast cluster is related to changes in sea surface temperatures (SSTs) of adjacent ocean basins. Prominent influences include the oscillation between El Niño and La Niña type conditions in the eastern and central Pacific, and variability of SSTs in the Indian Ocean. Rainfall variations are also linked to a mode of variability known as the Southern Annular Mode (SAM) which affects the strength of the summer easterly circulation over Australia (Hendon *et al*., 2007). For further details on these phenomena, see Chapter 4 in the Technical Report.

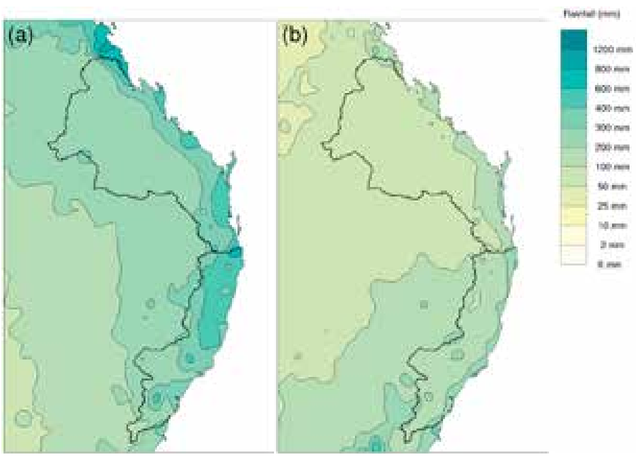


FIGURE 2.3: FOR THE 1986–2005 PERIOD, AVERAGE RAINFALL FOR (A) SUMMER (DECEMBER, JANUARY AND FEBRUARY) AND (B) WINTER (JUNE, JULY AND AUGUST)

3 SIMULATING REGIONAL CLIMATE

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

The skill of a climate model is assessed by comparing model simulations of the current climate with observational data sets (see Box 3.1 for details on the observed data used for model evaluation for the East Coast 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 East Coast cluster, models performed well in terms of simulating the timing and magnitude of the seasonal cycle for temperature (Figure 3.1 top panel). The majority of models also show considerable skill in simulating the timing of the seasonal rainfall patterns (Figure 3.1 bottom panel). The model ensemble median is similar to the rainfall observations throughout the year, while noting that the variation between models is notably larger for rainfall than for temperature. The ability to capture observed seasonality by models is considered when setting the confidence ratings derived for each variable, as described in Section 4.1. To see how the models performed across different parts of Australia and for additional variables, refer to Chapter 5 in the Technical Report.

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 is derived from the Australian Water Availability Project (AWAP) (Jones *et al.*, 2009) and from the Australian Climate Observations Reference Network – Surface Air Temperature (ACORN-SAT), a data set developed for the study of long-term changes in monthly and seasonal climate (Fawcett *et al.*, 2012).

The spatial resolution of climate model data (around 200 km between the edges of grid cells) is much coarser than observations. For the East Coast cluster, 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.

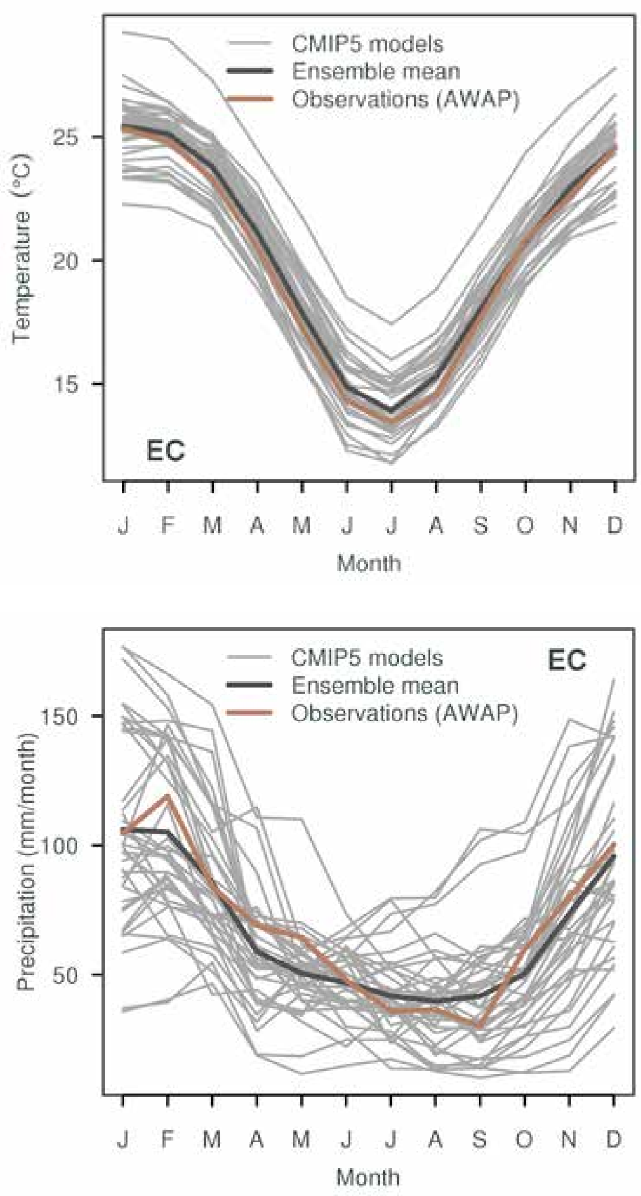


FIGURE 3.1: THE ANNUAL CYCLE OF TEMPERATURE (TOP PANEL) AND RAINFALL (BOTTOM PANEL) IN THE EAST COAST CLUSTER SIMULATED BY CMIP5 MODELS (GREY LINES) WITH MODEL ENSEMBLE MEAN (BLACK LINE) AND OBSERVED CLIMATOLOGY BASED ON AWAP FOR THE BASELINE PERIOD 1986–2005 (BROWN LINE).

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

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

4 THE CHANGING CLIMATE OF THE EAST COAST

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 East Coast 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 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 East Coast cluster consider model ranges of change, as simulated by the CMIP5 ensemble. However, the projections should be viewed in the context of the confidence ratings that are provided, which consider a broader range of evidence than just the model outputs. The projected change is assessed for two 20-year time 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.

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

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

The relative importance of each of these factors differs for each variable, different timeframes and spatial scale. For some variables with large natural variability, such as rainfall, the predominant source of differing projections in the early period is likely to be dominated by 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 the system used by the IPCC in the Fifth Assessment Report (Mastrandrea *et al*., 2010), whereby the confidence in a projected change is assessed based on the type, amount, quality and consistency of evidence (which can be process understanding, theory, model output, or expert judgment) and the extent of agreement amongst the different lines of evidence. Hence, this confidence rating does not equate precisely to probabilistic confidence. The levels of confidence used here are set as *low, medium, high* or *very high*. Note that although confidence may be high in the direction of change, in some cases confidence in magnitude of change may be *medium* or *low* (*e.g.* due to some known model deficiency), and then 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, especially since 1960 (Figure 4.2.1, 4.2.2). By 2013, mean temperature rose by about 1.0 °C in ECN and 0.8 °C in ECS since 1910 using a linear trend. There is variability in the long-term trends in daily minimum and maximum temperatures (Figure 4.2.3), but the highest values throughout the entire record have occurred in recent decades in all cases (*i.e.* for both the maximum and minimum temperature in the East Coast North and East Coast South sub-clusters).

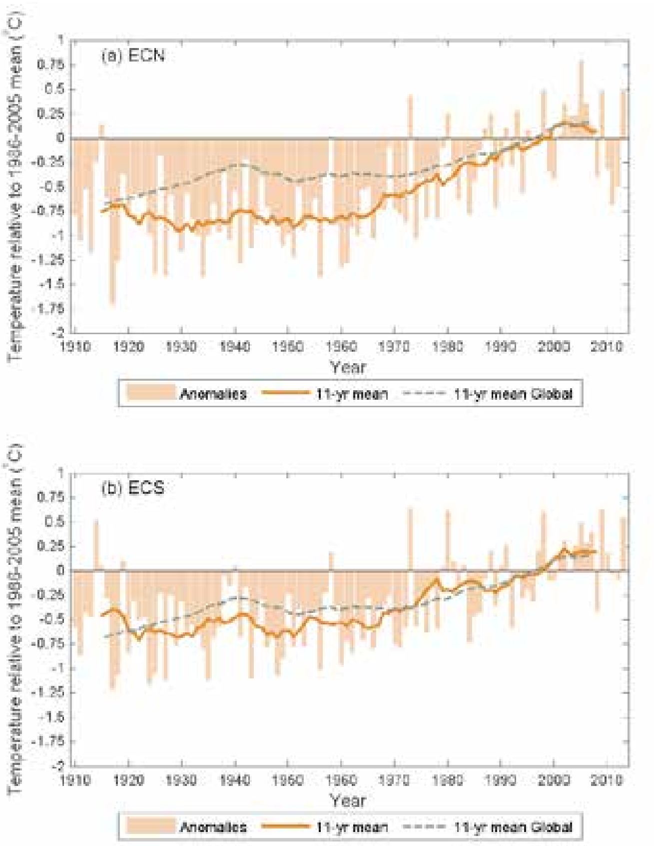


FIGURE 4.2.1: OBSERVED ANNUAL MEAN TEMPERATURE ANOMALIES (°C) FOR 1910–2013 COMPARED TO THE BASELINE 1986–2005 FOR (A) EAST COAST NORTH AND (B) EAST COAST SOUTH. CLUSTER AVERAGE DATA ARE FROM ACORN-SAT AND GLOBAL DATA ARE FROM HADCRUT3V (BROHAN *ET AL.*, 2006).

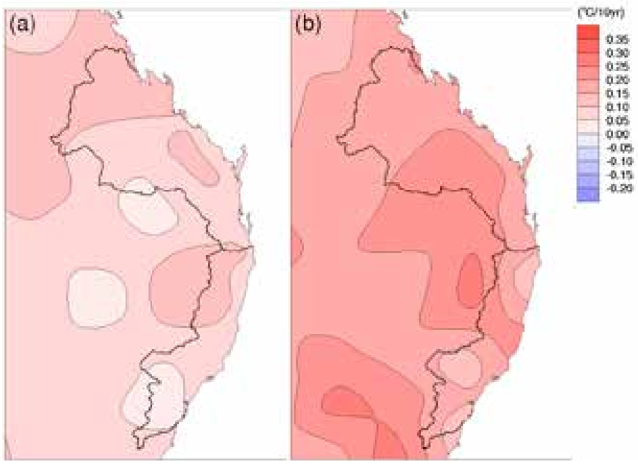


FIGURE 4.2.2: MAPS OF TREND IN MEAN TEMPERATURE (°C/10 YEARS) FOR (A) 1910–2013 AND (B) 1960–2013 (ACORN-SAT).

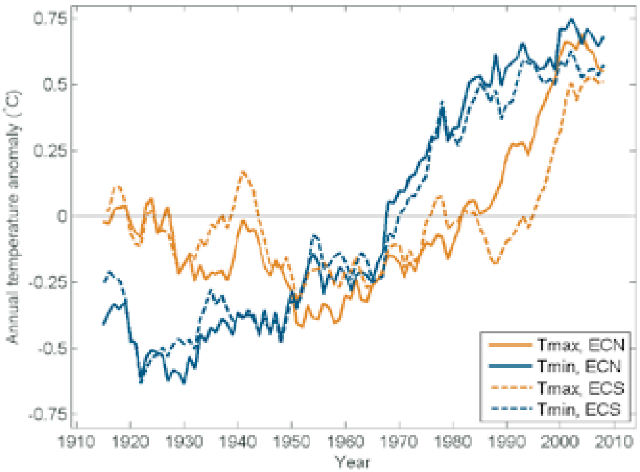
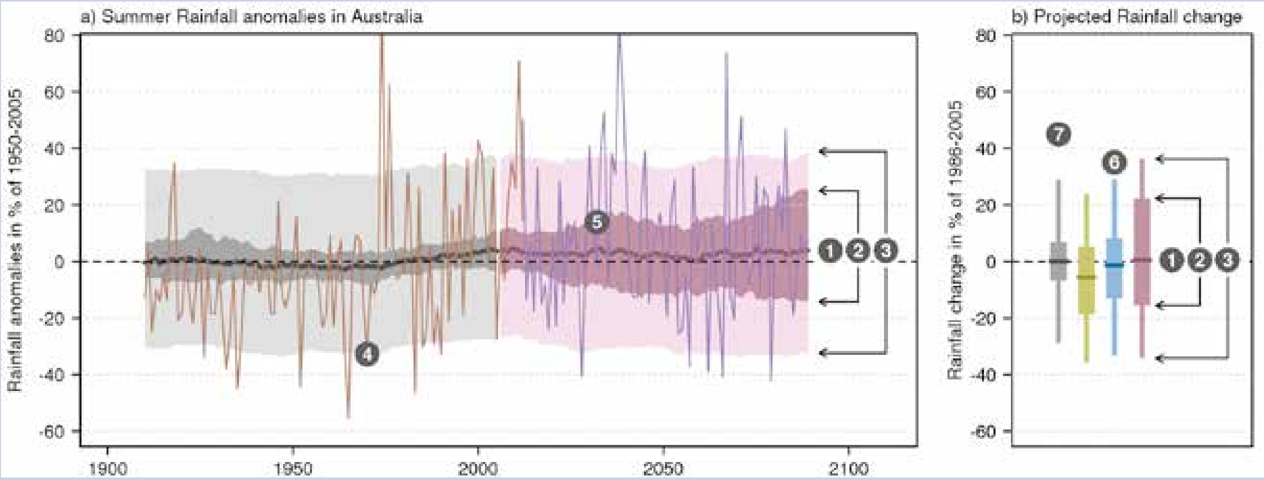


FIGURE 4.2.3: OBSERVED ANNUAL MEAN OF DAILY MAXIMUM (ORANGE LINE) AND MINIMUM (BLUE LINE) TEMPERATURE (°C, 11-YEAR RUNNING MEAN), PRESENTED AS ANOMALIES RELATIVE TO THEIR RESPECTIVE 1910–2013 MEAN VALUE (ACORN-SAT); EAST COAST NORTH (SOLID LINE) AND EAST COAST SOUTH (DASHED LINE).

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).

The East Coast cluster is projected in CMIP5 simulations to continue to warm throughout the 21st century, with a rate that strongly reflects the increase in global greenhouse gases (Figure 4.2.4). Tabulated projections for various time slices and RCPs are given in Table 1 in the Appendix. For the near future (2030), the warming is 0.4 to 1.3 °C (10th and 90th percentile), with only minor difference between the scenarios. The projected warming range for late in the century (2090) shows larger differences with 1.3 to 2.5 °C for RCP4.5, and 2.7 to 4.7 °C for RCP8.5. This clearly indicates the importance of the magnitude of the emissions on the rate of warming.

These projected warmings are large compared to natural year to year variability. For example, cold years in the late 21st century climate under RCP8.5 are likely to be warmer than warm years in the current climate. 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. The projected future temperatures show inter-annual variability of similar magnitude to that of observed data (*e.g.* the overlaid 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.

The warming rate of the East Coast cluster is in line with the majority of other clusters of Australia, with higher rates being projected for western and central Australia and somewhat lower overall rates for the southeast and Tasmania.

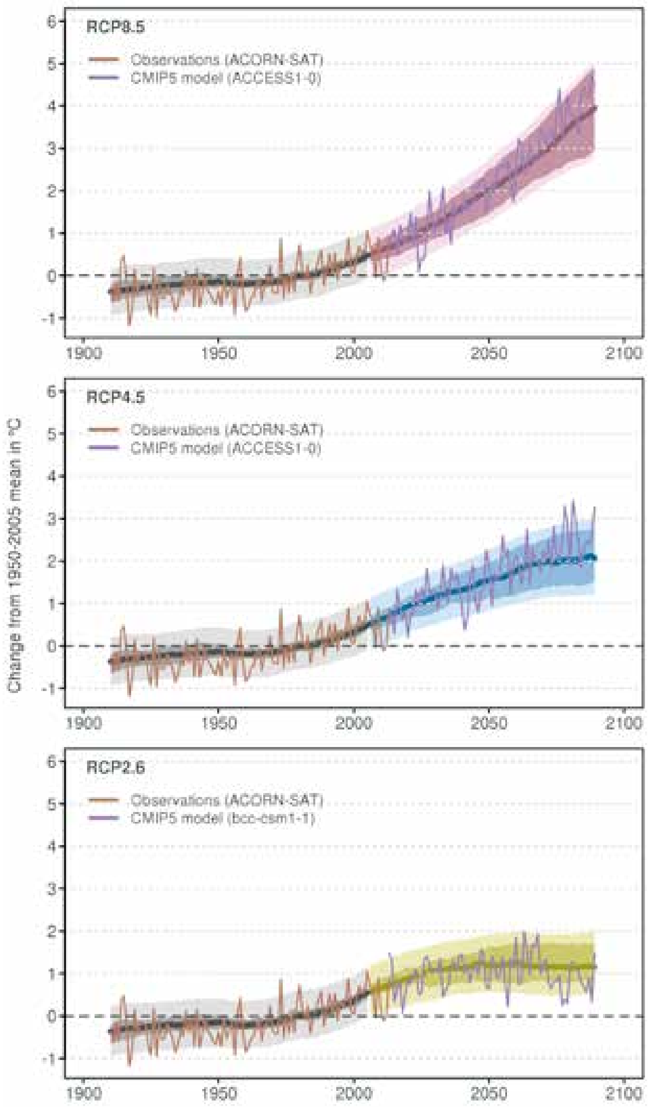


FIGURE 4.2.4: TIME SERIES FOR EAST COAST ANNUAL AVERAGE SURFACE AIR TEMPERATURE (°C) FOR 1910–2090, AS SIMULATED IN CMIP5 RELATIVE TO THE 1950–2005 MEAN. THE CENTRAL LINE IS THE MEDIAN VALUE, AND THE SHADING IS THE 10TH AND 90TH PERCENTILE RANGE OF 20-YEAR MEANS (INNER) AND SINGLE YEAR VALUES (OUTER).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

Changes to the spatial pattern of temperature in the cluster can be illustrated by adding the projected change in annual mean temperature to the current observed climatology. Figure 4.2.5 gives an example of this for the 2090 period following RCP8.5 and the median warming from the CMIP5 models. This case, which corresponds to a global warming of 3.7 °C, shows regional temperatures increasing from within the range of about 11 to 25 °C for the current climate up to a range of about 15 to 27 °C for the future climate. Projected warming in the CMIP5 models is similar across the four seasons in the East Coast, and is also broadly similar if maximum or minimum temperatures are considered rather than mean temperatures (Figure 4.2.6 and Appendix Table 1).

