Australian Government
Bureau of Meteorology

Wet Tropics — National Hydrological Projections Assessment report

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Cover image: Aerial view of the Daintree region, Queensland. Trace Rouda, 01 March 2018

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1 Introduction to the National Hydrological Projections

Australia’s climate is changing: temperatures are increasing and precipitation patterns are shifting, as described in the *State of the climate 2020* (CSIRO & Bureau of Meteorology 2020). On average, Australia has warmed by 1.44 ± 0.24 °C since national records began in 1910. Streamflow has changed across the country, broadly increasing in the north and decreasing in the south. The *State of the climate 2020* reports that, in Australia’s south-west, cool-season (May–October) precipitation has declined by around 16% since 1970. The decrease is even more pronounced for the winter months (May–July) for the same period. In the south-east of Australia, precipitation started to decline around 1990, and the average cool-season precipitation from 2000 to 2019 is now 12% less than last century (CSIRO & Bureau of Meteorology 2020). Along with this observed decline in precipitation, streamflow has declined substantially in both the south-west and south-east; changes in streamflow are typically disproportionally larger than changes in precipitation (Chiew 2006; Wasko et al. 2021; Zhang et al. 2016). In contrast, precipitation has increased across many northern parts of the country, and streamflow follows this trend (Zhang et al. 2016).

With rising greenhouse gas (GHG) levels in the atmosphere, temperature changes are projected to continue and intensify in the future, causing further warming and changes in all components of the climate and hydrological system (CSIRO & Bureau of Meteorology 2015). Given the limited water available for many Australian communities, businesses, governments and environments, these changes represent ongoing challenges to the management of Australia’s water resources. The future security of our food and energy supplies, and our ecosystems, depends on water availability, as the demand for water is also growing.

To ensure that future water needs are met, decision-makers need forward-looking datasets and methods to evaluate a range of conceivable futures while accounting for uncertainty. The National Hydrological Projections product suite supports the process of strategic decision-making processes for future water resource management, adaptation and water policy developments. It consists of nationally consistent hydrological projections datasets, information and guidance material on future changes in Australia’s projected hydrological variables.

The National Hydrological (NHP) Projections service complements projections work that has been undertaken by many federal and state governments, universities, and other organisations across Australia. A broad overview of available projections for Australia is given in Table 1.1. It is important to understand the varying nature of these projections including NHP in selected global climate models and their generation, greenhouse gas emission pathways, downscaling methods, spatial resolution, output variables and anticipated purpose ahead of their use. Further details about the Australian projections landscape, guidance material and readily available projections datasets can be found here: https://www.climatechangeinaustralia.gov.au/en/overview/about-site/landscape/

Table 1.1. Projections landscape for Australia

Name	State	Link
Climate Change in Australia	National	https://www.climatechangeinaustralia.gov.au/en/
Electricity Sector Climate Information	National	https://www.energy.gov.au/government-priorities/energy-security/electricity-sector-climate-information-esci-project
NSW and Australian Regional Climate Modelling project	New South Wales/Australian Capital Territory	https://climatedata-beta.environment.nsw.gov.au/
Climate Change NT	Northern Territory	https://climatechange.nt.gov.au/
Long Paddock	Queensland	https://www.longpaddock.qld.gov.au/qld-future-climate/
SA Climate Ready	South Australia	https://environment.sa.gov.au
Climate Futures for Tasmania	Tasmania	https://climatefutures.org.au/projects/climate-futures-tasmania/
Victorian Climate Projections 2019 Victorian Water and Climate Initiative	Victoria	https://www.climatechangeinaustralia.gov.au/en/projects/victorian-climate-projections-19 https://www.water.vic.gov.au/climate-change/reserach/vicwaci
Western Australian climate projections	Western Australia	https://www.wa.gov.au/government/publications/western-australian-climate-projections-summary

1.1 Developing the National Hydrological Projections

Broadly, the National Hydrological Projections were produced by choosing representative emission pathways (RCPs) and using a number of global climate model (GCM) inputs to run with a hydrological landscape water balance model (Figure 1.1).

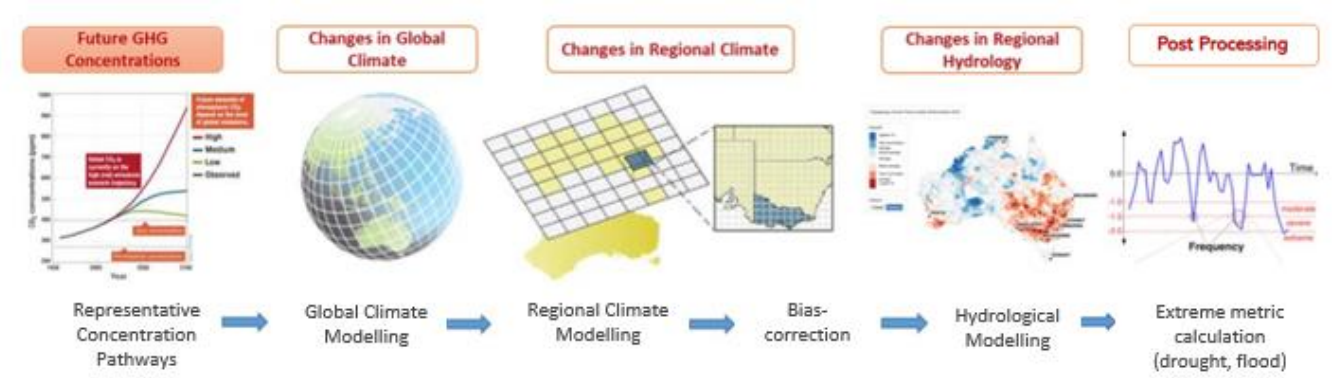

Figure 1.1. National Hydrological Projections workflow principles showing the processing steps: i) selecting representative concentration pathways, ii) running the 4 selected global climate models and also a regional climate model, iii) correcting the discrepancies between climate input and observation (bias correction) to produce the climate data, iv) running the climate data through a hydrological model to project hydrological changes and v) calculating projected hydrological extremes

State-of-the-art techniques were used to resolve the climate data to a finer geographic scale and correct for biases (to adjust for discrepancies between observations and the climate models). The resultant climate data was processed through a hydrological model to produce projections of future hydrological changes and extreme conditions.

Australian and international climate modelling groups simulate the world's weather and climate with global climate models under historical and future forcing from greenhouse gases as well as from atmospheric and solar forcing ('forcing' is the term used to describe the impacts of factors that affect Earth's climate). The models used for the National Hydrological Projections stem from the Coupled Model Intercomparison Project Phase 5 (CMIP5) (Taylor et al. 2012) undertaken by the World Climate Research Programme's Working Group on Coupled Modelling (WGCM) (PCMDI 2021).

First, 2 future scenarios were selected to represent potential future pathways of greenhouse gas concentrations, aerosols and other atmospheric chemical constituents: medium (RCP4.5) and high (RCP8.5) emissions of greenhouse gases (RCP stands for 'representative concentration pathway') (Figure 1.2). The medium RCP4.5 scenario sees emissions peak by mid-century at around 50% higher than the 2000 level then rapidly decline over 30 years before stabilising at half of the 2000 level. The high RCP8.5 greenhouse gas emission scenario simulates rapid emission increases through early and middle parts of the century to reach 950 ppm CO_2 by 2100. Both RCP4.5 and RCP8.5 were the only RCPs available for a dynamically downscaled regional climate model over Australia.

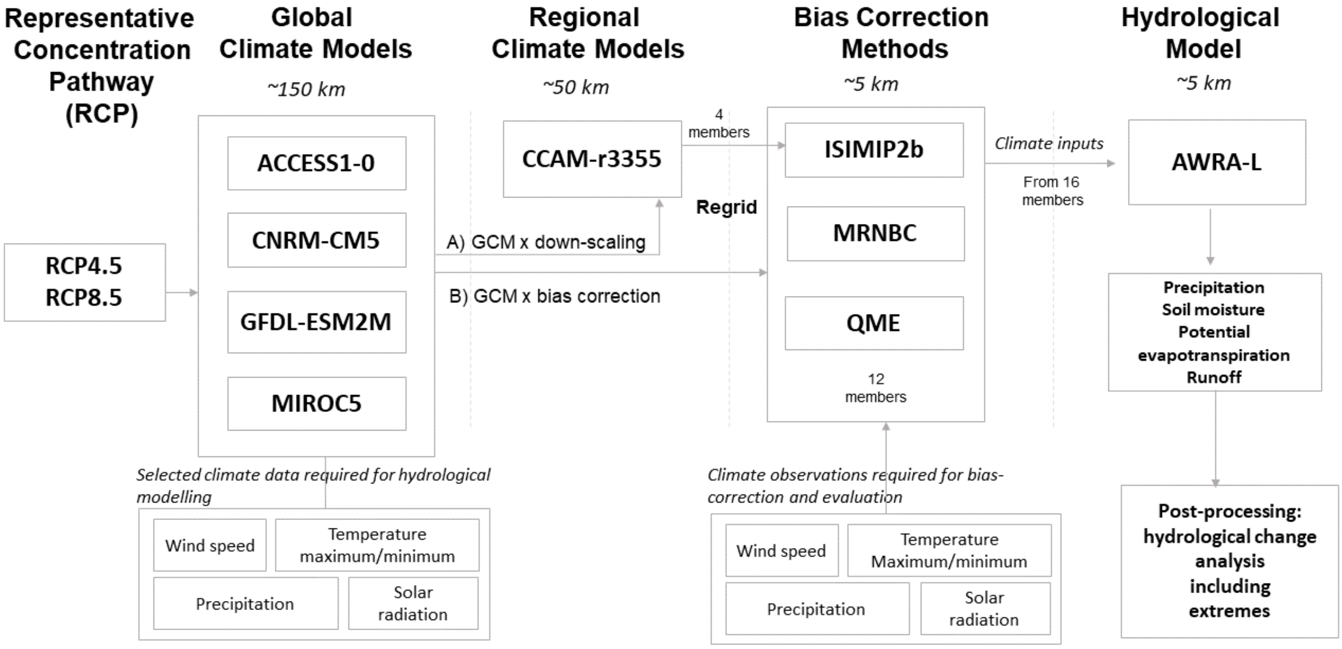

Figure 1.2. National Hydrological Projections showing details of the processing steps: i) 2 representative concentration pathways (RCP4.5 as medium and RCP8.5 as high) are selected, ii) 4 CMIP5 global climate models (GCMs) are selected, iii) path A – each GCM is downscaled by a regional climate model (RCM) to a 50km (0.5°) scale and then re-gridded to a 5 km (0.05°) scale. The RCM uses one bias-correction method (ISIMIP2b) that corrects the necessary climate inputs (precipitation, temperature, wind and solar radiation) against observations, iv) path B – each GCM is re-gridded to a 5 km (0.5°) scale and corrected directly using one of 3 bias-correction methods, and v) climate data from the 16-member ensemble is used to run the hydrological Australian Water Balance Model

(AWRA-L) to produce hydroclimate change information for precipitation, soil moisture, runoff and evapotranspiration. These hydroclimatic variables are processed to understand future changes on the Australian water cycle components, including extremes

As shown in Figure 1.2, 4 CMIP5 GCMs were chosen, each with a spatial resolution of about 150 kilometres (km) (Srikanthan et al. 2022). These climate models were chosen as a subset of the models used in the Climate Change in Australia assessment (see Chapter 5 in CSIRO & Bureau of Meteorology 2015). The 4 global climate models were selected to represent a range (wet, medium and dry) of plausible future climates across Australia and for their ability to provide all the necessary climate inputs for the Australian Water Resources Assessment Landscape hydrological model (AWRA-L, version 6.1) (Frost & Wright 2018). In addition, a regional climate model (RCM) was used to bring each of the 4 selected GCMs to a finer resolution output of about 50 square kilometres (km^2) over Australia. These regional models better account for regional climatic influences, such as local topography.

Before using climate inputs from climate models, biases in the global and regional climate model forcing were corrected against observations in a process called bias correction. Three bias-correction methods were applied to the climate data from the models, resulting in the following 16-member ensemble:

- 12 members – comprising each of the 4 global climate models corrected with 3 different bias-correction methods
- 4 members – comprising each of 4 global climate models, downscaled and adjusted to a finer resolution as a regional climate model and corrected with one bias-correction method (Figure 1.2).

Each ensemble member reflects the chosen characteristics of its bias-correction method; the range of ensemble members lets decision-makers select the approach best suited to their needs.

To examine future impacts of climate change and to inform decisions on adaptation, outputs from the climate modelling process were re-gridded to a 5 km scale and used in our hydrological model to provide projections at that scale across Australia. Using bias-corrected climate inputs of precipitation, temperature, wind and solar radiation from the 16-member ensemble, the hydrological AWRA-L model produced daily model outputs over Australia of soil moisture, runoff and potential evapotranspiration (the amount of evaporation and transpiration that would occur at a particular location when water available for this process is non-limited).

To assess hydrological changes, temporal results are aggregated in 30-year periods centred around 2030, 2050, 2070 and 2085 on annual and seasonal timescales. These results are shown as maps demonstrating the spatial variability of the region’s change signal or as graphs showing aggregated results across the regions.

