WET TROPICS

CLUSTER REPORT

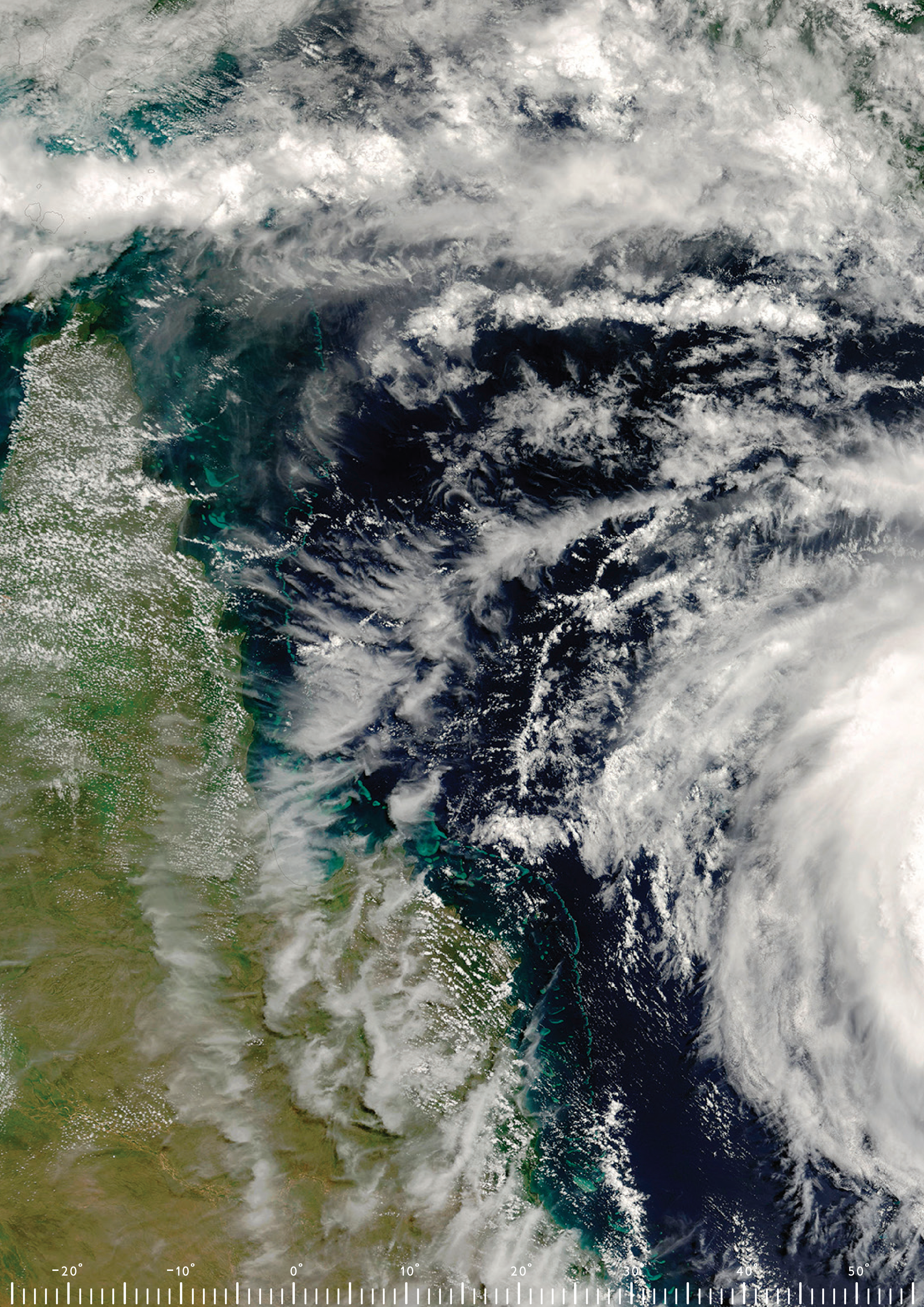
CLIMATE
CHANGE
IN AUSTRALIA

PROJECTIONS

FOR AUSTRALIA´S NRM REGIONS

CSIRO

Australian Government
Department of the Environment
Bureau of Meteorology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PREFACE

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

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

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

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

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

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

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

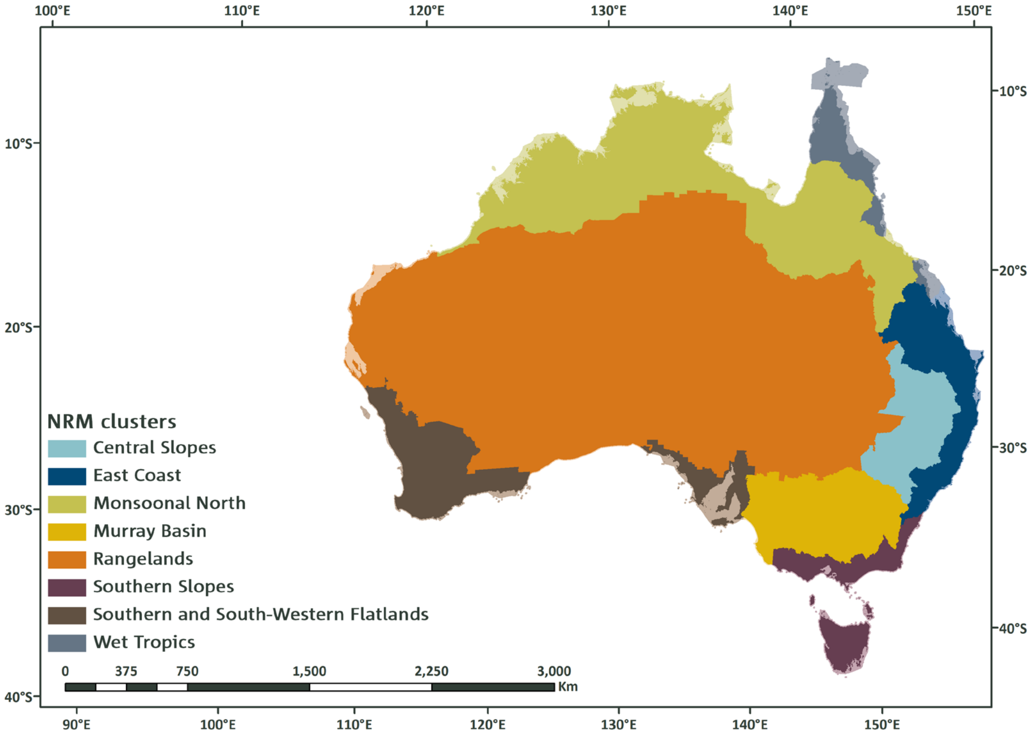

FIGURE A: THE EIGHT NATURAL RESOURCE MANAGEMENT (NRM) CLUSTERS

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

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

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

For each variable, the projected change is accompanied by a confidence rating. This rating follows the method used by the IPCC in the *Fifth Assessment Report*, whereby the confidence in a projected change is assessed based on the type, amount, quality and consistency of evidence (which can be process understanding, theory, model output, or expert judgment) 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

Temperatures in the cluster have been increasing since national observations began in 1910, especially since 1960. Between 1910 and 2013, mean surface air temperature increased by 1.1 °C using a linear trend. For the same period, daytime maximum temperatures have increased by 1.0 °C and overnight minimum temperatures have increased by 1.2 °C using a linear trend.

Continued substantial increases for the Wet Tropics cluster for mean, maximum and minimum temperature are projected with *very high confidence*.

For the near future (2030), the mean warming is around 0.3 to 1.1 °C above the climate of 1986–2005 (centred at 1995), with only minor differences between RCPs. For the late in the century (2090) mean warming is 1.0 to 2.0 °C for RCP4.5 and 2.3 to 3.9 °C for RCP8.5.

MORE FREQUENT AND HOTTER HOT DAYS

A substantial increase in the temperature on the hottest days, the frequency of hot days and the duration of warm spells is projected with *very high confidence*. For example, in Cairns, the number of days above 35 °C for 2090 is projected to change from 3 days currently to 11 days under RCP4.5 for median warming.

RAINFALL MAY CHANGE BUT DIRECTION OF CHANGE IS 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 by 2030 (20-year mean changes of -10 to +5 % annually, and with a larger range seasonally) as it has been in the recent past. Projected rainfall changes for later in the century have generally *low confidence*.

For 2090, the magnitude of summer and autumn changes is -15 to +10 % under RCP4.5 and -25 to +20 % under RCP8.5. The winter changes range from around -30 to +30 % under RCP4.5 and -40 to +45 % under RCP8.5. Such contrasting model simulations highlight the need to consider the possibility of both a drier and wetter climate in impact assessment in this cluster.

WIND SPEED INCREASE IN SPRING. FEWER BUT POSSIBLY MORE INTENSE TROPICAL CYCLONES

Small changes in mean surface wind speed are projected with *high confidence* under all RCPs for 2030. Larger changes are possible later in the century, but the direction of change cannot be reliably projected.

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*).

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

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

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 drought may change in this cluster.

MOSTLY SMALL CHANGES TO SOLAR RADIATION AND HUMIDITY

With *high confidence* little change is projected for solar radiation for 2030. By 2090 under RCP8.5, a decrease is projected with *low confidence*.

There is *high confidence* in little change in relative humidity for 2030. By 2090 under RCP8.5, increased relative humidity in spring and decreases in summer and autumn are projected with *low confidence*.

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

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

Changes in soil moisture and runoff are strongly influenced by changes in rainfall, but tend to be more negative due to the increase in potential evapotranspiration. Decreases in soil moisture are projected with *medium confidence*. More detailed hydrological modelling is needed to confidently assess changes to runoff.

LITTLE CHANGE TO FIRE FREQUENCY

In the Wet Tropics, where dry-season bushfires are common, the projected changes in rainfall are not expected to significantly change fire occurrence. There is *high confidence* in projections of little change to fire frequency. When and where fire does occur, there is *high confidence* that fire behaviour will be more extreme.

HIGHER SEA LEVELS AND MORE FREQUENT SEA LEVEL EXTREMES

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

There is *very high confidence* that sea level will continue to rise during the 21st century. By 2030, the projected range of sea level rise for the cluster coastline is 0.06 to 0.18 m above the 1986–2005 level, with only minor differences between RCPs. As the century progresses, projections are sensitive to emissions pathways. By 2090, RCP4.5 gives a rise of 0.27 to 0.65 m and RCP8.5 gives a rise of 0.40 to 0.87 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 levels along the Wet Tropics coastline 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 Wet Tropics in 2030, the vertical allowances are 11 to 14 cm for all RCPs, and by 2090 up to 57 cm for RCP4.5 and up to 79 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*. Across the coastal waters of the Wet Tropics in 2090, warming is projected in the range of 2.3 to 3.6 °C for RCP8.5.

About 30 % of the anthropogenic carbon dioxide emitted into the atmosphere over the past 200 years has been absorbed by the oceans. This has led to a 0.1 pH fall in the ocean’s surface water pH – a 26 % rise in acidity. Continued acidification will compromise the ability of calcifying marine organisms such as corals, oysters and some plankton to form their shells or skeletons. There is very *high confidence* that the ocean around Australia will become more acidic and also *high confidence* that the rate of ocean acidification will be proportional to carbon dioxide emissions. By 2030, pH is projected to fall by an additional 0.08 units in the coastal waters of the cluster. By 2090, pH is projected to decrease by up to 0.15 under RCP4.5 and up to 0.32 units under RCP8.5. These values would represent a 40 and 100 % increase in acidity respectively.

MAKING USE OF THESE PROJECTIONS FOR CLIMATE ADAPTATION PLANNING

These regional projections provide the best available science to support impact assessment and adaptation planning in the Wet Tropics 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 data from models that represents a particular change of interest (*e.g.* warmer and drier conditions).

1 THE WET TROPICS CLUSTER

This report describes climate change projections for the Wet Tropics cluster, which comprises four NRM regions in far north-east Queensland (namely Mackay Whitsunday, Wet Tropics, Cape York and Torres Strait, see Figure 1.1).

The cluster contains considerable biodiversity assets within state lands, national parks and parts of the Great Barrier Reef World Heritage Area. Considerable land is under Aboriginal ownership in the Cape York NRM region. The Torres Strait NRM region contains over 200 islands, 15 of which are inhabited mainly by traditional owners, and is unique in being bounded by an international border to the north. The Mackay Whitsunday and Wet Tropics NRM regions in the south derive major economic benefit from tourism, horticulture, and agricultural activities such as cane and banana farming, grazing, fishing and mining.

A more detailed description of impacts of climate change on this cluster can be found in the report *Climate Change Issues and Impacts in the Wet Tropics NRM Cluster* by Hilbert *et al*. (2014).

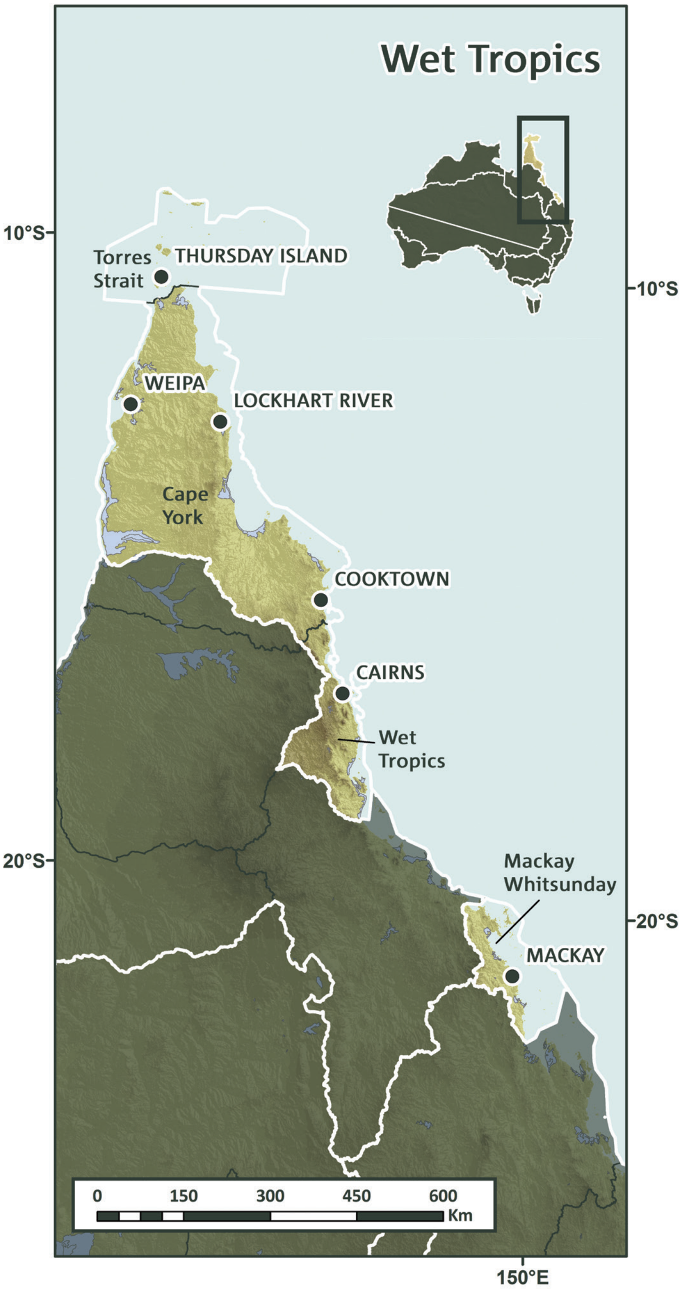

FIGURE 1.1: THE WET TROPICS CLUSTER AND MAIN LOCALITIES WITH RESPECT TO THE AUSTRALIAN CONTINENT.

2 CLIMATE OF WET TROPICS

The Wet Tropics climate is characterised by two seasons: the monsoonal wet season (generally from December to April), which is dominated by prevailing north-westerly winds; and the dry season (May to November), when south-easterly trade winds dominate. In the sections below, the current climate of Wet Tropics is presented for the period 1986–2005 (Box 3.1 presents the observational data sets used in this report).

Daily mean temperatures show little spatial variability in summer, with temperatures mostly from 27 to 30 °C and a little cooler in the higher terrain areas further inland (24 to 27 °C) (Figure 2.1a). In winter, there is a stronger north-south gradient, with average temperatures of 24 to 27 °C in the north and 15 to 18 °C in the southern inland areas (Figure 2.1b). The highest temperatures are experienced in January, with an average daily maximum temperature of 30 to 33 °C for large parts of the cluster (Figure 2.1c). The lowest temperatures occur mainly in July and exhibit a strong north-south gradient, with average minimum temperatures of 24 to 27 °C in the north and 12 to 15 °C in the southern inland (Figure 2.1d).

As a whole, the cluster exhibits a clear seasonal cycle in temperature, with daily mean temperatures ranging from about 26 °C in summer (January) to about 22 °C in winter (July), with maximum for the cluster about 33 °C in November and a minimum of about 16 °C in July (Figure 2.2).