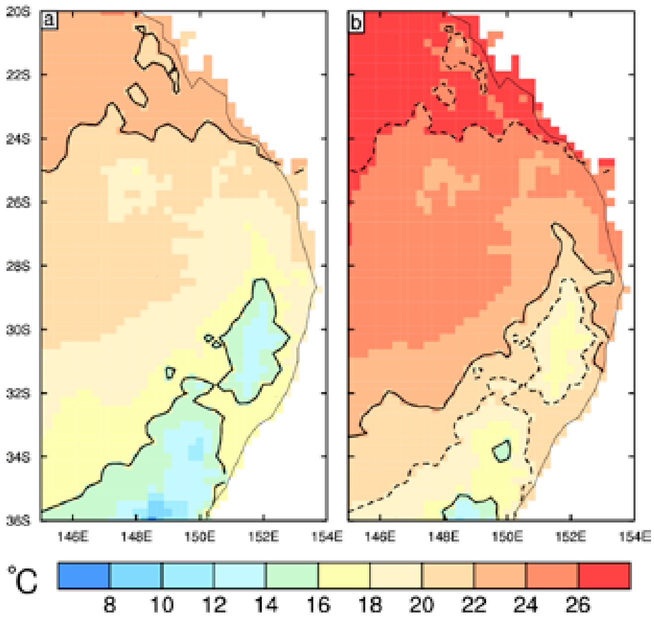


FIGURE 4.2.5: ANNUAL MEAN SURFACE AIR TEMPERATURE (°C), FOR THE PRESENT CLIMATE (A), AND FOR MEDIAN WARMING UNDER RCP8.5 FOR 2090 (B). THE PRESENT IS USING AWAP FOR 1986–2005 (USING A 0.25 DEGREE GRID IN BOTH LATITUDE AND LONGITUDE). FOR CLARITY, CONTOUR LINES FOR THE 16 AND 22 °C CONTOURS ARE SHOWN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

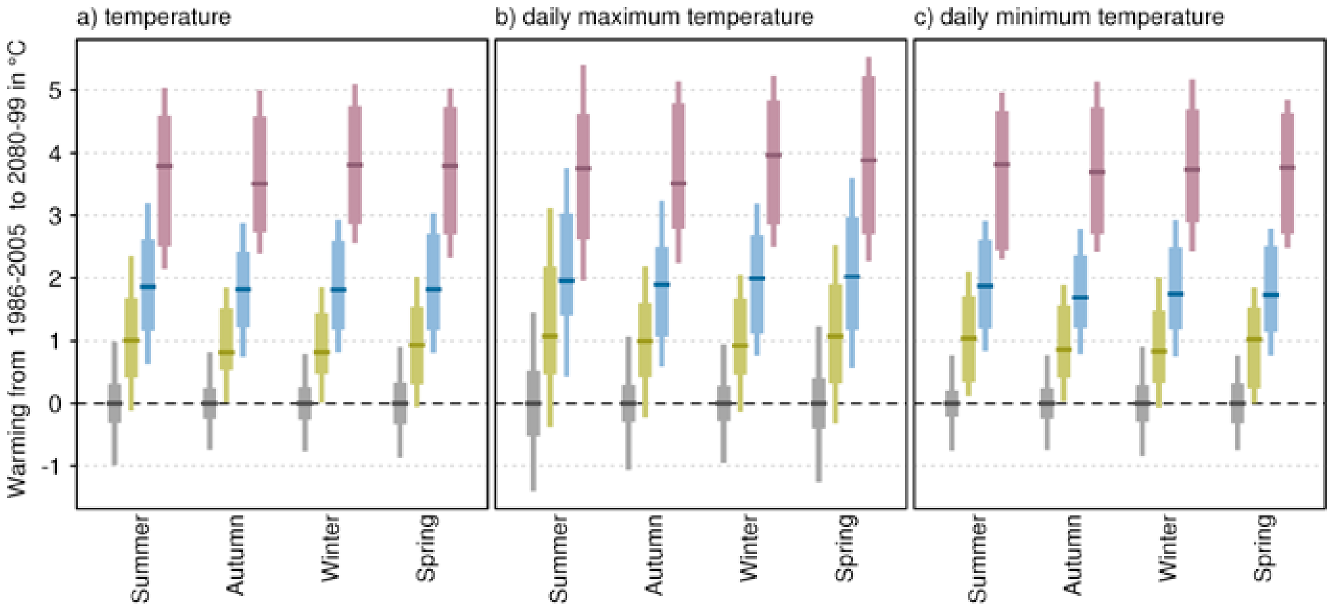


FIGURE 4.2.6: PROJECTED SEASONAL SURFACE AIR TEMPERATURE CHANGES FOR 2090. GRAPHS SHOW CHANGES TO THE (A) MEAN, (B) DAILY MAXIMUM AND (C) DAILY MINIMUM TEMPERATURE. TEMPERATURE ANOMALIES ARE GIVEN IN °C WITH RESPECT TO 1986–2005 MEAN UNDER RCP2.6 (GREEN), RCP4.5 (BLUE) AND RCP8.5 (PURPLE). NATURAL CLIMATE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

Downscaling generally does not lead to projected warming ranges that are notably different from those simulated by the CMIP5 GCM ensemble (Figure 4.2.7), with the exception of reduced warming of the daily minimum temperature in spring and summer in one of the two methods (SDM).

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

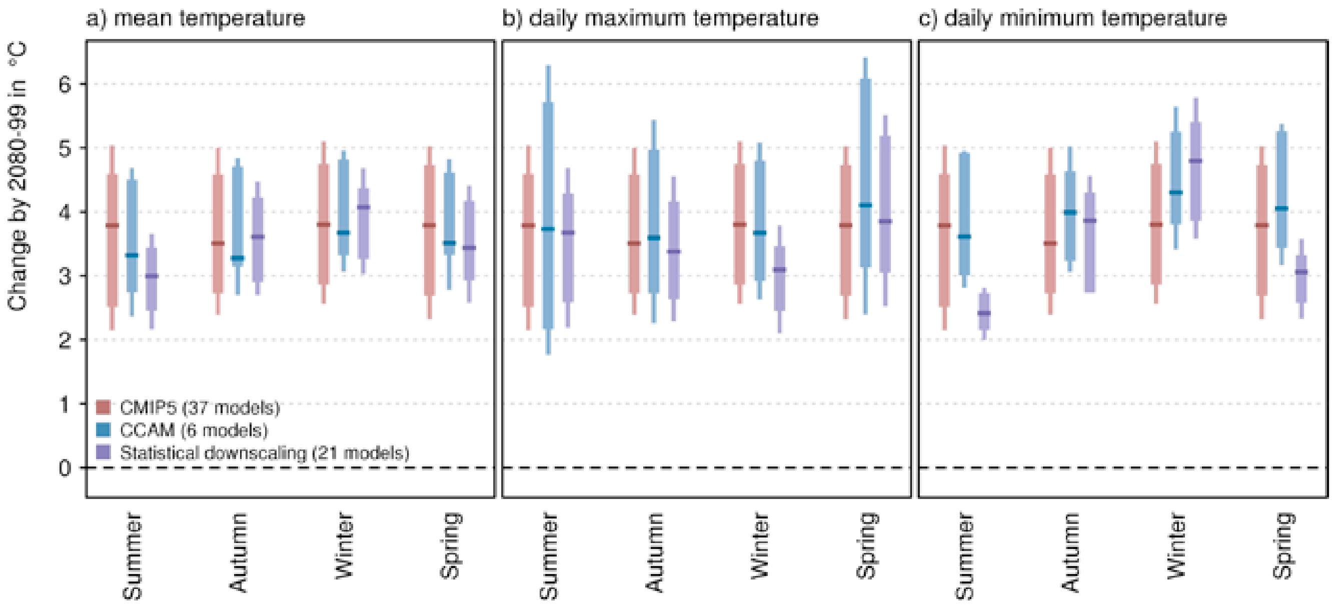


FIGURE 4.2.7: PROJECTED CHANGE FOR EAST COAST IN SEASONAL SURFACE AIR TEMPERATURE FOR 2090 USING CMIP5 GCMS AND TWO DOWNSCALING METHODS (CCAM AND SDM) UNDER RCP8.5 FOR THE (A) MEAN, (B) DAILY MAXIMUM AND (C) DAILY MINIMUM. TEMPERATURE ANOMALIES ARE GIVEN IN °C WITH RESPECT TO THE 1986–2005 MEAN. BAR 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 CMIP5 projected changes to measures such as: the warmest day in the year, warm spell duration and frost risk days (see definitions below).

BOX 4.3: HOW WILL THE FREQUENCY OF HOT DAYS AND FROST RISK DAYS CHANGE IN THE BRISBANE AND SYDNEY AREAS?

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

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

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

TABLE B4.3: CURRENT AVERAGE ANNUAL NUMBER OF DAYS (FOR THE 30-YEAR PERIOD 1981–2010) ABOVE 35 AND 40 °C AND BELOW 2 °C (FROSTS) FOR AMBERLEY RAAF BASE (INLAND FROM BRISBANE) (QLD) AND SYDNEY OBSERVATORY HILL (NSW) 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	AMBERLEY				SYDNEY			
	Current	2030 RCP4.5	2090 RCP4.5	2090 RCP8.5	Current	2030 RCP4.5	2090 RCP4.5	2090 RCP8.5
Over 35°C	12	18 (15 to 22)	27 (21 to 42)	55 (37 to 80)	3.1	4.3 (4.0 to 5.0)	6.0 (4.9 to 8.2)	11 (8.2 to 15)
Over 40°C	0.8	1.2 (1.1 to 1.6)	2.1 (1.5 to 3.9)	6.0 (2.9 to 11)	0.3	0.5 (0.5 to 0.8)	0.9 (0.8 to 1.3)	2.0 (1.3 to 3.3)
Below 2°C	22	16 (18 to 14)	11 (14 to 7.4)	3.1 (6.8 to 0.7)	0	0	0	0

Heat related extremes are projected to increase at the same rate as projected mean temperature with a substantial increase in the number of warm spell days. Figure 4.2.8 (2090 case only) gives the CMIP5 model simulated warming on the hottest day of the year averaged across the cluster, and the corresponding warming for the hottest day in 20 years (the 20-year return value, equal to a 5 % chance of occurrence within any one year). The rate of warming for these hot days is similar to that for all days (*i.e.*, the average warmings in the previous Section). There is a marked increase in a warm spell index, which is defined as the annual number of days for events that consist of at least six consecutive days with a cluster average maximum temperature above the 90th percentile (as an example, the 90th percentile for daily temperature maximum in Amberley is 32.6 °C based on BOM historical data from August 1941 to June 2014).

Given this similarity in projected warming, an indication of the change in frequency of hot days can be obtained by applying the mean warming for selected time slices and RCPs to the historical daily record at selected sites. This is illustrated in Box 4.3 for Amberley (inland of Brisbane), where it can be seen that the average number of days above 35 °C by late in the century (2090) approximately doubles under RCP4.5 and median model warming (from 12 days to 27 days per year), and the average number of days over 40 °C approximately triples (from 0.8 to 2.1 days per year). Similar results are also shown in Box 4.3 for Sydney.

Changes in the frequency of surface frost risk (defined here as days when the air temperature at a height of 2 metres is less than 2 °C) are also of potential importance to agriculture, energy demand and other sectors, as well as to the environment. Assessing frost occurrence directly from global model output is not reliable, in part because of varying biases in land surface temperatures. However, it is possible to evaluate what CMIP5 models say about changes to frost occurrences by superimposing the projected change in temperature onto the minimum daily temperature record. Statistical downscaling may also be used, with similar results (see Technical Report section 7.1)

Box 4.3 illustrates the change in frost risk days in Amberley using the simple approach (as was done for hot days, noting that actual occurrence of frost will depend on many local factors not represented by this method). Results show that for 2030 under RCP4.5 there is a 25 % reduction in frost days. For late in the 21st century, substantial reductions occur in frost days under RCP4.5 and RCP8.5. Relative to about 22 frost days in a period centred on 1995, models simulate a reduction to about 11 days under RCP4.5 and to about 3 days under RCP8.5.

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

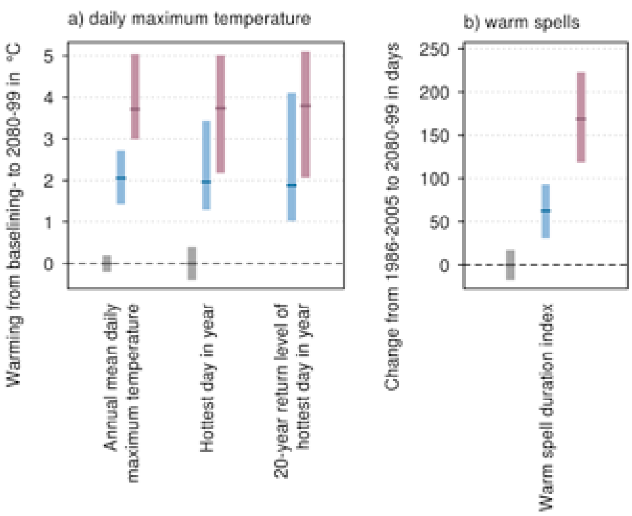


FIGURE 4.2.8: PROJECTED CHANGES IN SURFACE AIR TEMPERATURE EXTREMES BY 2090 IN (A) MEAN DAILY MAXIMUM TEMPERATURE, HOTTEST DAY OF THE YEAR AND THE 20-YEAR RETURN VALUE OF THE HOTTEST DAY OF THE YEAR (°C); AND (B) CHANGE IN THE NUMBER OF DAYS IN WARM SPELLS FOR EAST COAST (SEE TEXT FOR DEFINITION OF VARIABLES).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

4.3 RAINFALL

Rainfall in the cluster has not shown any long-term trend over the 20th century, but has demonstrated intermittent periods of wetter and drier conditions (Figure 4.3.1). During much of the early part of the 20th century, the cluster experienced extensive drying, including the Federation drought at the start of the century (from about 1895–1902) and the World War II drought from about 1935–1945 (Figure 4.3.1). The latter part of the 20th century saw a continuation of these variable conditions with individual years of very high rainfall, and sequences of years with below average rainfall. Around the beginning of the 21st century there was a period of below average years, often referred to as the Millennium drought. This was followed by a period of above average rainfall, with the highest annual rainfall on record shown in Figure 4.3.1 occurring during 2010 in the East Coast North sub-cluster, relating to the formation of a strong La Niña event. Although the rainfall in 2010 for the East Coast South sub-cluster was above average, it was not close to being a record high amount, consistent with previous studies showing that rainfall in this part of the Eastern Seaboard is less influenced by La Niña and El Niño conditions than other parts of Eastern Australia (such as the East Coast North sub-cluster and also to the west of the ridgeline of the Great Dividing Range).

Spatial trend patterns for the full duration of the rainfall record (1901 to 2012) show small changes of the order of -15 to 10 mm per decade (Figure 4.3.2). Somewhat stronger rainfall trends are generally seen in the more recent period (1960 to 2012) than in the full duration of the rainfall record. However, it is noted that these observed trends in rainfall throughout the East Coast cluster are not as significant as the case for temperature, with a *low confidence* in both the magnitude and sign of the observed rainfall trends.

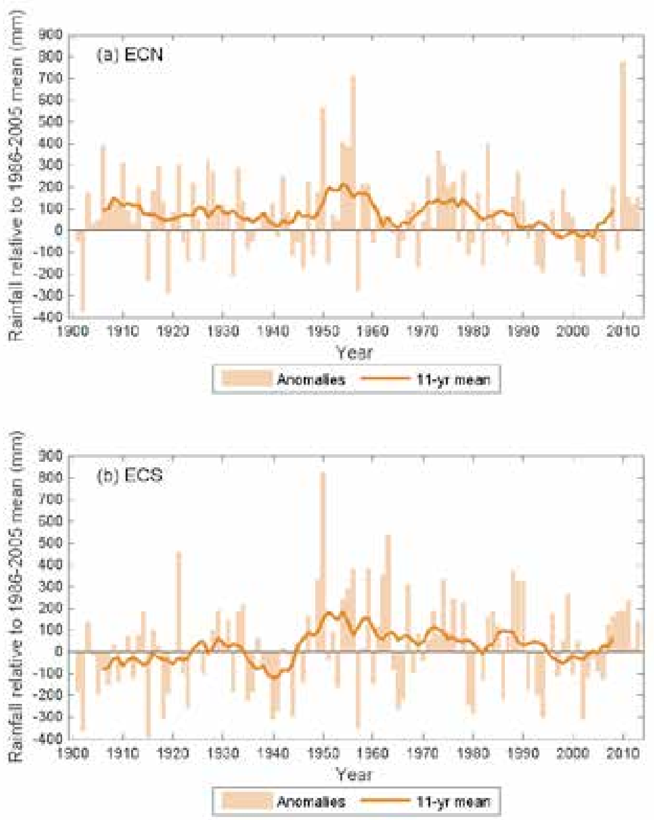


FIGURE 4.3.1: OBSERVED ANNUAL RAINFALL ANOMALIES (MM) FOR 1901–2013 COMPARED TO THE BASELINE 1986–2005 FOR (A) EAST COAST NORTH AND (B) EAST COAST SOUTH. DATA ARE FROM AWAP.