Each step of the National Hydrological Projections modelling chain is carefully evaluated to understand the uncertainties associated with the modelling process. Uncertainties in hydroclimate change analysis can come from multiple sources, including:

- how greenhouse gas emissions will change into the future
- the processes represented in the climate models
- the effect of bias-correction and downscaling processes
- the hydrological modelling itself.

More details on how we address these uncertainties are discussed in Chapter 3. Further information on these models and the choices made in their selection as well as the evaluation process are detailed in our scientific publications and reports.

1.2 National Hydrological Projections hydrological assessment reports

Projection results feature many sources of uncertainty, including uncertainty over future trajectories of atmospheric greenhouse gas concentrations, how a warmer climate will lead to changes to hydroclimatic features and feedback loops, and the ability of climate models to represent those features. Acknowledging these uncertainties, the National Hydrological Projections ensemble provides a unique opportunity to examine impacts of plausible future changes on Australia's hydroclimate and its water resources.

To understand future impacts on Australia's water resources, region-specific assessment reports have been prepared on plausible future hydrological changes, including changes in precipitation, runoff, potential evapotranspiration and soil moisture as well as changes in extremes including droughts and floods. These assessment reports are based on 8 regions, formed from clusters of natural resource management (NRM) regions of Australia, that can be affected differently by climate change. These regions broadly represent groups of similar climatic and biophysical settings in Australia and corresponding natural resources. The National Hydrological Projections build on these regions and the scientific work that was previously carried out by the Climate Change in Australia (CCiA) initiative (CCiA n.d. a). CCiA provided the most nationally comprehensive, robust and consistent scientific information on future climate changes for Australia. Projected climate change has been described in detail in the individual CCiA reports for the NRM clusters (CCiA n.d. b), with additional regional detail being provided through ongoing initiatives from Australian state governments. This work builds a complementary picture in the context of the regional hydrological cycle, regional water assets and its future impacts.

These hydrological assessment reports are a demonstration case of the applicability of the National Hydrological Projections data and plausible future water resource impact analysis across Australia. They are intended to provide a high-level regional picture and raise awareness of plausible hydrological changes for a water-sensitive audience, including Australia's water, energy and environmental managers; emergency and recovery services; transport operators; farmers; and people generally interested in future changes to water resources. The reports present information in the form of 'storylines' of plausible future occurrences of hydrological extreme events (e.g. floods) and long-term hydroclimatic changes. This information can be used to guide investment decisions and develop mitigation and adaptation strategies.

This report focuses on the Wet Tropics region and is structured as follows:

- Chapter 1 introduces the National Hydrological Projections.
- Chapter 2 describes the assessment region, including its physiographic and hydroclimatic characteristics, recent conditions and long-term hydroclimatic trends.
- Chapter 3 evaluates our ability to simulate future hydrological changes, including the multiple levels of uncertainty, whether the climate models chosen can represent the region's climate and how well the hydrological AWRA-L model performs in the region. It also presents the results from the evaluation of the bias-correction methods. This information provides important context for the following chapter.
- Chapter 4 assesses the region's future hydroclimate conditions, which are presented as available National Hydrological Projections storylines. Changes are shown for precipitation, evapotranspiration, soil moisture and runoff assessed against the reference period (1976–2005). The chapter also provides insights into plausible future extremes of wet and dry periods.
- Chapter 5 demonstrates the applicability of storylines by exploring future water-sensitive impacts of selected case studies.

All foundational National Hydrological Projections datasets underpinning the assessment report analyses are also available as application-ready datasets via the National Computational Infrastructure (NCI) Data Catalogue (https://dx.doi.org/10.25914/6130680dc5a51).

For further detailed regional analysis, guidance on the use of National Hydrological Projections data or further general information, please contact us via water@bom.gov.au.

2 Regional description and hydroclimate of the Wet Tropics region

Four natural resource management (NRM) regions, Mackay Whitsunday, Wet Tropics, Cape York and Torres Strait, constitute the Wet Tropics hydrological assessment region (Figure 2.1). This region covers globally significant savannas, wetlands and low-lying tropical islands, most of Australia's tropical rainforests, and a high proportion of the Great Barrier Reef World Heritage Area (Hilbert et al. 2014a).

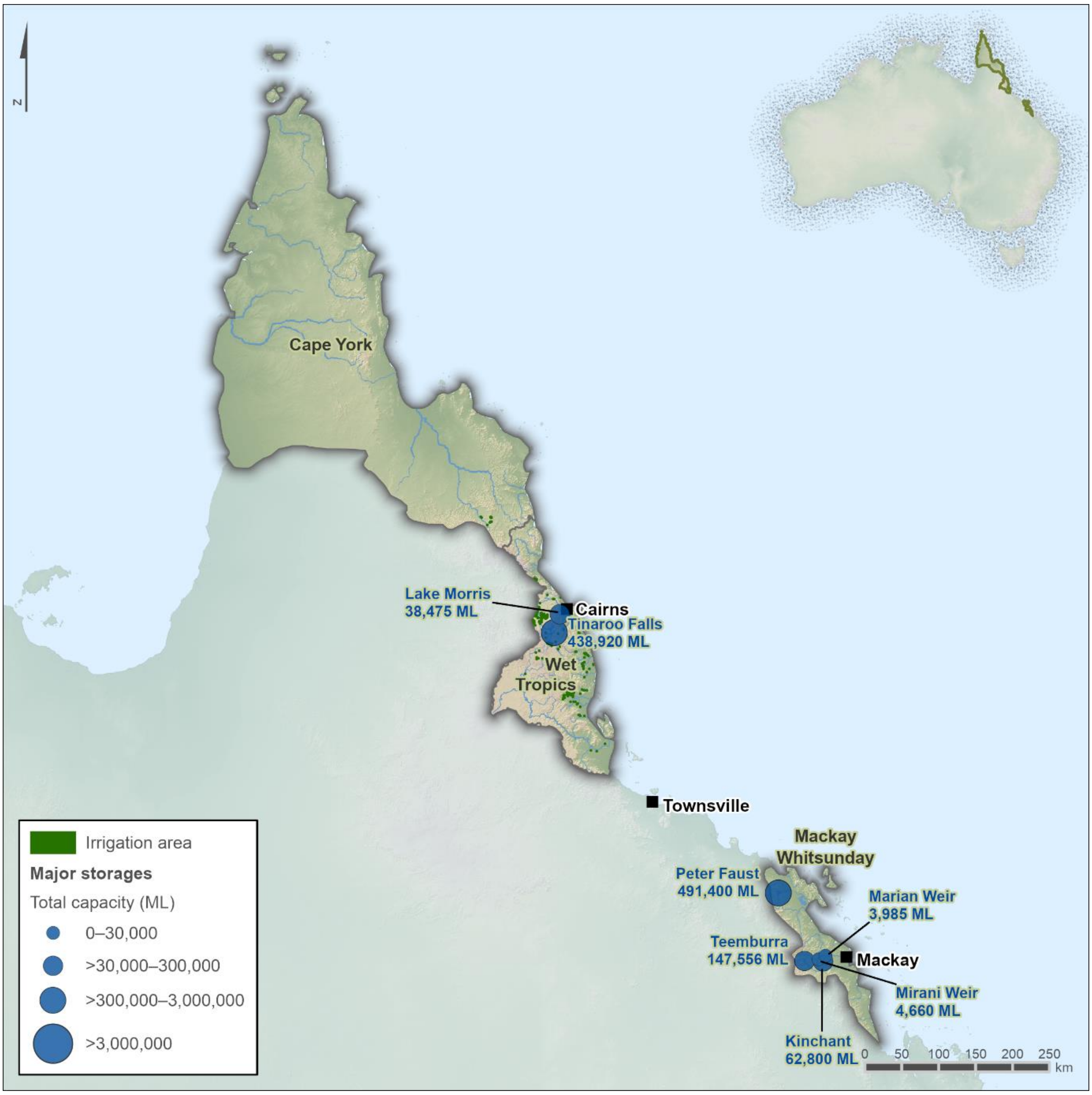

Figure 2.1. Wet Tropics region showing the northern and southern subregions

Approximately 50% of this region is under agricultural production. The vast majority of this agriculture is grazing cattle, and there is also horticulture (e.g. melon, tropical fruit and pumpkin) and broadacre cropping (e.g. sorghum, sugar cane, banana, avocado and potato). There are large areas of nature conservation, Indigenous land use and some forestry. The region has some of the most topographically diverse terrain in Australia, including flat, low-lying, floodplain landscapes, high altitudes associated with coastal ranges and tablelands, and a retreating escarpment in the coastal alluvial plains. The highest mountains in this region can be found south of Cairns, with peaks reaching altitudes of 1,600 m above sea level.

2.1 Climate

The Wet Tropics region is warm and experiences a wet season (November–April) dominated by north-westerly winds and a dry season (May–October) in which the south-easterly trade winds are dominant (McInnes et al. 2015; Troup 1961; Wheeler & McBride 2005; Zhang & Moise 2016). There is also a transitional period between wet and dry seasons in northern Australia, called the ‘build-up’, with high temperature and humidity as well as occasional precipitation events, typically from October to November. South-easterly trade winds bring consistent precipitation through the dry season to the east coast of the region. There is also a 'build-down' period in April and May when rain clouds have dispersed, and clear skies prevail.

Annual precipitation totals are generally greater than 1,000 mm across the Wet Tropics region. Some areas, particularly north and south of Cairns, have the highest annual precipitation totals in Australia – in excess of 3,000 mm. Rain falls predominantly during the monsoonal wet season (Figure 2.2a) when the monsoon arrives, typically by the end of December. The variation in local topography, including the height and orientation of mountain ranges and the direction of the coastline with respect to the prevailing moist south-easterly air stream, results in different precipitation regimes across the region (Johnson & Murray 2004). Tropical cyclones can also bring large amounts of precipitation to the region.

The start of the wet season can be determined by the shift in wind from westerly to easterly (signifying the start of the monsoon) or when precipitation since 1 September reaches 50 mm. Precipitation onset is typically in October or early November in the north and a little later in the south.

Precipitation during the Australian summer monsoon often occurs in a series of bursts that is sometimes associated with the Madden–Julian Oscillation (MJO), an eastward moving ‘pulse’ of cloud and precipitation near the equator that typically recurs every 30 to 60 days (Wheeler & McBride 2005).

The year-to-year variability in wet season precipitation tends to be lower in the northern areas of the region, such as the Torres Strait NRM region and northern Cape York NRM region, and more variable in southern areas, such as southern Cape York NRM region and the Wet Tropics and Mackay Whitsunday NRM regions. During a La Niña event, the waters in the Pacific Ocean surrounding the Wet Tropics are warmer than usual and precipitation is often greater than usual. In contrast, there is often less precipitation than usual during an El Niño year. El Niño and La Niña have greatest influence in the season prior to summer monsoon onset; they have less impact on precipitation variability once the monsoon season has started (Hilbert et al. 2014b; Suppiah et al. 2009; McInnes et al. 2015).

The Wet Tropics region’s precipitation also varies from decade to decade. Decadal variability in the Pacific Ocean can alter the influence of El Niño or La Niña on Australia's climate (Power et al. 1999). When the Pacific is in a longer term ‘La Niña like’ state, the association between El Niño or La Niña and Australian climate is strong.