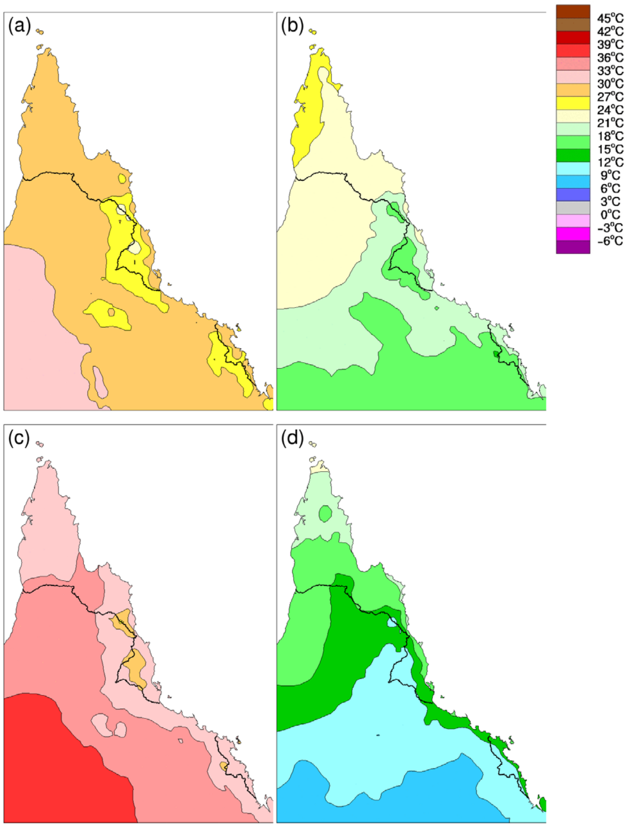

FIGURE 2.1: MAPS OF MEAN TEMPERATURES FOR THE PERIOD 1986–2005. (A) AVERAGE SUMMER DAILY MEAN TEMPERATURE, (B) AVERAGE WINTER DAILY MEAN TEMPERATURE, (C) AVERAGE JANUARY MAXIMUM DAILY TEMPERATURE AND (D) AVERAGE JULY MINIMUM DAILY TEMPERATURE.

There is a pronounced seasonal cycle in rainfall due to the influence of the north-west monsoon (Figure 2.2). The average annual rainfall is around 1,450 mm with the highest monthly total, over 350 mm, occurring in February. From May to October, monthly rainfall is less than 50 mm, with September being the driest month. In the summer half-year, rainfall ranges from approximately 600 to 1,200 mm, with high rainfall at the coast, declining sharply inland due to the effect of the topography, particularly in the regions of Cairns and Mackay (Figure 2.3). In the drier winter half year, rainfall is highest along the east coast with values up to about 400 mm, but with strong decreasing trends inland. The lowest amounts during the winter, 2 to 10 mm, occur in the west and extend to the Gulf of Carpentaria (Figure 2.3a and b).

Rainfall has low to moderate year to year variability relative to other parts of Australia during the summer half-year. The low rainfall totals during the winter half-year mean that variability is larger in this season, particularly inland. Rainfall variability is strongly related to changes in SSTs associated with El Niño Southern Oscillation (ENSO). Atmospheric moisture levels are typically higher during the La Niña phase when SSTs in the Australian region are higher, although the correlation between rainfall and ENSO is weaker during the peak monsoon months of December to February, with stronger correlations present in the pre-monsoon season from September to November (McBride and Nicholls, 1983).

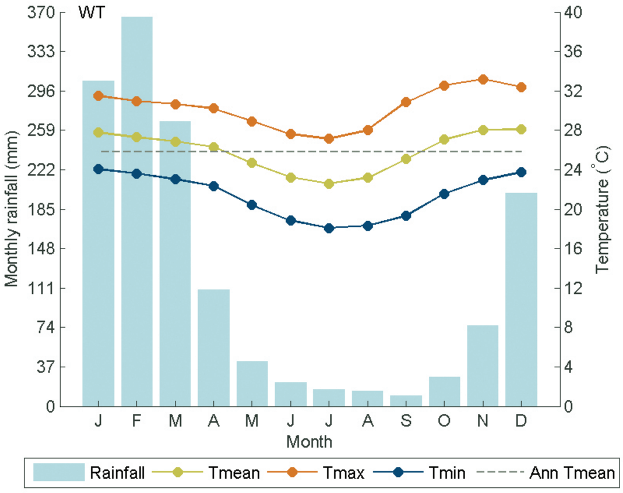

FIGURE 2.2: MONTHLY RAINFALL (BLUE BARS) AND TEMPERATURE CHARACTERISTICS FOR THE WET TROPICS CLUSTER (1986–2005). TMEAN IS MONTHLY MEAN TEMPERATURE (GREEN LINE), TMAX IS MONTHLY MEAN MAXIMUM TEMPERATURE (ORANGE LINE), TMIN IS MONTHLY MEAN MINIMUM TEMPERATURE (BLUE LINE) AND ANN TMEAN IS THE ANNUAL AVERAGE OF MEAN TEMPERATURE (GREY LINE) (25.8 °C). TEMPERATURE AND RAINFALL DATA ARE FROM AWAP.

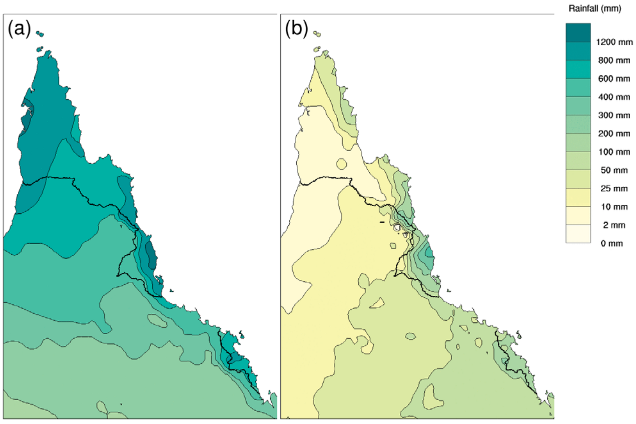

FIGURE 2.3: FOR THE 1986–2005 PERIOD, AVERAGE RAINFALL FOR THE (A) SUMMER HALF-YEAR (OCTOBER TO FEBRUARY) AND THE (B) WINTER HALF-YEAR (MARCH TO SEPTEMBER).

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 Wet Tropics 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 Wet Tropics, models performed well in simulating the timing and magnitude of the seasonal cycle for temperature (Figure 3.1a). The majority of models simulated the timing of the seasonal rainfall patterns well, although the majority of models overestimated summer rainfall (about 0.5 to 1 mm/day discrepancy between the model median and the observed regional mean, Figure 3.1b). To see how the models performed across different parts of Australia, refer to Chapter 5 in the Technical Report.

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

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

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

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

The ability of CMIP5 models to simulate key modes of climatic variability affecting the region has also been assessed. Significantly, the connection between ENSO variations and rainfall is reasonably well simulated and has improved over the previous generation of climate models. However, all models have at least some significant shortcomings across a range of tests (more details in Chapter 5 of the Technical Report). Some of these shortcomings are noted in the context of interpreting specific projection results in the Chapter that follows. No single or small number of models performed considerably better than others for the Wet Tropics cluster.

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

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

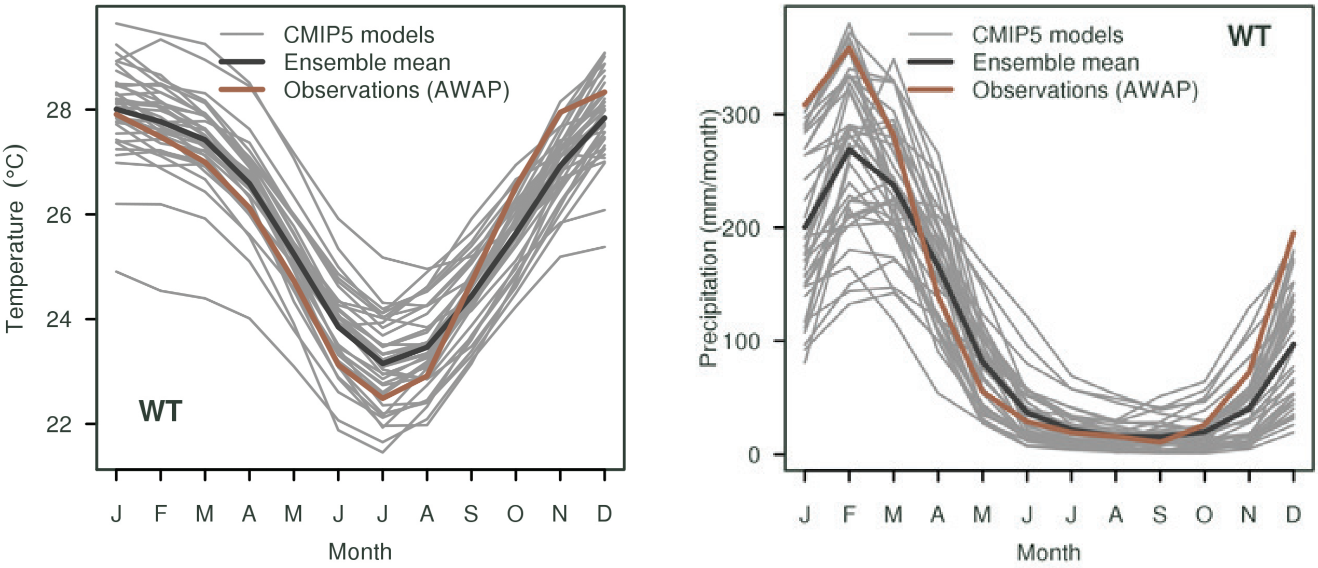

FIGURE 3.1: THE ANNUAL CYCLE OF TEMPERATURE (LEFT) AND RAINFALL (RIGHT) IN THE WET TROPICS CLUSTER SIMULATED BY CMIP5 MODELS (GREY LINES) WITH MODEL ENSEMBLE MEAN (BLACK LINE) AND OBSERVED CLIMATOLOGY BASED ON AWAP (BROWN LINES) FOR THE BASELINE PERIOD 1986–2005.

4 THE CHANGING CLIMATE OF THE WET TROPICS

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

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

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

The relative importance of each of these factors differs for each variable, different timeframes and spatial scale. For some variables with large natural variability, such as rainfall, the predominant reason for differing projections in the early period is likely to be natural variability rather than differences in emission scenarios (the influence of which becomes relatively more important as greenhouse gas concentrations increase). In addition, unpredictable events, such as large volcanic eruptions, and processes not included in models, could influence climate over the century. See 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). When confidence is low, only qualitative assessments are given. More information on the method used to assess confidence in the projections is provided in Section 6.4 of the Technical Report.

4.2 TEMPERATURE

Surface air temperatures in the cluster have been increasing since national records began in 1910, especially since 1960 (Figure 4.2.1, 4.2.2). From 1910–2013, mean temperature has risen by 1.1 °C using a linear trend. For the same period, daytime maximum temperatures have risen by 1.0 °C while overnight minimum temperatures have increased by 1.2 °C using a linear trend (Figure 4.2.3). The higher trend in daily maximum temperature than daily minimum temperature in the early-mid part of the 20th century (Figure 4.3.1) is most likely due to the somewhat drier than average conditions during this period. During dry conditions, less energy is consumed by evaporation and proportionally more energy is felt as heat. This effect is strongest during the day.

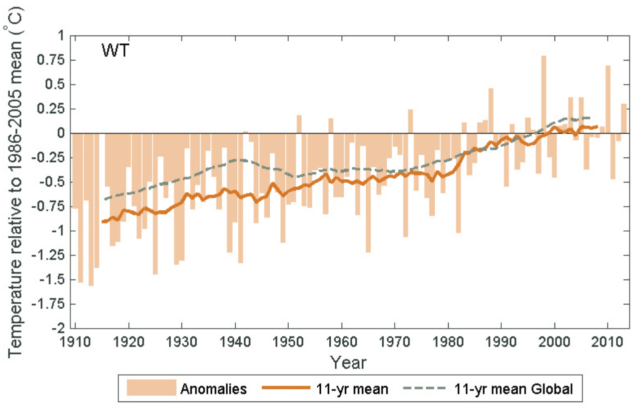


FIGURE 4.2.1: OBSERVED ANNUAL MEAN TEMPERATURE ANOMALIES (°C) FOR 1910–2013 COMPARED TO THE BASELINE 1986–2005 FOR WET TROPICS. CLUSTER AVERAGE DATA ARE FROM ACORN-SAT AND GLOBAL DATA ARE FROM HADCRUT3V (BROHAN ET AL., 2006).

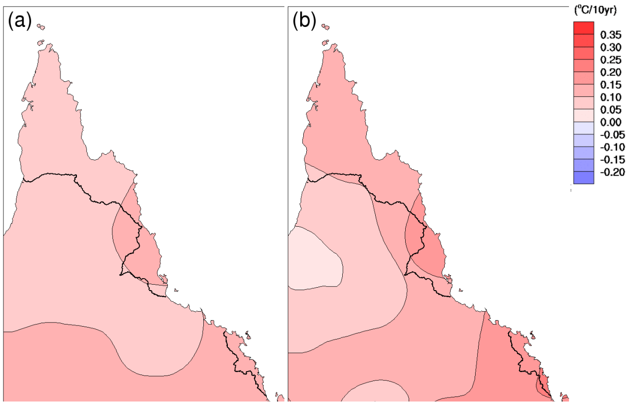


FIGURE 4.2.2: MAPS OF TREND IN MEAN TEMPERATURE (°C/10YEARS) FOR (A) 1910–2013 AND (B) 1960–2013 (ACORN-SAT).

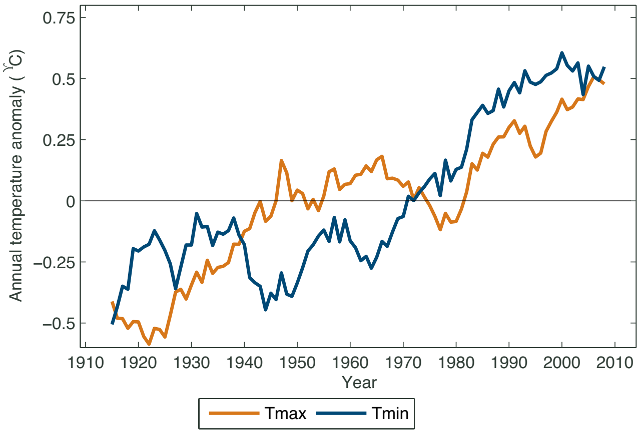
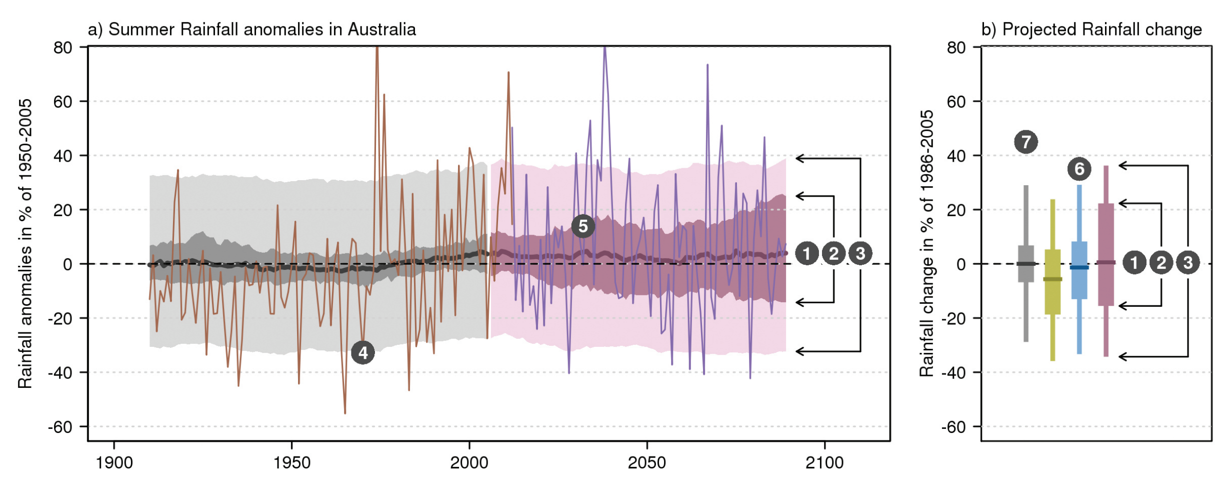


FIGURE 4.2.3: OBSERVED ANNUAL MEAN OF DAILY MAXIMUM (ORANGE LINE) AND MINIMUM (BLUE LINE) TEMPERATURE (°C, 11-YEAR RUNNING MEAN), PRESENTED AS ANOMALIES RELATIVE TO THEIR RESPECTIVE 1910–2013 MEAN VALUE (ACORN-SAT).