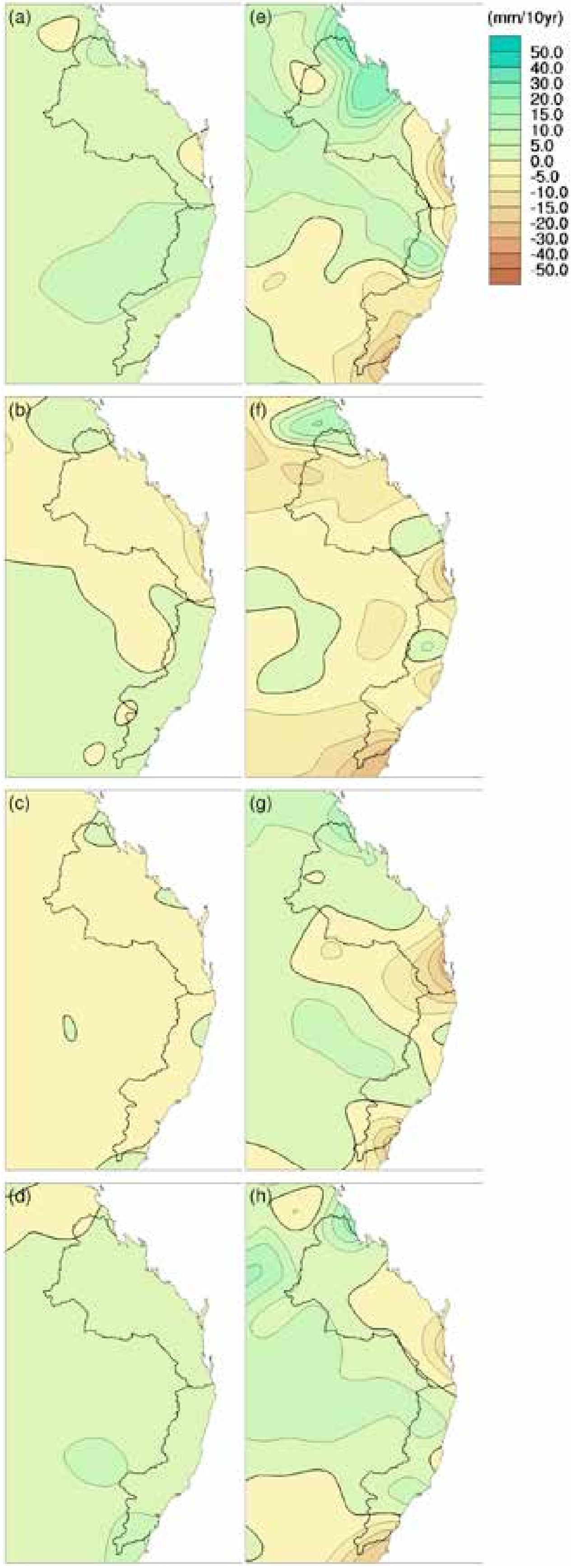


FIGURE 4.3.2: MAPS OF SEASONAL RAINFALL TRENDS (MM/DECADE). THE LEFT COLUMN OF MAPS SHOWS FOR (A) SUMMER, (B) AUTUMN, (C) WINTER AND (D) SPRING FOR 1901–2013. THE RIGHT COLUMN SHOWS TRENDS FOR (E) SUMMER, (F) AUTUMN, (G) WINTER AND (H) SPRING FOR 1960–2013.

Simulated annual rainfall changes for the 21st century are small compared to natural variability under RCP2.6 and RCP4.5, but changes become evident in some models under RCP8.5 by 2090 (Figure 4.3.3, Table 1 in the Appendix). Relative to the CCIA (2007) projections (based on the CMIP3 model archive), these new projections are broadly similar, with only small differences such as a slightly wetter projection for Australia as a whole, including the East Coast cluster (see the Technical Report for further details on comparing CMIP3 and CMIP5 projections).

Changes to the spatial distribution of rainfall in the cluster can be illustrated by applying the CMIP5 projected change in annual mean rainfall onto the mapped observed climatology. Figure 4.3.4 gives an example of this for late in the 21st century (2090) for RCP8.5. The figure displays the dry (10th percentile) and wet (90th percentile) case of the simulated model range relative to the observed climatology.

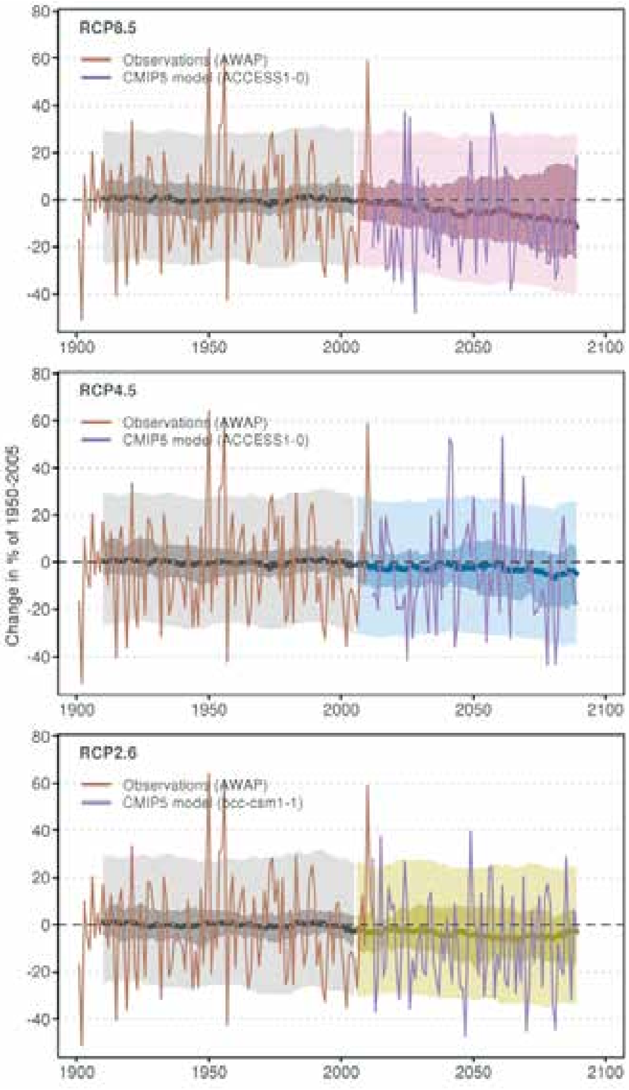


FIGURE 4.3.3: TIME SERIES FOR EAST COAST ANNUAL RAINFALL FOR 1910–2090, AS SIMULATED IN CMIP5 MODELS, EXPRESSED AS A PERCENTAGE RELATIVE TO THE 1950–2005 MEAN. THE CENTRAL LINE IS THE MEDIAN VALUE, AND THE SHADING IS THE 10TH AND 90TH PERCENTILE RANGE OF 20-YEAR MEANS (INNER) AND SINGLE YEAR VALUES (OUTER). THE GREY SHADING INDICATES THE PERIOD OF THE HISTORICAL SIMULATION, WHILE THREE FUTURE SCENARIOS ARE SHOWN WITH COLOUR-CODED SHADING: RCP8.5 (PURPLE), RCP4.5 (BLUE) AND RCP2.6 (GREEN). AWAP OBSERVATIONS (BEGINNING 1901) AND PROJECTED VALUES FROM A TYPICAL MODEL ARE SHOWN. TIME SERIES PLOTS ARE EXPLAINED IN BOX 4.2.

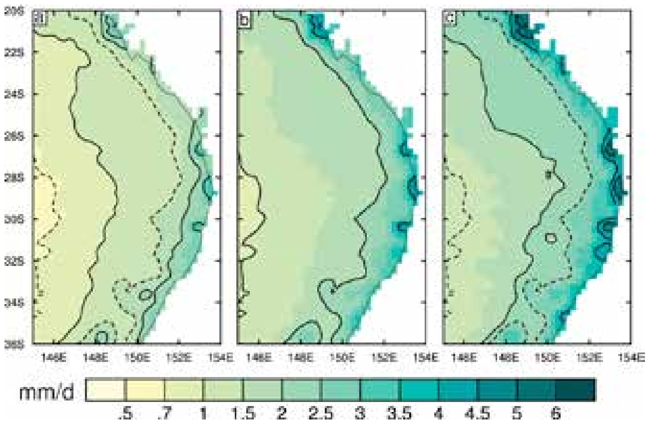


FIGURE 4.3.4: ANNUAL MEAN RAINFALL (MM/DAY), FOR THE PRESENT CLIMATE (B), AND FOR DRIER END OF THE PROJECTED MODEL RANGE (A) AND WETTER END OF THE PROJECTED MODEL RANGE (C). THE PRESENT CLIMATE USES THE AWAP DATASET FOR 1986–2005, (BASED ON A 0.25 DEGREE LATITUDE / LONGITUDE GRID). THE DRIER AND WETTER CASES USE THE 10TH AND 90TH PERCENTILE CHANGES AT 2090, FOR RCP8.5. FOR CLARITY, THE 1, 2 AND 4 MM/DAY CONTOURS ARE PLOTTED WITH SOLID BLACK LINES. IN (A) AND (C) THE SAME CONTOURS FROM THE ORIGINAL CLIMATE (B) ARE PLOTTED AS DOTTED LINES.

The seasonal response by models is also mixed, though with the exception of summer in the East Coast South (11 % increase), most ensemble medians indicate a seasonal decrease (Figure 4.3.5). During winter and spring, the model ensemble median values indicate a decrease in rainfall (of about 10–30 %) for the East Coast North and East Coast South sub-clusters for 2090 following RCP8.5 (Table 1 in the Appendix and Figure 4.3.5). Such contrasting model simulations highlight the need to consider the risk of both a drier and wetter climate in impact assessment in this cluster.

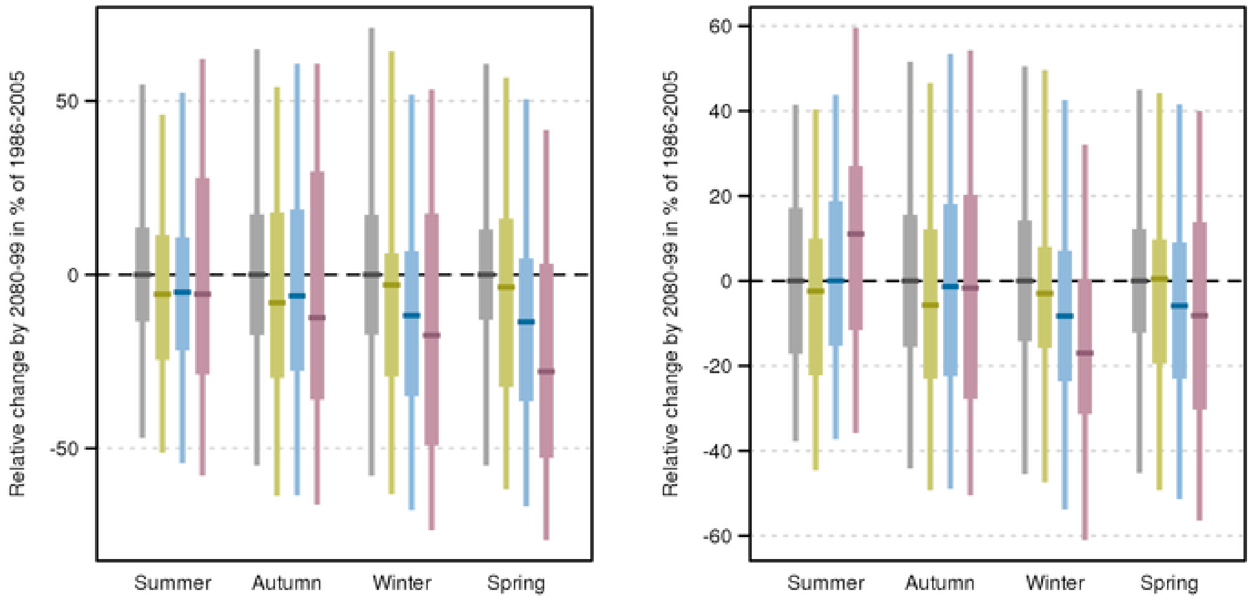


FIGURE 4.3.5: PROJECTED SEASONAL RAINFALL CHANGES FOR EAST COAST NORTH (LEFT PANEL) AND EAST COAST SOUTH (RIGHT PANEL). RAINFALL ANOMALIES ARE GIVEN IN PER CENT WITH RESPECT TO THE 1986–2005 MEAN UNDER RCP2.6 (GREEN), RCP4.5 (BLUE) AND RCP8.5 (PURPLE) FOR 2090. NATURAL CLIMATE VARIABILITY IS REPRESENTED BY THE GREY BAR. BAR PLOTS ARE EXPLAINED IN BOX 4.2.

Downscaled rainfall projections for the East Coast cluster (Figure 4.3.6) are broadly similar to the GCM results, although the dynamical method (CCAM based on six models only) shows some notable differences in autumn and winter as does the statistical method (based on 22 models) during spring and summer. Physical processes that might explain a projected summer increase in the East Coast South sub-cluster under the high emission scenario remain unclear. On the other hand, a projected decrease in winter is consistent with a projected reduction in the number of storms in this sub-cluster (as detailed in the Technical Report). In relation to the projected decrease in spring rainfall in East Coast North, it is noted in the Technical Report that confidence in spring changes for the broader eastern Australia region are low due to greater complexity of rainfall bearing systems in that season relative to the case for winter, reflected in the mixed messages amongst GCMs and downscaling techniques (*e.g.* the GCMs results indicate a decrease in spring rainfall in East Coast North, but the statistical downscaling results indicate an increase).

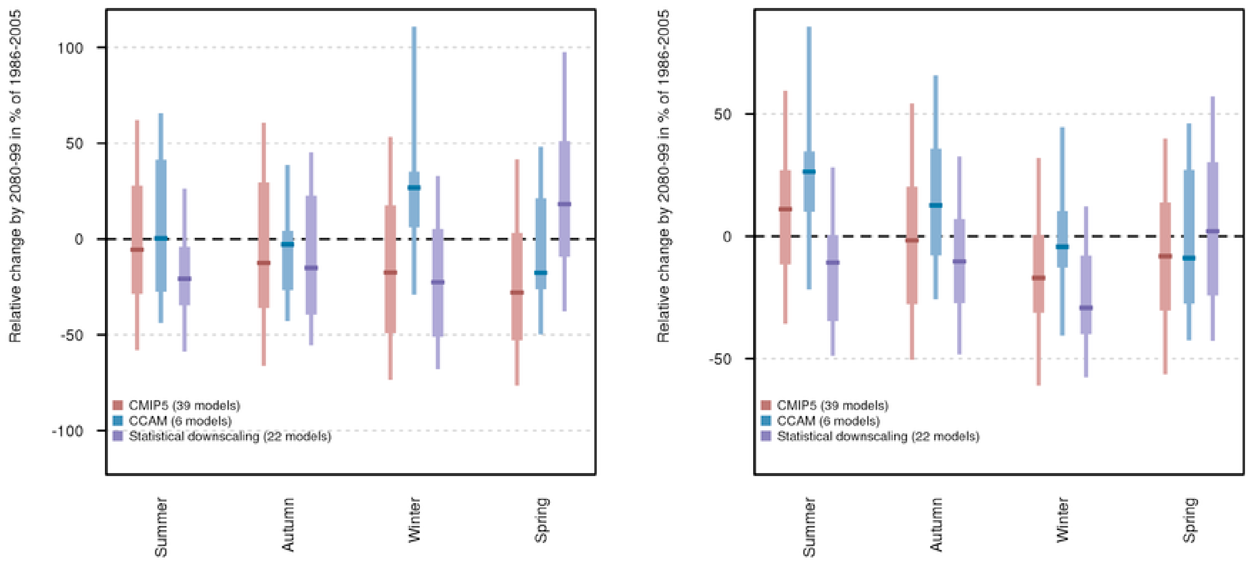


FIGURE 4.3.6: PROJECTED CHANGE IN SEASONAL RAINFALL FOR 2090 USING CMIP5 GCMS AND TWO DOWNSCALING METHODS (CCAM AND SDM) FOR EAST COAST NORTH (LEFT PANEL) AND EAST COAST SOUTH (RIGHT PANEL). RAINFALL ANOMALIES ARE GIVEN IN PER CENT WITH RESPECT TO WITH RESPECT TO 1986–2005 UNDER RCP8.5. BAR PLOTS ARE EXPLAINED IN BOX 4.2.

In summary, there is *high confidence* that natural climate variability will remain the major driver of rainfall changes in the next few decades in this cluster: 20-year mean changes of -15 to +10 % annually, and -30 to +20 % seasonally relative to the climate of 1986–2005 (Appendix Table 1).

In East Coast North by late in the 21st century under RCP4.5 and RCP8.5, models show a range of results but with little change or decrease being more common, particularly in winter and spring. However, uncertainty over driving processes and some inconsistent results from downscaling mean that the direction of change is not reliably projected. The magnitude of possible seasonal differences from the climate of 1986–2005 indicated by GCM results range from around -35 to +20 % under RCP4.5 and -55 to +30 % under RCP8.5 (Table 1 in the Appendix).

By late in the 21st century under RCP4.5 and RCP8.5 in East Coast South, a decrease in winter rainfall is projected with medium confidence based on strong model agreement and good understanding of the contributing underlying physical mechanisms driving this change (fewer winter storms). A range of changes is projected in the other seasons, with a tendency for increase in summer, but uncertainty over driving processes and some inconsistent results from downscaling mean that the direction of change cannot be reliably projected. The magnitude of possible seasonal differences from the climate of 1986–2005 indicated by GCM results range from around -25 to +20 % under RCP4.5 and -30 to +25 % under RCP8.5.

4.3.1 HEAVY RAINFALL EVENTS

In a warming climate, extreme rainfall events are expected to increase in magnitude mainly due to a warmer atmosphere being able to hold more moisture (Sherwood *et al.*, 2010).

Daily rainfall amounts from the CMIP5 simulations have been analysed and the maximum values determined in each year and within 20-year periods. The CMIP5 models simulate an increase in the annual maximum 1-day value and the 20-year return value for 2090 relative to the baseline period 1986–2005 (Figure 4.3.7 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 clearly shows that while the projection for mean rainfall is tending towards decrease in the cluster, the extremes are projected to increase. This type of response (change in mean relative to extremes) is found in all other clusters, and is also supported by different lines of evidence (see Technical Report Section 7.2.2).

The magnitudes of the simulated changes in extreme rainfall indices are strongly dependent on emission scenario and the future time period. Furthermore, the magnitude of the change simulated by GCMs is somewhat uncertain because many of the weather systems that generate extreme rainfall are not well resolved by GCMs (such as tropical cyclones, East Coast Lows, intense frontal systems and severe thunderstorms). Thus in summary, there is high confidence that the intensity of heavy rainfall extremes will increase in the cluster, but the magnitude of change cannot be reliably projected.