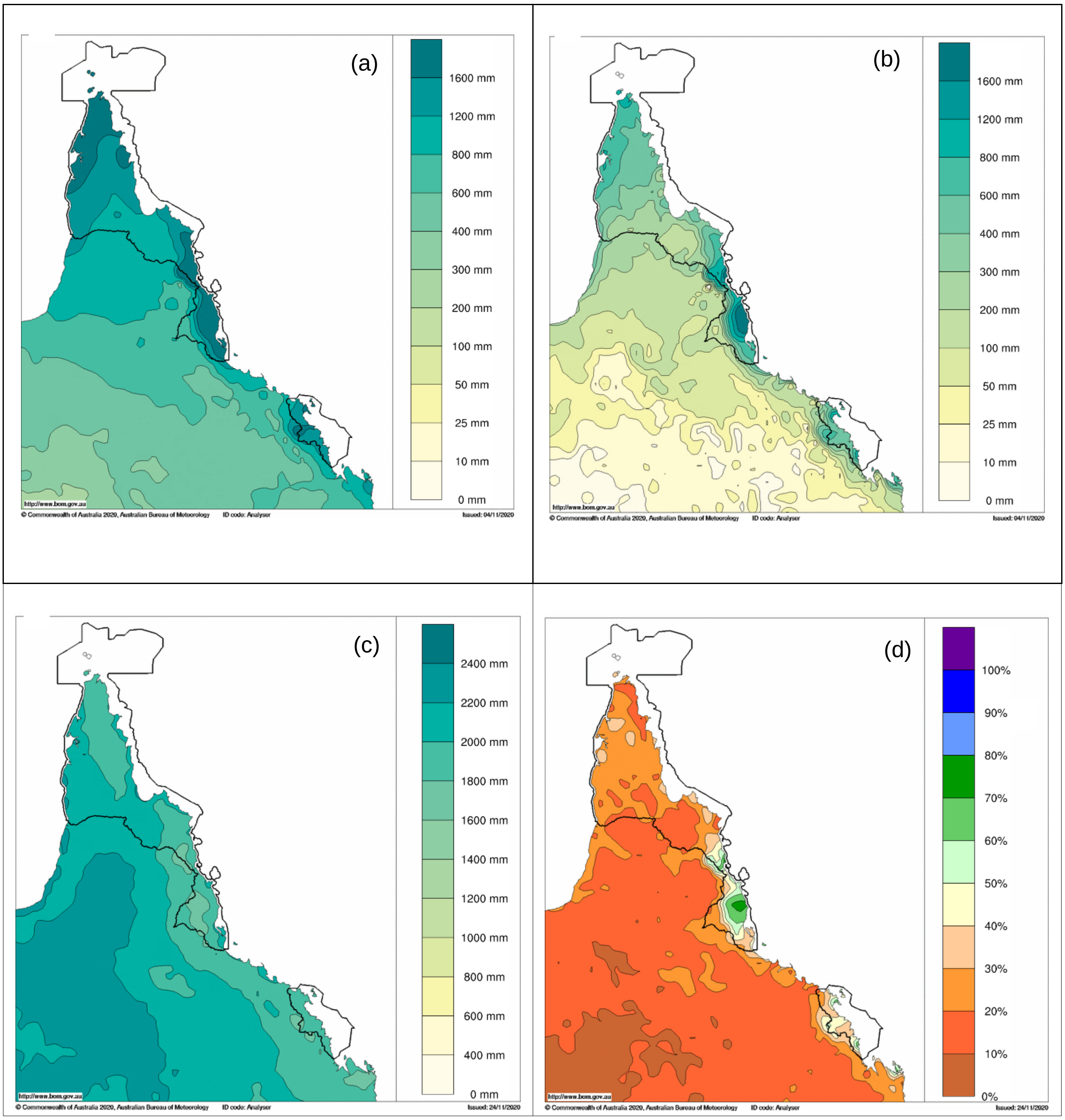

Figure 2.2. Wet Tropics annual average hydroclimate (1976–2005) showing (a) observed precipitation and AWRA-L modelled values for (b) runoff, (c) potential evapotranspiration and (d) soil moisture

In the Wet Tropics region, the highest monthly precipitation occurs in February and the lowest in September (Figure 2.3). Monthly averages in runoff and soil moisture simulated over the historical period (1976–2005) using the AWRA-L hydrological model follow the pattern of precipitation (Figure 2.3). The model estimates a high volume of runoff in the eastern Wet Tropics region, particularly adjacent to the coast (Figure 2.2b). Importantly, the Wet Tropics NRM part of the region contributes 7% to the Australia's annual runoff while comprising only 0.26% of Australia's land area (Pearson 2018). Monthly streamflow peaks in the wet season months of January and February (Pearson 2018). Streamflow in the Wet Tropics region is strongly seasonal and varies considerably from year to year. In the dry season, orographic precipitation (formed as air mass rises over mountains) and forest cloud moisture captures provide for perennial flow in rainforest regions (McJannet et al. 2007). Soil moisture as modelled by the AWRA-L model is typically highest in the southern part of the Wet Tropics region (Figure 2.2d).

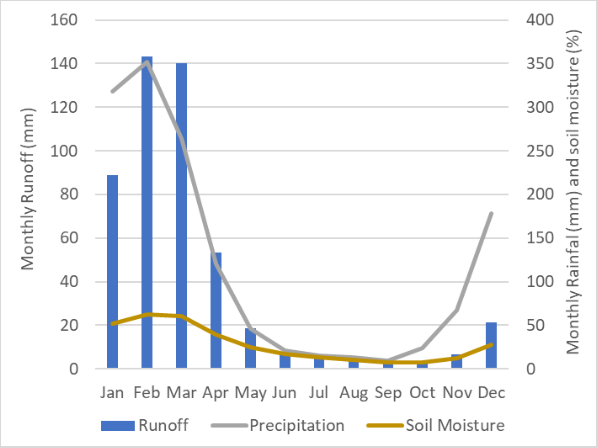

Figure 2.3. Monthly average observed precipitation and AWRA-L modelled runoff and soil moisture for the Wet Tropics subregions for the reference period (1976–2005)

The Wet Tropics region experiences widespread warm wet season temperatures of between 27 °C and 30 °C, and cooler dry season temperatures of between 18 °C and 25 °C (Figure 2.4). The coolest temperatures occur in the south. Figure 2.4 shows that, in terms of average temperature, December is the hottest month of the year and July is the coolest. Monthly potential evapotranspiration is high from October to December and is lowest in June and July. In other words, monthly potential evapotranspiration follows the same pattern as temperature with the highest values occurring in the build-up to the wet monsoon season when daily maximum temperatures are highest (Figure 2.4). Spatially the annual potential evapotranspiration is higher in the western inland parts of the region (Figure 2.2c).

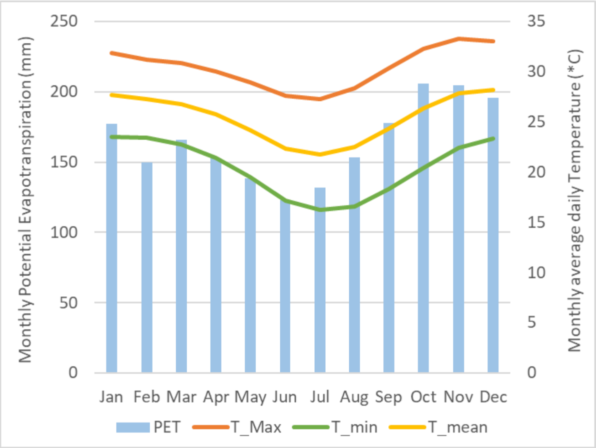

Figure 2.4. Monthly average observed temperature and AWRA-L modelled potential evapotranspiration for the Wet Tropics regions for the reference period (1976–2005)

2.2 Recent hydroclimatic trends and condition

Since the beginning of historical records in 1850s, the average temperature in the Wet Tropics has increased by about 0.9 °C. Minimum temperature have increased on average (0.9 °C) slightly more than maximum temperature (0.8 °C) (Suppiah et al. 2010). In that time, the average number of hot days (daily maximum temperature over 35 °C) has increased, and the number of cold days has decreased (Hilbert et al. 2014a). Inter-annual variability in temperature is strongly driven by the El Niño–Southern Oscillation (ENSO). Warmer years (such as 1998) are generally associated with El Niño events. Since 1950, average sea-surface temperatures have been increasing in the Wet Tropics region. They have increased by about 1 °C in Torres Strait and around northern Cape York Peninsula compared with about 0.6 °C elsewhere in the region (Hilbert et al. 2014a).

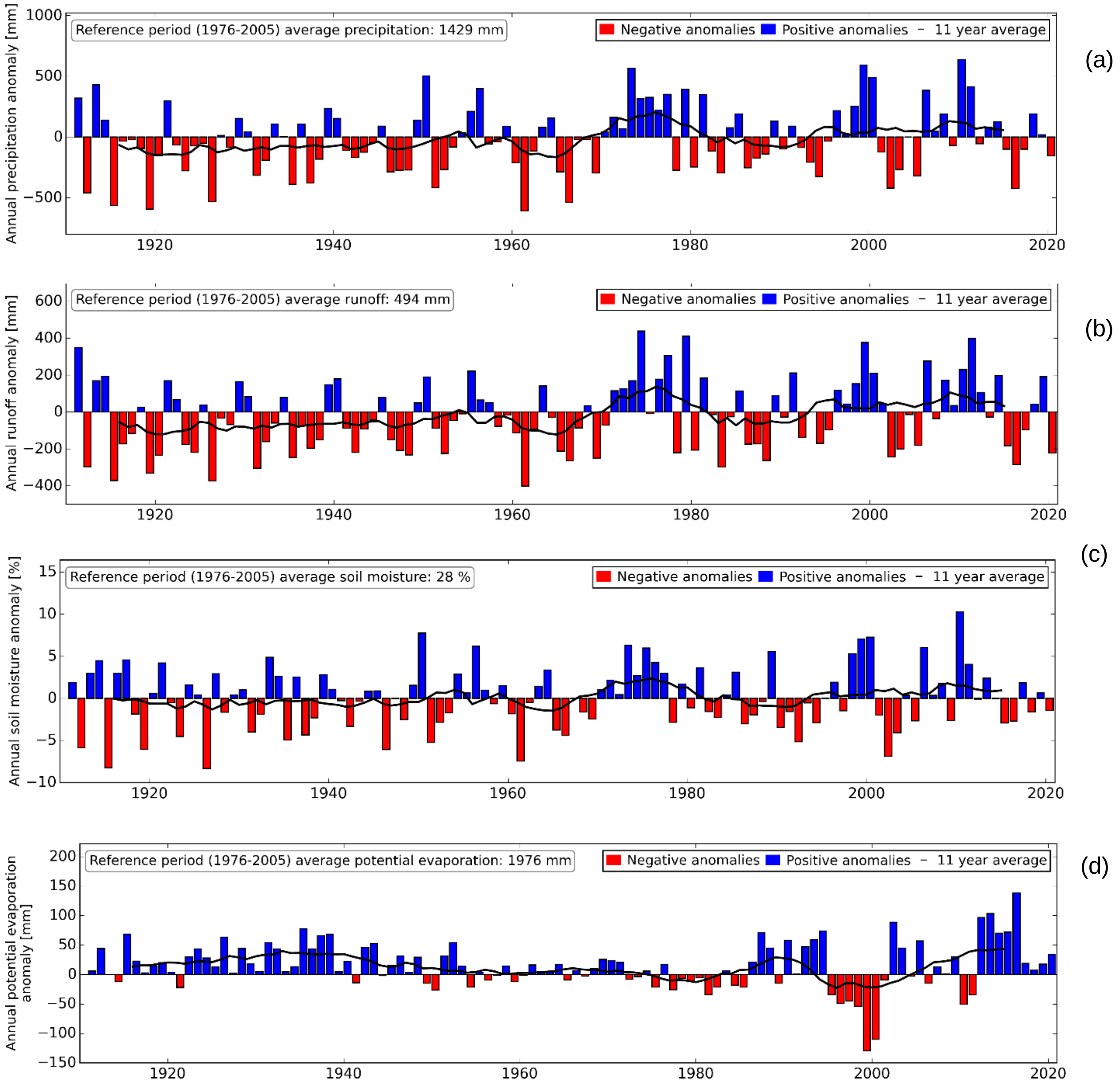

Figure 2.5. Wet Tropics annual anomalies relative to the reference period (1976–2005) mean in (a) observed precipitation and AWRA-L modelled values for (b) runoff, (c) soil moisture and (d) potential evapotranspiration

While precipitation across the Wet Tropics region is monsoon dominated, there can be large variation in year-to-year precipitation totals (Figure 2.5a). Historically, the region experienced a mix of drier and wetter periods in the early 20th century and more frequent wetter-than-average years since the 1970s (Regional Weather and Climate Guides); however, no long-term trend in annual precipitation is evident throughout the 20th century (McInnes et al. 2015; Bureau of Meteorology 2021). The Bureau of Meteorology (2021) reported an increase in monsoonal rain in northern Cape York NRM and a decrease in the Wet Tropics NRM region over the historical period (1976–2005), although monsoonal rains have been reliable throughout the Wet Tropics region as a whole.

Precipitation, runoff, and soil moisture follow similar patterns for the long-term average (11-year moving average) (Figure 2.5). The annual precipitation variability in the entire region during the past century shows fluctuations on multi-decadal time scales (e.g. the 1920s, 1930s, 1940s, 1960s and 1990s were dry decades and the 1970s was a wet period). The runoff and soil moisture simulated over the historical period (1976–2005) using the AWRA-L hydrological model follow a similar pattern to the precipitation with the highest runoff volumes peaking during the late wet season (Figures 2.2, 2.3 and 2.5). Large year-to-year variability in runoff and soil moisture is observed, although there are no detectable long-term trends, a finding supported by Pearson (2018). The average annual evapotranspiration in this region (from 1976 to 2005) is 1,976 mm, and the annual anomalies vary from year to year but have increased in recent years (Figure 2.5d).

2.3 Water availability and management

The Wet Tropics region has high total annual precipitation and streamflow and a high level of physical water availability relative to its use over the year. The rivers on the eastern side of the region, such as Lockhart, Daintree and Mossman rivers, drain to the Coral Sea. The rivers located on the western part of Cape York, such as the Ducie, Embley, Ward and Holroyd rivers, drain into the Gulf of Carpentaria. River flows are strongly seasonal, and major inflows into storages occur during the wet season months from November to April. Storing water is important to meet irrigation water demand of crops during the dry season (May–October). As water availability is generally much greater than water demand, water use allocations and actual diversions vary little between years.