BOX 4.2: UNDERSTANDING PROJECTION PLOTS



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

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

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

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

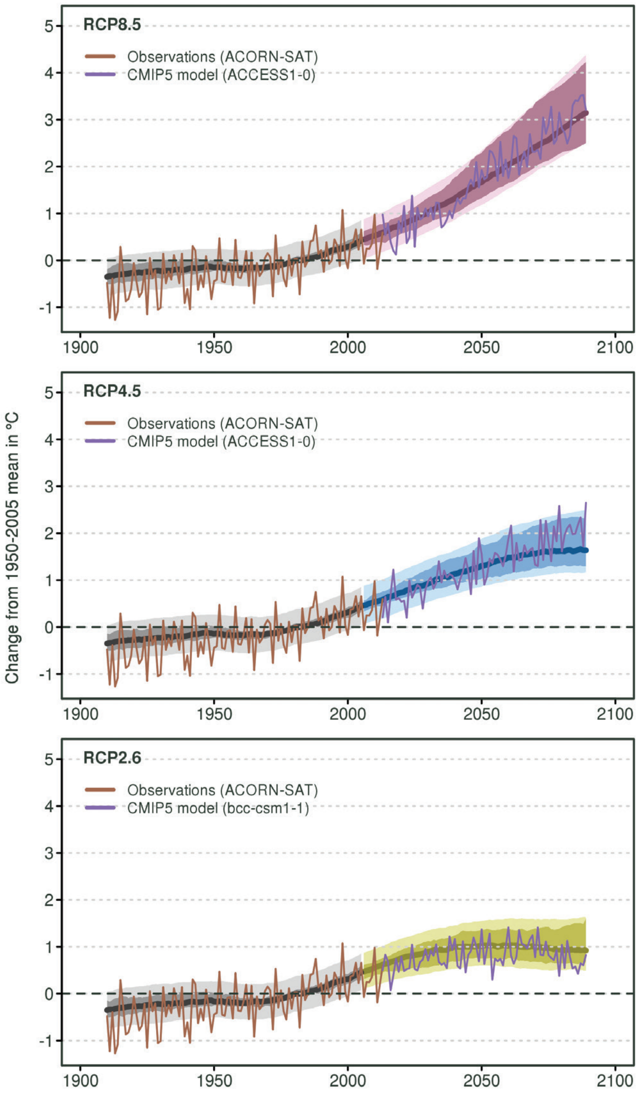


FIGURE 4.2.4: TIME SERIES FOR WET TROPICS ANNUAL AVERAGE SURFACE AIR TEMPERATURE (°C) FOR 1910–2090, AS SIMULATED IN CMIP5 RELATIVE TO THE 1950–2005 MEAN. THE CENTRAL LINE IS THE MEDIAN VALUE, AND THE SHADING IS THE 10TH AND 90TH PERCENTILE RANGE OF 20-YEAR MEANS (INNER) AND SINGLE YEAR VALUES (OUTER).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

In CMIP5 simulations, the Wet Tropics cluster is projected to continue to warm throughout the 21st century, at a rate that strongly reflects the increase in global greenhouse gases (Figure 4.2.4). Table 1 (in the Appendix) presents projected warmings for various time slices and RCPs. For 2030, the warming is 0.3 to 1.1 °C (10th to 90th percentile), with only minor difference between the emission scenarios. The projected changes to temperature for 2090 show larger differences with 1.0 to 2.0 °C for RCP4.5 and 2.3 to 3.9 °C for RCP8.5.

These warmings are large compared to natural year to year variability. For example, cold years become warmer than warm years in the current climate by 2050 under RCP8.5 and warmer than most current warm years under RCP4.5. This is illustrated in Figure 4.2.4 by overlaying the simulated year to year variability in one simulation and comparing this to the historical variability. This comparison also illustrates that individual model runs produce temporal variability similar to that of observed temperature, as well as a warming trend. Furthermore, future warming shows 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 time scales. The Wet Tropics cluster is likely to warm a little less than other clusters (see Figure 7.1.4 in the Technical Report).

Changes to the spatial pattern of temperature in the cluster can be illustrated by applying the projected change in annual mean temperature onto the mapped observed climatology. Figure 4.2.5 gives an example of this for northern Australia for the 2090 period following the high emission scenario RCP8.5 and the median warming from the CMIP5 models. This case, which corresponds to a global warming of 3.7 °C, shows regional temperatures increasing from within the range of about 21 to 27 °C for the current climate up to a range of about 25 to 31 °C for the future climate.

Projected warming in the CMIP5 models is similar across four 3-month seasons, and is also broadly similar if maximum or minimum temperatures are considered rather than mean temperatures (Figure 4.2.6 and Table 1 in the Appendix).

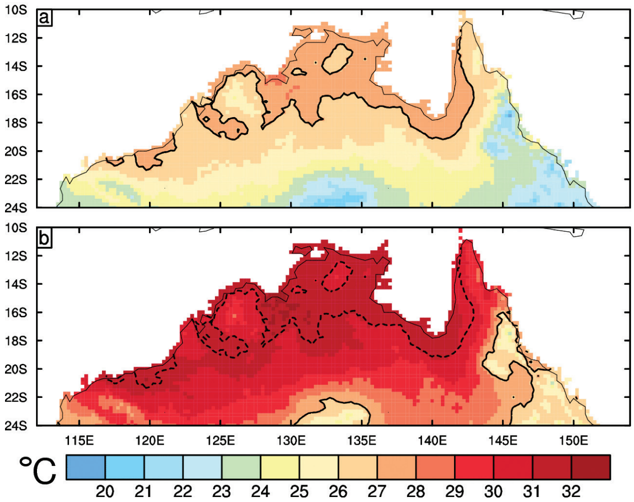


FIGURE 4.2.5: ANNUAL MEAN SURFACE AIR TEMPERATURE (°C), FOR THE PRESENT CLIMATE (A), AND FOR MEDIAN WARMING UNDER RCP8.5 2090 (B). THE PRESENT CASE USES AWAP DATA SET FOR 1986–2005 (BASED ON A 0.25 DEGREE GRID). FOR CLARITY, A CONTOUR LINE FOR 27 °C IS SHOWN IN (A) WITH SOLID BLACK LINES. IN (B) THE SAME CONTOUR FROM THE ORIGINAL CLIMATE IS PLOTTED AS A DOTTED LINE.

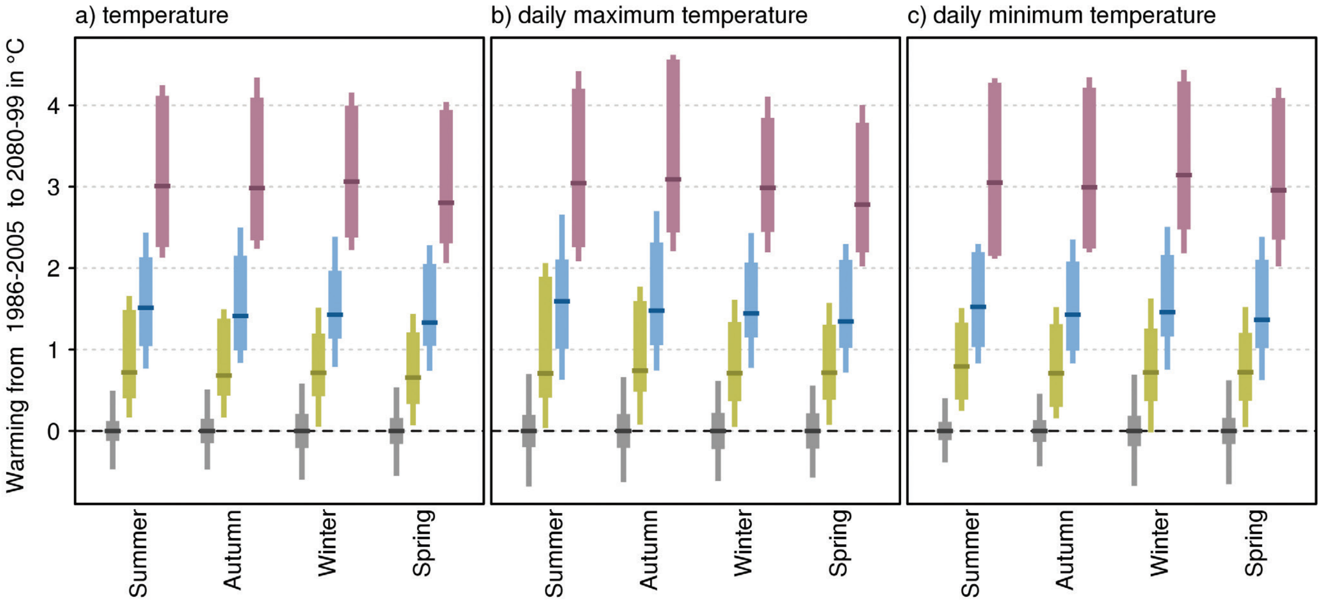


FIGURE 4.2.6: PROJECTED SEASONAL SURFACE AIR TEMPERATURE CHANGES FOR 2090. GRAPHS SHOW CHANGE IN: (A) MEAN, (B) DAILY MAXIMUM AND C) DAILY MINIMUM TEMPERATURE. TEMPERATURE ANOMALIES ARE GIVEN IN °C RELATIVE TO THE 1986–2005 MEAN UNDER RCP2.6 (GREEN), RCP4.5 (BLUE) AND RCP8.5 (PURPLE). NATURAL CLIMATE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

No significantly different trends are seen for the dynamical downscaling method (CCAM), with strong overlap in model ensemble spread for downscaled results and GCM results for each season. The statistical downscaling method (SDM) generally does not lead to projected warming ranges that differ from those simulated by the CMIP5 GCM ensemble, with the exception of reduced warming in summer and autumn. Figure 4.2.7 presents a comparison of downscaling results and GCM results, and shows simulated change in 2090 following RCP8.5 (which gives the strongest climate change response, and hence best illustrates the differences between methods).

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 give *very high confidence* in substantial warming for the Wet Tropics cluster for the annual and seasonal projections for mean, maximum and minimum surface air temperature.

4.2.1 EXTREMES

Changes to temperature extremes often lead to greater impacts than changes to the mean climate. To assess impact on extremes, researchers examine CMIP5 projected changes in measures of warm spell duration and the warmest day in the year (see definitions below).

Heat-related extremes are projected to increase at the same rate as projected mean temperature, with a substantial increase in the number of warm spell days.

Figure 4.2.8 (2090 case only) gives the CMIP5 model simulated warming on the hottest day of the year averaged across the cluster, and the corresponding warming for the hottest day in 20 years (20-year return value, equal to a 5 % chance of occurrence within any one year). The rate of warming for these hot days is similar to that for all days (*i.e.* the average warmings in the previous section). There is a marked increase in a warm spell index, which is defined as the annual count of days for events with at least six consecutive days with a cluster average temperature maximum above the 90th percentile (as an example, the 90th percentile for daily temperature maximum in Cairns is 32.2 °C based on Bureau of Meteorology historical data for January 1910 to June 2014).

Given the similarity in projected warming for the mean and annual daily maximum temperature, an indication of the change in frequency of hot days locally can be obtained by applying the projected changes for maxima for selected time slices and RCPs to the historical daily record at selected sites. This is illustrated in Box 4.3 for Cairns, where the number of days above 35 °C by 2090 more than triples under the RCP4.5 and median model ensemble warming.

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

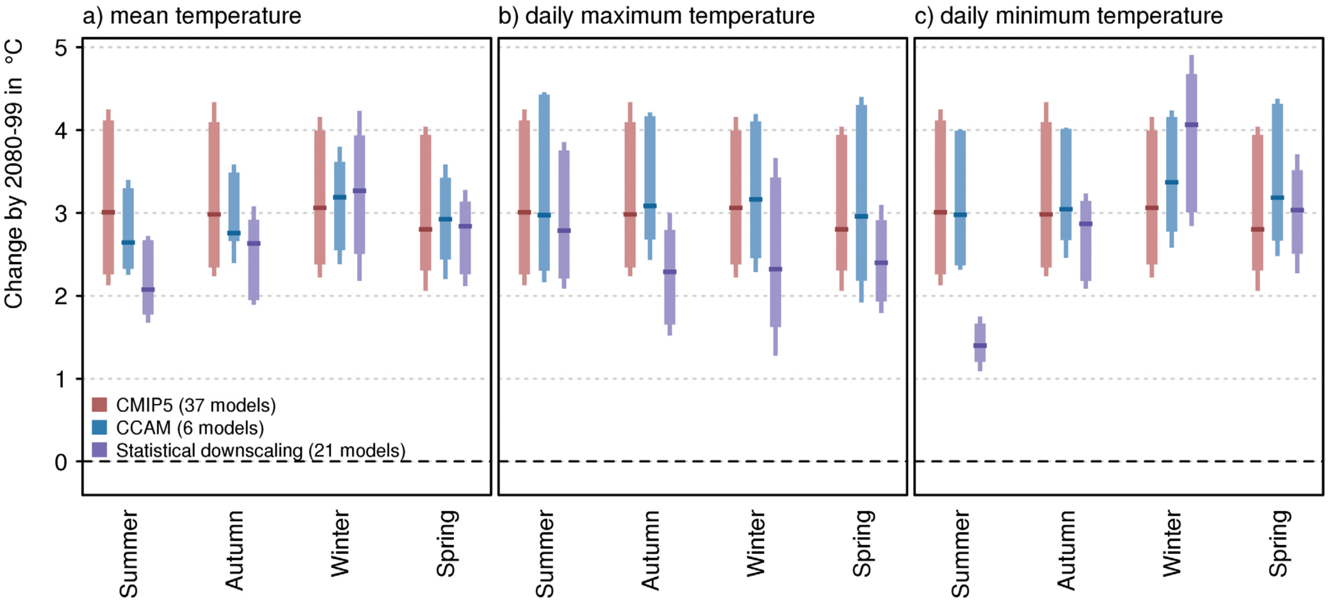


FIGURE 4.2.7: PROJECTED CHANGE IN SEASONAL SURFACE AIR TEMPERATURE FOR 2090 USING CMIP5 GCMS AND TWO DOWNSCALING METHODS (CCAM AND SDM) UNDER RCP8.5 FOR THE: (A) MEAN, (B) DAILY MAXIMUM AND (C) DAILY MINIMUM TEMPERATURE. TEMPERATURE ANOMALIES ARE GIVEN IN °C RELATIVE TO THE 1986–2005 MEAN. BAR PLOTS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

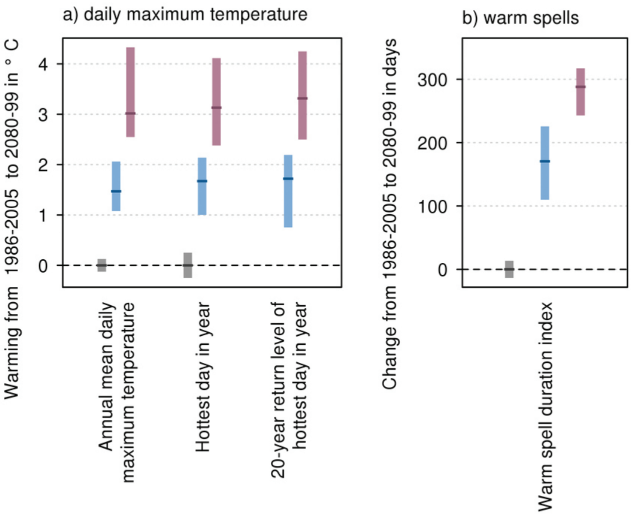


FIGURE 4.2.8: PROJECTED CHANGES IN SURFACE AIR TEMPERATURE EXTREMES BY 2090 IN (A) MEAN DAILY MAXIMUM TEMPERATURE, HOTTEST DAY OF THE YEAR AND THE 20-YEAR RETURN VALUE OF THE HOTTEST DAY OF THE YEAR (°C); AND (B) CHANGE IN THE NUMBER OF DAYS IN WARM SPELLS FOR WET TROPICS (SEE TEXT FOR DEFINITION OF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

BOX 4.3: HOW WILL THE FREQUENCY OF HOT DAYS CHANGE IN CAIRNS?

To illustrate what the CMIP5 projected warming implies for changes to the occurrence of hot days at a station in Wet Tropics, a simple downscaling example was conducted whereby the projected change in temperature was added to an observed time series for Cairns.

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 temperatures above 35 and 40 °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 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 FOR CAIRNS AIRPORT (QLD) BASED ON ACORN-SAT. ESTIMATES FOR THE FUTURE ARE CALCULATED USING THE MEDIAN CMIP5 WARMING FOR 2030 AND 2090, AND WITHIN BRACKETS THE 10TH AND 90TH PERCENTILE CMIP5 WARMING FOR THESE PERIODS, APPLIED TO THE 30-YEAR ACORN-SAT STATION SERIES. NUMBERS ARE TAKEN FROM TABLE 7.1.2 AND TABLE 7.1.3 IN THE TECHNICAL REPORT.