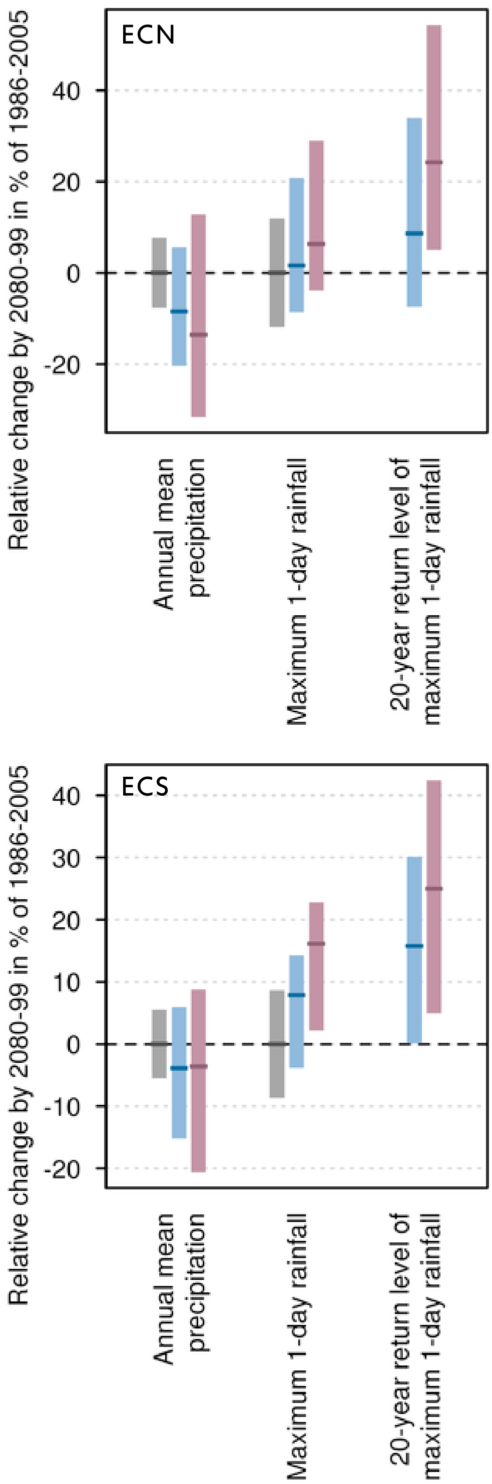


FIGURE 4.3.7: PROJECTED CHANGES IN MEAN RAINFALL, MAGNITUDE OF ANNUAL MAXIMUM 1-DAY RAINFALL AND MAGNITUDE OF THE 20-YEAR RETURN VALUE FOR THE 1-DAY RAINFALL FOR 2090 FOR EAST COAST NORTH (TOP) AND EAST COAST SOUTH (BOTTOM) (SEE TEXT FOR DEFINITION OF VARIABLES). CHANGES ARE GIVEN IN PERCENTAGE WITH RESPECT TO THE 1986–2005 MEAN FOR RCP4.5 (BLUE AND RCP8.5 (PURPLE). NATURAL CLIMATE VARIABILITY IS REPRESENTED BY THE GREY BAR. BAR PLOTS ARE EXPLAINED IN BOX 4.2.

4.3.2 DROUGHT

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

Projected changes to drought share much of the uncertainty of mean rainfall change, and there is no clear indication on changes to drought conditions (Figure 4.3.8). Under RCP8.5, there is an increase in the proportion of time spent in drought through the 21st century. However, the picture is less clear for RCP4.5. The 90th percentile of the model range under RCP8.5 suggest that extreme drought could become more frequent in some models and the duration could increase. But other models (see 10th percentile) show change in the opposite direction.

Meteorological drought will continue to be a regular feature of regional climate. It may change its characteristics as the climate warms, but there is *low confidence* in projecting how the frequency and duration of extreme drought may change, although there is *medium confidence* that the time spent in drought will increase over the course of the 21st century under RCP8.5.

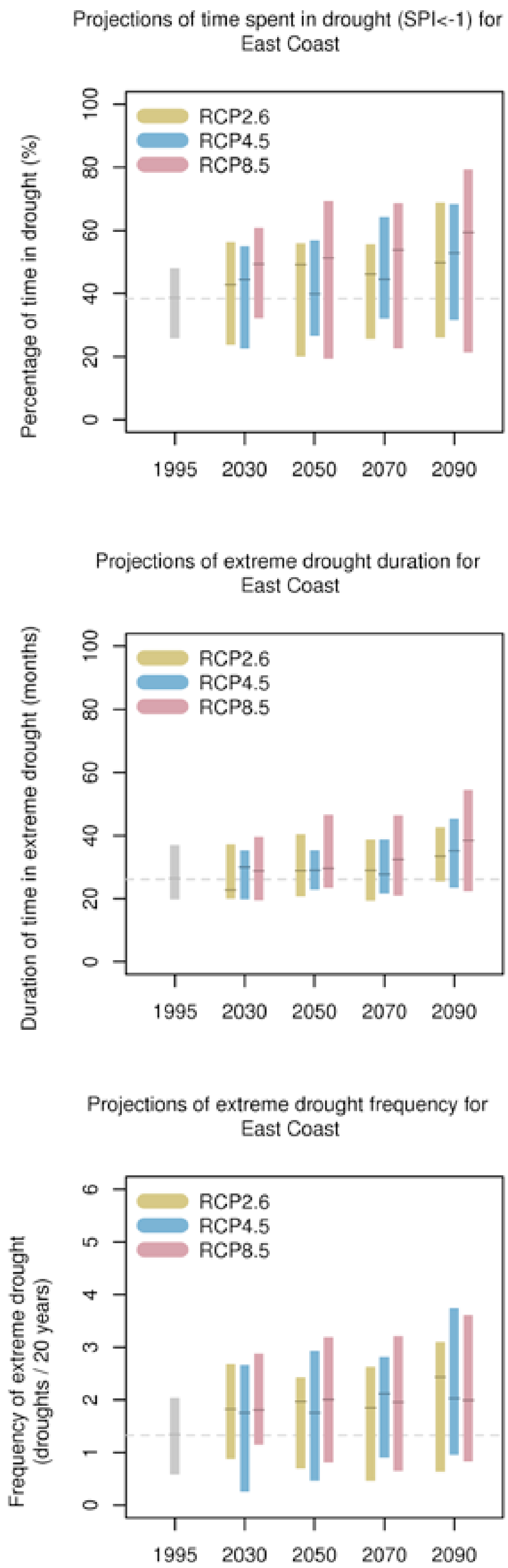


FIGURE 4.3.8: SIMULATED CHANGES IN DROUGHT BASED ON THE STANDARDISED PRECIPITATION INDEX (SPI). THE MULTI-MODEL ENSEMBLE RESULTS FOR EAST COAST SHOW THE PERCENTAGE OF TIME IN DROUGHT (SPI LESS THAN -1) (TOP), DURATION OF EXTREME DROUGHT (MIDDLE) AND FREQUENCY OF EXTREME DROUGHT (BOTTOM) FOR EACH 20-YEAR PERIOD CENTRED ON 1995, 2030, 2050, 2070 AND 2090 UNDER RCP2.6 (GREEN), RCP4.5 (BLUE) AND RCP8.5 (PURPLE). NATURAL CLIMATE VARIABILITY IS REPRESENTED BY THE GREY BAR. SEE TECHNICAL REPORT CHAPTER 7.2.3 FOR DEFINITION OF DROUGHT INDICES. BAR PLOTS ARE EXPLAINED IN BOX 4.2.

4.4 WINDS, STORMS AND WEATHER SYSTEMS

4.4.1 MEAN WINDS

The surface mean wind climate is driven by the large-scale circulation pattern of the atmosphere; when pressure gradients are strong, winds are strong. For the East Coast cluster, the mean wind conditions are influenced by the annual cycle of the intensity and position of the sub-tropical ridge (STR) of high pressure, which helps delineate the mid-latitude westerly winds to the south from the southeast trade winds to the north. Any trends in observed winds are difficult to establish due to sparse coverage of wind observations and difficulties with instruments and the changing circumstances of anemometer sites (McVicar *et al.*, 2012, Troccoli et al., 2012).

With *high confidence*, changes to seasonal surface winds projected for East Coast are small overall (ranging from about -2 % to 2 % seasonally) for 2030 under both RCP4.5 and 8.5. For 2090, changes are projected with *medium confidence* to remain small under RCP4.5 with *medium to high agreement* amongst models on little change. For RCP8.5 there is high agreement amongst models on substantial increase in surface winds in spring in East Coast North and substantial decrease in winter in East Coast South (Figure 4.4.1). The projected winter reductions in East Coast South are likely related to a projected southward movement of storm tracks and the sub-tropical ridge. This would lead to a weakening of westerly winds in the East Coast South sub-cluster. The increase during spring in East Coast North is more difficult to understand as this is a shoulder season during which large scale circulation moves between more established patterns during summer and winter. Taking this into account, in East Coast North, spring wind speed for late in the century (2090) under RCP8.5 is projected to increase with *low confidence*. Little change is projected for other seasons. In East Coast South, winter wind speed for late in the century (2090) is projected to decrease with *medium confidence*, with little change projected for other seasons.

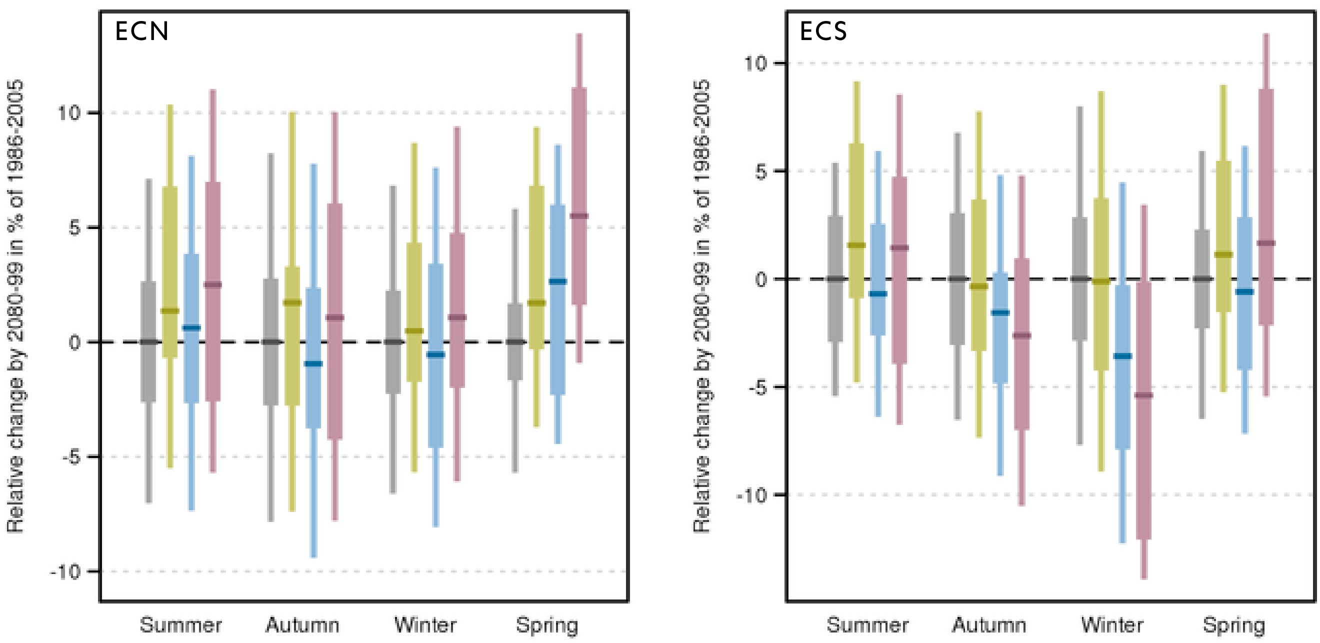


FIGURE 4.4.1: PROJECTED NEAR-SURFACE WIND SPEED CHANGES FOR 2090 FOR EAST COAST NORTH (LEFT) AND EAST COAST SOUTH (RIGHT). ANOMALIES ARE GIVEN IN PERCENT WITH RESPECT TO THE 1986–2005 MEAN FOR RCP2.6 (GREEN), RCP4.5 (BLUE) AND RCP8.5 (PURPLE), WITH GREY BARS SHOWING THE EXTENT OF NATURAL CLIMATE VARIABILITY.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

4.4.2 EXTREME WINDS

The projections of extreme wind (1-day annual maximum speed) presented here need to be considered in light of several limitations imposed on this variable. These include the limited number of GCMs that provide wind data, and the need to estimate wind speed indirectly from the model outputs that are available. Furthermore, the intensity of observed extreme wind speeds across land is strongly modified by surrounding terrain (including vegetation and other 'obstacles') that are not resolved at the relevant scale in GCMs. Many meteorological systems generating extreme winds are not represented explicitly in the models. For these reasons, confidence in model estimated changes for the East Coast cluster are lowered and their value is foremost in the direction of change rather than changes in magnitude. See further details in the Technical Report Chapter 7.4.

In light of the limitations mentioned above, projections of extreme winds indicate that reductions are more likely than increases based on the model ensemble median. This is the case for the annual maximum daily wind speed and the 20-year return value of the maximum daily wind speed, under the RCP4.5 and RCP8.5 scenarios (Fig. 4.4.2), where a 20-year return value is equivalent to a 5 % chance occurrence within any one year. For the East Coast cluster, there is generally *medium confidence* in a decrease in extreme wind speeds, noting that this is broadly consistent with projected changes to the large-scale circulation at these latitudes.

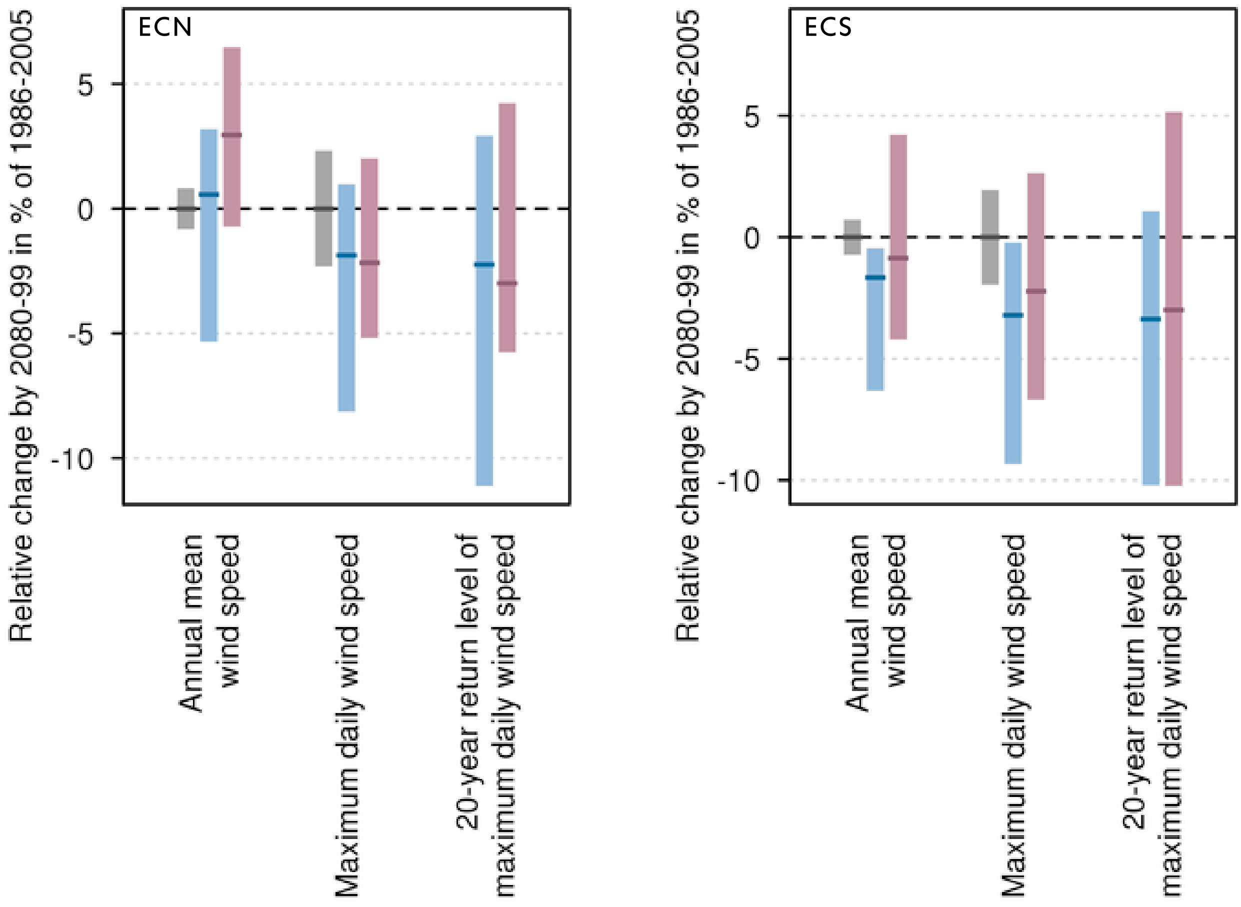


FIGURE 4.4.2: PROJECTED NEAR-SURFACE ANNUAL MEAN WIND SPEED, ANNUAL MAXIMUM DAILY WIND SPEED AND THE 20-YEAR RETURN VALUE FOR THE ANNUAL MAXIMUM DAILY WIND SPEED FOR 2090 FOR EAST COAST NORTH (LEFT) AND EAST COAST SOUTH (RIGHT). ANOMALIES ARE GIVEN IN PER CENT WITH RESPECT TO THE 1986–2005 MEAN FOR RCP2.6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

4.4.3 TROPICAL AND EXTRA-TROPICAL CYCLONES

Tropical cyclones can have severe impacts on the Eastern Seaboard region through the occurrence of extreme wind and rainfall events during the warmer months of the year. In the Australian region (from 90–160 ˚E), the mean number of tropical cyclones is 11 per year, while the mean number for the eastern Australian region (from 142.5–160 ˚E) is 4 per year. This is based on the time period from the 1981/1982 wet season to the 2012/2013 wet season, noting that this time period is unlikely to have significant satellite related errors, in contrast to the time period prior to the 1981/1982 summer (Dowdy and Kuleshov, 2012). There is a significant negative trend in the number of tropical cyclones in the Australian region based on high-quality observations during this period (Dowdy 2014). Callaghan and Power (2010) also reported a decreasing trend in tropical cyclones making landfall over eastern Australia, based on various information sources.

Projected changes in tropical cyclone frequency have been assessed in the CMIP5 GCMs over the north-east Australian region, from both the large-scale environmental conditions that promote cyclones and from direct simulation of cyclone-like synoptic features (see Section 7.3.3 of the Technical Report). Results in this region generally indicate a decrease in the formation of tropical cyclones. These results are broadly consistent with current projections of cyclones over the globe (IPCC 2013, section 14.6.1) which indicate little change through to substantial decrease in frequency. It is also anticipated that the proportion of the most intense storms will increase over the century while the intensity of associated rainfall may increase further, as can be anticipated from Section 4.3.1 here. The projection of a larger proportion of storms decaying south of 25 °S in the late 21st century is likely to impact the East Coast cluster, although this projection is made with *low confidence.* In summary, based on global and regional studies, tropical cyclones are projected with *medium confidence* to become less frequent with projected increases in the proportion of the most intense storms.