There are some water storages in this region for town water supply, small scale irrigation, hydro-electricity and recreational purposes. These include Tinaroo Falls Dam, Peter Faust Dam, Lake Morris, Marian Weir, Mirani Weir, Kinchant Dam and Teemburra Dam (Figure 2.1). The largest are Peter Faust Dam north of Mackay with a capacity of 491 GL and Tinaroo Falls Dam in Cairns with a capacity of 439 GL.

Water storages can alter natural flow regimes, which can lead to loss of habitat, breeding failure and even extinction of some species. The rules that govern storage releases and limit abstractions are designed to achieve environmental objectives, that is, to retain various temporal flow characteristics at different nodes along the rivers. The volume of water released will depend upon the environmental flow objectives and flow conditions. Various performance indicators are used for assessing environmental flow objectives. As some of these catchments drain into the Great Barrier Reef World Heritage Area, water quality management is important and is managed through the *Reef 2050 long-term sustainability plan* (Commonwealth of Australia 2015).

Some rivers in this region, particularly those draining into the Gulf of Carpentaria and into the Coral Sea, such as the Wenlock River, are still largely intact and are free flowing. Rivers in this region are home to many important freshwater assets, such as threatened species and wetlands of national significance, and are also significant for commercial and recreational fisheries. During the dry season, natural groundwater discharge plays a vital role in maintaining dry season stream flows. However, some reaches of these rivers are reduced to a series of waterholes, which can act as important refugia for aquatic biota.

3 Ability to simulate hydroclimatic conditions of the Wet Tropics region

Assessing how well climate and hydrological models simulate key elements of the hydroclimate for Australia and the Wet Tropics region is an essential part of understanding the potential future impacts of climate change. Assessments of model performance against observations and the latest scientific understanding of hydroclimatic processes provide a basis for confidence, in the sense of enabling trust in sets of projections. Models are not expected to reproduce observations exactly but rather are assessed in terms of their ability to capture important aspects of variability and their representation of important processes. Bias correction is an important step in the process of hydrological impact modelling. It brings information simulated by global climate models about the impacts on our climate system of rising greenhouse gases together with our best representation of hydrological processes at local scales (in this case, the assessment region). Bias-corrected climate data and the simulated hydrological output data are compared against observations to assess the performance of the models and processes. For a detailed description of the modelling process and a technical assessment of performance, please see the National Hydrological Projections technical report (Srikanthan et al. 2022).

Climate and hydrological models are always an imperfect representation of the reality (and plausible future) and are therefore associated with various sources of uncertainties. These uncertainties are intrinsic to hydroclimatic modelling and arise from the selection of climate models and the differences in model responses in a warming climate. These differences include the representation of climate drivers and their expression through, for example, El Niño and La Niña events and can also include the uncertainty of future human behaviours affecting greenhouse gas emissions. Further sources of uncertainties stem from the influence of bias corrections as well as from the hydrological modelling and the representation of hydrological processes itself. Thus, we can never forecast the exact time series of Australian temperature, precipitation and other climate drivers, and the National Hydrological Projections will differ from observations over short to medium periods. These uncertainties influence our ability to simulate the hydroclimate in Australia. This section briefly introduces the models and methods used in these National Hydrological Projections and assesses our ability to simulate the hydroclimate of the Wet Tropics in the context of the uncertainties. More details on the methods used can be found in the technical report (Srikanthan et al. 2022).

A number of choices were made in developing the datasets used in these National Hydrological Projections. Four global climate models (GCMs) were selected: ACCESS1-0, CNRM-CM5, GFDL-ESM2M and MIROC5. These models were selected from the suite of 42 models in the international Coupled Model Intercomparison Project Phase 5 (CMIP5). These 4 were chosen because they fulfilled important requirements, including the following:

- GCM data was available for input into the hydrological models.
- The GCM had been used to force one or more dynamical downscaling models.
- The GCM represents the large-scale drivers of climate and weather variability well.
- The GCM simulates Australia’s precipitation, temperature, wind and radiation relatively well.
- The 4 models together represent the range of future precipitation and temperature changes relative to the spread of the 42 models of the CMIP5 ensemble.

The range of climate responses from each GCM, in any particular year, derives from the particular state of the weather and large-scale variability occurring within that model in that year. Each GCM models its own weather, and the climate varies over the longer term of the simulation in response to changing atmospheric levels of greenhouse gases, aerosols and ozone in the upper atmosphere (and the Antarctic ozone hole).

In addition, one atmosphere-only climate model was used to ‘downscale’ the GCMs from their 150 km resolution to 50 km. CCAM, CSIRO’s Conformal Cubic Atmospheric Model, is a global model in which the grid point spacing is stretched to have fine resolution over Australia. Additional dynamically downscaled data was available to the National Hydrological Projections under the Victorian Climate and Water Initiative (VicWACI) and other initiatives of the Victorian Government. Another regional model known as WRF (Weather Research and Forecasting model) dynamically downscaled the GCMs to about 50 km through the New South Wales Government–led partnership NARCliM (NSW and ACT Regional Climate Modelling). NARCliM output was included in the historical era simulations using the hydrological model but was not available for projections at the time of the release. The aim is to include further downscaling models in future updates to the projections service.

Three bias-correction methods were implemented to improve the representation of local climate conditions and reduce biases relative to observed data. First, the output of the GCMs and downscaling model were scaled down from their original scale (about 150 × 150 km) to 5 × 5 km resolution using a conservative re-gridding method; then the bias correction was applied. Each of the bias-correction methods is designed to preserve various features of the climate signal such as trend, inter-annual variability or seasonality of a climate variable.

The ability of each ensemble member to simulate the future hydroclimate of the Wet Tropics region was assessed by evaluating its ability to reproduce the observations and observation-based model results of the 1976 to 2005 reference period. This evaluation let us identify any biases in the models that were likely to be carried forward into future projections. A range of evaluation techniques and statistics were used to evaluate the ability of the ensemble to simulate the hydroclimate of each individual region.

The following 3 bias-correction methods were used:

- ISIMIP2b, a quantile-based method that preserves the trend in the data (Hempel et al. 2013)
- QME, a quantile-based method that models the extremes well (Dowdy 2020)
- MRNBC, a method that preserves the interdependence among the variables as well the low-frequency characteristics (Johnson & Sharma 2012; Mehrotra & Sharma 2016).

The bias-corrected data was evaluated to assess the effectiveness of the bias-correction methods. The AWRA-L model (see Section 3.2) was then run with the bias-corrected climate data as input.

3.1 Ability to simulate the key climate drivers

The skill of the 4 National Hydrological Projections GCMs (among other GCMs) to represent the key large-scale drivers of Australia’s climate was assessed previously by the Climate Change in Australia initiative (Moise et al. 2015). This assessment provided a basis for placing confidence in the model’s projection for Australia and identified individual ensemble members or ensemble groups that may have significant performance issues in simulating a key aspect of climate variability.

Many CMIP5 GCMs have a bias in the Pacific Ocean whereby the ENSO signal extends too far towards Australia along the equator. This bias is minimal in the 4 National Hydrological Projections models selected; thus they represent the processes influencing climate variability in northern and eastern Australia reasonably well (Brown et al. 2016). A common bias seen in the eastern Indian Ocean in the Australian spring is relatively small in 3 of the models. However, CNRM-CM5 has this bias, which might limit the expected increase in the frequency of extreme positive Indian Ocean Dipole events and their expression through dry conditions in south-east Australia (Wang et al. 2017).

The 4 GCMs chosen for these projections, ACCESS1-0, CNRM-CM5, MIROC5 and GFDL-ESM2M (Table 3.1), were found to represent the weather-scale features influencing northern Australia well, and their future changes should be considered reliable. However, CMIP5 GCMs in general do not capture the eastward propagating sub-seasonal monsoon activity, cloudiness and rain linked to the Madden–Julian Oscillation (Moise et al. 2015).

Table 3.1. Details of selected global climate models

Climate model	Type	Institute	Country of origin	Reference
ACCESS1-0	Global	CSIRO and Bureau of Meteorology	Australia	Collier and Uhe (2012)
CNRM-CM5	Global	Centre National de Recherches Météorologiques – Groupe d'études de l'Atmosphère Météorologique (CNRM-GAME) and Centre Européen de Recherche et de Formation Avancée	France	Voldoire et al. (2013)
GFDL-ESM2M	Global	Geophysical Fluid Dynamics Laboratory, National Oceanic and Atmospheric Administration (NOAA)	USA	Dunne et al. (2012)
MIROC5	Global	Japan Agency for Marine-Earth Science and Technology (JAMSTEC)	Japan	Watanabe et al. (2010)
CCAM r3355	Regional	CSIRO	Australia	Rafter et al. (2019)

For completion, MIROC5 fulfils the requirements for inclusion in our ensemble although it does not represent the weather features that are important for the southern Australian climate as well as some others and might be considered less reliable. However, its inclusion helps the National Hydrological Projections GCM ensemble embrace the range indicated by the full range of 42 CMIP5 models (Srikanthan et al. 2022).

3.2 Hydrological modelling: the Australian Water Resources Assessment Landscape model (AWRA-L)

The Bureau's operational Australian Water Resources Assessment Landscape model (hereafter AWRA-L) was used to project root zone soil moisture, potential evapotranspiration and runoff. AWRA-L is a daily semi-distributed water balance model based on a 5 × 5 km (0.05°) grid. It models hydrological processes separately for each spatial unit, called a hydrologic response unit (HRU). At each grid cell it simulates the flow of water through the landscape: precipitation entering the grid cell, passing through the vegetation and soil moisture stores, and leaving the grid cell through evapotranspiration, runoff or deep drainage to the groundwater (Figure 3.1). Each grid cell in AWRA-L is divided into 2 HRUs, these represent deep-rooted vegetation (trees) and shallow-rooted vegetation (grass). The spatial distribution of the HRUs remains static over time and does not reflect land use change.

The AWRA-L model is calibrated at the national scale to match streamflow, soil moisture and evapotranspiration observations from across the country. This calibration enables a nationally consistent dataset, but model evaluation results can vary between regions and landscape features (Frost & Wright 2018).

Model performance can be affected by the number of calibration catchments local to the region or representative of the landscape feature. AWRA-L better captures the runoff dynamics in wetter regions and periods, while discontinuous runoff regimes, consisting of long dry periods followed by short periods of extreme precipitation, are more difficult to characterise. A positive bias in runoff can result in areas with extended periods of no flows in central and northern Australia. Groundwater–surface water interactions are not well represented in AWRA-L, resulting in a drop in performance in areas where there is a high dependency on the contribution of baseflow to the generation of streamflow.

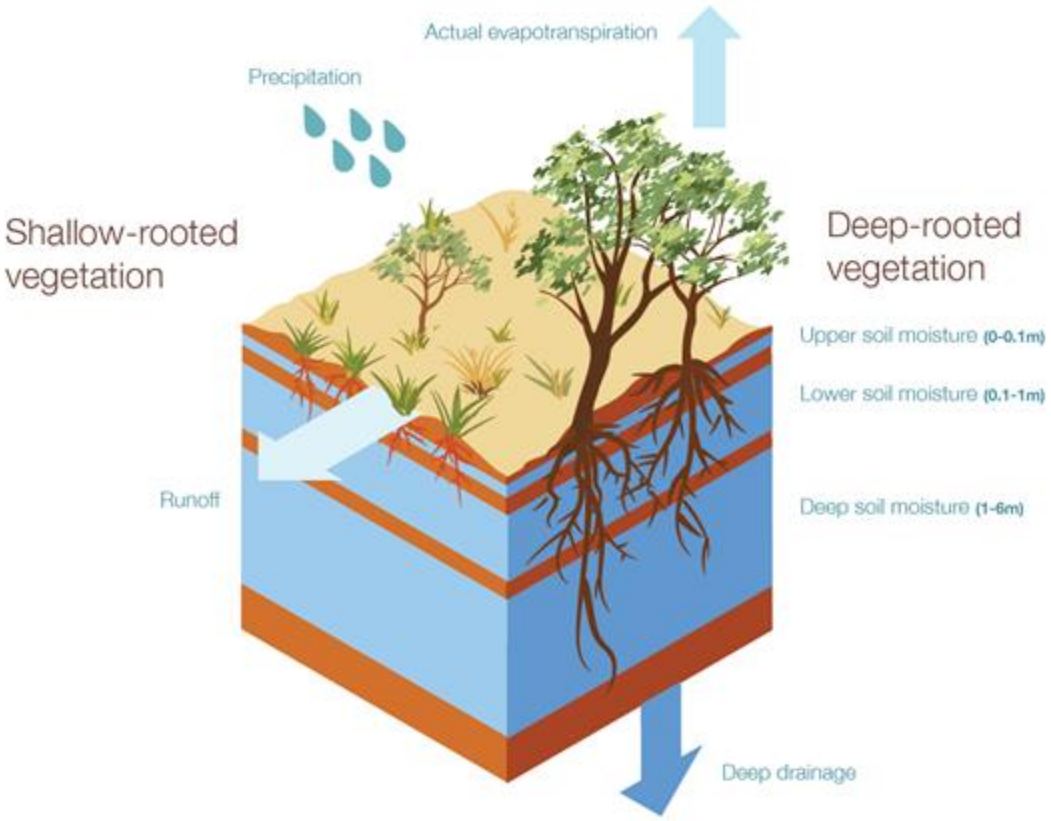

Figure 3.1. AWRA-L model grid cell with key water stores, fluxes and the hydrologic response units of deep- and shallow-rooted vegetation

The Bureau's operational AWRA-L was chosen as the hydrological model based on the evaluation and benchmarking of the available national models presented in Frost and Wright (2018). Importantly, this evaluation considered runoff, soil moisture and actual evapotranspiration in the assessment of the models. AWRA-L was run independently using the bias-corrected GCM climate data as input. The lack of feedback between the GCMs and AWRA-L means that the potential role of increased carbon dioxide levels on vegetation growth and evapotranspiration rates are not modelled (Greve et al. 2017; Yang et al. 2019). Future land use changes and vegetation changes resulting from future temperature and water availability changes are also not considered in AWRA-L or the GCMs. Together these factors will grow in importance over time, adding an extra facet of uncertainty to the soil moisture and runoff projections later in the century. A detailed description of the quantification of the AWRA-L model uncertainty can be found in Azarnivand et al. (2022).