THRESHOLD	CURRENT	2030 RCP4.5	2090 RCP2.6	2090 RCP4.5	2090 RCP8.5
Over 35 °C	3	5.5 (4.4 to 7.9)	5.5 (4.4 to 14)	11 (7.4 to 22)	48 (24 to 105)
Over 40 °C	0	0.1 (0.1 to 0.2)	0.1 (0.1 to 0.3)	0.3 (0.2 to 0.4)	0.7 (0.5 to 2.0)

4.3 RAINFALL

There is no long-term trend evident in the rainfall record for the 20th century. Rather there are intermittent periods of wetter and drier conditions (Figure 4.3.1). The latter part of the 20th century has seen more variable conditions with individual years of very high rainfall, and sequences of years with below average rainfall, notably in the early 1990s and 2000s. The 1970s were a wet period. These rainfall fluctuations can in part be related to changes in SSTs associated with the El Niño Southern Oscillation.

Figure 4.3.2 (a) to (d) presents spatial patterns of rainfall trend for the full duration of the rainfall record (1901–2012). There are increases in summer of up to about 15 mm/decade and minor decreases in winter except for the northern Cape York Peninsula. Slightly stronger trends occurred in the more recent period (1960–2013), with stronger positive trends in summer and in spring on the east coast, as per Figure 4.3.2 (e) and (h). In the latter period, there are mostly drying trends in autumn over Queensland, Figure 4.3.2(f), but much of northern Cape York exhibits increasing trends. In winter, much of Queensland has experienced a weak increasing trend 4.3.2 (g). None of these trends are marked given the effect of natural fluctuations.

Under all three RCPs, simulated annual rainfall changes for the 21st century are small compared to natural variability, but changes become evident in some models under RCP8.5 by 2090 (Figure 4.3.3 and Table 1 in the Appendix) albeit only with medium agreement between models on the direction of change (decrease, with a range of -25 to +20 %).

Changes to the spatial distribution of rainfall in the cluster can be illustrated by applying the CMIP5 projected change in annual mean rainfall onto the observed climatology. Figure 4.3.4 gives an example of this for late in the century (2090) following the high emission scenario RCP8.5 and the rainfall change from the CMIP5 models. The figure displays the dry (10th percentile) and wet (90th percentile) case of the simulated model range relative to the observed climatology. For the drier case, characteristic rainfall rates decrease from about 4 to 5 mm/day to 1.5 to 3 mm/day, while for the wetter case, rates increase to about 5 to 8 mm/day.

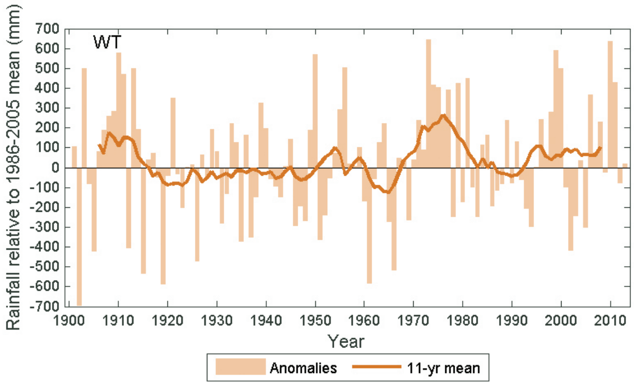


FIGURE 4.3.1: OBSERVED ANNUAL RAINFALL ANOMALIES (MM) FOR 1901–2013 COMPARED TO THE BASELINE 1986–2005. DATA ARE FROM AWAP.

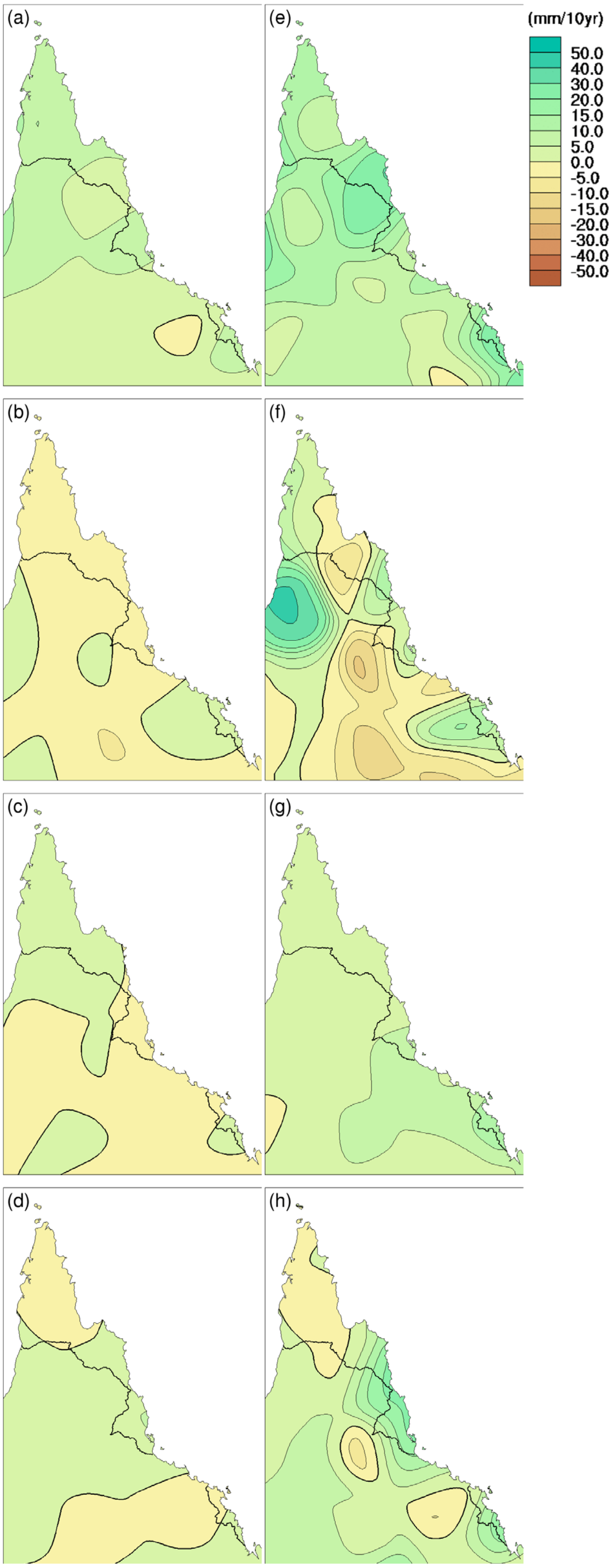


FIGURE 4.3.2: MAPS OF SEASONAL RAINFALL TRENDS (MM/DECADE). THE LEFT COLUMN OF MAPS SHOWS TRENDS FOR (A) SUMMER, (B) AUTUMN, (C) WINTER AND (D) SPRING FOR 1901–2013. THE RIGHT COLUMN SHOWS TRENDS FOR (E) SUMMER, (F) AUTUMN, (G) WINTER AND (H) SPRING FOR 1960–2012.

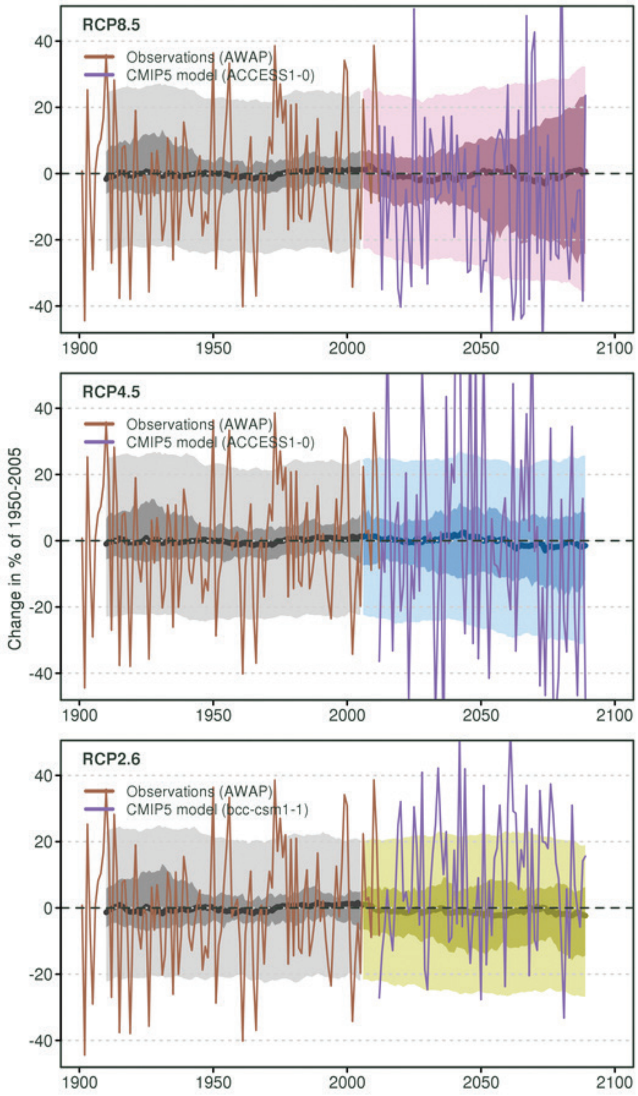


FIGURE 4.3.3: TIME SERIES FOR WET TROPICS ANNUAL RAINFALL FOR 1910–2090, AS SIMULATED IN CMIP5 EXPRESSED AS A PERCENTAGE RELATIVE TO THE 1950–2005 MEAN. THE CENTRAL LINE IS THE MEDIAN VALUE, AND THE SHADING IS THE 10TH AND 90TH PERCENTILE RANGE OF 20-YEAR MEANS (INNER) AND SINGLE YEAR VALUES (OUTER). THE GREY SHADING INDICATES THE PERIOD OF THE HISTORICAL SIMULATION, WHILE THREE FUTURE SCENARIOS ARE SHOWN WITH COLOUR-CODED SHADING: RCP8.5 (PURPLE), RCP4.5 (BLUE) AND GREEN 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.

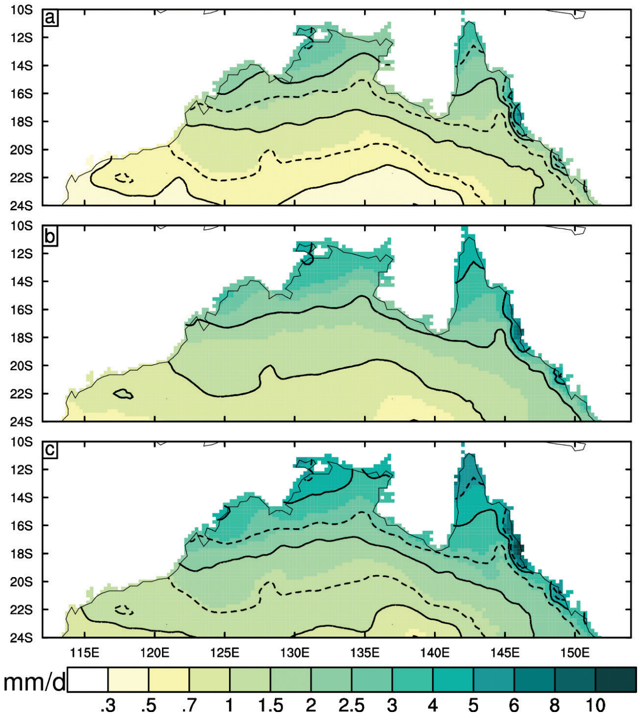


FIGURE 4.3.4: ANNUAL MEAN RAINFALL (MM/DAY) FOR THE PRESENT CLIMATE (B), AND FOR DRIER END OF THE PROJECTED MODEL RANGE (A) AND WETTER END OF THE MODEL RANGE (C). THE PRESENT IS USING THE AWAP DATA SET FOR 1986–2005 (BASED ON A 0.25 DEGREE LONGITUDE-LATITUDE GRID). THE DRIER AND WETTER CASES USE THE 10TH AND 90TH PERCENTILE CHANGES AT 2090 UNDER RCP8.5. FOR CLARITY, THE 0.5, 1, 2 AND 4 MM/DAY CONTOURS ARE PLOTTED WITH SOLID BLACK LINES. IN (A) AND (C) THE SAME CONTOURS FROM THE ORIGINAL CLIMATE (B) ARE PLOTTED AS DOTTED LINES.

In summer and autumn, most (but not all) models simulate changes that would not be clearly evident against natural variability, even under RCP8.5 at 2090 (Figure 4.3.5 and Table 1 in the Appendix). The seasonal changes at 2090 are around -15 to +10 % under RCP4.5 and -25 to +20 % under RCP8.5. However, by late in the century (2090) there is slight agreement amongst models for a decrease in winter and spring under RCP8.5. Possible winter changes are around -30 to +30 % under RCP4.5 and -40 to +45 % under RCP8.5. Spring changes are larger, but the very low baseline rainfall in this season means that these figures need to be interpreted with care. Such contrasting model simulations highlight the need to consider the risk of both a drier and wetter climate in impact assessments.

Figure 4.3.6 presents downscaled rainfall projections for the Wet Tropics. The dynamical method (CCAM: based on six models only) shows some notable differences from the GCMs, with projected decreases in summer and autumn and increases in winter. The broader GCM ensemble projects little change. In spring, the dynamical method projects little change while the GCM ensemble indicates a slight decrease in rainfall. The differences may relate to the small sample-size for the CCAM simulations, or the skill of the different models in simulating different processes that are important for rainfall in this region, such as the monsoon onset, the Madden-Julian Oscillation (MJO) and tropical circulation, which can have opposite impacts on model projected rainfall changes. However, the statistical downscaling method (SDM: which used 22 models) projects changes that are broadly similar to the GCM ensemble in all seasons.

In summary, there is *high confidence* that natural climate variability will remain the major driver of rainfall changes by 2030 in this cluster (20-year mean changes of -10 to +5 % annually, and larger changes seasonally, relative to the climate of 1986–2005). Projected rainfall changes for later in the century (2090) are generally of *low confidence*. This is because of the range of simulated changes, which is due to the large spread in skill amongst models to simulate regionally important processes, such as the monsoon onset, the MJO and the tropical circulation. Also, models may not adequately represent the influence of coastal orography on rainfall.

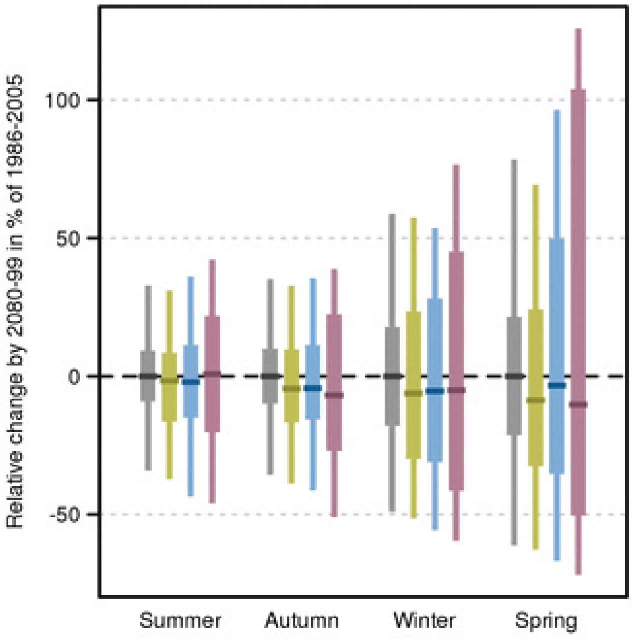


FIGURE 4.3.5: PROJECTED SEASONAL RAINFALL CHANGES FOR 2090. RAINFALL ANOMALIES ARE GIVEN IN PER CENT WITH RESPECT TO THE 1986–2005 MEAN FOR RCP2.6 (GREEN), RCP4.5 (BLUE) AND RCP8.5 (PURPLE). NATURAL CLIMATE VARIABILITY IS REPRESENTED BY THE GREY BARS. BAR PLOTS ARE EXPLAINED IN BOX 4.2.

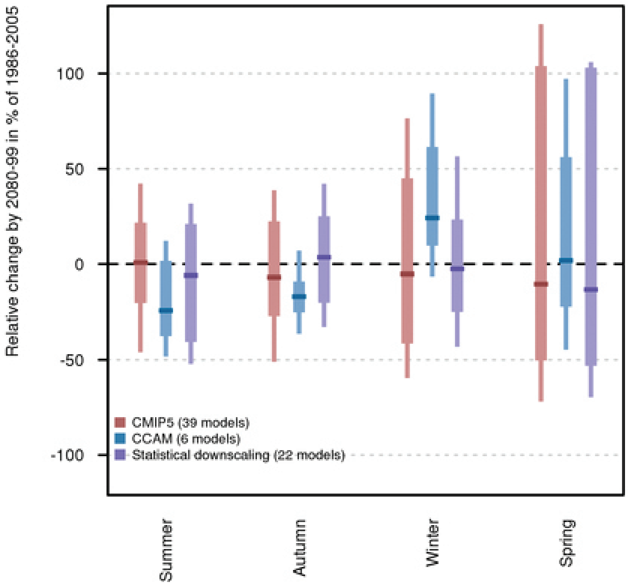


FIGURE 4.3.6: PROJECTED CHANGE IN SEASONAL RAINFALL FOR 2090 USING CMIP5 GCMS AND TWO DOWNSCALING METHODS (CCAM AND SDM). RAINFALL ANOMALIES ARE GIVEN IN PER CENT WITH RESPECT TO 1986–2005 UNDER RCP8.5. BAR PLOTS ARE EXPLAINED IN BOX 4.2.