East Coast Lows (ECL) are low pressure systems that occur in eastern Australia. These systems are often cut off from (*i.e.* not embedded within) the storm track region associated with the prevailing westerly winds to the south of the subtropical ridge. Eastern Australia is a favoured location for the formation of these extra-tropical cyclones (Dowdy *et al.*, 2013a). A considerable proportion of the heavy rainfall events in the central Eastern Seaboard can be associated with the occurrence of ECLs (Pepler and Rakich, 2010; Dowdy *et al.*, 2013b). Projections suggest that increasing greenhouse gas concentrations will lead to fewer ECLs late in the century (Dowdy *et al.*, 2014). The direction of change indicated by the projections of ECL occurrence is consistent with an observed trend towards reduced storminess in eastern and southern Australia since 1890 (Alexander *et al.*, 2011).

4.5 SOLAR RADIATION

By 2030, the CMIP5 models overall simulate little change in radiation (about -0.7 to +2 %) for both RCP4.5 and RCP8.5. For 2090, projected seasonal changes range from -1.5 to 4.5 % for RCP4.5 and -3.4 to 5 % for RCP8.5 (Table 1 in the Appendix, Figure 4.7.1). However, an Australian model evaluation suggested that some models are not able to adequately reproduce the climatology of solar radiation (Watterson *et al.*, 2013). Globally, CMIP3 and CMIP5 models appear to underestimate the observed trends in some regions due to underestimation of aerosol direct radiative forcing and deficient aerosol emission inventories (Allen *et al.*, 2013). Taking this into account, there is *high confidence* in little change for 2030; and by 2090, *low confidence* in increased winter and spring radiation with little change in the other seasons.

4.6 RELATIVE HUMIDITY

CMIP5 projections of relative humidity in the East Coast cluster indicate an overall decrease (Figure 4.7.1). For 2030, seasonal projected changes for both RCP4.5 and 8.5 are -2 to 1 % (10 to 90th percentile range). For 2090, the seasonal projected ranges are -3.5 to 0.5 % under RCP4.5 and -3.5 to 1.9 % under RCP8.5 (Table 1 in the Appendix). A decrease in relative humidity away from coasts is expected because an increase in moisture holding capacity of a warming atmosphere and the greater warming of land compared to sea leads to increases in relative humidity over ocean and decreases over continents. This general tendency for decrease away from coasts 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, and by 2090 there is *medium confidence* in decrease.

4.7 POTENTIAL EVAPOTRANSPIRATION

Projected changes for potential evapotranspiration using Morton's wet-environmental potential evapotranspiration (McMahon *et al.*, 2013 and Technical Report Section 7.5.3) suggest increases for all seasons in the East Coast cluster. Overall, models generally show high (for 2030) or very high (2090) agreement on substantial increase in evapotranspiration. Despite having *high confidence* in an increase, there is only *medium confidence* about 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 wet-environmental potential evapotranspiration using observed climate variables (Kirono and Kent 2011).

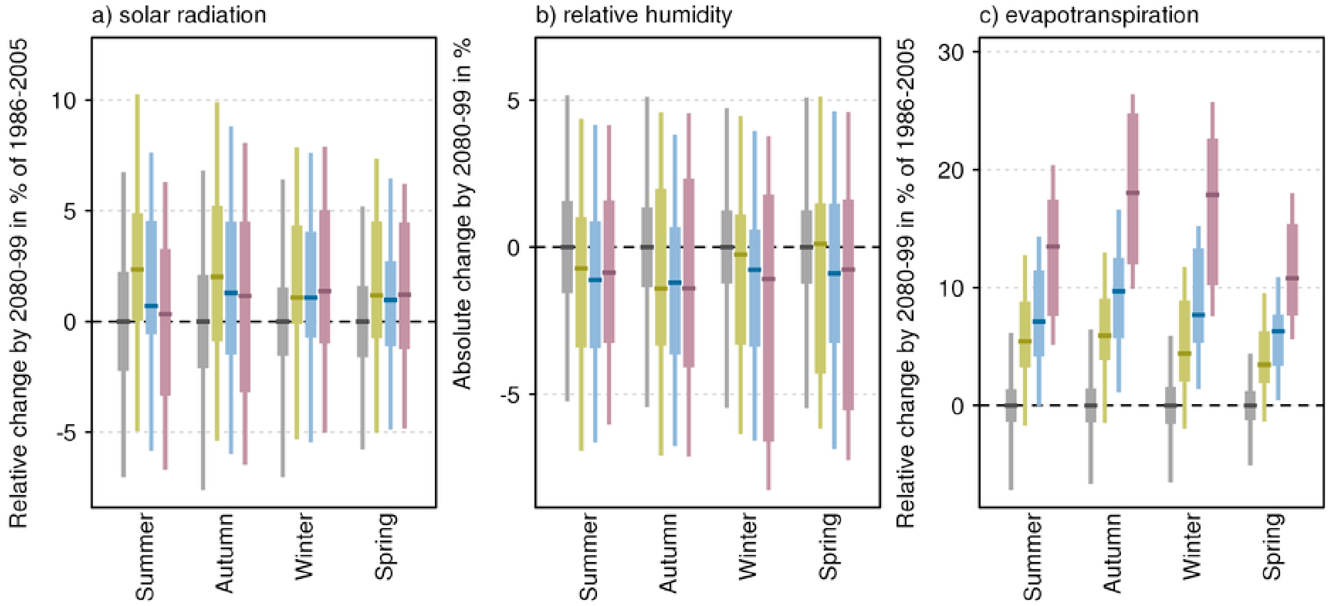


FIGURE 4.7.1: PROJECTED CHANGES IN (A) SOLAR RADIATION (%), (B) RELATIVE HUMIDITY (%, ABSOLUTE CHANGE) AND (C) WET-ENVIRONMENTAL POTENTIAL EVAPOTRANSPIRATION (%) FOR EAST COAST IN 2090. THE BAR PLOTS SHOW SEASONAL PROJECTIONS WITH RESPECT TO THE 1986–2005 MEAN FOR RCP2.6 (GREEN), RCP4.5 (BLUE) AND RCP8.5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

4.8 SOIL MOISTURE AND RUNOFF

Increases in potential evapotranspiration rates (Figure 4.7.1) combined with decreases (though less certain) in rainfall (Figure 4.3.5) 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, we do not present runoff and soil moisture as directly-simulated by the GCMs. Instead, the results of hydrological models forced by CMIP5 simulated rainfall and potential evapotranspiration are presented. Soil moisture is estimated using a dynamic hydrological model based on an extension of the Budyko framework (Zhang *et al.*, 2008), and runoff is estimated by the long-term annual water and energy balance using the Budyko framework (Teng *et al.*, 2012).

Runoff is presented as change in 20-year averages, derived from output of a water balance model. The latter uses input from CMIP5 models as smoothed time series (30-year running means), the reason 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, particularly in winter and spring (Figure 4.8.1). The annual changes for RCP8.5 by 2090 indicate medium model agreement on substantial decrease (Appendix Table 1). The percentage changes in soil moisture are strongly influenced by those in rainfall, but tend to be more negative due to the strong increase in potential evapotranspiration. Given the potential limitations of this method, there is only *medium confidence* that soil moisture will decline.

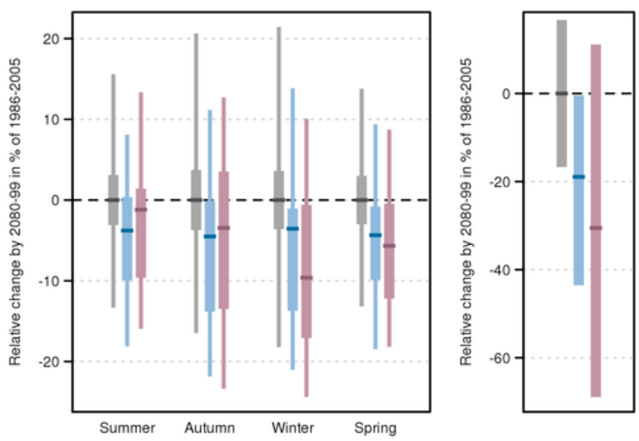


FIGURE 4.8.1: PROJECTED CHANGE IN SEASONAL SOIL MOISTURE (LEFT) AND ANNUAL RUNOFF (RIGHT) (BUDYKO METHOD – SEE TEXT) IN EAST COAST FOR 2090. ANOMALIES ARE GIVEN IN PER CENT WITH RESPECT TO THE 1986–2005 MEAN FOR RCP4.5 (BLUE) AND RCP8.5 (PURPLE) WITH GREY BARS SHOWING THE EXTENT OF NATURAL VARIABILITY.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

For East Coast, runoff could decrease by 2090, as indicated by the model ensemble median under RCP4.5 and RCP8.5(Figure 4.8.1). There is *low confidence* in these projections because even though there is a moderate level of agreement on the direction of change by the models, the method used is not able to consider changes to rainfall intensity, seasonality and changes in vegetation characteristics, factors that each could impact future runoff.

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

4.9 FIRE WEATHER

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

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

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

A period centred on 1995 (*i.e.* 1981–2010) serves as the baseline. These records are modified using the changes from the three models for four 30-year time slices (centred on 2030, 2050, 2070 and 2090) and the RCP4.5 and RCP8.5 emission scenarios. In the East Coast cluster, significant fire activity occurs in areas characterised by forests and woodlands – fuel is abundant. The 'weather switch', well characterised by FFDI, is key to understanding bushfire occurrence – the most severe fire weather conditions typically occur during spring and summer in the East Coast cluster (Dowdy *et al*., 2009).

Seven stations are used here in the analysis for this cluster: Rockhampton, Brisbane Airport (AP), Amberley, Coffs Harbour, Williamtown, Sydney AP and Richmond. Focusing on the 2030 and 2090 time slices, the results indicate increased fire weather risk in the future (Table 4.9.1). Increased temperature combined with lower rainfall results in a higher drought factor. Across the cluster, the sum of all daily FFDI values over a year (ΣFFDI from July to June) is broadly indicative of general fire weather risk. This index increases by 5 % under RCP4.5 by 2030; to 12 % under RCP8.5 by 2030; and by 13 % under RCP 4.5 by 2090, or 30 % under RCP8.5, by 2090. The number of days with a 'severe' fire danger rating increases by 20 % (RCP4.5) to 45 % (RCP8.5) by 2030, and around 45 % (RCP4.5) to 130 % (RCP8.5) by 2090.

If considering indices on an individual station and model basis, there is considerable variability from the cluster mean values (Table 4.9.1 and Table 2 in Appendix). The baseline fire climate varies, with the harshest fire weather conditions found at Amberley and Rockhampton. Coffs Harbour, where annual rainfall is significantly higher than the other stations, has the mildest fire climate. In general, the largest relative changes to fire weather in both 2030 and 2090 potentially occur in the East Coast North sub-cluster, a result of stronger rainfall declines. However, significant changes to fire weather are expected at all stations, particularly by 2090 for RCP8.5.

There is also considerable variability in the projections driven by the choice of climate models for this analysis. Temperature projections fall within a narrow range for most models, while projected rainfall varies more significantly. In most models, a rainfall decline is predicted, but the magnitude of the decline varies. Despite this variability, there is *high confidence* that climate change will result in a harsher fire-weather climate in the future. This is seen in the mean changes (Table 4.9.1) and when examining individual models and RCPs (Table 2 in the Appendix). However, there is *low confidence* in the magnitude of the change, largely due to the considerable uncertainty associated with the rainfall projections. The Technical Report shows that this cluster has a particularly large uncertainty in rainfall projections, especially in spring, the peak fire weather season for this cluster.

Fires ignited by lightning account for a high proportion of the total area burnt by fires in Australia's extra-tropical regions (Dowdy and Mills, 2012). Projected changes in fires caused by lightning have not been examined for Australia, and projected future changes in human ignitions of fires are difficult to estimate in a meaningful way. Consequently there is currently *low confidence* in projected changes to fire ignitions in the future, while noting that some studies indicate more lightning in a warmer world (Price and Rind, 1994).

TABLE 4.9.1: CLUSTER MEAN ANNUAL VALUES OF MAXIMUM TEMPERATURE (T; °C), RAINFALL (R; MM), DROUGHT FACTOR (DF; NO UNITS), THE NUMBER OF SEVERE FIRE DANGER DAYS (SEV; FFDI GREATER THAN 50 DAYS PER YEAR) AND CUMULATIVE FFDI (Σ 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. SEVEN STATIONS ARE USED IN THE AVERAGING: BRISBANE AIRPORT, AMBERLEY, ROCKHAMPTON, COFFS HARBOUR, WILLIAMTOWN, SYDNEY AIRPORT AND RICHMOND.

VARIABLE	1995 BASELINE	2030 RCP4.5	2030 RCP8.5	2090 RCP4.5	2090 RCP8.5
T	24.9	26.0	26.3	27.2	28.8
R	1077	946	917	916	896
DF	6.3	6.4	6.5	6.6	6.9
SEV	0.9	1.1	1.3	1.3	2.1
ΣFFDI	2359	2481	2634	2675	3077

4.10 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 both the terrestrial and marine environments in coastal regions. This is discussed at length in Chapter 8 of the Technical Report. Of particular significance for the terrestrial environment of the East Coast cluster is the impact of sea level rise and changes to the frequency of extreme sea levels. Impacts on coastal regions 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. For consistency we focus on those sites that have continuous longer-term tide gauge measurements available.

4.10.1 SEA LEVEL

Changes in sea level are caused primarily by changes in ocean density ('thermal expansion') and changes in ocean mass due to the exchange of water with the terrestrial environment, 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 Sydney (Figure 4.9.1), Gladstone and Brisbane (Appendix Table 3). As per previous sections, sea level rise values are provided for 2030 and 2090 periods relative to the 1986–2005 period (Appendix Table 3).

Continued increase in sea level for the East Coast cluster region 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 greenhouse gas emissions grow (Figure 4.10.1). For the first decades of the 21st century the projections are almost independent of the emissions 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 a sea level rise of about 30 % higher than the RCP4.5 level by 2090. Significant interannual variability will continue through the 21st century. An indication of its expected magnitude is given by the dashed lines in Figure 4.10.1. In the near future (2030), the projected range of sea level rise for the East Coast cluster coastline is 0.08 to 0.18 m above 1986–2005, with only minor differences between RCPs. For late in the century (2090), it is 0.30 to 0.65 m for RCP4.5 and 0.44 to 0.88 for RCP8.5 (Appendix Table 3). 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. A major cause of storm surges along the coast of the East Coast cluster region from New South Wales to Southeast Queensland is East Coast Lows (McInnes and Hubbert, 2001).

The duration of these weather events may run to several days and they are often accompanied by high rainfall.

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 East Coast 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 East Coast in 2030 the vertical allowances along the cluster coastline are in the range of 0.13 to 0.15 m for all RCPs; 0.55 to 0.63 for RCP4.5 by 2090; and 0.78 to 0.89 m for RCP8.5 by 2090 (see Table 3 in the Appendix).

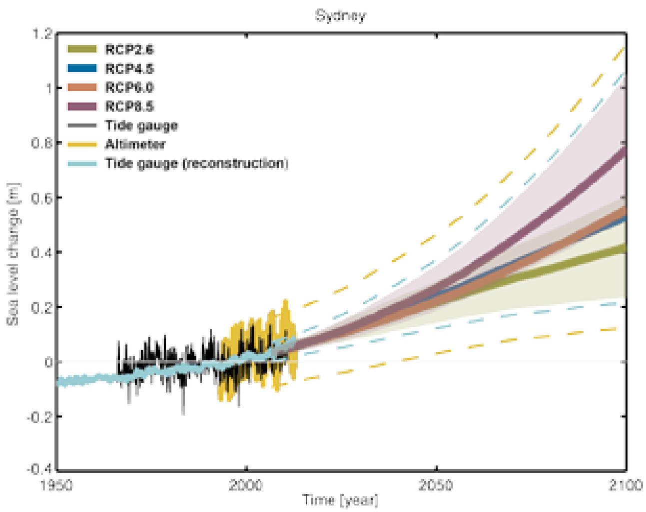


FIGURE 4.10.1: OBSERVED AND PROJECTED RELATIVE SEA LEVEL CHANGE (METRES) FOR SYDNEY (WHERE THERE ARE CONTINUOUS RECORDS AVAILABLE FOR THE PERIOD 1966–2010). THE OBSERVED TIDE GAUGE RELATIVE SEA LEVEL RECORDS ARE INDICATED IN BLACK, WITH THE SATELLITE RECORD (SINCE 1993) IN MUSTARD AND TIDE GAUGE RECONSTRUCTION (WHICH HAS LOWER VARIABILITY) IN CYAN. MULTI-MODEL MEAN PROJECTIONS (THICK PURPLE AND OLIVE LINES) FOR 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.

4.10.2 SEA SURFACE TEMPERATURE, SALINITY AND ACIDIFICATION

Sea surface temperature (SST) has increased significantly across the globe over recent decades (IPCC, 2013) with enhanced warming associated with the East Australian Current (Wu *et al.*, 2012). Warming is generally largest in the southern part of the East Coast region and smallest in the north. For 2030, the range of projected SST increase for Gladstone is 0.3 to 0.8 °C under RCP2.6 and 0.5 to 1.0 °C for RCP8.5. For Sydney it is 0.5 to 1.4 °C under RCP2.6 and 0.7 to 1.5 °C for RCP8.5 (see Appendix Table 3). For 2090, there is a much larger range of warming between the different emission scenarios. For Gladstone the range of increase is projected to be 0.4 to 1.3 °C for RCP2.6 and 2.1 to 3.5 °C for RCP8.5. For Sydney it is 0.4 to 1.6 °C for RCP2.6 and 2.8 to 5.7 °C for RCP8.5.

Changes in the hydrological cycle and strengthening of the East Australian Current has led to an increase in salinity over south eastern Australia (*e.g.* Durack and Wijffels, 2010). Ocean salinity in coastal waters will be affected by changes to rainfall and evaporation; and this in turn can affect stratification and mixing, and potentially nutrient supply. Changes to salinity across the coastal waters of the East Coast cluster span a large range that includes possible increases and decreases, particularly over the longer term and higher emission scenarios indicated in Table 3 (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.*, 2014) and this has led to a 0.1 unit change in the ocean's surface water pH and a 26 % increase in the concentration of hydrogen ions in seawater (Raven *et al.*, 2005). As the 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 is projected to be as much as 0.08 lower. By 2090 under RCP4.5 it is projected to be as much as 0.16 units lower and 0.33 units lower for RCP8.5. These changes are also accompanied by reductions in aragonite saturation state (see Appendix Table 3) 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 the resilience and viability of marine ecosystems.

In summary, there is *very high confidence* that sea surface temperatures will continue to rise along the East Coast 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 around Australia 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.