3.3 Ability to simulate the hydroclimate of the Wet Tropics region

The 4 GCMs were chosen to represent the range of future precipitation and temperature changes for Australia as described in the National Hydrological Projections technical report (Srikanthan et al. 2022). The 4 selected GCMs were compared to the entire ensemble of 42 CMIP5 Climate Change in Australia (CCiA) models to see how these models represent wet or dry futures (Figure 3.2). This provides an overview of how the selected GCMs rank relative to the full CMIP5 ensemble across Australia and respective climate variables.

The 4 global climate models chosen for these projections, ACCESS1-0, CNRM-CM5, MIROC5 and GFDL-ESM2M (Table 3.1), were found to represent Australia's weather-scale features well, and their future changes should be considered reliable (Grose et al. 2015) In the Wet Tropics, the majority (3 out of 4 GCMs) of the 4 selected CMIP5 models project a decrease in precipitation for 2030. In 2070, 2 of the models project a decrease and 2 models project an increase in precipitation. Overall, the 4 GCMs are representative of the projected future precipitation in the Wet Tropics, but they do not capture the extreme dry or wet ends of the full suite of CMIP5 GCMs (Figure 3.2). The full CMIP5 ensemble of 42 models projects an increase in temperature in the Wet Tropics, and the 4 selected models capture the central to lower end of this range. Overall, the 4 GCMs adequately represent the future climate projected by the 42 CMIP5 GCMs for the Wet Tropics, where more GCMs project a drier climate by 2030. However, by 2070 about half of the GCMs project a drier and half project a wetter future climate. The 4 selected GCMs do not project as great a range of drier and wetter future climates as is projected by the full suite of CMIP5 GCMs.

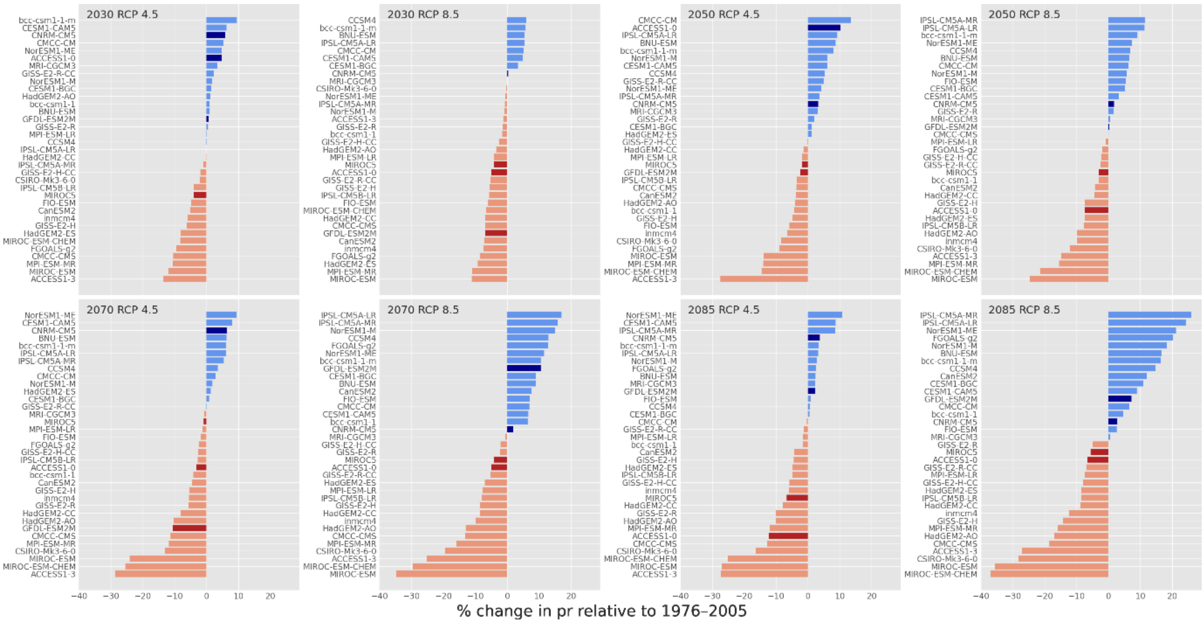

Figure 3.2. Ranking of the Wet Tropics region precipitation projections for the GCMs used in this study (shown in darker colours) compared to the CCiA ensemble for RCP4.5 and RCP8.5 for 2030, 2050, 2070 and 2085. The horizontal bars indicate the change signal – the difference of the regional average quantity from the monthly pattern for the reference period (1976–2005)

Simulated hydroclimate data for the current climate (produced by the 16-member ensemble) is assessed by comparing it with observational datasets from AWAP (Jones et al., 2009). In addition, three outputs (soil moisture, runoff and potential evapotranspiration) obtained by forcing the AWRA-L model with AWAP and bias corrected data were also compared. Since the models are not perfect representations of the world, the simulated data will not exactly match the observed data. A certain tolerance level is used in assessing the model simulations. The precipitation and temperature observation networks have a good coverage across the Wet Tropics and are suitable for evaluation purposes. The evaluation of the ability of the ensemble members to replicate the reference period (1976–2005) observations and model runs revealed overall minimal bias in the Wet Tropics. Evaluation criteria, such as representing the seasonality of the climate variables, are found to be largely preserved in all ensemble members (see Appendix Figures 8.1 to 8.10). There are some seasonal precipitation biases for individual ensemble members or ensemble groups, including a tendency for the ensemble members to underestimate September to November precipitation (of maximal 15% for ACCESS1-0 bias corrected with ISIMIP2b) and winter precipitation (all MRNBC bias-correction ensemble members). However, all the bias-correction approaches can satisfactorily replicate inter-annual and inter-seasonal variability.

Biases in the hydrological variables, including potential evapotranspiration, soil moisture and runoff, are calculated by comparing the results produced by the ARWA-L model forced with observed climate inputs and those modelled by the ensemble for the 1976 to 2005 reference period. While both positive and negative biases occur across the seasons for potential evapotranspiration, there is an overall small (<2%) negative bias in the ensemble. Ensemble members bias corrected using the QME approach have the highest positive bias in potential evapotranspiration, particularly from June to November. Most of the ensemble members have a bias of less than 5% for soil moisture and there is an even spread between positive and negative. The exceptions are models that are bias corrected with QME, which show a positive bias of up to 25% for September to November and a negative bias for December to February of up to 10% (see Appendix Figures 8.15 and 8.16). The evaluation statistics reveal the ability of the ensemble members to replicate the historical model runoff satisfactorily for most but not all models: MRNBC bias-corrected ensemble members show the least bias for AWRA-L modelled runoff over all the seasons (negative bias less than 10%). Other models show both negative and positive biases, between –10% (QME) and 55% (QME and GFDL-ESM2M_ISIMIP2b) for September to November and during the low-flow months from June to November).

It is important to consider the ability of the AWRA-L model to represent the hydrology in this tropical landscape. The vegetation of the Wet Tropics region is dominated by agricultural land, natural reserve, and forest and is characterised by the shallow- and deep-rooted hydrologic response unit in the AWRA-L model (Frost et al. 2018).

The runoff regime in the Wet Tropics is discontinuous in large parts of the region with extended periods of no runoff, mostly during the dry season months from May to October, making it difficult for the AWRA-L model to capture this variability. AWRA-L is a nationally calibrated model with 19 of the 305 calibration catchments in the Wet Tropics region. The performance of the continentally calibrated AWRA-L model for the Wet Tropics is good based on the median monthly Nash–Sutcliffe coefficient of efficiency (NSE) (Nash & Sutcliffe 1970) greater than 0.6. Wasko and Nathan (2019) analysed streamflow trends post 1970 for both streamflow observations and modelled runoff from the AWRA-L model. They found a combination of positive and negative trends in the runoff at 17 streamflow sites across the region. The AWRA-L model was able to match the trend direction for 59% of sites for annual volumes and 82% for both summer and winter flows compared to historical observations.

In summary, the ability of the National Hydrological Projections ensemble members to simulate the hydroclimate for the Wet Tropics region is satisfactory. The AWRA-L simulated runoff, soil moisture, and potential evapotranspiration from the bias-corrected climate data is satisfactory for most of ensemble members across the Wet Tropics region, although it should be noted that runoff shows most differences, and some ensemble members have a positive bias.

4 Available National Hydrological Projections storylines for the Wet Tropics region

Generally, projections provide a collection of plausible future ‘storylines’ rather than a forecast or likelihood of a specific outcome. Individually each ensemble member represents an internally consistent future storyline. Thus, while the ensemble members are based on slightly different physics, they all are built on plausible representations of physical processes. Individual ensemble members are the most appropriate method to represent this internal consistency and are a key element of establishing a storyline. No 2 ensemble members will follow the same changes in the many different climate features that can be considered.

The National Hydrological Projections used in this report allow for a unique region-wide assessment of projected hydroclimatic changes of the Wet Tropics region. Results below are drawn from the assessment of the 16-member ensemble of hydroclimatic variables. The projected hydroclimate for the region is presented in this chapter as a set of available plausible future changes of key hydrological variables or storylines. It presents a set of key figures representing the change in the hydroclimate into the future under 2 different representative concentration pathways and showing how this change varies within the Wet Tropics region.

In addition to the National Hydrological Projections, previous climate projections result for the region are described in the Wet Tropics CCiA report (McInnes et al. 2015). State-based datasets provide further projection information for the region, and Queensland projections information can be found on the Long Paddock website (Syktus et al. 2020). Queensland projections use 10 climate models in total. Each of the GCM outputs used in Syktus et al. (2020) is downscaled using CCAM to 50 km resolution, as used in the National Hydrological Projections. Queensland projections then downscale projections data to 10 km. Basic climate variables are provided as well as wind and potential evapotranspiration, but Syktus et al. (2020) does not provide other hydrological variables.

4.1 Interpreting the National Hydrological Projections storylines

The projected future conditions are represented by the degree of change relative to the conditions of the reference period (1976–2005). Each of the 16-member ensemble is run for this reference period and for the future. As described in Chapter 3, each ensemble member is evaluated on the basis of the differences between the modelled reference period and the observations. These differences inform our assessment of the change in conditions projected by each ensemble member for the future. The change can be presented in absolute values (e.g. millimetres of precipitation) or as a relative proportion of the mean for the region (e.g. a 10% increase in precipitation). There is significant value in interpreting both absolute and relative values depending on the application.

Chapter 3 outlines how an ensemble of GCMs and bias-correction methods has been used to develop a range of plausible future conditions. This spread in the 16-member ensemble represents a range of plausible future conditions that decision-makers can use to explore impacts. The median of the 16-member ensemble represents a mid-range view of those plausible futures. The results are communicated against a series of future 30-year periods, which are referred to by their midpoint. For example, the results reported against 2050 represent the average of the 2036–2065 period. This allows us to identify general trends into the future beyond annual fluctuations. Results from other projections are discussed to contextualise where these storylines fit in a broader understanding of plausible futures.

Spatial variations in the projected conditions are represented by the differences in ensemble median and only presented for the futures, representative concentration pathways and units that are most relevant to the key finding in the region. Inter-annual variability is visually represented by a single ensemble member (ACCESS1-0_ISIMIP2b) in the time series graphs. This single ensemble member time series should not be interpreted as a forecast for individual years; it is designed to model the extent to which the shorter-term climate drivers are likely to vary from the annual values.

Summary tables present key findings from multiple levels of evidence: projected results that describes the spread of the 16-member ensemble, concordance with historical trends reached by previous studies if available, and the assessment of the ability of the ensemble to simulate the hydroclimate in the region.