4.3.1 HEAVY RAINFALL EVENTS

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

The CMIP5 models simulate an increase in the annual maximum 1-day value and the 20-year return value for the period 2080–2099 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 trends in the two extreme indices with that of the annual mean rainfall (Figure 4.3.7) clearly shows that while the median projection for mean rainfall is tending towards little change, the extremes are projected to increase. This pattern (change in mean relative to extremes) is found in all other NRM clusters, and is supported by results from other studies (see Technical Report, Section 7.2.2).

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

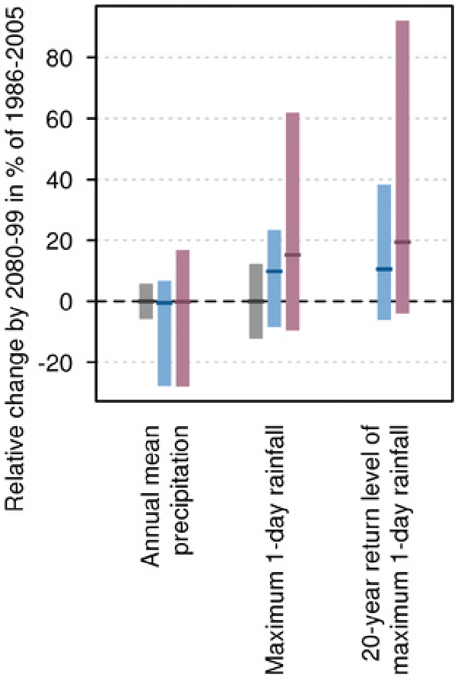


FIGURE 4.3.7: PROJECTED CHANGES IN MEAN RAINFALL, MAGNITUDE OF ANNUAL MAXIMUM 1-DAY RAINFALL AND MAGNITUDE OF THE 20-YEAR RETURN VALUE FOR THE 1-DAY RAINFALL FOR 2090 (SEE TEXT FOR DEFINITION OF VARIABLES). CHANGES ARE GIVEN IN PERCENTAGE WITH RESPECT TO THE 1986–2005 MEAN FOR RCP4.5 (BLUE) AND RCP8.5 (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, the Standardised Precipitation Index (SPI) was selected as a measure of meteorological drought. Duration of time spent in drought and changes to the duration and frequency of droughts of different severities were calculated for different levels of severity (mild, moderate, severe, and extreme). Section 7.2.3 of the Technical Report presents details on calculation of the SPI, as well as 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, although there is a simulated tendency for an increase in extreme drought frequency (Figure 4.3.8). Given the importance of the ENSO for rainfall in the Wet Tropics cluster, it is worth noting that there is some indication that these events will intensify under global warming, which would lead to an intensification of El Niño driven drying (Power *et al.*, 2013).

In summary, meteorological drought will continue to be a regular feature of regional climate. It may change its characteristics as the climate warms, but due to uncertainty in rainfall projections, there is *low confidence* in projecting how the frequency and duration of drought may change.

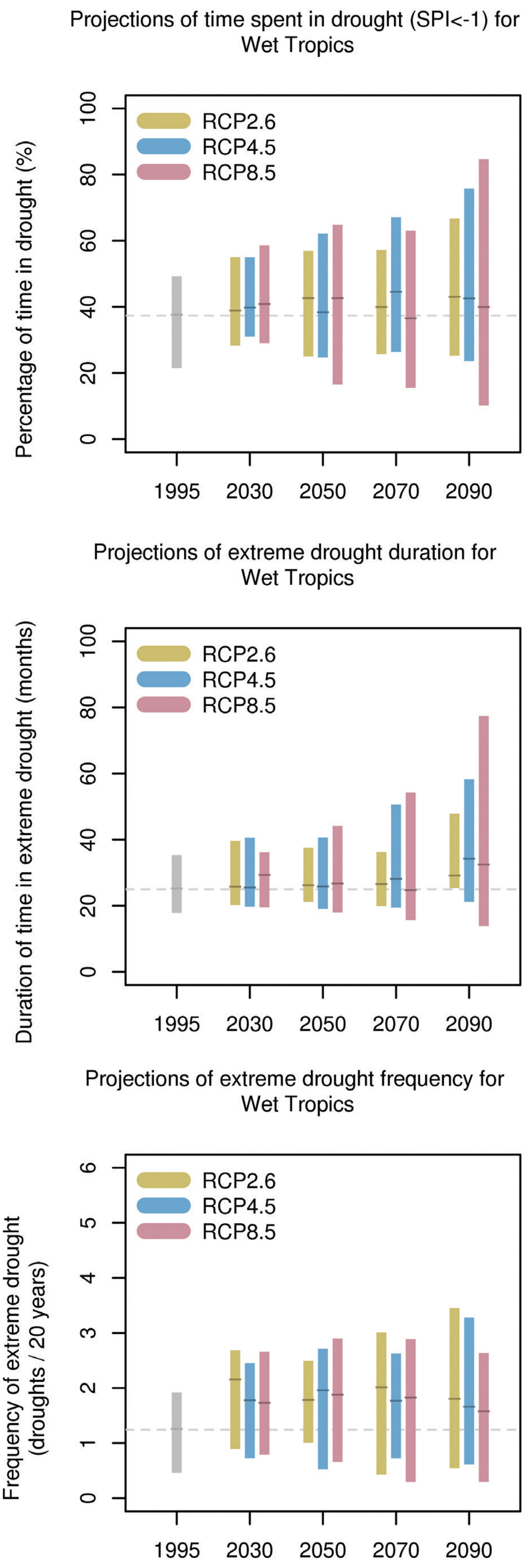


FIGURE 4.3.8: SIMULATED CHANGES IN DROUGHT BASED ON THE STANDARDISED PRECIPITATION INDEX (SPI). THE MULTI-MODEL ENSEMBLE RESULTS FOR WET TROPICS SHOW THE PERCENTAGE OF TIME IN DROUGHT (SPI LESS THAN -1) (TOP), DURATION OF EXTREME DROUGHT (MIDDLE) AND FREQUENCY OF EXTREME DROUGHT (BOTTOM) FOR EACH 20-YEAR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

4.4 WINDS, STORMS AND WEATHER SYSTEMS

4.4.1 MEAN WINDS

The surface wind climate is driven by the large-scale circulation pattern of the atmosphere: when pressure gradients are strong, winds are strong. For the Wet Tropics, the primary wind system is the south-easterly trade winds. During December to April, monsoonal north-westerlies can affect the cluster. Any trends in observed winds are difficult to establish due to sparse observations and difficulties with instruments and changing circumstances of anemometer sites (Jakob, 2010). McVicar *et al.*, (2012) and Troccoli *et al.*, (2012) have reported weak and conflicting trends across Australia (although they considered winds at different heights).

Changes to seasonal surface winds are projected to be small (about -4 to +10 % seasonally) for the near future (2030) with *high confidence* (Figure 4.4.1 and Table 1 in the Appendix). Late in the 21st century, projected changes for summer and autumn are also small (about -5 to +10 % seasonally) under both RCP4.5 and RCP8.5, although there is a tendency for increases in spring and winter under RCP2.6 and RCP8.5. These changes are not well understood so the projections are of *low confidence*.

4.4.2 EXTREME WINDS

Extreme winds create hazardous conditions for marine and terrestrial activities and infrastructure. Figure 4.4.2 compares the future change in annual wind speed with the changes projected for two extreme wind metrics. For RCP8.5, there is an increase in annual maximum daily wind speed and 20-year return values (equivalent to a 5 % chance occurrence within any one year). The range of change shows a large spread across the models, with some showing strong decrease. For RCP4.5, there is little change in annual maximum daily wind speed but a decrease in the 20-year return value. Because of the various shortcomings associated with modelling extremes in near-surface winds, including the inability of GCMs to resolve small scale meteorological systems such as tropical cyclones, there is generally *low confidence* in extreme wind projections in the Wet Tropics.

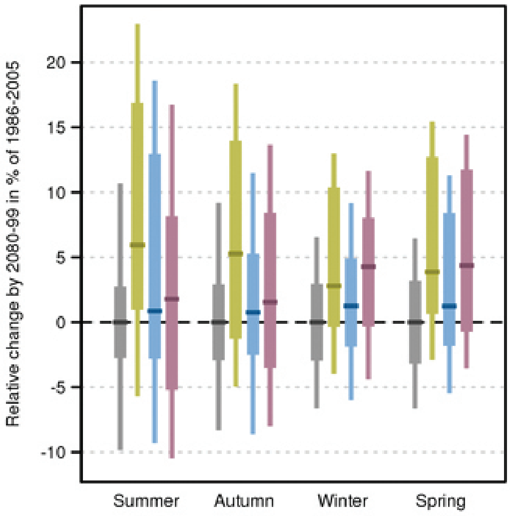


FIGURE 4.4.1: PROJECTED NEAR-SURFACE WIND SPEED CHANGES FOR 2090 FOR WET TROPICS. ANOMALIES ARE GIVEN IN PER CENT WITH RESPECT TO THE 1986–2005 MEAN FOR RCP2.6 (GREEN), RCP4.5 (BLUE) AND RCP8.5 (PURPLE) WITH GREY BARS SHOWING THE EXTENT OF NATURAL CLIMATE VARIABILITY. BAR PLOTS ARE EXPLAINED IN BOX 4.2.

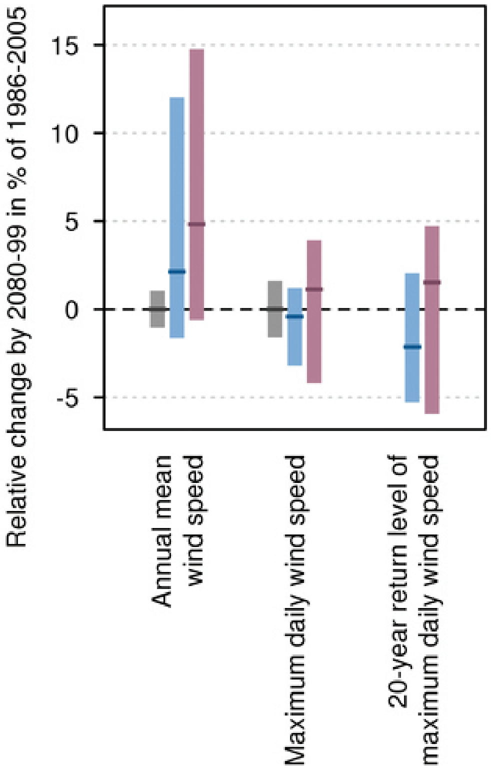


FIGURE 4.4.2: PROJECTED NEAR-SURFACE ANNUAL MEAN WIND SPEED, ANNUAL MAXIMUM DAILY WIND SPEED AND THE 20-YEAR RETURN VALUE FOR THE ANNUAL MAXIMUM DAILY WIND SPEED FOR 2090 FOR WET TROPICS. ANOMALIES ARE GIVEN IN PER CENT WITH RESPECT TO THE 1986–2005 MEAN FOR RCP2.6 (GREEN), RCP4.5 (BLUE) AND RCP8.5 (PURPLE)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

4.4.3 TROPICAL CYCLONES

Tropical cyclones are the major cause of severe weather in the Wet Tropics, causing strong winds, heavy rainfall, storm surges and severe ocean wave conditions.

Projected changes in tropical cyclone frequency have been assessed in the current generation of GCMs over the Australian northeast and northwest regions, 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 indicate a decrease in the formation of tropical cyclones. These results are broadly consistent with projections of tropical cyclones over the globe (IPCC, 2013: Section 14.6.1), that indicate little change through to substantial decrease in frequency.

The proportion of the most intense cyclones is likely to increase over the century while the intensity of associated rainfall may increase further, as described in Section 4.3.1.

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

4.5 SOLAR RADIATION

By 2030, models simulate little change in radiation (about -1 to +2 %) for both RCP4.5 and RCP8.5. Later in the century (2090), projected seasonal changes are generally less than +/- 5 %, with some tendency for decreases (Table 1 in the Appendix, Figure 4.7.1). However, an Australian evaluation of models suggested that some are not able to adequately reproduce the climatology of solar radiation (Watterson *et al*., 2013). Globally, CMIP3 and CMIP5 models appear to underestimate the observed trends in some regions due to underestimation of aerosol direct radiative forcing and/or deficient aerosol emission inventories (Allen *et al*., 2013). Hence, we have *high confidence* in little change for 2030, whereas by 2090 under RCP8.5, larger changes in radiation are present in some models (mainly decreases), but the causes of these changes are not well understood and these projections are of *low confidence*.

4.6 RELATIVE HUMIDITY

CMIP5 projections of relative humidity in the Wet Tropics indicate an overall tendency for decreases (Figure 4.7.1). For 2030, seasonal changes for both RCP4.5 and RCP8.5 are in the range of ± 2 % with generally medium or high model agreement on little change. For 2090, under RCP8.5, there is a tendency for decreases in summer and autumn and for increases in spring, although the seasonal changes are within ± 4 % (Table 1 in the Appendix) and the causes of these changes are not well understood.

In summary, there is *high confidence* on little change in relative humidity for the near future (2030). By 2090 under RCP8.5, there is *low confidence* on increased relative humidity in spring and decreases in summer and autumn.

4.7 POTENTIAL EVAPOTRANSPIRATION

Projected changes for potential evapotranspiration using Morton's wet-environmental potential evapotranspiration (McMahon *et al*., (2013) and Technical Report Section 7.6) suggest increases for all seasons (Figure 4.7.1). There is not much difference in projected increases amongst the four seasons, with projected seasonal changes generally less than 5 % in 2030 and generally less than 10 % for RCP4.5 and up to 20 % for RCP8.5 in 2090 (Table 1 in the Appendix). In absolute terms, changes are largest in summer and autumn, particularly for RCP8.5.

Overall, models generally show high agreement by 2030, and very high agreement by 2090, 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 potential evapotranspiration (Kirono and Kent, 2011).

4.8 SOIL MOISTURE AND RUNOFF

Increases in potential evapotranspiration rates (Figure 4.7.1) combined with changes in rainfall (Figure 4.4.3) 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 prsented. 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.

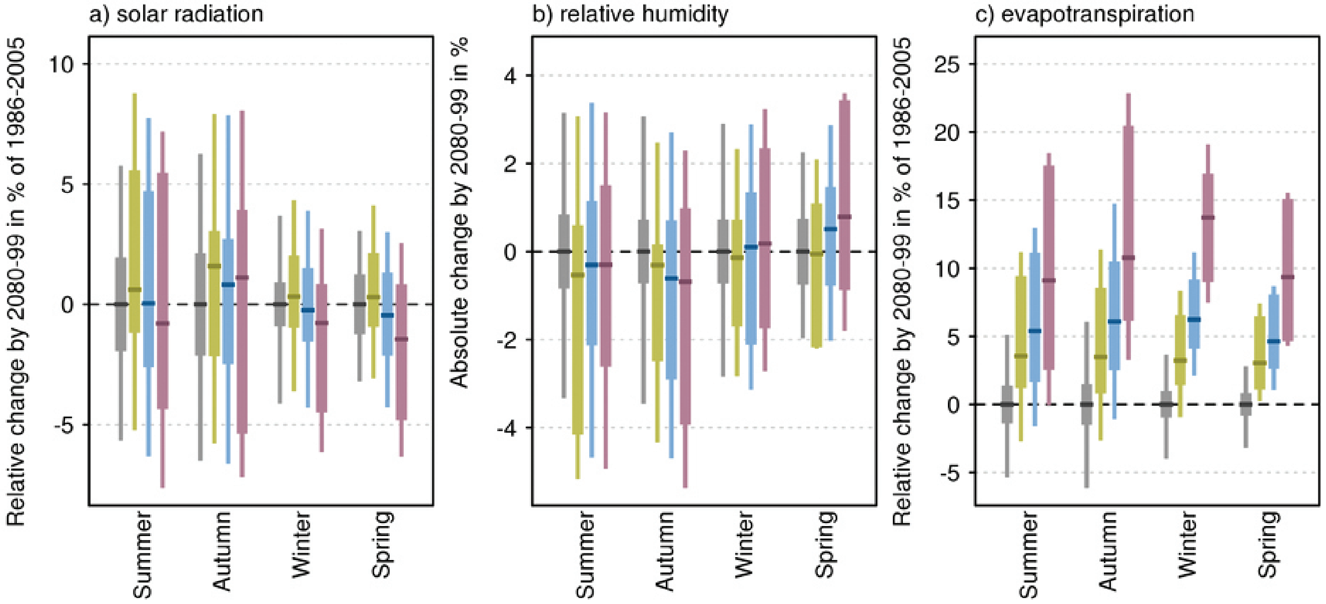


FIGURE 4.7.1: PROJECTED CHANGES IN (A) SOLAR RADIATION (%), (B) RELATIVE HUMIDITY (%, ABSOLUTE CHANGE) AND (C) WET-ENVIRONMENTAL POTENTIAL EVAPOTRANSPIRATION (%) FOR WET TROPICS IN 2090. THE BAR PLOTS SHOW SEASONAL PROJECTIONS WITH RESPECT TO THE 1986–2005 MEAN FOR RCP2.6 (GREEN), RCP4.5 (BLUE) AND RCP8.5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

Decreases in soil moisture are projected, particularly in winter and spring (Figure 4.8.1). The projected annual changes for RCP8.5 late in the century (2090) range from around −20 to +5 % with medium model agreement on decreases, except spring where there is medium agreement on little change (Table 1 in the Appendix). 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.