4.11 OTHER PROJECTION MATERIAL FOR THE CLUSTER

For the East Coast area, previous projection products include the nationwide *Climate Change in Australia* projections, produced by the CSIRO and BOM in 2007 (CSIRO and BOM, 2007); regional projections derived for New South Wales by its Government's Department for Environment and Heritage[2] (*NSW Climate Impact Profile*); projections presented in the Climate Q document[3], delivered as part of the Queensland state Government's Climate Smart Strategy (based on the CSIRO and BOM 2007 projections); and the Consistent Climate Scenarios derived for the Queensland Government by the Commonwealth Department of Agriculture, Fisheries and Forestry[4]. In addition to these projections, a new set of regional projections are currently under production by the New South Wales Office for Environment and Heritage and the NSW/ACT Regional Climate Modelling project (also known as NARCliM)[5]. These previous projections (as well as the upcoming NARCliM work) build on climate change information derived from the previous generation of GCMs included in the CMIP3 archive. A very brief comparison of the projections with regard to temperature and rainfall follows below.

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

The 2010 projections from the New South Wales Office for Environment and Heritage are based on the A2 SRES scenario for 2050 using four CMIP3 climate models, which makes a like for like comparison difficult since there is no equivalent to the SRES A2 emission scenario amongst the RCPs (A2 falls between RCP6.0 and RCP8.5 in terms of carbon dioxide concentration, though around 2050 it is somewhat closer to RCP8.5). Nevertheless, a broad comparison can be made to give an idea of where the 2010 NSW projections sit relative to the projections presented here. Looking at the North Coast, Hunter and Sydney/Central Coast region, which overlaps significantly with the East Coast South sub-cluster, the range of warming for the three regions varies between 1 and 3 °C. This range is wider and extends to warmer temperatures than those projected here by RCP4.5 and RCP8.5 (Figure 4.2.4).

For rainfall for the same region, the 2010 NSW projections suggest increase (expressed as 'likely' for the Sydney and Hunter regions) in all seasons except for winter in 2050 (Environment, 2010). This is a wetter projection than what is presented here for East Coast South, where all seasons show mixed response, with a somewhat larger number of models showing decreases rather than increases in winter and spring (Figure 4.2.5). In summer, more models simulate increases when following RCP8.5 (for 2090). Hence, the CMIP5 projections presented here show a larger range of potential rainfall changes compared to the 2010 NSW projections.

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

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

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

4 http://www.longpaddock.qld.gov.au/climateprojections/about.html

5 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 that are of interest to the user. These products are described in detail in Chapter 9 of the Technical Report.

www.climatechangeinaustralia.gov.au

5.1 IDENTIFYING FUTURE CLIMATE SCENARIOS

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

The challenge for practitioners lies in selecting which models to look at, 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 East Coast cluster for 2060 (years 2050–2069) under the RCP4.5 scenario. The table organises the models into groupings according to their simulated changes to rainfall (rows) and temperature (columns). Regarding rainfall, models simulate increases and decreases from *much drier* (less than -15 %) to *much wetter* (greater than 15 %), with 14 of 27 models showing drying conditions (less than -5 %) compared to four models showing rainfall increases (greater than 5 %) and nine models showing *little change* (-5 to 5 % change). With regard to temperature, most models show results ranging from *warmer* (0.5 to 1.5 °C warmer) to *hotter* (1.5 to 3 °C warmer), 9 and 18 models respectively, with no models falling into the lowest category *slightly warmer* (0 to 0.5 °C warmer) or the highest category *much hotter* (greater than 3.0 °C warmer). When considering the two variables together, it can be seen that the most commonly simulated climate for the 2060 under RCP4.5 is a *hotter and drier climate* (7 of 27 models).

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

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 East Coast 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 assessment of the on-going 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 %

		Annual surface temperature (°C)			
		Slightly warmer 0 to +0.5	Warmer +0.5 to 1.5	Hotter +1.5 to +3.0	Much hotter > +3.0
Annual rainfall (%)	Much wetter > +15.0				
	Wetter +5.0 to +15.0		3 of 27 models	1 of 27 models	
	Little change -5.0 to +5.0		5 of 27 models	4 of 27 models	
	Drier -15.0 to -5.0		1 of 27 models	7 of 27 models	
	Much drier < -15.0			6 of 27 models	

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

BOX 5.2: INDICATIVE CLIMATE SCENARIOS FOR THE EAST COAST 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 East Coast 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 climate of Brisbane and Sydney is given as an example. These were generated using the method described in Chapter 9.3.5 of the Technical Report and are based on matching annual average rainfall (within +/- 5 %) and maximum temperature (within +/- 1 °C). 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 warmer) with *little change in rainfall* (-5 to +5 %). This could occur by 2030 under any emission scenario, but may persist through to late in the century under RCP2.6. In this case, Brisbane's future climate would be more like the current climate of Hervey Bay (QLD) and Sydney's future climate would be more like that of Newcastle.
- *Warmer* (0.5 to 1.5 °C warmer) and *wetter* (5 to 15 % increase). This would occur by 2030 under any emission scenario, but may persist through to late in the century under RCP2.6. In this case, Brisbane's climate would be more like that of Atherton (QLD) and Sydney's future climate would be more like that of Yamba.
- *Hotter* (1.5 to 3.0 °C warmer), and *drier* (5 to 15 % reduction). This is also possible by 2050 under RCP4.5 or RCP8.5. In this case, Brisbane's climate would be more like that of Bundaberg (QLD) and Sydney's future climate would be more like that of Brisbane (QLD).
- *Hotter* (1.5 to 3.0 °C warmer), and *much drier* (greater than 15 % reduction). This is possible mid- to late century in the northern part of the cluster and especially under RCP4.5 and RCP8.5. In this case, Brisbane's future climate would be more like Bowen (QLD) and Sydney's future climate would be more like that of Grafton.
- *Much hotter* (greater than 3.0 °C warmer), and *much drier* (greater than 15 % reduction). This is also possible late in the century under RCP8.5 in the northern part of the cluster. In this case, Brisbane's future climate would be more like Ayr (QLD) and Sydney's future climate would be more like that of Bundaberg (QLD).

Future Realisations for the East Coast cluster

Annual Rainfall (%)		Annual Surface Temperature (°C): Slightly Warmer 0 to +0.5			Warmer +0.5 to +1.5			Hotter +1.5 to +3.0			Much Hotter > +3.0		
	RCP	2030	2050	2090	2030	2050	2090	2030	2050	2090	2030	2050	2090
Much Wetter > +15.0	2.6												
	4.5				1								
	8.5									2			
Wetter +5.0 to +15.0	2.6				2	3	1						
	4.5				1	2	2			1			
	8.5				2	1			2				3
Little Change −5.0 to +5.0	2.6	1			10	4	6						
	4.5				15	8			3	7			
	8.5				13	1			8				2
Drier −15.0 to −5.0	2.6				4	5	3		2	1			
	4.5				7	4	2		6	8			
	8.5				6	1		1	8				8
Much Drier < −15.0	2.6				1	2	4		2	3			
	4.5				3				4	7			
	8.5				5			2	8	1			13

By when and under what greenhouse gas pathway could this occur (colour code=% of models for that period/RCP)? Not projected | <10% | 10-33% | 33-66%

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

FIGURE B5.2: A TABLE BASED ON OUTPUT FROM CLIMATE FUTURES SHOWING CATEGORIES OF FUTURE CLIMATE PROJECTIONS FOR THE EAST COAST 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 IN THIS EXAMPLE VARIES FOR DIFFERENT EMISSIONS PATHWAYS). A COLOUR CODE INDICATES HOW OFTEN A PARTICULAR CLIMATE IS SIMULATED AMONGST THE CONSIDERED MODELS (% OCCURRENCE). THE SCENARIOS DESCRIBED IN THE TEXT ARE HIGHLIGHTED BOLD.

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APPENDIX

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

VARIABLE	SEASON	2030, RCP2.6	2030, RCP4.5	2030, RCP8.5	2090, RCP2.6	2090, RCP4.5	2090, RCP8.5
Temperature (°C)	**Annual**	**0.8 (0.4 to 1.1)**	**0.9 (0.6 to 1.2)**	**1 (0.6 to 1.3)**	**0.9 (0.5 to 1.5)**	**1.9 (1.3 to 2.5)**	**3.7 (2.7 to 4.7)**
	DJF	0.7 (0.5 to 1.3)	0.9 (0.5 to 1.3)	0.9 (0.5 to 1.4)	1 (0.4 to 1.7)	1.9 (1.2 to 2.6)	3.8 (2.5 to 4.6)
	MAM	0.7 (0.4 to 1.1)	0.9 (0.5 to 1.2)	1 (0.5 to 1.3)	0.8 (0.5 to 1.5)	1.8 (1.2 to 2.4)	3.5 (2.7 to 4.6)
	JJA	0.9 (0.5 to 1.2)	0.9 (0.5 to 1.2)	1 (0.7 to 1.4)	0.8 (0.5 to 1.4)	1.8 (1.2 to 2.6)	3.8 (2.9 to 4.7)
	SON	0.8 (0.3 to 1.2)	0.9 (0.5 to 1.2)	1 (0.6 to 1.4)	0.9 (0.3 to 1.5)	1.8 (1.2 to 2.7)	3.8 (2.7 to 4.7)
Temperature maximum (°C)	**Annual**	**0.8 (0.4 to 1.2)**	**0.9 (0.6 to 1.3)**	**1.1 (0.5 to 1.4)**	**1 (0.5 to 1.7)**	**1.9 (1.3 to 2.7)**	**3.6 (2.9 to 4.8)**
	DJF	0.8 (0.4 to 1.2)	1 (0.5 to 1.5)	0.9 (0.5 to 1.6)	1.1 (0.5 to 2.2)	2 (1.4 to 3)	3.7 (2.6 to 4.6)
	MAM	0.8 (0.2 to 1.2)	1 (0.5 to 1.3)	1 (0.4 to 1.3)	1 (0.4 to 1.6)	1.9 (1.1 to 2.5)	3.5 (2.8 to 4.8)
	JJA	0.8 (0.4 to 1.2)	1 (0.5 to 1.3)	1 (0.6 to 1.6)	0.9 (0.5 to 1.7)	2 (1.1 to 2.7)	4 (2.9 to 4.8)
	SON	0.8 (0.3 to 1.4)	1 (0.6 to 1.3)	1.1 (0.6 to 1.7)	1.1 (0.3 to 1.9)	2 (1.2 to 3)	3.9 (2.7 to 5.2)
Temperature minimum (°C)	**Annual**	**0.7 (0.5 to 1.1)**	**0.9 (0.6 to 1.1)**	**1 (0.7 to 1.3)**	**0.9 (0.5 to 1.5)**	**1.8 (1.3 to 2.4)**	**3.7 (2.7 to 4.7)**
	DJF	0.8 (0.5 to 1.2)	0.9 (0.6 to 1.2)	0.9 (0.5 to 1.3)	1 (0.3 to 1.7)	1.9 (1.2 to 2.6)	3.8 (2.5 to 4.7)
	MAM	0.7 (0.4 to 1.1)	0.8 (0.6 to 1.1)	0.9 (0.5 to 1.3)	0.9 (0.4 to 1.6)	1.7 (1.2 to 2.4)	3.7 (2.7 to 4.7)
	JJA	0.7 (0.4 to 1.2)	0.9 (0.5 to 1.2)	1 (0.6 to 1.3)	0.8 (0.3 to 1.5)	1.7 (1.2 to 2.5)	3.7 (2.9 to 4.7)
	SON	0.7 (0.3 to 1.2)	0.9 (0.5 to 1.2)	0.9 (0.6 to 1.4)	1 (0.2 to 1.5)	1.7 (1.1 to 2.5)	3.8 (2.7 to 4.6)
Rainfall (%)	**Annual**	**-3 (-12 to 8)**	**-3 (-14 to 3)**	**-4 (-16 to 7)**	**-4 (-20 to 6)**	**-8 (-18 to 9)**	**-13 (-25 to 14)**
	DJF	0 (-11 to 17)	-3 (-14 to 12)	-1 (-16 to 14)	-5 (-19 to 15)	-4 (-16 to 13)	2 (-21 to 26)
	MAM	-4 (-18 to 21)	-4 (-21 to 15)	-6 (-16 to 9)	-7 (-27 to 15)	-6 (-24 to 17)	-9 (-32 to 27)
	JJA	-6 (-18 to 12)	-4 (-23 to 8)	-8 (-28 to 13)	-2 (-22 to 6)	-14 (-29 to 5)	-17 (-44 to 6)
	SON	-2 (-22 to 11)	-4 (-20 to 12)	-5 (-23 to 12)	-2 (-25 to 13)	-10 (-31 to 5)	-19 (-44 to 7)
Sea level pressure (hPa)	**Annual**	**0.3 (0 to 0.7)**	**0.2 (0 to 0.6)**	**0.3 (0 to 0.8)**	**0.3 (0 to 0.7)**	**0.5 (0 to 1.1)**	**0.9 (0.3 to 1.7)**
	DJF	0.1 (-0.2 to 0.7)	0.2 (-0.3 to 0.6)	0.3 (-0.3 to 0.9)	0.3 (-0.2 to 0.8)	0.3 (-0.4 to 0.9)	0.4 (-0.4 to 1.1)
	MAM	0.1 (-0.2 to 0.7)	0.1 (-0.3 to 0.6)	0.2 (-0.3 to 0.7)	0.2 (-0.1 to 0.8)	0.3 (-0.4 to 0.7)	0.5 (-0.4 to 1.2)
	JJA	0.3 (-0.1 to 1.3)	0.4 (0 to 0.9)	0.6 (-0.1 to 0.9)	0.3 (-0.3 to 0.9)	0.8 (0.1 to 1.6)	1.5 (0.5 to 3.1)
	SON	0.3 (-0.1 to 1.1)	0.2 (-0.2 to 1)	0.4 (-0.1 to 1)	0.4 (0 to 0.9)	0.6 (0 to 1.5)	1.1 (0.1 to 2.6)
Solar radiation (%)	**Annual**	**1.1 (-0.2 to 2)**	**0.6 (-0.6 to 1.6)**	**0.8 (-0.7 to 1.9)**	**1.7 (0 to 3.9)**	**1 (-0.2 to 2.9)**	**0.7 (-1.9 to 3.5)**
	DJF	0.6 (-1.1 to 2.6)	0.4 (-1.4 to 2.6)	0.2 (-1.9 to 2.4)	2.3 (0 to 4.9)	0.7 (-0.6 to 4.5)	0.3 (-3.4 to 3.3)
	MAM	1.4 (-1.6 to 4.4)	0.6 (-0.9 to 3.3)	0.7 (-1.3 to 3.7)	2 (-0.9 to 5.2)	1.3 (-1.5 to 4.5)	1.2 (-3.2 to 4.5)
	JJA	0.6 (-0.6 to 3.7)	0.7 (-1.2 to 3.1)	0.9 (-1 to 3.4)	1.1 (-0.1 to 4.3)	1.1 (-0.7 to 4.1)	1.4 (-1 to 5)
	SON	1.1 (-0.7 to 3)	0.6 (-1.6 to 1.6)	0.2 (-1.1 to 2.8)	1.2 (-0.8 to 4.5)	1 (-1.1 to 2.7)	1.2 (-1.2 to 4.5)

VARIABLE	SEASON	2030, RCP2.6	2030, RCP4.5	2030, RCP8.5	2090, RCP2.6	2090, RCP4.5	2090, RCP8.5
Relative humidity (%, absolute)	**Annual**	**-0.2 (-1.3 to 0.7)**	**-0.5 (-1.9 to 1.1)**	**-0.7 (-1.8 to 1)**	**-0.6 (-3.9 to 1)**	**-1.1 (-3.5 to 0.5)**	**-1 (-3.5 to 1.9)**
	DJF	-0.1 (-1.4 to 0.9)	-0.5 (-2.4 to 0.7)	-0.3 (-1.9 to 1.5)	-0.7 (-3.4 to 1)	-1.1 (-3.4 to 0.9)	-0.9 (-3.3 to 1.6)
	MAM	-0.4 (-2.5 to 2.4)	-0.5 (-2.8 to 1.3)	-0.6 (-2.3 to 2.1)	-1.4 (-3.4 to 2)	-1.2 (-3.7 to 0.7)	-1.4 (-4.1 to 2.3)
	JJA	-0.2 (-2.5 to 1.1)	-0.1 (-2 to 1.2)	-0.3 (-3.6 to 1)	-0.2 (-3.3 to 1.1)	-0.8 (-3.4 to 0.6)	-1.1 (-6.6 to 1.8)
	SON	-0.3 (-2.1 to 1.8)	-0.4 (-2.2 to 1.5)	-0.5 (-2.8 to 1.6)	0.1 (-4.3 to 1.5)	-0.9 (-3.3 to 1.5)	-0.8 (-5.5 to 1.6)
Evapo-transpiration (%)	**Annual**	**3.4 (2.1 to 4.5)**	**3.5 (2.2 to 4.8)**	**3.8 (2.6 to 5.7)**	**4.7 (3.4 to 7.6)**	**7.2 (5.1 to 10.2)**	**14.6 (8.7 to 18.3)**
	DJF	3 (1.9 to 4.8)	3.9 (1.5 to 5.5)	3.6 (1.4 to 7)	5.4 (3.2 to 8.8)	7.1 (4.2 to 11.5)	13.5 (7.6 to 17.5)
	MAM	4.5 (0.3 to 7.6)	4.2 (1.9 to 6.7)	5.4 (2.9 to 8.5)	5.9 (3.8 to 9)	9.7 (5.7 to 12.5)	18 (12 to 24.8)
	JJA	3.4 (1.7 to 8.5)	3.4 (2 to 6.3)	4.6 (1.5 to 6.9)	4.4 (2 to 8.9)	7.7 (5.3 to 13.3)	17.9 (10.2 to 22.6)
	SON	2.8 (0.7 to 5.9)	2.8 (1.2 to 4.2)	3.1 (1.8 to 4.4)	3.5 (1.9 to 6.3)	6.3 (3.4 to 7.7)	10.8 (7.6 to 15.4)
Soil moisture (Budyko) (%)	**Annual**	**NA**	**-1.6 (-5.9 to 0.3)**	**-2.5 (-6.7 to -0.8)**	**NA**	**-4.8 (-11.5 to -0.9)**	**-5.3 (-12.3 to -0.2)**
	DJF		-0.9 (-4.3 to 3.2)	-3.1 (-5.9 to 2.6)		-3.8 (-9.9 to 0.4)	-1.2 (-9.6 to 1.4)
	MAM		-0.7 (-9.7 to 3.5)	-2.7 (-9.1 to -0.5)		-4.5 (-13.8 to -0.2)	-3.5 (-13.5 to 3.5)
	JJA		-1.6 (-6.7 to 1.6)	-3.8 (-12.1 to 0.3)		-3.5 (-13.7 to -1.1)	-9.6 (-17.1 to -0.6)
	SON		-2.7 (-6.1 to 1)	-2.9 (-8.2 to 2.4)		-4.4 (-9.9 to -0.8)	-5.7 (-12.2 to -0.5)
Wind speed (%)	**Annual**	**0.4 (-0.4 to 2.1)**	**-0.5 (-2 to 1.2)**	**0.6 (-0.8 to 2)**	**1.5 (-0.7 to 3.9)**	**0 (-2.1 to 1.6)**	**1.3 (-1.9 to 6)**
	DJF	1.1 (-1.1 to 2.6)	-0.9 (-2.3 to 1.2)	0.9 (-1.4 to 2.7)	2 (-0.6 to 5.7)	0.4 (-2 to 2.5)	1.7 (-3.3 to 6.2)
	MAM	-0.2 (-2.3 to 2.5)	-0.3 (-3.2 to 2.3)	0.1 (-2.7 to 3.2)	1 (-1.6 to 2.3)	-1.1 (-4.3 to 1.5)	-0.3 (-3.2 to 3.9)
	JJA	0.4 (-1.4 to 1.2)	-1 (-3.8 to 0.7)	0.1 (-1.7 to 1.9)	0.4 (-1.3 to 3.3)	-1.4 (-4.8 to 1.8)	-0.4 (-4.5 to 2.1)
	SON	0.9 (-1.2 to 3.9)	0.5 (-1.4 to 2.3)	0.9 (-0.8 to 4.4)	1.5 (-0.5 to 5.5)	1.7 (-2.6 to 4.4)	4.1 (1.5 to 9.9)

TABLE 1B: AS FOR TABLE 1A, BUT FOR EAST COAST NORTH.