4.2 Precipitation

Projections for annual mean precipitation of the 16-member ensemble in the Wet Tropics region show that both increases and decreases are plausible. With high year-to-year variability, both dry and wet years are plausible, as demonstrated by the climate model ACCESS1-0_ISIMIP2b in Figure 4.1. The median mostly projects decreases (Figure 4.1 and 4.2), but also some increases at particular times and in some areas (Figure 4.3 to 4.4). The large spread of the ensemble, with both increases and decreases in annual precipitation being plausible, makes the ensemble median not very reliable as an indicator of the change signal. There are no clear differences in either the change signal or the spatial pattern of projected precipitation changes between representative concentration pathways. This similarity between representative concentration pathways is a key indicator of uncertainty in projections for this region, as it remains unclear if this is because emission forcing will not drive changes that exceed natural variability or because the models do not adequately simulate the response of key rain-bearing climate drivers to a warming climate. McInnes et al. (2015) and Hilbert et al. (2014a) concluded that natural climate variability will remain the major driver of precipitation changes into the future.

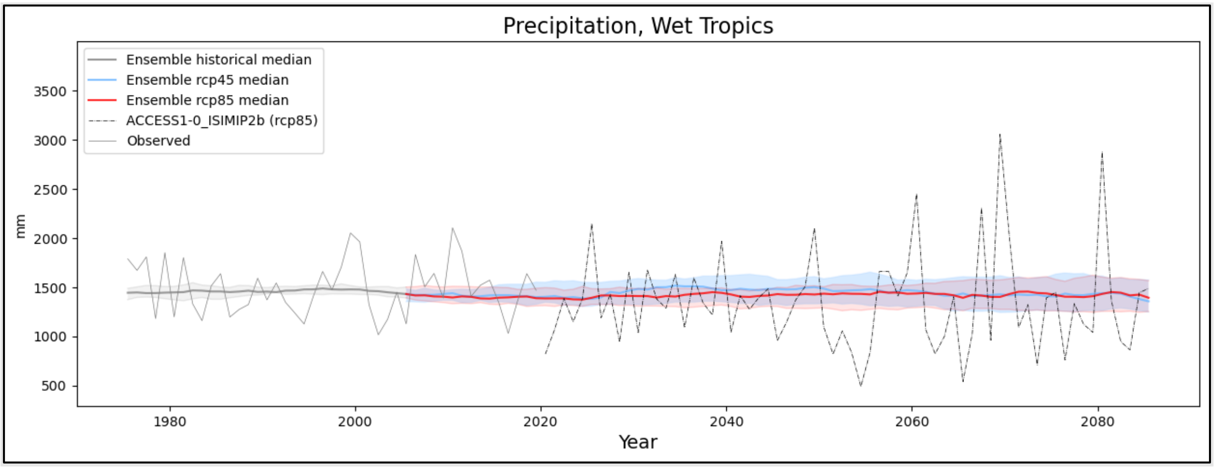

Figure 4.1. Annual modelled precipitation projected to 2099 by the 16-member ensemble for RCP4.5 (blue) and RCP8.5 (red) in the Wet Tropics region. The shaded areas represent the 10th to 90th percentile range for all ensemble members in the historical and future time periods. The time series for ACCESS1-0_ISIMIP2b (RCP8.5) is included (dotted line) to show the variability projected for an individual ensemble member. The grey line represents the observed historical median precipitation based on AWAP data

The largest decreases to precipitation are projected to occur in the wet season (Figure 4.4b), and projected precipitation reductions are greatest along the coastal regions (Figure 4.3). An expected rise in the average altitude of the orographic cloud layer due to global warming could intensify the effects of longer and more variable dry seasons (Pounds et al. 1999), reducing the capacity of the canopy in mountain rainforests to capture much cloud (Still et al. 1999).

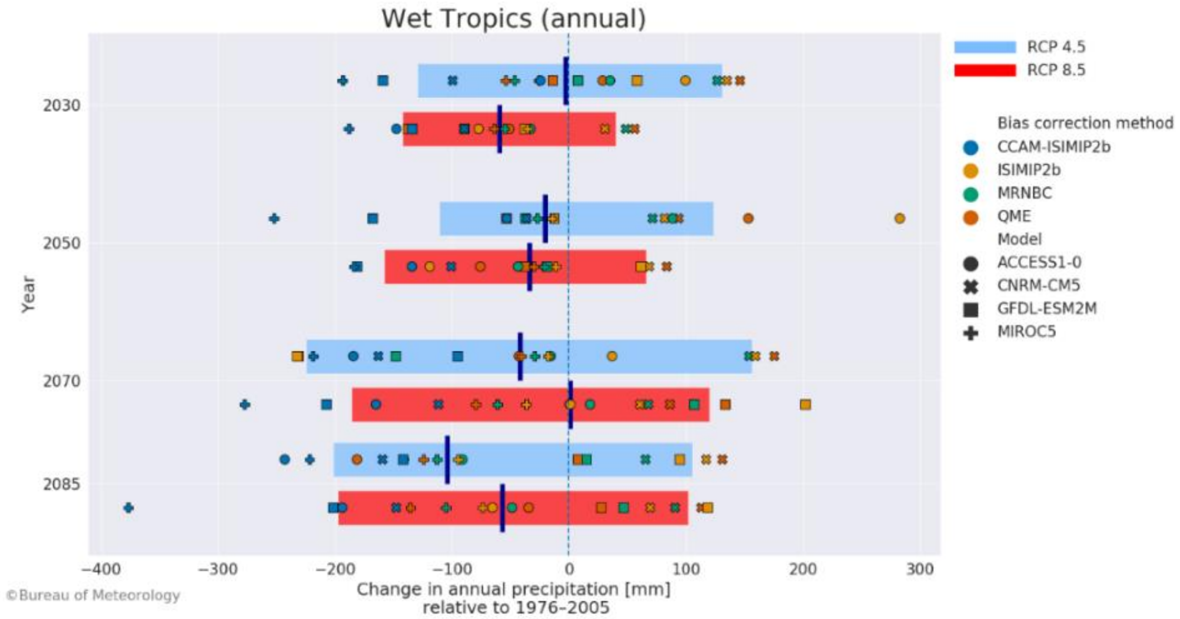

Figure 4.2. Change in annual precipitation (mm) projected by each ensemble member for 2030, 2050, 2070 and 2085 in the Wet Tropics region. The red bar shows the 10th to 90th percentiles for RCP8.5. The blue bar shows the 10th to 90th percentiles for RCP4.5. The dark blue line shows the ensemble median. The change is relative to the reference period (1976–2005)

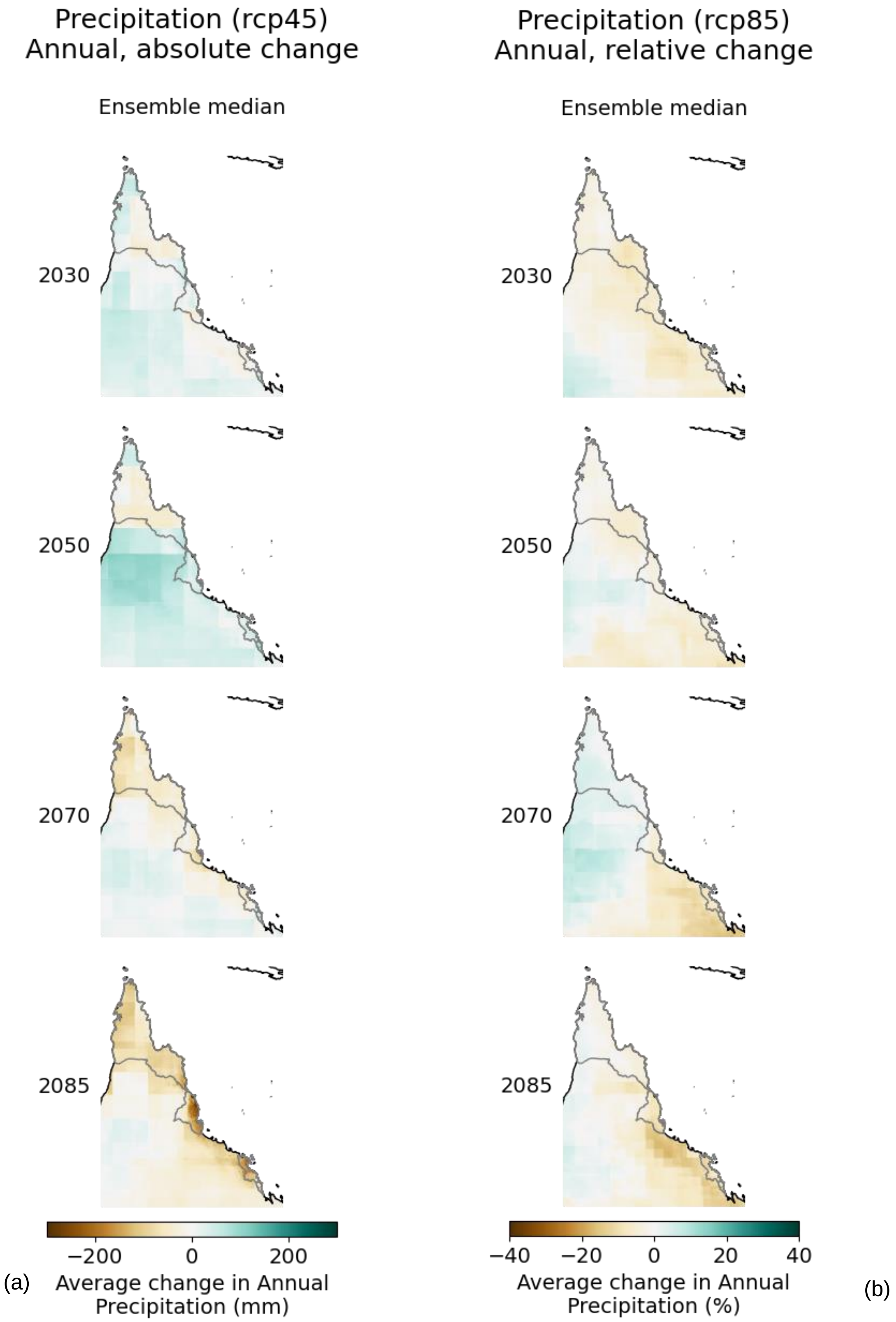

Figure 4.3. Absolute change (mm) (median) in annual precipitation projected across the Wet Tropics region for 2030, 2050, 2070 and 2085 for (a) RCP4.5 and (b) RCP8.5. The change is relative to the reference period (1976–2005)

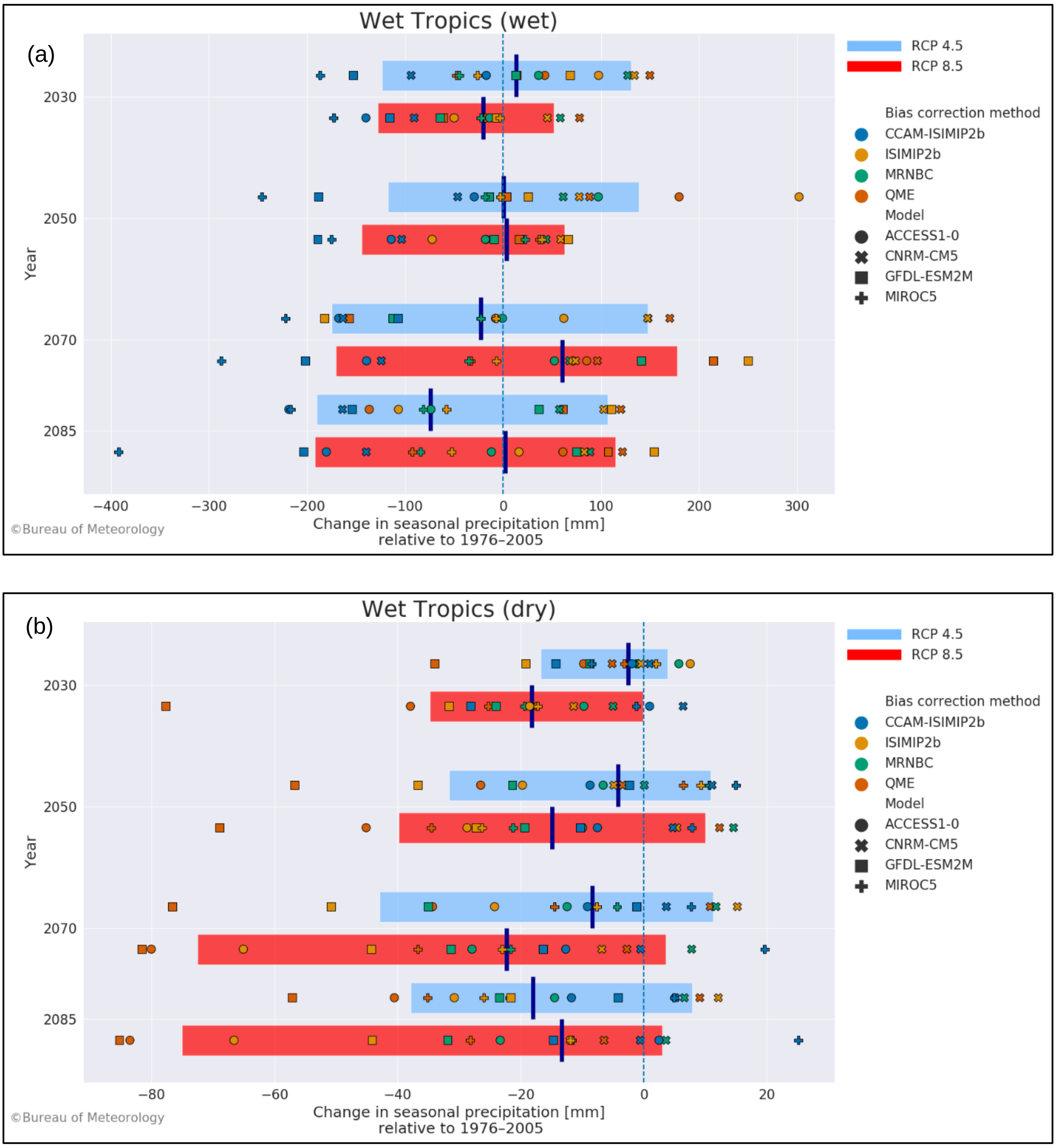

Figure 4.4. Absolute change in modelled precipitation (mm) projected by each ensemble member for (a) wet season (November–April) and (b) dry season (May–October) for 2030, 2050, 2070 and 2085 in the Wet Tropics region. The red bar shows the 10th to 90th percentiles for RCP8.5. The blue bar shows the 10th to 90th percentiles for RCP4.5. The dark blue line shows the ensemble median. The change is relative to the reference period (1976–2005)

The assessment summary of future changes to precipitation is given in Table 4.1.