Runoff could increase or decrease following RCP4.5 and RCP8.5 for 2090 relative to 1986–2005, though the majority of models suggest decreases, as indicated by the negative median change (Figure 4.8.1). There is *low confidence* in these projections because in addition to low agreement on direction of change by the models, the method used is not able to consider changes to rainfall intensity, seasonality and changes in vegetation characteristics.

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

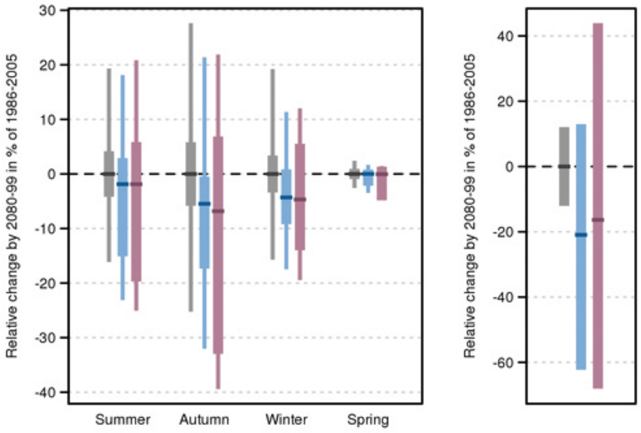


FIGURE 4.8.1: PROJECTED CHANGE IN SEASONAL SOIL MOISTURE (LEFT) AND ANNUAL RUNOFF (RIGHT) (BUDYKO METHOD – SEE TEXT) IN WET TROPICS FOR 2090. ANOMALIES ARE GIVEN IN PER CENT WITH RESPECT TO THE 1986–2005 MEAN FOR RCP4.5 (BLUE) AND RCP8.5 (PURPLE) WITH GREY BARS SHOWING THE EXTENT OF NATURAL VARIABILITY.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

4.9 FIRE WEATHER

Bushfire occurrence depends on four ‘switches’: 1) ignition, either human-caused or from natural sources such as lightning; 2) fuel abundance or load; 3) fuel dryness, where lower moisture contents are required for fire, and; 4) suitable weather conditions for fire spread, generally hot, dry and windy (Bradstock, 2010). The settings of the switches depend on meteorological conditions across a variety of time scales, particularly the fuel conditions. Given this strong dependency on the weather, climate change will have a significant impact on future fire weather (*e.g.* Hennessy *et al.*, 2005; Lucas *et al.*, 2007; Williams *et al.*, 2009; Clarke *et al.*, 2011; Grose *et al.*, 2014). In the Wet Tropics, Clarke *et al.*, (2013) indicate a significant increasing trend in observed fire weather for the period 1973 to 2010 at Mackay, but none in the northern portion of the cluster.

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 30-year 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. However, in the Wet Tropics, the weather conditions are often conducive to fire activity, and the limiting switch in these regions is fuel availability (*e.g.* Williams *et al.*, 2009). Hence, rainfall is more important than FFDI to understanding future bushfire in this cluster. Two stations are used in the analysis for this cluster: Cairns and Mackay.

Focusing on the 2030 and 2090 time slices, the results indicate a tendency towards increased fire weather danger in the future, a result of rising temperatures and declining rainfall (Table 4.9.1). The drought factor (DF) remains about the same. The sum of all daily FFDI values over a year (∑FFDI) is broadly indicative of general fire weather danger and increases around 4 to 6 % by 2030 and around 5 % under RCP4.5 and around 13 % under RCP8.5 by 2090. Severe fire weather days are only rarely, if ever, observed in this cluster in the current climate. This situation is not projected to change in the future.

Across much of the cluster, bushfire is frequent, occurring annually in some areas. As noted above, the primary determinant of bushfires in this cluster is fuel availability, which varies according to rainfall. Land use (*e.g.* grazing) is also an important determinant of fuel availability. Rainfall primarily occurs from October to March. After the wet season, fuel dries and eventually burns, with fire activity and intensity peaking just before the onset of the next wet season. The extent of the area affected by bushfire activity depends primarily on the amount and location of the rain. Table 4.9.1 indicates that slightly drier conditions are projected in the cases considered here (although a broader range of rainfall changes are simulated in the full set of CMIP5 models – see Section 4.2).

Table 2 in the Appendix shows the same results for individual stations and models. Rainfall varies across most of the cluster, loosely following a north to south gradient. In the northern portion of the cluster (Cairns), rainfall totals are higher than observed further south (Mackay). Rainfall also decreases away from the east coast, where the two stations used here are located. Inter-annual variability of the monsoon, tropical cyclone activity and the El Niño Southern Oscillation are some of the key factors influencing rainfall.

Table 2 in the Appendix also highlights differences in future rainfall projections between the three models. Most simulations using the GFDL-ESM2M and the MIROC5 models indicate a drying climate, with rainfall reductions of 10 to 15 % being typical. In most scenarios, the CESM-CAM projects an increase in rainfall, typically around 5 %. These increases are smaller in the west. Not all model and scenario combinations follow this pattern; the GFDL-ESM2M simulations for 2090 under RCP4.5 show increasing rainfall, while the MIROC5 simulations for 2090 under RCP8.5 show a decrease.

As rainfall totals are quite high, the relatively small projected changes give *high confidence* in projections of little change to future fire frequency. Even in the drier simulations, there is still a ‘wet season’ that results in significant rainfall and the growth of vegetation, ultimately leading to bushfire. With higher temperatures, there is *medium* to *high confidence* that fire behaviour will be more extreme.

One significant factor not accounted for in this analysis is changes to fuel characteristics. One climate-driven potential vegetation change is expansion or contraction of rainforests, which are areas of low fire activity. Other changes to fuel characteristics could arise from changes in land use, the introduction of exotic species or the result of a higher carbon dioxide background. Consideration of these factors requires additional modelling efforts.

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

VARIABLE	1995 BASELINE	2030 RCP4.5	2030 RCP8.5	2090 RCP4.5	2090 RCP8.5
T	27.9	28.7	28.9	29.6	31.0
R	1773	1661	1627	1740	1692
DF	6.2	6.3	6.3	6.3	6.4
SEV	0.0	0.0	0.0	0.0	0.0
∑FFDI	1524	1580	1612	1606	1721

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 coastal terrestrial and marine environments. This is discussed at length in Chapter 8 of the Technical Report. Impacts of sea level rise and changes to the frequency of extreme sea levels 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 and coastal fisheries.

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 Mackay (Figure 4.10.1). Values for this and other locations are provided for the 2030–2090 periods relative to the 1986–2005 period in Table 3 in the Appendix.

Continued increase in sea level for the Wet Tropics 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 emission scenario, but they begin to separate significantly from about 2050. For higher greenhouse gas emissions, particularly for RCP8.5, the rate of rise continues to increase through the 21st century and results in sea level rise about 30 % higher than the RCP4.5 level by 2100. Significant inter-annual variability will continue through the 21st century. An indication of its expected magnitude is given by the dotted lines in Figure 4.10.1. In the near future (2030), the projected range of sea level rise for the Cairns coastline (Table 3 in the Appendix) is 0.09 to 0.18 m above 1986–2005, with only minor differences between RCPs. For late in the century (2090) it is 0.31 to 0.65 m for RCP 4.5 and 0.44 to 0.87 m for RCP 8.5. 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 caused by a combination of factors including astronomical tides, storm surges and wind-waves, exacerbated by rising sea levels. Along the Wet Tropics coastline, the majority of severe storm surges occur in conjunction with tropical cyclones. Additionally, variations in north-westerly winds during the monsoon season can lead to higher than normal sea levels within the Gulf of Carpentaria (Oliver and Thompson, 2011). Strong and persistent south-easterly trade winds can elevate sea levels within the Torres Strait (Green *et al.*, 2010).

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 Wet Tropics 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 Wet Tropics in 2030 the vertical allowances along the cluster coastline are in the range 0.14 m on the east coast and 0.12 m in the Gulf of Carpentaria for all RCPs. By 2090, ranges along the coast are from 0.48 to 0.57 m for RCP4.5 and 0.67 to 0.79 m for RCP8.5 (see Table 3 in the Appendix).

4.10.2 SEA SURFACE TEMPERATURE, SALINITY AND ACIDIFICATION

Sea surface temperature (SST) has increased significantly across the globe over recent decades (IPCC, 2013). Increases in SST pose a significant threat to the marine environment through biological changes in marine species, including in local abundance, community structure, and enhanced coral bleaching risk. The projected warming is generally largest in the south of the Wet Tropics region and smallest in the Gulf of Carpentaria. For 2030, the range of projected SST increase for Mackay is 0.4 to 0.8 °C under RCP2.6 and 0.5 to 1.0 °C for RCP8.5 and for Weipa it is 0.3 to 0.8 °C under RCP2.6 and 0.5 to 1.0 °C for RCP8.5 (see Table 3 in the Appendix). For 2090, there is a much larger range of warming between the different scenarios. For Mackay, the range of projected increase is 0.4 to 1.3 °C for RCP2.6 and 2.2 to 3.4 °C for RCP8.5 and for Weipa it is 0.2 to 1.2 °C for RCP2.6 and 2.3 to 3.6 °C for RCP8.5.

Ocean salinity in coastal waters will be affected by changes to rainfall and evaporation. Changes in salinity can affect stratification and mixing, and potentially nutrient supply. Changes to salinity across the coastal waters of the Wet Tropics span a large range that includes possible increases and decreases, particularly over the longer term and higher emission scenarios as indicated in Table 3 in the Appendix. The relatively shallow Gulf of Carpentaria reveals a larger sensitivity to such projected changes than the east coast (see Table 3 in the Appendix). Locally salinity can also be affected by riverine input.

About 30 % of the anthropogenic carbon dioxide emitted into the atmosphere over the past 200 years has been absorbed by the oceans (Ciais *et al*., 2013) and this has led to a 0.1 unit change in the ocean's surface water pH, which represents a 26 % increase in the concentration of hydrogen ions in seawater (Raven *et al*., 2005). As 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 change is projected to be another 0.08 units lower. By 2090, it is projected to be up to 0.15 units lower for RCP4.5 and up to 0.32 units lower for RCP8.5. This represents an additional increase in hydrogen ion concentration of 40 and 100 % respectively. These changes are also accompanied by reductions in aragonite saturation state (see Table 3 in the Appendix) and together with SST changes will affect all levels of the marine food web, and make it harder for calcifying marine organisms to build their hard shells, potentially affecting resilience and viability of marine ecosystems.

In summary, there is *very high confidence* that sea surface temperatures will continue to rise along the Wet Tropics coastline, with the magnitude of the warming dependent on emission scenarios. Changes in salinity are related to changes in the hydrological cycle and are of *low confidence*. There is *very high confidence* that the ocean around Australia will become more acidic, showing a net 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 Wet Tropics, previous projection products includes the nationwide Climate Change in Australia projections, produced by the CSIRO and BOM in 2007 (CSIRO and BOM, 2007), and projections presented in the *Climate Q* document[2], from the Queensland Government based on the CSIRO and BOM 2007 projections. A brief comparison of the projections with regard to temperature and rainfall follows.

In comparison to the 2007 projections, the warming patterns suggested by the CMIP5 models are more uniform, with a less pronounced west-east gradient in warming (Figure A.1 of the Technical Report). The CMIP5 projections are slightly wetter (Figure A.2 of the Technical Report).

The previous 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).

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[2] http://www.agdf.org.au/information/sustainable-development/climate-q

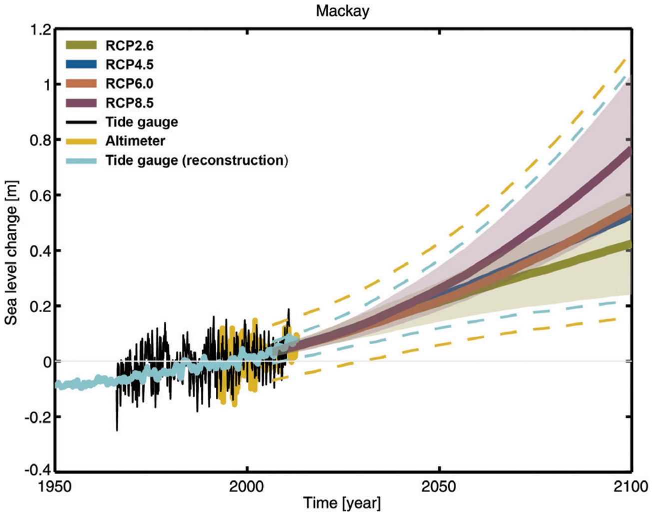


FIGURE 4.11.1: OBSERVED AND PROJECTED RELATIVE SEA LEVEL CHANGE (METRES) FOR MACKAY (WHICH HAS A CONTINUOUS RECORD AVAILABLE FOR THE PERIOD 1966–2010). THE OBSERVED TIDE GAUGE RELATIVE SEA LEVEL RECORDS ARE INDICATED IN BLACK, WITH THE SATELLITE RECORD (SINCE 1993) IN MUSTARD AND TIDE GAUGE RECONSTRUCTION (WHICH HAS LOWER VARIABILITY) IN CYAN. MULTI-MODEL MEAN PROJECTIONS (THICK PURPLE AND OLIVE LINES) FOR THE RCP8.5 AND RCP2.6 EMISSIONS SCENARIO WITH UNCERTAINTY RANGES SHOWN BY THE PURPLE AND OLIVE SHADED REGIONS FROM 2006 TO 2100. THE MUSTARD AND CYAN DASHED LINES ARE AN ESTIMATE OF INTER-ANNUAL VARIABILITY IN SEA LEVEL (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.

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.

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 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.

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

5.2 DEVELOPING CLIMATE SCENARIOS USING THE CLIMATE FUTURES TOOL

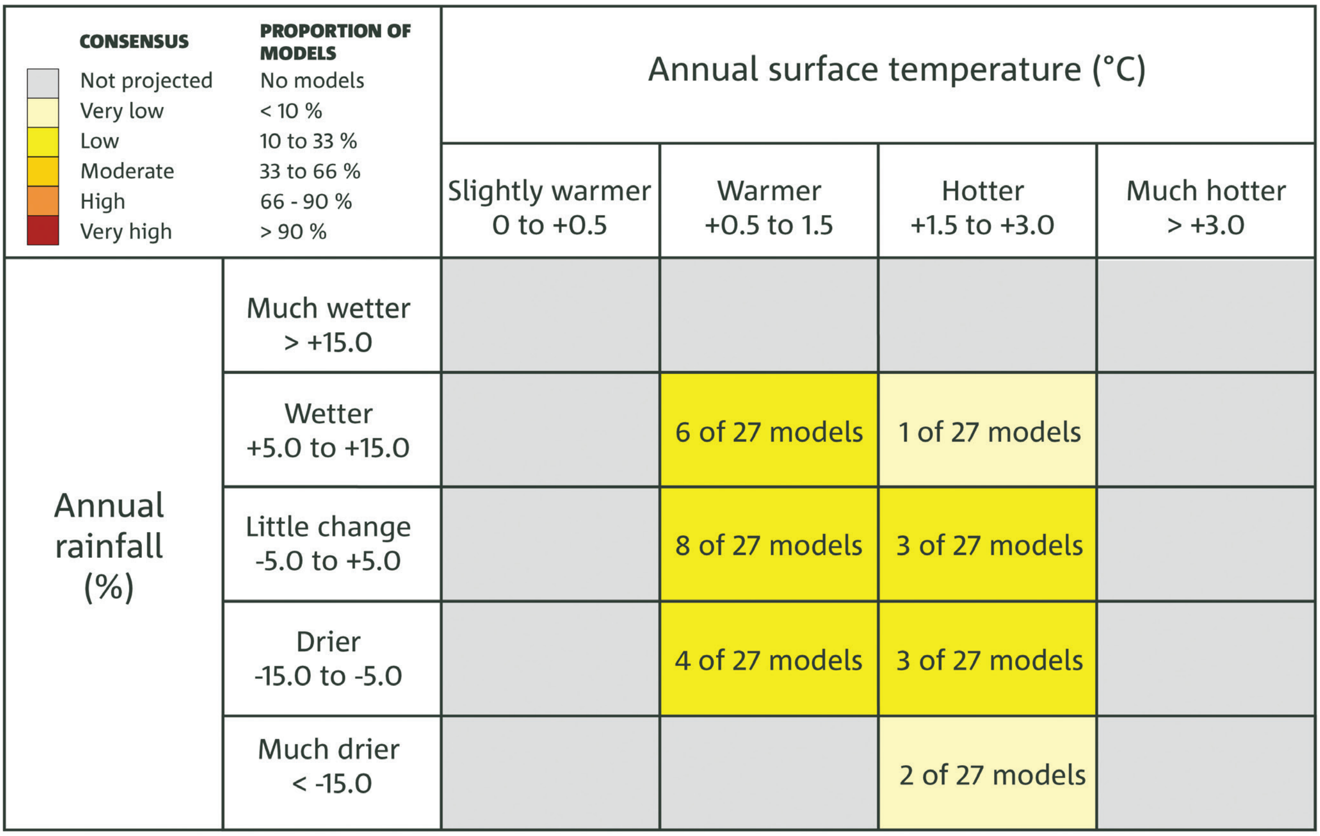
The example presented in Figure 5.1 represents the changes, as simulated by CMIP5 models, in temperature and rainfall in the Wet Tropics for 2060 (2050–2069) under the RCP4.5 scenario. The table organises the models into groupings according to their simulated changes to rainfall (rows) and temperatures (columns). Regarding rainfall, models simulate increases and decreases from *much drier* (less than -15 %) to *wetter* (+5 to 15 %), with 9 of 27 models showing drying conditions (less than -5 %) compared to seven models showing rainfall increases (greater than 5 %) and 11 models showing little change (-5 to 5 % change). With regard to temperature, models show results ranging from *warmer* (0.5 to 1.5 °C warmer) to *hotter* (1.5 to 3 °C warmer), with no models falling into the lowest category *slightly warmer* (0 to 0.5 °C warmer) nor the highest category *much hotter* (greater than 3.0 °C warming). The greatest number of models falls into the *warmer* category (18 of 27 models). When considering the two variables together, the most commonly simulated climate for 2060 under RCP4.5 is a *warmer and little change* climate (8 of 27 models).