VARIABLE	SEASON	2030, RCP2.6	2030, RCP4.5	2030, RCP8.5	2090, RCP2.6	2090, RCP4.5	2090, RCP8.5
Temperature (°C)	Annual	0.8 (0.4 to 1.1)	0.9 (0.6 to 1.2)	1 (0.6 to 1.3)	0.9 (0.4 to 1.5)	1.8 (1.2 to 2.6)	3.7 (2.5 to 4.7)
	DJF	0.7 (0.4 to 1.3)	0.8 (0.5 to 1.4)	0.9 (0.5 to 1.4)	0.9 (0.4 to 1.7)	1.9 (1.1 to 2.7)	3.7 (2.4 to 4.5)
	MAM	0.7 (0.4 to 1.1)	1 (0.5 to 1.2)	1 (0.4 to 1.4)	0.8 (0.4 to 1.5)	1.8 (1.1 to 2.6)	3.6 (2.6 to 4.7)
	JJA	0.9 (0.4 to 1.2)	0.9 (0.5 to 1.3)	1 (0.6 to 1.4)	0.9 (0.5 to 1.4)	1.9 (1.2 to 2.7)	4 (2.8 to 4.8)
	SON	0.8 (0.3 to 1.1)	1 (0.5 to 1.2)	1 (0.5 to 1.4)	0.9 (0.3 to 1.5)	1.8 (1.1 to 2.6)	3.7 (2.6 to 4.5)
Temperature maximum (°C)	Annual	0.8 (0.4 to 1.2)	0.9 (0.6 to 1.3)	1 (0.5 to 1.4)	0.9 (0.4 to 1.8)	1.9 (1.2 to 2.9)	3.6 (2.9 to 4.7)
	DJF	0.7 (0.3 to 1.3)	1 (0.4 to 1.5)	0.9 (0.5 to 1.6)	1 (0.4 to 2.3)	1.9 (1.3 to 3.1)	3.7 (2.6 to 4.7)
	MAM	0.8 (0 to 1.2)	1 (0.5 to 1.3)	1 (0.3 to 1.3)	1 (0.2 to 1.6)	1.9 (1.1 to 2.7)	3.4 (2.6 to 4.8)
	JJA	0.8 (0.4 to 1.3)	1 (0.5 to 1.3)	1 (0.5 to 1.6)	1 (0.3 to 1.7)	2.1 (1.1 to 2.9)	3.9 (2.8 to 4.8)
	SON	0.7 (0.3 to 1.3)	1 (0.6 to 1.4)	1.1 (0.5 to 1.5)	1.1 (0.3 to 1.9)	1.9 (1.1 to 2.9)	3.8 (2.7 to 5)
Temperature minimum (°C)	Annual	0.7 (0.4 to 1.1)	0.9 (0.6 to 1.2)	1 (0.7 to 1.4)	0.9 (0.4 to 1.4)	1.8 (1.2 to 2.5)	3.7 (2.6 to 4.7)
	DJF	0.8 (0.5 to 1.2)	0.9 (0.5 to 1.3)	0.9 (0.4 to 1.4)	1 (0.3 to 1.7)	1.8 (1.1 to 2.6)	3.7 (2.3 to 4.7)
	MAM	0.7 (0.4 to 1.1)	0.9 (0.6 to 1.2)	1 (0.5 to 1.3)	0.9 (0.4 to 1.7)	1.7 (1.2 to 2.5)	3.6 (2.5 to 4.8)
	JJA	0.8 (0.4 to 1.2)	1 (0.5 to 1.2)	1 (0.7 to 1.5)	0.8 (0.4 to 1.5)	1.9 (1.1 to 2.7)	3.9 (2.9 to 4.9)
	SON	0.7 (0.2 to 1.2)	0.9 (0.4 to 1.3)	0.9 (0.6 to 1.4)	1 (0.2 to 1.6)	1.8 (1.1 to 2.6)	3.7 (2.5 to 4.5)
Rainfall (%)	Annual	-4 (-13 to 12)	-4 (-16 to 4)	-6 (-17 to 8)	-6 (-23 to 6)	-9 (-21 to 7)	-16 (-32 to 17)
	DJF	-1 (-14 to 21)	-5 (-17 to 16)	-5 (-18 to 16)	-6 (-25 to 11)	-5 (-22 to 11)	-6 (-29 to 28)
	MAM	-6 (-23 to 29)	-5 (-23 to 15)	-8 (-21 to 12)	-8 (-30 to 18)	-6 (-28 to 19)	-12 (-36 to 30)
	JJA	-5 (-26 to 12)	-5 (-27 to 8)	-10 (-34 to 14)	-3 (-29 to 6)	-12 (-35 to 7)	-17 (-49 to 18)
	SON	-2 (-28 to 15)	-5 (-23 to 16)	-8 (-29 to 11)	-4 (-32 to 16)	-14 (-36 to 5)	-28 (-53 to 3)
Sea level pressure (hPa)	Annual	0.2 (0 to 0.7)	0.2 (0 to 0.6)	0.3 (0 to 0.7)	0.3 (-0.1 to 0.7)	0.5 (0.1 to 1.1)	0.8 (0.2 to 1.6)
	DJF	0.1 (-0.3 to 0.6)	0.2 (-0.3 to 0.7)	0.3 (-0.3 to 0.9)	0.3 (-0.1 to 0.9)	0.3 (-0.3 to 0.9)	0.4 (-0.4 to 1.1)
	MAM	0.1 (-0.2 to 0.7)	0.1 (-0.3 to 0.5)	0.2 (-0.2 to 0.6)	0.2 (-0.1 to 0.8)	0.4 (-0.4 to 0.7)	0.5 (-0.4 to 1.2)
	JJA	0.3 (-0.1 to 1.1)	0.4 (0 to 0.7)	0.5 (0 to 0.9)	0.3 (-0.2 to 0.8)	0.8 (0.1 to 1.4)	1.3 (0.5 to 2.8)
	SON	0.4 (-0.1 to 1)	0.2 (-0.2 to 1)	0.4 (-0.1 to 0.9)	0.4 (0 to 0.9)	0.5 (0 to 1.3)	1 (0.2 to 2.4)
Solar radiation (%)	Annual	1 (-0.6 to 2)	0.5 (-0.7 to 1.7)	0.7 (-0.9 to 1.8)	1.3 (-0.1 to 3.9)	1.1 (-0.5 to 2.8)	0.8 (-2.1 to 3.1)
	DJF	0.7 (-1.8 to 3.1)	0.5 (-1.4 to 2.8)	0.7 (-2.5 to 1.8)	1.6 (-0.2 to 5.5)	0.7 (-1.2 to 4.6)	0.8 (-3.9 to 3.5)
	MAM	1.4 (-2.2 to 3.9)	0.6 (-1.3 to 3.1)	0.7 (-1.4 to 3.7)	2.1 (-1.1 to 4.8)	1.5 (-2.4 to 4.8)	0.8 (-3.4 to 4.5)
	JJA	0.4 (-1.3 to 3.3)	0.4 (-1.6 to 2.8)	0.7 (-1.6 to 3.1)	0.7 (-0.7 to 4.6)	0.5 (-1.2 to 3.8)	0.3 (-1.9 to 4.3)
	SON	0.9 (-0.9 to 2.7)	0.4 (-1.5 to 2)	0.2 (-1 to 3)	1.2 (-0.9 to 4.4)	0.6 (-1.2 to 3.1)	1.2 (-1.2 to 4.6)
Relative humidity (%, absolute)	Annual	-0.1 (-1.5 to 0.9)	-0.5 (-1.8 to 1.3)	-0.7 (-2.1 to 1.3)	-0.6 (-4 to 1.3)	-0.9 (-3.7 to 0.7)	-1.2 (-3.5 to 2.5)
	DJF	-0.3 (-1.7 to 1.1)	-0.5 (-2.8 to 1.1)	-0.6 (-2.2 to 2.1)	-0.9 (-3.1 to 1)	-1.2 (-4.6 to 0.8)	-1.1 (-4.1 to 2.3)
	MAM	-0.6 (-2.6 to 3.3)	-0.3 (-2.8 to 1.3)	-0.6 (-2.6 to 1.8)	-1.5 (-3.4 to 2.9)	-1.3 (-4.8 to 1.2)	-1.5 (-5.3 to 3.4)
	JJA	-0.2 (-3 to 1.6)	0 (-1.8 to 1.5)	-0.2 (-3.9 to 1.7)	-0.3 (-4 to 1.6)	-0.6 (-3.9 to 1.3)	-0.7 (-7.3 to 2.1)
	SON	-0.2 (-2.4 to 1.7)	-0.4 (-1.9 to 1.8)	-0.6 (-2.5 to 1.8)	-0.1 (-4.7 to 1.9)	-0.9 (-3.2 to 1.8)	-0.9 (-5 to 1.9)
Evapo-transpiration (%)	Annual	3.1 (1.9 to 4.8)	3.5 (2.1 to 4.9)	3.5 (2.6 to 5.6)	4.5 (2.8 to 8.2)	7.4 (4.3 to 10.6)	14.1 (8.2 to 19)
	DJF	2.8 (1 to 4.7)	3.8 (1.1 to 5.6)	3.6 (0.6 to 7.7)	5 (2.2 to 9.4)	6.8 (3.5 to 11.8)	13.4 (5.7 to 18)
	MAM	4 (0.3 to 7.4)	4.6 (1.5 to 6.8)	4.9 (3.1 to 8.8)	6.3 (2.1 to 8.6)	9.2 (5.7 to 12.7)	18.2 (11.4 to 25.3)
	JJA	3.2 (1.9 to 8.9)	3.5 (1.6 to 6.2)	4.3 (1 to 7.1)	4.2 (2 to 9.7)	7.7 (5 to 13.9)	16.5 (10 to 22.5)
	SON	2.6 (0.5 to 5.5)	2.7 (1.3 to 4.4)	3.1 (1.5 to 4.2)	3.1 (1.5 to 6.6)	6 (3.4 to 7.8)	11.2 (6.9 to 15.7)

VARIABLE	SEASON	2030, RCP2.6	2030, RCP4.5	2030, RCP8.5	2090, RCP2.6	2090, RCP4.5	2090, RCP8.5
Soil moisture (Budyko) (%)	**Annual**	**NA**	**-2.2 (-4.7 to 1)**	**-3.3 (-5 to -0.3)**	**NA**	**-4.7 (-9.7 to 0.2)**	**-4.9 (-10.9 to 1.6)**
	DJF		-1 (-5.9 to 3.2)	-0.7 (-6.7 to 5.3)		-2.8 (-11.1 to 0.2)	-1 (-10.3 to 5.5)
	MAM		-1.4 (-8.1 to 3.5)	-2.7 (-7.4 to -0.7)		-4 (-11.7 to 0.9)	-2.8 (-13.3 to 1.6)
	JJA		-1.5 (-6.8 to 1.8)	-5.7 (-11.1 to 2.1)		-3 (-13.4 to 1.2)	-8 (-14.9 to 1.1)
	SON		-1.8 (-5.9 to 2.1)	-2.8 (-4.6 to 0.7)		-3.2 (-7.6 to 0.2)	-3.7 (-8.2 to 0)
Wind speed (%)	**Annual**	**0.7 (-0.2 to 2.2)**	**0 (-2.1 to 1.4)**	**0.8 (-0.5 to 3.6)**	**1.2 (-0.6 to 5.1)**	**0.5 (-2.5 to 3.6)**	**2.2 (-1.2 to 6.5)**
	DJF	1.3 (-1.6 to 2.8)	-0.6 (-3 to 1.3)	1.1 (-1.7 to 3.2)	1.4 (-0.7 to 6.8)	0.6 (-2.7 to 3.8)	2.5 (-2.6 to 7)
	MAM	-0.2 (-2.7 to 2.7)	-0.2 (-3 to 3.6)	0.4 (-2.8 to 4.5)	1.7 (-2.8 to 3.3)	-0.9 (-3.8 to 2.4)	1.1 (-4.3 to 6)
	JJA	0.4 (-0.8 to 1.7)	-0.8 (-3.2 to 1.9)	1 (-0.9 to 2.4)	0.5 (-1.7 to 4.3)	-0.6 (-4.6 to 3.4)	1.1 (-2 to 4.7)
	SON	1.4 (0 to 3.9)	0.6 (-1.4 to 3.2)	1.9 (-0.4 to 5.5)	1.7 (-0.3 to 6.8)	2.6 (-2.3 to 6)	5.5 (1.6 to 11.1)

TABLE 1C: AS FOR TABLE 1A, BUT FOR EAST COAST SOUTH.