Table 4.1. Assessment summary of future changes in precipitation in the Wet Tropics region

Feature	Largest plausible range of change	Additional evidence: plausible process	Additional evidence: ability to simulate	Summary statement
Dry season precipitation	RCP4.5 −79 to 15 mm/season (−11% to 44%) RCP8.5 −85 to 25 mm/season (−53% to 19%)	Precipitation in the dry season (May–October) shows strong variability with El Niño–Southern Oscillation (ENSO). An expected rise in the average altitude of the orographic cloud layer due to global warming could intensify the effects of longer and more variable dry seasons (Pounds et al. 1999).	All GCMs are considered suitable in simulating ENSO, which is key driver of dry season precipitation variability.	Increases and decreases in dry season precipitation are plausible. The median indicates decreases are more likely. In absolute terms, the changes in dry season precipitation are not significant in context of annual precipitation totals.
Wet season precipitation	RCP4.5 −246 to 302 mm/season (−18.9% to 243.8%) RCP8.5 −288 to 250 mm/season (−22% to 19%)	Wet season precipitation variability is strongly influenced by ENSO events. El Niño and La Niña episodes tend to produce drier and wetter wet seasons, respectively. Short-lived but high-intensity precipitation bursts, which are linked to the Madden–Julian Oscillation (MJO), are evidence of sub-seasonal precipitation variability within the Australian monsoon.	All GCMs are deemed suitable for representing ENSO events. However, models fundamentally disagree on projected changes to northern Australian summer rain in a warmer world. This is probably linked to uncertainty in circulation change at the largest scales (e.g. hemispheric changes) and might be sensitive to aerosol forcing. Also, GCMs may not adequately represent the influence of eastern seaboard topography on precipitation. GCMs vary in their response – some favouring an early, others a late monsoon season retreat – depending on each models' circulation changes. This variation contributes to spread either side of the median.	Increases and decreases in wet season precipitation are possible, with no trend evident in the ensemble members median. Given uncertainty in process understanding, both drier and wetter futures are plausible with global warming.

4.3 Runoff

Projections of annual runoff indicate both increases and decreases are plausible under both greenhouse gas emissions scenarios (Figure 4.6), largely reflecting projected changes to precipitation. Figure 4.5 shows the time series plot of the projected median of the mean annual runoff from the 16-member ensemble along with the annual runoff projected from ACCESS1-0_ISIMIP2b for RCP8.5. Runoff across the Wet Tropics region is projected to be dominated by the large seasonal and year-to-year variability driven by high precipitation variability (4.5). As Figure 4.5 shows extremes are projected to be larger compared to the historical period. The spatial distribution of the absolute change in runoff is shown in Figure 4.7.

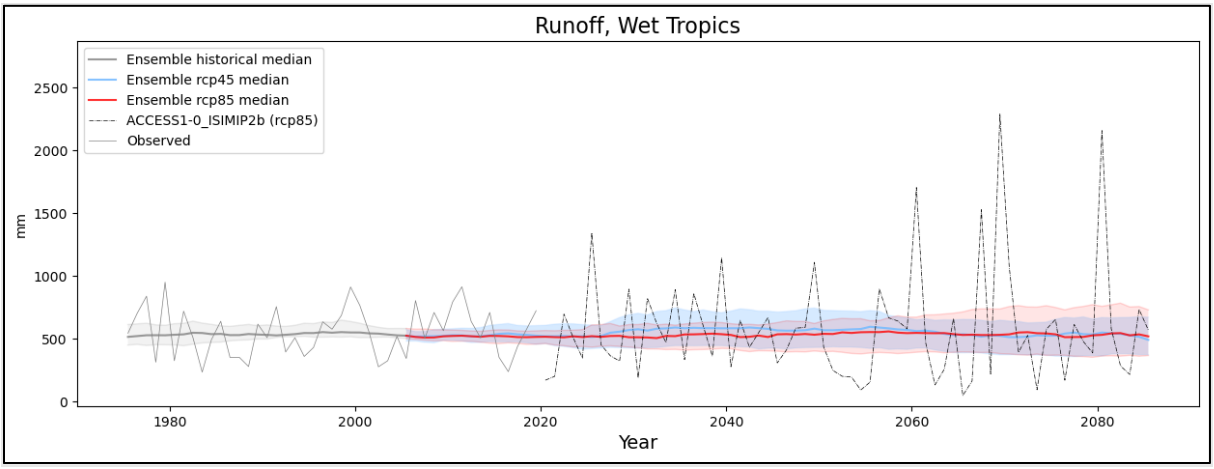

Figure 4.5. Annual modelled runoff (mm) projected to 2099 by ensemble members for RCP4.5 (blue) and RCP8.5 (red) greenhouse gas emission scenarios in the Wet Tropics region. The shaded areas represent the 10th to 90th percentile range for all ensemble members in the historical and future time periods. The time series for ACCESS1-0_ISIMIP2b (RCP8.5) is included (dotted line) to show the variability projected for an individual ensemble member. The grey line represents the modelled historical median runoff

The uncertainties associated with projected changes to precipitation, therefore, also apply to runoff. Wet season runoff changes do not vary significantly between greenhouse gas emission scenarios (Figure 4.8b). The median of the 16-member ensemble projects decreases for dry season runoff (Figure 4.8a), with the RCP8.5 projecting larger decreases and plausibly being related to both increased potential evapotranspiration and less precipitation (from an already low base) in the dry season.

Some of the largest runoff decreases for this region are projected in coastal catchments, such as the Tully, Johnston and Herbert river catchments south of Cairns and the Pioneer and O'Connell river catchments near Mackay; these follow the spatial pattern of projected decrease in precpitation (Figure 4.7).

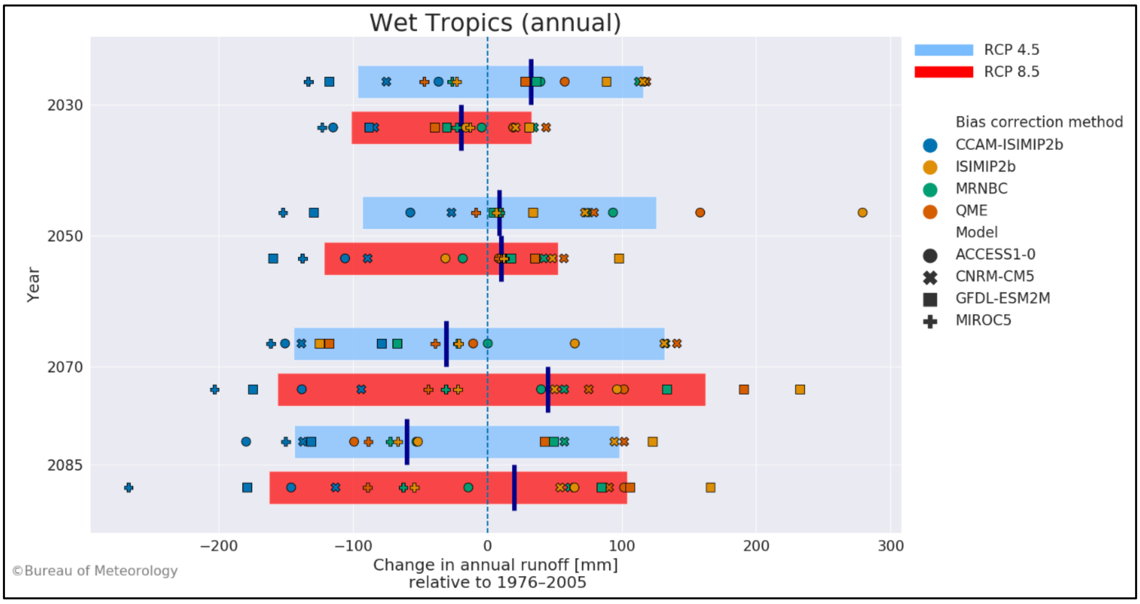

Figure 4.6. Absolute change in annual runoff (mm) projected by each ensemble member for 2030, 2050, 2070 and 2085 in the Wet Topics region. The red bar shows the 10th to 90th percentiles for RCP8.5. The blue bar shows the 10th to 90th percentiles for RCP4.5. The dark blue line shows the ensemble median. The change is relative to the reference period (1976–2005)

By late century, decreases for these catchments are projected under both emission scenarios. These catchments are home to tropical rainforests, which could face negative impacts associated with reductions in runoff. The catchments are also water sources for regional centres, so reductions in runoff could indicate vulnerabilities for consumptive water use supply. However, median runoff in the Cape York Peninsula is projected to both increase and decrease; RPC4.5 shows a plausible drying after mid-century while RCP8.5 shows a wetter future (Figure 4.7).

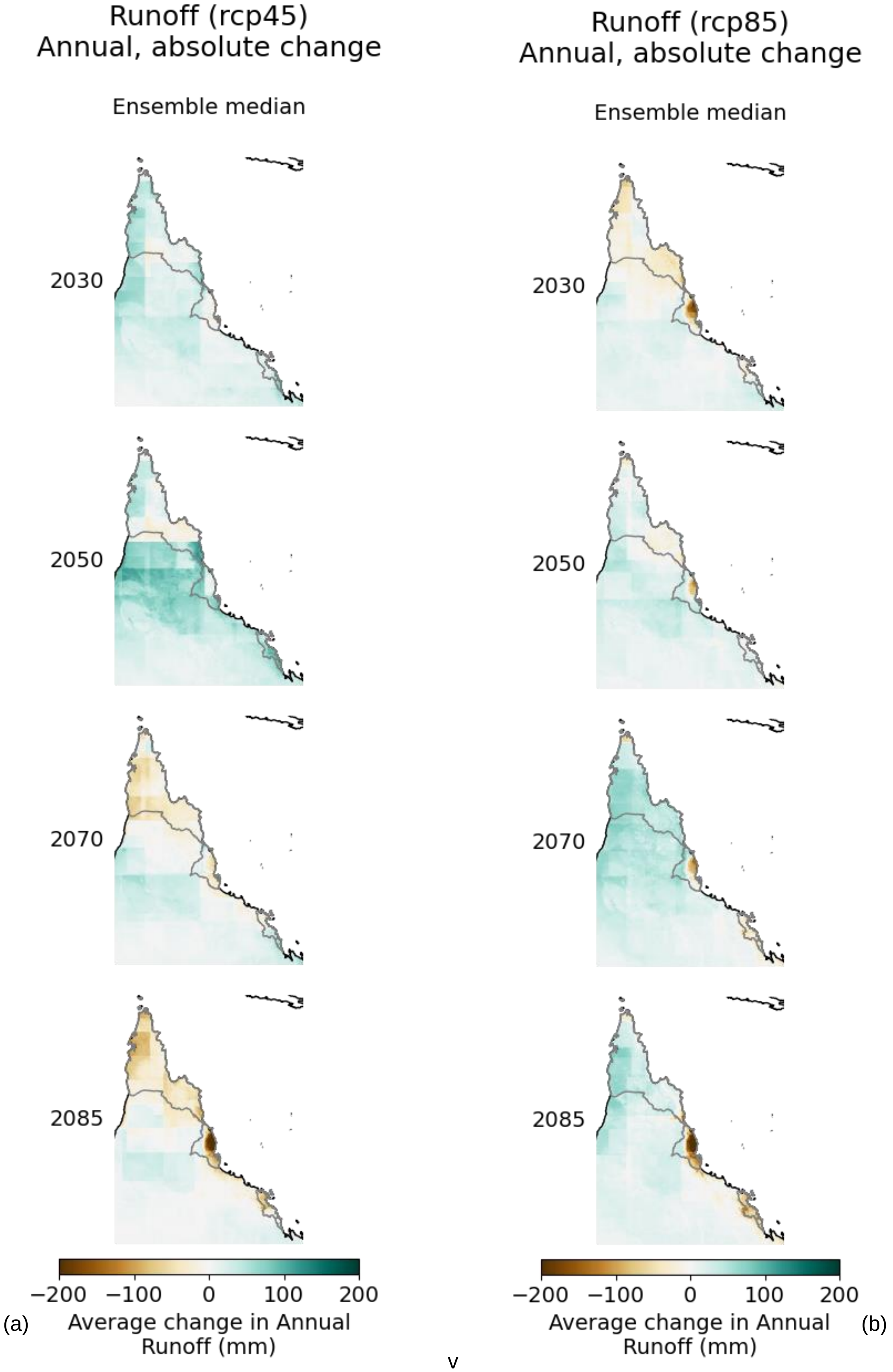

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Figure 4.7. Absolute change (mm) (median) in annual modelled runoff projected across the Wet Tropics region for 2030, 2050, 2070 and 2085 for (a) RCP4.5 and (b) RCP8.5. This change is relative to the reference period (1976–2005)