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

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 Wet Tropics 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 comparing simulations from different climate model ensembles (such as the earlier CMIP3 ensemble, or ensembles of downscaled results). Comparing model spread simulated by different generations of GCMs in *Climate Futures* allows assessment of the ongoing relevance of existing impact studies based on selected CMIP3 models, as well as comparison of 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		6 of 27 models	1 of 27 models	
	Little change -5.0 to +5.0		8 of 27 models	3 of 27 models	
	Drier -15.0 to -5.0		4 of 27 models	3 of 27 models	
	Much drier < -15.0			2 of 27 models	

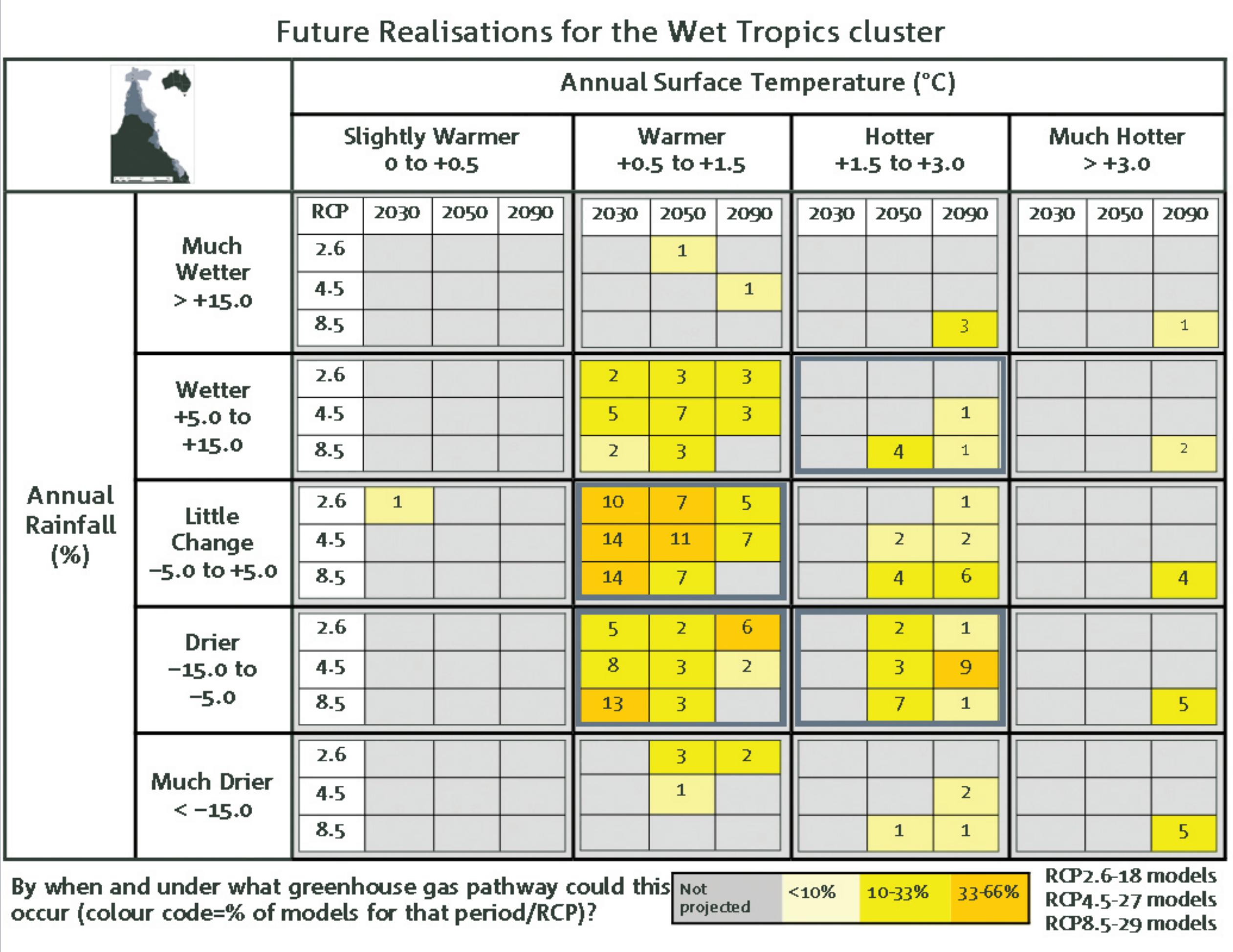
FIGURE 5.1: AN EXAMPLE TABLE BASED ON OUTPUT FROM THE CLIMATE FUTURES WEB TOOL SHOWING RESULTS FOR THE WET TROPICS WHEN ASSESSING PLAUSIBLE CLIMATE FUTURES FOR 2060 UNDER RCP4.5, AS DEFINED BY GCM SIMULATED ANNUAL RAINFALL (% CHANGE) AND TEMPERATURE (°C WARMING).

BOX 5.2: INDICATIVE CLIMATE SCENARIOS FOR THE WET TROPICS 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 Wet Tropics is illustrated here. Combining the results in Climate Futures for 2030, 2050, and 2090, under the RCP2.6, RCP4.5, and RCP8.5, gives a set of future climate scenarios (see Figure B5.2). From these, four 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 Cairns 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 +/- 1.0 °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 or RCP4.5.
- *Hotter* (1.5 to 3.0 °C warmer), but *drier* (5 to 15 % reduction). This is possible by 2050 under RCP4.5 or RCP8.5 and 2090 under RCP4.5. In this case Cairns' future climate would be more like the current climate of Weipa.
- *Warmer* (0.5 to 1.5 °C warmer) and *wetter* (5 to 15 % increase). This is also possible early or mid-century under any emission scenario, or late in the century with lower emissions. In this case, Cairns' future climate will be more like the current climate of Mossman.
- *Warmer* (0.5 to 1.5 °C warmer) and *drier* (5 to 15 % reduction). This could occur by 2030 under any emission scenario, but may persist through to late in the century under RCP2.6. In this case, Cairns' future climate would be more like the current climate of Lockhart River (Cape York).

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



Future Realisations for the Wet Tropics 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					1							
	4.5						1						
	8.5									3			1
Wetter +5.0 to +15.0	2.6				2	3	3						
	4.5				5	7	3			1			
	8.5				2	3			4	1			2
Little Change −5.0 to +5.0	2.6	1			10	7	5			1			
	4.5				14	11	7		2	2			
	8.5				14	7			4	6			4
Drier −15.0 to −5.0	2.6				5	2	6		2	1			
	4.5				8	3	2		3	9			
	8.5				13	3			7	1			5
Much Drier < −15.0	2.6					3	2						
	4.5					1				2			
	8.5								1	1			5

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

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

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

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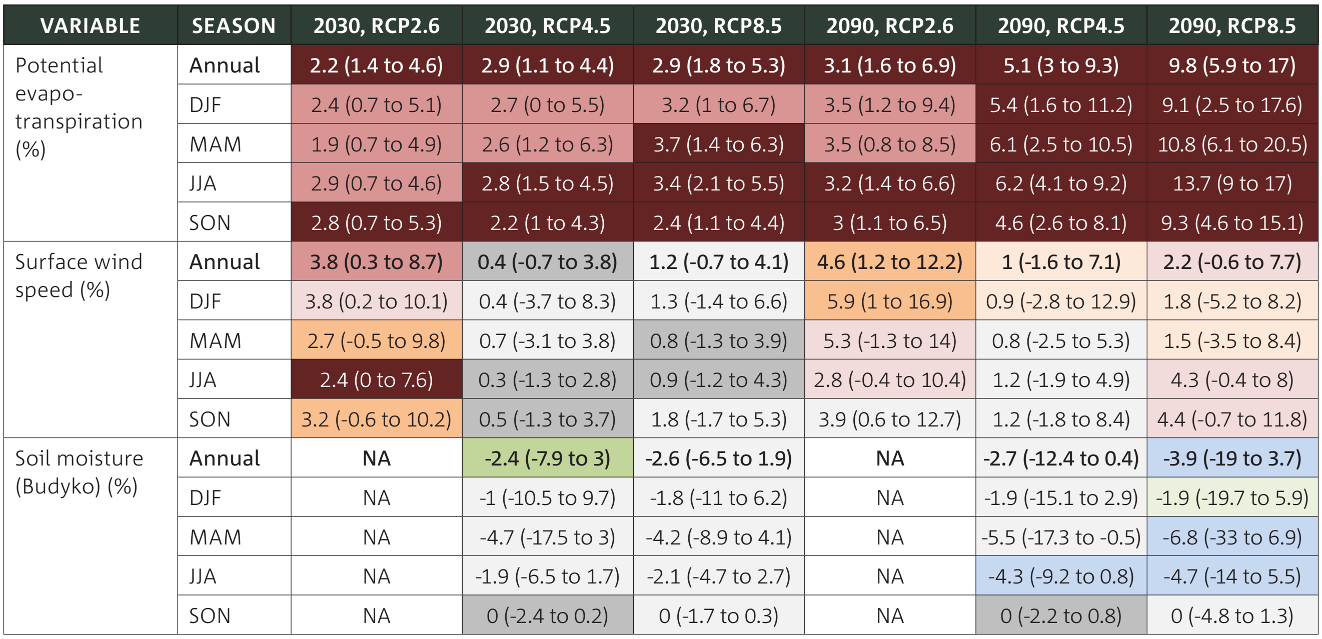
APPENDIX

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

VARIABLE	SEASON	2030, RCP2.6	2030, RCP4.5	2030, RCP8.5	2090, RCP2.6	2090, RCP4.5	2090, RCP8.5
Temperature mean (°C)	**Annual**	**0.6 (0.3 to 0.9)**	**0.7 (0.6 to 1)**	**0.8 (0.6 to 1.1)**	**0.7 (0.4 to 1.4)**	**1.4 (1 to 2)**	**2.9 (2.3 to 3.9)**
	DJF	0.7 (0.4 to 1)	0.7 (0.5 to 1.1)	0.8 (0.6 to 1.1)	0.7 (0.4 to 1.5)	1.5 (1 to 2.1)	3 (2.3 to 4.1)
	MAM	0.6 (0.4 to 0.9)	0.7 (0.5 to 1.1)	0.8 (0.5 to 1.1)	0.7 (0.4 to 1.4)	1.4 (1 to 2.2)	3 (2.3 to 4.1)
	JJA	0.6 (0.2 to 0.9)	0.7 (0.4 to 0.9)	0.8 (0.5 to 1.1)	0.7 (0.4 to 1.2)	1.4 (1.1 to 2)	3 (2.4 to 4)
	SON	0.6 (0.3 to 0.9)	0.7 (0.5 to 1)	0.7 (0.5 to 1)	0.7 (0.3 to 1.2)	1.3 (1 to 2)	2.8 (2.3 to 3.9)
Temperature maximum (°C)	**Annual**	**0.6 (0.3 to 1)**	**0.7 (0.6 to 1.1)**	**0.8 (0.6 to 1.2)**	**0.7 (0.4 to 1.6)**	**1.4 (1.1 to 2.1)**	**2.9 (2.3 to 3.9)**
	DJF	0.6 (0.3 to 1.1)	0.7 (0.4 to 1.1)	0.8 (0.5 to 1.2)	0.7 (0.4 to 1.9)	1.6 (1 to 2.1)	3 (2.3 to 4.1)
	MAM	0.6 (0.4 to 1.1)	0.7 (0.6 to 1.1)	0.8 (0.6 to 1.1)	0.7 (0.5 to 1.6)	1.5 (1.1 to 2.3)	3.1 (2.4 to 4)
	JJA	0.6 (0.2 to 1)	0.7 (0.5 to 1)	0.8 (0.6 to 1.1)	0.7 (0.4 to 1.3)	1.4 (1.1 to 2)	3.1 (2.4 to 4)
	SON	0.6 (0.3 to 0.9)	0.7 (0.5 to 1)	0.8 (0.6 to 1.1)	0.7 (0.4 to 1.3)	1.3 (1 to 2)	2.8 (2.3 to 3.9)
Temperature minimum (°C)	**Annual**	**0.6 (0.3 to 0.9)**	**0.7 (0.5 to 1)**	**0.8 (0.6 to 1.1)**	**0.7 (0.4 to 1.3)**	**1.4 (1.1 to 2.1)**	**3 (2.3 to 4.2)**
	DJF	0.7 (0.4 to 1)	0.7 (0.5 to 1)	0.8 (0.5 to 1.1)	0.8 (0.4 to 1.3)	1.5 (1 to 2.2)	3 (2.2 to 4.3)
	MAM	0.6 (0.3 to 1)	0.7 (0.5 to 1)	0.8 (0.5 to 1.1)	0.7 (0.3 to 1.3)	1.4 (1 to 2.1)	3 (2.2 to 4.2)
	JJA	0.6 (0.2 to 0.9)	0.7 (0.4 to 1)	0.8 (0.5 to 1.1)	0.7 (0.4 to 1.3)	1.5 (1.2 to 2.2)	3.1 (2.5 to 4.3)
	SON	0.6 (0.2 to 0.9)	0.7 (0.5 to 1)	0.7 (0.5 to 1)	0.7 (0.4 to 1.2)	1.4 (1 to 2.1)	3 (2.4 to 4.1)
Rainfall (%)	**Annual**	**-2 (-9 to +6)**	**0 (-11 to +6)**	**-3 (-12 to +4)**	**-2 (-16 to +5)**	**-2 (-12 to +8)**	**-2 (-26 to +21)**
	DJF	-1 (-10 to +6)	+0 (-18 to +11)	-1 (-14 to +11)	-2 (-16 to +8)	-2 (-15 to +11)	+1 (-20 to +22)
	MAM	-3 (-12 to +7)	-3 (-10 to +5)	-5 (-13 to +9)	-5 (-17 to +10)	-4 (-16 to +11)	-7 (-27 to +22)
	JJA	-1 (-29 to +19)	+0 (-26 to +22)	-4 (-26 to +28)	-6 (-30 to +24)	-5 (-31 to +28)	-5 (-41 to +45)
	SON	-5 (-32 to +32)	0 (-34 to +25)	-5 (-37 to +27)	-9 (-33 to +24)	-3 (-35 to +50)	-10 (-50 to +104)
Solar radiation (%)	**Annual**	**0.4 (-0.5 to 1.5)**	**0 (-0.6 to 1.2)**	**0.2 (-0.8 to 1.2)**	**0.7 (-0.8 to 2.7)**	**0.1 (-1.6 to 2.2)**	**-0.3 (-4.7 to 2.2)**
	DJF	0.3 (-1.1 to 2.7)	0.2 (-1.9 to 2.5)	0.2 (-1.6 to 2.9)	0.6 (-1.2 to 5.6)	0 (-2.6 to 4.7)	-0.8 (-4.4 to 5.5)
	MAM	0.9 (-1.4 to 2.5)	0.4 (-1.2 to 2)	0.8 (-1.3 to 2.6)	1.6 (-2.2 to 3.1)	0.8 (-2.5 to 2.7)	1.1 (-5.4 to 3.9)
	JJA	0.1 (-1.3 to 1.7)	0.1 (-1.2 to 1.8)	0.3 (-1.4 to 1.4)	0.3 (-1 to 2)	-0.2 (-1.6 to 1.5)	-0.8 (-4.5 to 0.8)
	SON	0.2 (-1.4 to 2.3)	0.2 (-1.2 to 1.1)	-0.1 (-1.2 to 1.4)	0.3 (-0.9 to 2.1)	-0.5 (-2.1 to 1.3)	-1.4 (-4.8 to 0.8)
Relative humidity (%, absolute)	**Annual**	**-0.3 (-0.8 to +0.4)**	**-0.1 (-0.9 to +0.6)**	**-0.1 (-1.2 to +0.4)**	**-0.3 (-1.6 to +0.5)**	**0 (-1 to +0.7)**	**+0.1 (-1.9 to +1.5)**
	DJF	-0.6 (-1.8 to +0.7)	0 (-1 to +1)	-0.2 (-1.4 to +1)	-0.5 (-4.2 to +0.6)	-0.3 (-2.1 to +1.1)	-0.3 (-2.6 to +1.5)
	MAM	-0.2 (-1.1 to +0.4)	+0 (-1.2 to +0.6)	-0.3 (-1.4 to +0.7)	-0.3 (-2.5 to +0.2)	-0.6 (-2.9 to +0.7)	-0.7 (-3.9 to +1)
	JJA	+0.1 (-1.2 to +0.6)	+0.1 (-1 to +0.7)	-0.2 (-1.1 to +0.7)	-0.1 (-1.7 to +0.7)	+0.1 (-2.1 to +1.3)	+0.2 (-1.7 to +2.4)
	SON	+0.1 (-0.9 to +1)	+0.1 (-0.6 to +1)	+0.2 (-0.9 to +1)	-0.1 (-2.2 to +1.1)	+0.5 (-0.8 to +1.5)	+0.8 (-0.9 to +3.4)