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 (0.5 to 1.1)**	**0.9 (0.6 to 1.1)**	**1 (0.7 to 1.3)**	**1 (0.6 to 1.5)**	**1.8 (1.3 to 2.5)**	**3.7 (2.9 to 4.6)**
	DJF	0.8 (0.6 to 1.2)	0.9 (0.6 to 1.3)	1 (0.5 to 1.3)	1.2 (0.5 to 1.7)	1.9 (1.2 to 2.6)	3.7 (2.8 to 4.5)
	MAM	0.8 (0.5 to 1.1)	0.8 (0.5 to 1.1)	0.9 (0.6 to 1.3)	0.9 (0.6 to 1.4)	1.7 (1.2 to 2.4)	3.7 (2.9 to 4.6)
	JJA	0.7 (0.4 to 1.1)	0.9 (0.4 to 1.1)	0.9 (0.6 to 1.2)	0.8 (0.5 to 1.4)	1.7 (1.3 to 2.3)	3.6 (3 to 4.5)
	SON	0.8 (0.4 to 1.3)	0.9 (0.6 to 1.3)	1 (0.6 to 1.5)	0.9 (0.5 to 1.7)	1.9 (1.2 to 2.8)	3.9 (3 to 5.3)
Temperature maximum (°C)	Annual	**0.8 (0.6 to 1.1)**	**0.9 (0.6 to 1.2)**	**1.1 (0.7 to 1.4)**	**1.1 (0.5 to 1.6)**	**2 (1.3 to 2.7)**	**3.8 (3 to 4.9)**
	DJF	0.8 (0.6 to 1.5)	1 (0.5 to 1.5)	1 (0.6 to 1.5)	1.4 (0.6 to 2)	2 (1.4 to 2.7)	3.8 (2.8 to 4.5)
	MAM	0.8 (0.4 to 1.2)	0.9 (0.5 to 1.2)	0.9 (0.6 to 1.3)	1 (0.6 to 1.6)	1.8 (1.3 to 2.5)	3.7 (2.8 to 4.6)
	JJA	0.8 (0.5 to 1.1)	1 (0.6 to 1.2)	1.1 (0.7 to 1.4)	1 (0.5 to 1.5)	1.9 (1.2 to 2.7)	3.8 (2.9 to 4.9)
	SON	0.9 (0.4 to 1.6)	1 (0.6 to 1.4)	1.1 (0.6 to 1.9)	1.1 (0.4 to 1.8)	2 (1.2 to 3.3)	4.1 (3 to 5.9)
Temperature minimum (°C)	Annual	**0.7 (0.5 to 1)**	**0.9 (0.6 to 1)**	**1 (0.7 to 1.2)**	**0.9 (0.6 to 1.6)**	**1.7 (1.3 to 2.4)**	**3.8 (2.9 to 4.7)**
	DJF	0.8 (0.5 to 1.2)	0.9 (0.6 to 1.3)	0.9 (0.7 to 1.3)	1.1 (0.5 to 1.9)	1.9 (1.3 to 2.8)	3.8 (2.9 to 5)
	MAM	0.7 (0.4 to 1.1)	0.8 (0.5 to 1.1)	0.9 (0.5 to 1.3)	0.8 (0.6 to 1.5)	1.6 (1.1 to 2.3)	3.7 (2.8 to 4.8)
	JJA	0.7 (0.3 to 1)	0.8 (0.3 to 1)	0.9 (0.5 to 1.1)	0.8 (0.4 to 1.4)	1.6 (1 to 2.1)	3.5 (2.8 to 4.4)
	SON	0.8 (0.4 to 1.2)	0.8 (0.6 to 1.1)	1 (0.7 to 1.3)	0.8 (0.5 to 1.6)	1.9 (1.1 to 2.5)	3.9 (3 to 4.9)
Rainfall (%)	Annual	**-2 (-9 to 7)**	**-3 (-10 to 6)**	**-1 (-11 to 6)**	**-2 (-16 to 8)**	**-2 (-16 to 9)**	**-3 (-20 to 16)**
	DJF	1 (-13 to 18)	1 (-10 to 15)	2 (-13 to 14)	-2 (-22 to 10)	0 (-15 to 19)	11 (-12 to 27)
	MAM	-2 (-16 to 8)	-3 (-22 to 15)	-3 (-13 to 14)	-6 (-23 to 12)	-1 (-22 to 18)	-2 (-28 to 20)
	JJA	-2 (-19 to 10)	-5 (-18 to 14)	-8 (-20 to 12)	-3 (-16 to 8)	-8 (-24 to 7)	-17 (-31 to 1)
	SON	-3 (-18 to 18)	-1 (-19 to 12)	-3 (-20 to 11)	0 (-19 to 10)	-6 (-23 to 9)	-8 (-30 to 14)
Sea level pressure (hPa)	Annual	**0.3 (0 to 0.8)**	**0.3 (0 to 0.7)**	**0.4 (-0.1 to 0.9)**	**0.3 (0 to 0.7)**	**0.6 (0 to 1)**	**1 (0.3 to 1.9)**
	DJF	0.2 (-0.4 to 0.8)	0.2 (-0.4 to 0.6)	0.3 (-0.3 to 0.8)	0.1 (-0.4 to 0.6)	0.3 (-0.6 to 0.8)	0.4 (-0.6 to 1.1)
	MAM	0.1 (-0.3 to 0.7)	0.2 (-0.4 to 0.7)	0.2 (-0.4 to 0.8)	0.2 (-0.4 to 0.7)	0.3 (-0.3 to 0.8)	0.6 (-0.3 to 1.3)
	JJA	0.4 (-0.3 to 1.5)	0.4 (-0.1 to 1.1)	0.7 (-0.2 to 1.2)	0.5 (-0.4 to 1.1)	1 (0.1 to 2.1)	1.9 (0.5 to 3.7)
	SON	0.5 (-0.1 to 1.3)	0.3 (-0.3 to 1.3)	0.5 (-0.2 to 1.3)	0.4 (-0.1 to 1.1)	0.7 (0 to 1.6)	1.4 (0.1 to 3.1)
Solar radiation (%)	Annual	**1.2 (-0.2 to 3)**	**0.5 (-0.5 to 1.9)**	**0.8 (-0.7 to 2.7)**	**2.3 (0.2 to 4.6)**	**1.5 (-0.3 to 3.7)**	**1.3 (-1.2 to 3.4)**
	DJF	1.4 (-1.1 to 4.1)	0.1 (-1.9 to 3)	0.2 (-1.4 to 3.2)	3 (0 to 6.7)	1 (-1.8 to 3.6)	0 (-4 to 3.8)
	MAM	1.6 (-1.6 to 4.6)	0.6 (-1.5 to 4)	0.7 (-1.3 to 4.1)	3 (-1 to 6.5)	1.1 (-1.3 to 6)	0.9 (-3 to 5.8)
	JJA	1.4 (0 to 4.2)	1.3 (-0.9 to 4.3)	2.2 (-0.2 to 4.1)	2.4 (-0.1 to 4.7)	2.5 (0 to 4.8)	4.1 (1.3 to 8.1)
	SON	1.4 (-1.3 to 3.2)	0.7 (-1.6 to 1.7)	0.4 (-1.7 to 3.5)	1.6 (-1.5 to 4.8)	1.7 (-1.5 to 3.2)	1.2 (-1.2 to 4.2)
Relative humidity (%, absolute)	Annual	**-0.3 (-1.2 to 0.7)**	**-0.5 (-1.6 to 0.8)**	**-0.6 (-1.4 to 0.9)**	**-0.5 (-2.9 to 0.7)**	**-1 (-3.1 to 0.3)**	**-1.5 (-3.8 to 1.3)**
	DJF	0 (-1.3 to 2)	-0.2 (-1.7 to 1.6)	-0.3 (-1.9 to 1.2)	-0.7 (-4.5 to 0.6)	-0.7 (-2.7 to 1.2)	-0.7 (-2.4 to 2.9)
	MAM	-0.2 (-2.4 to 0.9)	-0.2 (-3.2 to 1.4)	-0.5 (-1.6 to 1.2)	-0.8 (-3.2 to 0.4)	-1.1 (-2.9 to 0.7)	-1 (-4.6 to 1.6)
	JJA	-0.1 (-1.3 to 0.3)	-0.6 (-2.1 to 0.5)	-0.7 (-2.4 to 0.6)	-0.8 (-2.6 to 0.8)	-1.1 (-2.8 to 0.2)	-2.2 (-5.8 to 0.1)
	SON	-0.5 (-1.5 to 2.6)	-0.5 (-2.4 to 1.1)	-0.4 (-3.4 to 1.6)	-0.1 (-3.2 to 1.8)	-1.3 (-4.7 to 1)	-2.1 (-7 to 1.5)
Evapo-transpiration (%)	Annual	**3.9 (2.7 to 5.9)**	**3.4 (2.3 to 4.4)**	**4.2 (2.3 to 6)**	**5.9 (4.2 to 6.8)**	**7.8 (5.3 to 9.5)**	**14.3 (10.1 to 18.1)**
	DJF	4.2 (2 to 6)	3.1 (1.6 to 5.7)	4.4 (1.9 to 6.8)	6.6 (4.6 to 8.4)	7.6 (5.3 to 10.7)	13 (8.5 to 17.5)
	MAM	4.5 (-0.4 to 8.8)	3.6 (0.5 to 7.4)	5.2 (2.3 to 9.4)	6.3 (3.9 to 9.8)	9.1 (6.1 to 13.2)	19.3 (12.8 to 24)
	JJA	4.1 (2 to 7.3)	3.9 (2.1 to 8)	5.7 (1.7 to 8.1)	5.4 (2.4 to 6.7)	8.7 (5.5 to 14.1)	20.6 (13.2 to 25.6)
	SON	3.6 (1 to 7.1)	3 (-0.3 to 4.1)	3 (1 to 6.2)	3.8 (1.4 to 7.1)	7.2 (2.6 to 8.2)	11.4 (7.4 to 15.4)

VARIABLE	SEASON	2030, RCP2.6	2030, RCP4.5	2030, RCP8.5	2090, RCP2.6	2090, RCP4.5	2090, RCP8.5
Soil moisture (Budyko) (%)	**Annual**	**NA**	**-2.1 (-10.2 to 2)**	**-4.1 (-9.9 to 2.5)**	**NA**	**-6.4 (-13.1 to -0.2)**	**-8.7 (-15.4 to 2.4)**
	DJF		-1 (-6 to 4.8)	-2.7 (-8.6 to 2.1)		-5.9 (-13.3 to 1.9)	-3 (-11.2 to 4.6)
	MAM		-1 (-12.8 to 7.6)	-3.2 (-8.6 to 4.7)		-5.7 (-15.8 to 0.5)	-4.8 (-15.9 to 5.3)
	JJA		-2.1 (-10.8 to 4.7)	-3 (-12.8 to 3.2)		-5.4 (-14.3 to 0.5)	-13 (-18.3 to 7.3)
	SON		-4.2 (-7.9 to 0.6)	-5 (-13.4 to 5.5)		-7.7 (-14.7 to -0.1)	-9.1 (-20.8 to -1.4)
Wind speed (%)	**Annual**	**0 (-1.8 to 2.7)**	**-1.1 (-2.9 to 0.5)**	**-0.5 (-2.3 to 1.9)**	**0.6 (-2 to 4.1)**	**-1 (-4.2 to 0.2)**	**-1.1 (-6.9 to 4.2)**
	DJF	0.6 (-1.9 to 3.2)	-1 (-2.3 to 1.3)	0.7 (-2 to 3)	1.6 (-0.9 to 6.3)	-0.7 (-2.6 to 2.6)	1.4 (-3.9 to 4.7)
	MAM	-0.7 (-1.9 to 2.4)	-1.7 (-4.2 to 2.1)	-1.5 (-3.9 to 0.7)	-0.3 (-3.3 to 3.7)	-1.6 (-4.8 to 0.3)	-2.6 (-7 to 1)
	JJA	-0.2 (-4.4 to 3.6)	-1.6 (-6 to 0.9)	-0.7 (-6.3 to 1.6)	-0.1 (-4.2 to 3.7)	-3.6 (-7.9 to -0.3)	-5.4 (-12.1 to -0.1)
	SON	-0.2 (-1.9 to 5.5)	-0.5 (-3.2 to 2.8)	0.7 (-3.6 to 3.2)	1.1 (-1.6 to 5.5)	-0.6 (-4.2 to 2.9)	1.7 (-2.1 to 8.8)

LEGEND

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

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

STATION	VARIABLE	1995 BASELINE	2030, RCP4.5			2030, RCP8.5			2090, RCP4.5			2090, RCP8.5		
			CESM	GFDL	MIROC	CESM	GFDL	MIROC	CESM	GFDL	MIROC	CESM	GFDL	MIROC
Rock-hampton (ECN)	T	28.7	29.5	30.2	29.7	29.9	30.3	30.3	31.1	31.1	30.8	32.9	32.9	31.9
	R	805	719	564	705	732	532	648	710	549	679	728	450	736
	DF	7.5	7.5	7.9	7.5	7.4	8.0	7.7	7.6	8.0	7.6	7.7	8.4	7.6
	SEV	0.6	0.7	1.0	0.8	0.8	1.4	0.9	0.9	1.3	0.8	1.8	2.4	1.0
	ΣFFDI	3355	3305	4020	3400	3459	4142	3712	3603	4150	3622	4070	4991	3647
Amberley (ECN)	T	27.2	28.0	28.6	28.2	28.4	28.7	28.7	29.6	29.5	29.2	31.3	31.3	30.4
	R	854	761	597	741	777	569	671	752	585	716	759	467	760
	DF	7.1	7.1	7.5	7.1	7.1	7.7	7.4	7.3	7.7	7.3	7.4	8.2	7.3
	SEV	1.3	1.3	2.2	1.7	1.6	2.5	2.0	2.0	2.4	1.8	3.1	4.1	2.1
	ΣFFDI	3113	3065	3743	3179	3221	3888	3472	3371	3898	3390	3845	4755	3419
Brisbane AP (ECN)	T	25.4	26.1	26.8	26.4	26.6	26.9	26.9	27.8	27.7	27.4	29.5	29.5	28.6
	R	1185	1043	809	1038	1080	767	934	1040	782	988	1063	638	1062
	DF	6.4	6.3	6.8	6.3	6.3	7.0	6.6	6.5	7.0	6.5	6.7	7.6	6.6
	SEV	0.6	0.7	1.0	0.7	0.7	1.2	0.8	0.9	1.0	0.7	1.4	1.7	0.8
	ΣFFDI	2016	1960	2523	2032	2074	2636	2262	2179	2636	2190	2539	3327	2207
Coffs Harbour (ECS)	T	23.5	24.4	24.7	24.6	24.9	24.8	24.8	26.2	25.7	25.3	28.2	27.4	26.7
	R	1677	1555	1434	1683	1565	1382	1609	1549	1316	1640	1551	1114	1794
	DF	5.3	5.4	5.6	5.4	5.5	5.7	5.5	5.7	5.8	5.5	5.9	6.3	5.5
	SEV	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.1	0.2	0.2	0.2	0.4	0.1
	ΣFFDI	1288	1312	1467	1283	1409	1551	1390	1486	1607	1340	1816	2058	1359
William-town (ECS)	T	23.3	24.2	24.5	24.4	24.7	24.6	24.6	26.0	25.5	25.1	28.1	27.2	26.5
	R	1120	1052	963	1139	1062	925	1081	1039	890	1115	1013	738	1197
	DF	5.4	5.5	5.7	5.5	5.6	5.8	5.6	5.8	6.0	5.7	6.2	6.6	5.8
	SEV	1.3	1.3	1.5	1.4	1.6	1.9	1.7	1.9	2.0	1.5	3.1	3.7	1.6
	ΣFFDI	2065	2071	2269	2075	2238	2413	2208	2344	2500	2155	2918	3168	2202
Sydney AP (ECS)	T	22.5	23.4	23.7	23.6	23.8	23.8	23.8	25.1	24.7	24.3	27.2	26.3	25.6
	R	1094	969	877	1048	977	843	991	953	816	1022	927	674	1094
	DF	5.8	5.8	6.0	5.9	5.9	6.1	5.9	6.1	6.3	6.0	6.5	6.8	6.1
	SEV	1.1	1.2	1.5	1.3	1.5	1.6	1.5	1.6	1.9	1.4	2.5	3.0	1.4
	ΣFFDI	2029	2014	2205	2009	2169	2330	2130	2276	2443	2083	2816	3068	2129
Richmond (ECS)	T	23.9	24.9	25.2	25.0	25.3	25.2	25.2	26.6	26.2	25.8	28.7	27.8	27.1
	R	810	728	672	782	725	632	759	721	623	769	709	523	843
	DF	6.3	6.5	6.7	6.4	6.5	6.7	6.5	6.8	7.0	6.6	7.1	7.5	6.7
	SEV	1.2	1.3	1.4	1.4	1.4	2.0	1.5	1.6	2.0	1.4	3.5	4.0	1.6
	ΣFFDI	2647	2651	2877	2638	2817	3009	2781	2979	3176	2743	3574	3881	2830

TABLE 3: PROJECTED ANNUAL CHANGE IN SIMULATED MARINE CLIMATE VARIABLES FOR 2020–2039 (2030) AND 2080–2099 (2090) PERIODS RELATIVE TO 1986–2005 PERIOD FOR EAST COAST, 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)	Gladstone (151.31, -23.85)	0.13 (0.08-0.17)	0.13 (0.09-0.17)	0.13 (0.09-0.18)	0.38 (0.22-0.54)	0.47 (0.30-0.64)	0.64 (0.44-0.86)
	Brisbane (153.17, -27.37)	0.13 (0.09-0.17)	0.13 (0.09-0.18)	0.14 (0.09-0.18)	0.39 (0.23-0.55)	0.47 (0.31-0.65)	0.65 (0.45-0.87)
	Sydney (151.23, -33.86)	0.13 (0.09-0.18)	0.13 (0.09-0.18)	0.14 (0.10-0.19)	0.38 (0.22-0.54)	0.47 (0.30-0.65)	0.66 (0.45-0.88)
Sea allowance (m)	Gladstone (151.31, -23.85)	0.13	0.13	0.14	0.45	0.55	0.78
	Brisbane (153.17, -27.37)	0.14	0.14	0.15	0.52	0.63	0.89
	Sydney (151.23, -33.86)	0.14	0.14	0.15	0.48	0.59	0.84
Sea surface temperature (°C)	Gladstone (51.31, -23.85)	0.7 (0.3 to 0.8)	0.7 (0.5 to 1.0)	0.8 (0.5 to 1.0)	0.7 (0.4 to 1.3)	1.5 (1.1 to 1.9)	2.9 (2.1 to 3.5)
	Brisbane (153.17, -27.37)	0.6 (0.4 to 0.9)	0.8 (0.5 to 1.0)	0.8 (0.6 to 1.0)	0.8 (0.5 to 1.4)	1.5 (1.1 to 1.9)	2.9 (2.2 to 3.6)
	Sydney (151.23, -33.86)	0.8 (0.5 to 1.4)	0.9 (0.6 to 1.3)	1.0 (0.7 to 1.5)	0.7 (0.4 to 1.6)	1.5 (1.2 to 2.9)	3.1 (2.8 to 5.7)
Sea surface salinity	Gladstone (51.31, -23.85)	-0.04 (-0.08 to 0.20)	-0.01 (-0.24 to 0.19)	0.02 (-0.06 to 0.13)	-0.08 (-0.15 to 0.30)	-0.10 (-0.18 to 0.38)	-0.14 (-0.26 to 0.45)
	Brisbane (153.17, -27.37)	-0.04 (-0.12 to 0.10)	-0.05 (-0.27 to 0.08)	0.01 (-0.06 to 0.12)	-0.09 (-0.19 to 0.24)	-0.07 (-0.41 to 0.32)	-0.12 (-0.56 to 0.43)
	Sydney (151.23, -33.86)	0.01 (-0.07 to 0.34)	0.01 (-0.13 to 0.34)	0.04 (-0.02 to 0.17)	-0.02 (-0.18 to 0.14)	0.00 (-0.06 to 0.56)	-0.02 (-0.16 to 1.85)
Ocean pH	Gladstone (51.31, -23.85)	-0.06 (-0.07 to -0.06)	-0.07 (-0.07 to -0.06)	-0.08 (-0.08 to -0.07)	-0.06 (-0.07 to -0.06)	-0.15 (-0.15 to -0.14)	-0.32 (-0.33 to -0.31)
	Brisbane (153.17, -27.37)	-0.06 (-0.07 to -0.06)	-0.07 (-0.07 to -0.06)	-0.08 (-0.08 to -0.07)	-0.07 (-0.07 to -0.06)	-0.15 (-0.15 to -0.14)	-0.32 (-0.33 to -0.31)
	Sydney (151.23, -33.86)	-0.07 (-0.07 to -0.06)	-0.07 (-0.07 to -0.06)	-0.08 (-0.08 to -0.07)	-0.07 (-0.08 to -0.07)	-0.16 (-0.16 to -0.15)	-0.33 (-0.33 to -0.31)
Aragonite saturation	Gladstone (51.31, -23.85)	-0.34 (-0.37 to -0.29)	-0.36 (-0.38 to -0.34)	-0.41 (-0.46 to -0.38)	-0.34 (-0.38 to -0.29)	-0.76 (-0.78 to -0.72)	-1.53 (-1.61 to -1.42)
	Brisbane (153.17, -27.37)	-0.34 (-0.37 to -0.29)	-0.36 (-0.38 to -0.34)	-0.41 (-0.45 to -0.37)	-0.34 (-0.38 to -0.29)	-0.76 (-0.79 to -0.70)	-1.52 (-1.60 to -1.39)
	Sydney (151.23, -33.86)	-0.29 (-0.35 to -0.23)	-0.29 (-0.36 to -0.27)	-0.33 (-0.42 to -0.28)	-0.35 (-0.38 to -0.24)	-0.67 (-0.77 to -0.58)	-1.31 (-1.53 to -1.16)

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 Program
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
EC	East Coast cluster
ECL	East Coast Low
ECN	East Coast sub-cluster North
ECS	East Coast sub-cluster South
ENSO	El Niño Southern Oscillation
FFDI	Forest Fire Danger Index
GCMs	General Circulation Models or Global Climate Models
IOD	Indian Ocean Dipole
IPCC	Intergovernmental Panel on Climate Change
LLS	Local Land Service
MSLP	Mean Sea level Pressure
NARCliM	NSW/ACT Regional Climate Modelling project
NRM	Natural Resource Management
RCP	Representative Concentration Pathway
SAM	Southern Annular Mode
SEACI	South East Australian Climate Initiative
SPI	Standardised Precipitation Index
SRES	Special Report on Emissions Scenarios
SST	Sea Surface Temperature
STR	Sub-tropical Ridge
TCs	Tropical Cyclones

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.

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