VARIABLE	SEASON	2030, RCP2.6	2030, RCP4.5	2030, RCP8.5	2090, RCP2.6	2090, RCP4.5	2090, RCP8.5
Potential evapo-transpiration (%)	**Annual**	**2.2 (1.4 to 4.6)**	**2.9 (1.1 to 4.4)**	**2.9 (1.8 to 5.3)**	**3.1 (1.6 to 6.9)**	**5.1 (3 to 9.3)**	**9.8 (5.9 to 17)**
	DJF	2.4 (0.7 to 5.1)	2.7 (0 to 5.5)	3.2 (1 to 6.7)	3.5 (1.2 to 9.4)	5.4 (1.6 to 11.2)	9.1 (2.5 to 17.6)
	MAM	1.9 (0.7 to 4.9)	2.6 (1.2 to 6.3)	3.7 (1.4 to 6.3)	3.5 (0.8 to 8.5)	6.1 (2.5 to 10.5)	10.8 (6.1 to 20.5)
	JJA	2.9 (0.7 to 4.6)	2.8 (1.5 to 4.5)	3.4 (2.1 to 5.5)	3.2 (1.4 to 6.6)	6.2 (4.1 to 9.2)	13.7 (9 to 17)
	SON	2.8 (0.7 to 5.3)	2.2 (1 to 4.3)	2.4 (1.1 to 4.4)	3 (1.1 to 6.5)	4.6 (2.6 to 8.1)	9.3 (4.6 to 15.1)
Surface wind speed (%)	**Annual**	**3.8 (0.3 to 8.7)**	**0.4 (-0.7 to 3.8)**	**1.2 (-0.7 to 4.1)**	**4.6 (1.2 to 12.2)**	**1 (-1.6 to 7.1)**	**2.2 (-0.6 to 7.7)**
	DJF	3.8 (0.2 to 10.1)	0.4 (-3.7 to 8.3)	1.3 (-1.4 to 6.6)	5.9 (1 to 16.9)	0.9 (-2.8 to 12.9)	1.8 (-5.2 to 8.2)
	MAM	2.7 (-0.5 to 9.8)	0.7 (-3.1 to 3.8)	0.8 (-1.3 to 3.9)	5.3 (-1.3 to 14)	0.8 (-2.5 to 5.3)	1.5 (-3.5 to 8.4)
	JJA	2.4 (0 to 7.6)	0.3 (-1.3 to 2.8)	0.9 (-1.2 to 4.3)	2.8 (-0.4 to 10.4)	1.2 (-1.9 to 4.9)	4.3 (-0.4 to 8)
	SON	3.2 (-0.6 to 10.2)	0.5 (-1.3 to 3.7)	1.8 (-1.7 to 5.3)	3.9 (0.6 to 12.7)	1.2 (-1.8 to 8.4)	4.4 (-0.7 to 11.8)
Soil moisture (Budyko) (%)	**Annual**	**NA**	**-2.4 (-7.9 to 3)**	**-2.6 (-6.5 to 1.9)**	**NA**	**-2.7 (-12.4 to 0.4)**	**-3.9 (-19 to 3.7)**
	DJF	NA	-1 (-10.5 to 9.7)	-1.8 (-11 to 6.2)	NA	-1.9 (-15.1 to 2.9)	-1.9 (-19.7 to 5.9)
	MAM	NA	-4.7 (-17.5 to 3)	-4.2 (-8.9 to 4.1)	NA	-5.5 (-17.3 to -0.5)	-6.8 (-33 to 6.9)
	JJA	NA	-1.9 (-6.5 to 1.7)	-2.1 (-4.7 to 2.7)	NA	-4.3 (-9.2 to 0.8)	-4.7 (-14 to 5.5)
	SON	NA	0 (-2.4 to 0.2)	0 (-1.7 to 0.3)	NA	0 (-2.2 to 0.8)	0 (-4.8 to 1.3)

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
🟨	Low model agreement on the direction of 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
Cairns	T	29.2	30.0	30.0	30.1	30.2	30.2	30.3	31.1	30.7	31.0	32.7	32.1	32.1
	R	1991	2067	1823	1816	1993	1734	1838	2163	2002	1802	2079	1869	1866
	DF	6.1	6.1	6.4	6.1	6.0	6.4	6.2	6.0	6.2	6.2	6.0	6.4	6.2
	SEV	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	ΣFFDI	1745	1734	1900	1805	1732	1948	1858	1757	1836	1912	1906	2053	1926
Mackay	T	26.6	27.4	27.4	27.5	27.6	27.6	27.7	28.5	28.1	28.4	30.1	29.5	29.5
	R	1557	1544	1351	1370	1539	1298	1362	1623	1511	1343	1583	1372	1389
	DF	6.3	6.3	6.6	6.3	6.2	6.7	6.4	6.3	6.5	6.5	6.4	6.8	6.5
	SEV	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	ΣFFDI	1303	1286	1405	1349	1288	1456	1392	1319	1373	1440	1441	1542	1457

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 WET TROPICS, 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)	Mackay (149.23, -21.10)	0.13 (0.08-0.17)	0.13 (0.09-0.17)	0.14 (0.09-0.18)	0.38 (0.22-0.55)	0.47 (0.30-0.64)	0.64 (0.44-0.87)
	Cairns (145.78, -16.92)	0.13 (0.09-0.17)	0.13 (0.09-0.17)	0.14 (0.09-0.18)	0.40 (0.24-0.56)	0.48 (0.31-0.65)	0.65 (0.44-0.87)
	Ince Point (142.31, -10.51)	0.11 (0.06-0.16)	0.11 (0.07-0.16)	0.12 (0.08-0.17)	0.36 (0.20-0.53)	0.45 (0.27-0.63)	0.61 (0.41-0.84)
	Weipa (141.87, -12.67)	0.11 (0.06-0.16)	0.11 (0.07-0.16)	0.12 (0.07-0.16)	0.36 (0.20-0.53)	0.44 (0.27-0.62)	0.60 (0.40-0.83)
Sea allowance (m)	Mackay (149.23, -21.10)	0.13	0.14	0.14	0.43	0.53	0.73
	Cairns (145.78, -16.92)	0.14	0.14	0.14	0.48	0.57	0.79
	Ince Point (142.31, -10.51)	0.12	0.12	0.13	0.42	0.51	0.71
	Weipa (141.87, -12.67)	0.11	0.12	0.12	0.40	0.48	0.67
Sea surface temperature (°C)	Mackay (149.23, -21.10)	0.6 (0.4 to 0.8)	0.7 (0.5 to 0.9)	0.8 (0.5 to 1.0)	0.7 (0.4 to 1.3)	1.5 (1.1 to 1.8)	2.9 (2.2 to 3.4)
	Cairns (145.78, -16.92)	0.6 (0.3 to 0.8)	0.7 (0.4 to 0.9)	0.8 (0.5 to 1.0)	0.6 (0.3 to 1.1)	1.3 (1.0 to 1.8)	2.6 (2.3 to 3.5)
	Ince Point (142.31, -10.51)	0.6 (0.3 to 0.9)	0.7 (0.4 to 1.0)	0.7 (0.5 to 1.0)	0.7 (0.2 to 1.1)	1.3 (1.0 to 1.8)	2.6 (2.3 to 3.6)
	Weipa (141.87, -12.67)	0.5 (0.3 to 0.8)	0.7 (0.5 to 0.9)	0.7 (0.5 to 1.0)	0.7 (0.2 to 1.2)	1.3 (1.0 to 1.7)	2.6 (2.3 to 3.6)
Sea surface salinity	Mackay (149.23, -21.10)	-0.06 (-0.12 to 0.12)	-0.07 (-0.33 to 0.06)	-0.03 (-0.07 to 0.10)	-0.11 (-0.23 to 0.22)	-0.12 (-0.51 to 0.29)	-0.19 (-0.72 to 0.39)
	Cairns (145.78, -16.92)	-0.06 (-0.15 to 0.15)	-0.06 (-0.35 to 0.06)	-0.04 (-0.12 to 0.11)	-0.15 (-0.31 to 0.21)	-0.13 (-0.67 to 0.27)	-0.18 (-1.10 to 0.36)
	Ince Point (142.31, -10.51)	0.05 (-0.10 to 0.59)	-0.03 (-0.14 to 0.62)	0.05 (-0.12 to 0.96)	0.01 (-0.17 to 0.55)	-0.07 (-0.36 to 0.29)	-0.28 (-0.81 to 0.89)
	Weipa (141.87, -12.67)	0.06 (-0.09 to 0.53)	-0.00 (-0.07 to 0.81)	0.09 (-0.09 to 1.27)	0.12 (-0.15 to 0.80)	-0.08 (-0.38 to 0.72)	-0.17 (-0.74 to 1.01)

VARIABLE	LOCATION	2030, RCP2.6	2030, RCP4.5	2030, RCP8.5	2090, RCP2.6	2090, RCP4.5	2090, RCP8.5
Ocean acidification	Mackay (149.23, -21.10)	-0.06 (-0.06 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 (-0.32 to -0.31)
	Cairns (145.78, -16.92)	-0.06 (-0.06 to -0.06)	-0.06 (-0.07 to -0.06)	-0.07 (-0.08 to -0.07)	-0.06 (-0.07 to -0.06)	-0.14 (-0.15 to -0.14)	-0.31 (-0.32 to -0.31)
	Ince Point (142.31, -10.51)	-0.06 (-0.06 to -0.05)	-0.06 (-0.07 to -0.05)	-0.07 (-0.08 to -0.06)	-0.06 (-0.06 to -0.06)	-0.14 (-0.14 to -0.12)	-0.31 (-0.31 to -0.26)
	Weipa (141.87, -12.67)	-0.06 (-0.06 to -0.06)	-0.06 (-0.07 to -0.06)	-0.07 (-0.08 to -0.07)	-0.06 (-0.06 to -0.05)	-0.14 (-0.15 to -0.13)	-0.31 (-0.31 to -0.29)
Aragonite saturation	Mackay (149.23, -21.10)	-0.35 (-0.36 to -0.29)	-0.36 (-0.39 to -0.35)	-0.41 (-0.46 to -0.38)	-0.35 (-0.38 to -0.29)	-0.76 (-0.78 to -0.71)	-1.55 (-1.61 to -1.44)
	Cairns (145.78, -16.92)	-0.34 (-0.36 to -0.29)	-0.36 (-0.40 to -0.34)	-0.41 (-0.45 to -0.38)	-0.35 (-0.38 to -0.30)	-0.77 (-0.79 to -0.73)	-1.53 (-1.61 to -1.49)
	Ince Point (142.31, -10.51)	-0.33 (-0.36 to -0.23)	-0.36 (-0.37 to -0.18)	-0.41 (-0.45 to -0.24)	-0.33 (-0.36 to -0.28)	-0.76 (-0.86 to -0.58)	-1.57 (-1.67 to -1.19)
	Weipa (141.87, -12.67)	-0.31 (-0.36 to -0.27)	-0.34 (-0.36 to -0.26)	-0.41 (-0.42 to -0.21)	-0.31 (-0.36 to -0.24)	-0.75 (-0.86 to -0.64)	-1.51 (-1.67 to -1.37)

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

ABBREVIATIONS

ACORN-SAT	Australian Climate Observations Reference Network – Surface Air Temperature
AWAP	Australian Water Availability Project
BOM	Australian Bureau of Meteorology
CCAM	Conformal cubic atmospheric model
CCIA	Climate Change in Australia
CMIP5	Coupled Model Intercomparison Project (Phase 5)
CSIRO	Commonwealth Scientific and Industrial Research Organisation
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
MJO	Madden-Julian Oscillation
NRM	Natural Resource Management
RCP	Representative Concentration Pathway
SAM	Southern Annular Mode
SPI	Standardised precipitation index
SRES	Special Report on Emissions Scenarios
SST	Sea surface temperature
STR	Sub-tropical Ridge
WT	Wet Tropics cluster

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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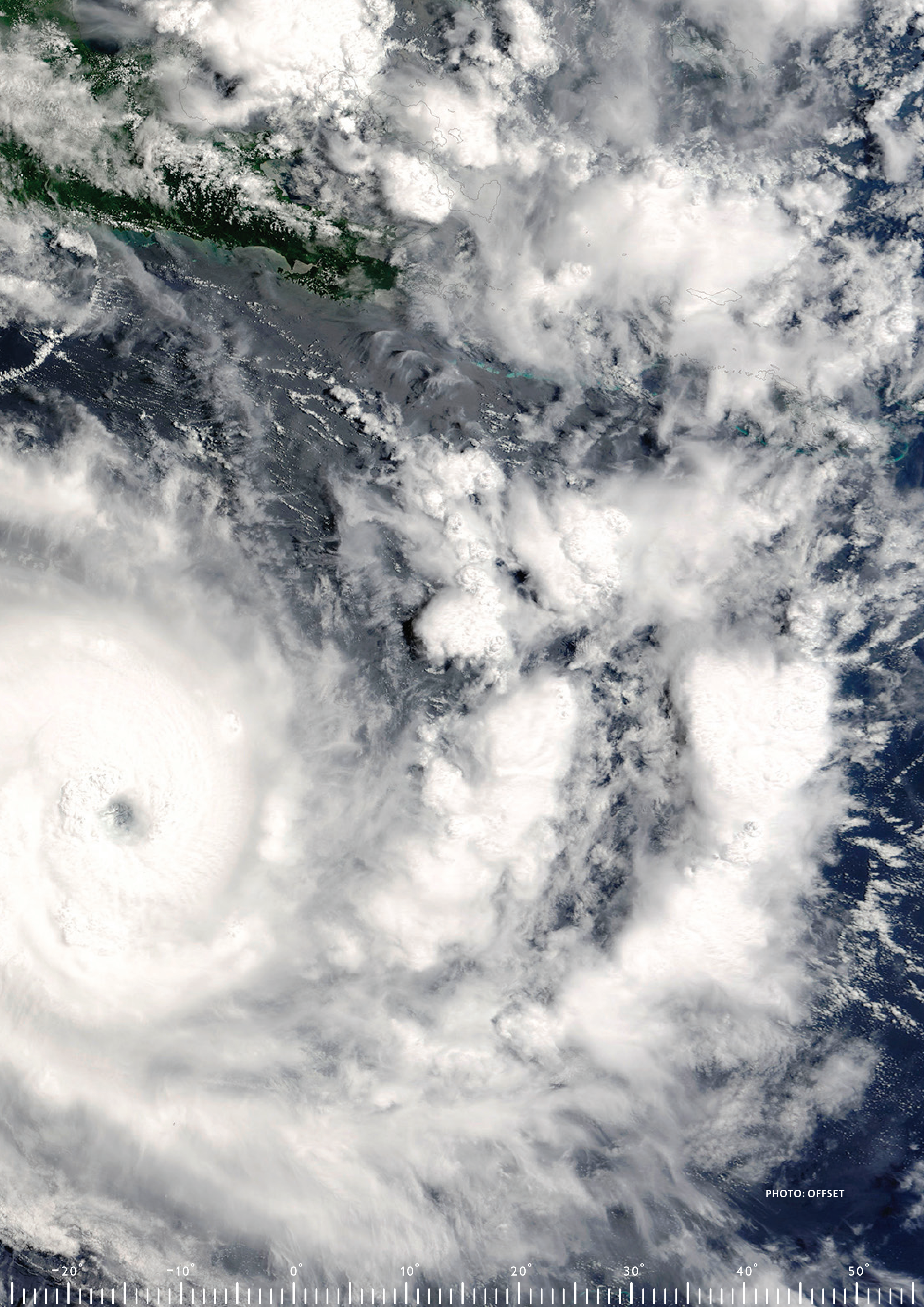

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