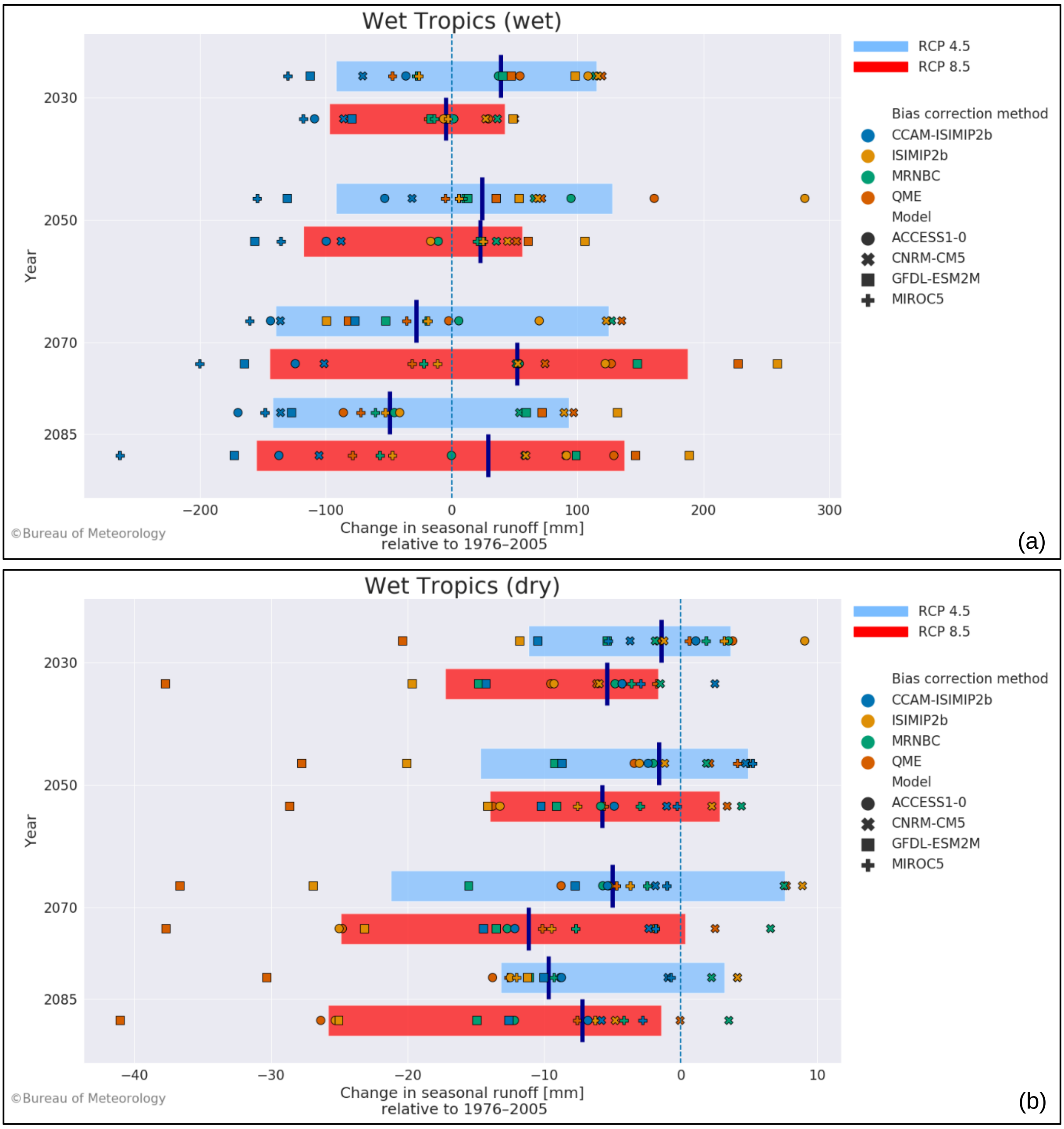

Figure 4.8. Absolute change (mm) projected by each ensemble member for (a) wet season (November–April) and (b) dry season (May–October) runoff for 2030, 2050, 2070 and 2085 in the Wet Tropics region. The red bar shows the 10th to 90th percentiles for RCP8.5. The blue bar shows the 10th to 90th percentiles for RCP4.5. The dark blue line shows the ensemble median. This change is relative to the reference period (1976–2005)

The assessment summary for changes in runoff in given in Table 4.2.

Table 4.2. Assessment summary for changes in runoff in the Wet Tropics region

Feature	Largest plausible range of change	Additional evidence: plausible process	Additional evidence: ability to simulate	Summary statement
Dry season runoff	RCP4.5 −37 to 9 mm/season (−54% to 18%) RCP8.5 −38 to 7 mm/season (−59% to 15%)	No trend observed in any season with both increases and decreasing streamflow trends observed.	Reduced dry season precipitation drives decreases in runoff. Increased potential evapotranspiration and subsequent drying of catchments could also contribute to decreases in dry season runoff.	Both increases and decreases are projected, with the median indicating decreases. In absolute terms, the entire projected range is very small in comparison to wet season precipitation totals. Larger decreases are projected for RCP8.5 than RCP4.5.
Wet season runoff	RCP4.5 −155 to 286 mm/season (−33% to 54%) RCP8.5 −264 to 259 mm/season (−56% to 46%)		The trend in runoff mostly follows the increases and decrease in wet season precipitation (Table 4.1).	Large increases and decreases are projected for wet season runoff in all future time periods, with no significant difference between emission scenarios. Observed trends suggest increases may be more plausible than decreases. This is also consistent with increased runoff generated from higher-intensity precipitation. However, the driest ensemble member is considered equally plausible as there is little understanding of the processes by which wet season rain-bearing climate drivers respond to a warmer climate.

4.4 Soil moisture

Projected changes to annual soil moisture range from little increases (under both RCPs) to large decreases (Figure 4.10). Figure 4.9 shows the time series plot of the projected median of the mean annual soil moisture from the 16-member ensemble along with the annual soil moisture projected from ACCESS1-0_ISIMIP2b for RCP8.5. Soil moisture across the Wet Tropics region is projected to be dominated by the large seasonal and year-to-year variability driven by high precipitation variability (4.9). As Figure 4.5 shows extremes are projected to be larger compared to the historical period tending towards drier extremes. The spatial distribution of the absolute change in soil moisture is shown in Figure 4.11.Most storylines project decreases in modelled soil moisture in the Wet Tropics region over the century (Figure 4.10 to Figure 4.12).

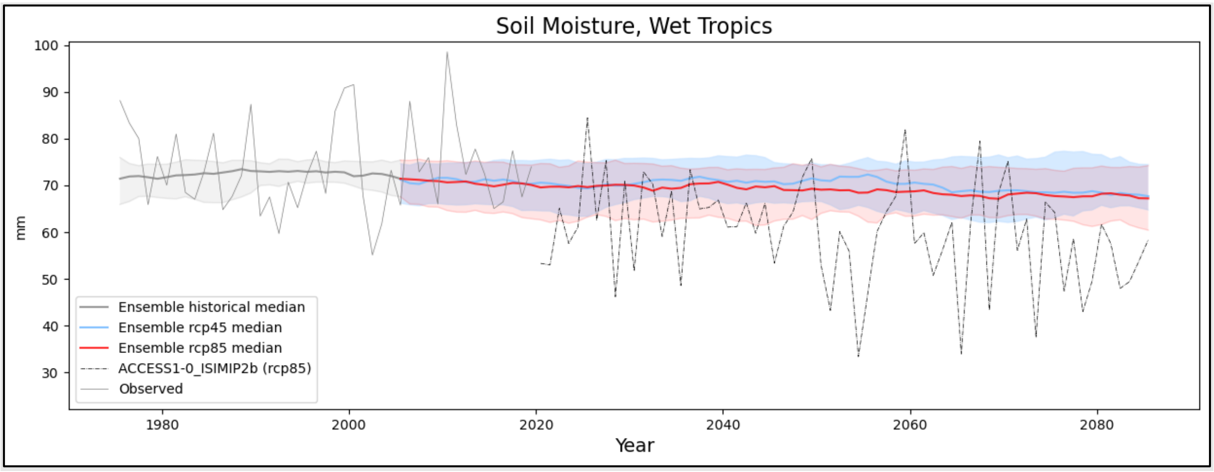

Figure 4.9. Annual modelled root zone soil moisture projected to 2099 by ensemble members for RCP4.5 (blue) and RCP8.5 (red) in the Wet Tropics region. The shaded areas represent the 10th to 90th percentile range for all ensemble members in the historical and future time periods. The time series for ACCESS1-0_ISIMIP2b (RCP8.5) is included (dotted line) to show the variability projected for an individual ensemble member. The grey line represents the modelled historical median soil moisture

The projected soil moisture decreases are larger for RCP8.5 than for RCP4.5 and are also larger in absolute terms during the wet season, when soil moisture stores are typically replenished (Figure 4.11). However the decrease in soil moisture in relative terms are larger during the dry season, suggesting a more rapid depletion in soil moisture stores due to higher evapotranspiration (Figure 4.12). Decreases in soil moisture are projected to be widespread across the region and greatest along the southern part of the region (Figure 4.11), around Cairns (in the Herbert, Tully and Johnston river catchments) and Mackay. This is consistent with the projected decrease in precipitation and runoff (see Sections 4.2 and 4.3), as well as increases in potential evapotranspiration (see Section 4.5) in this region.

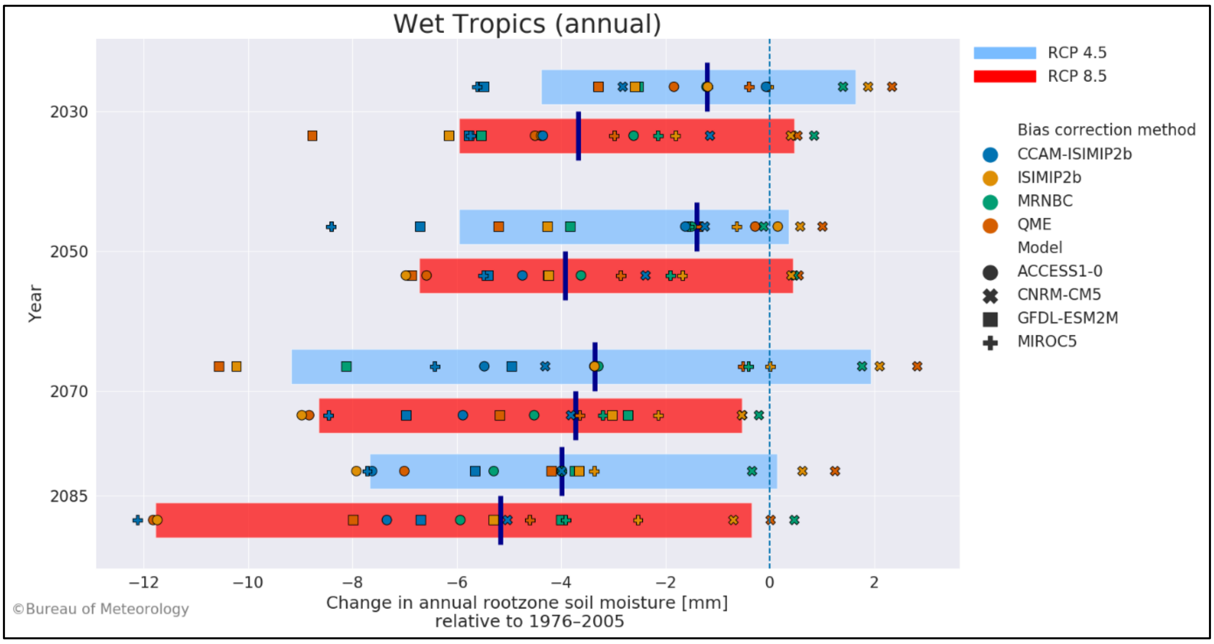

Figure 4.10. Absolute change (mm) in annual root zone soil moisture projected by each ensemble member for 2030, 2050, 2070 and 2085 in the Wet Tropics region. The red bar shows the 10th to 90th percentiles for RCP8.5. The blue bar shows the 10th to 90th percentiles for RCP4.5. The dark blue line shows the ensemble median. The change is relative to the reference period (1976–2005)

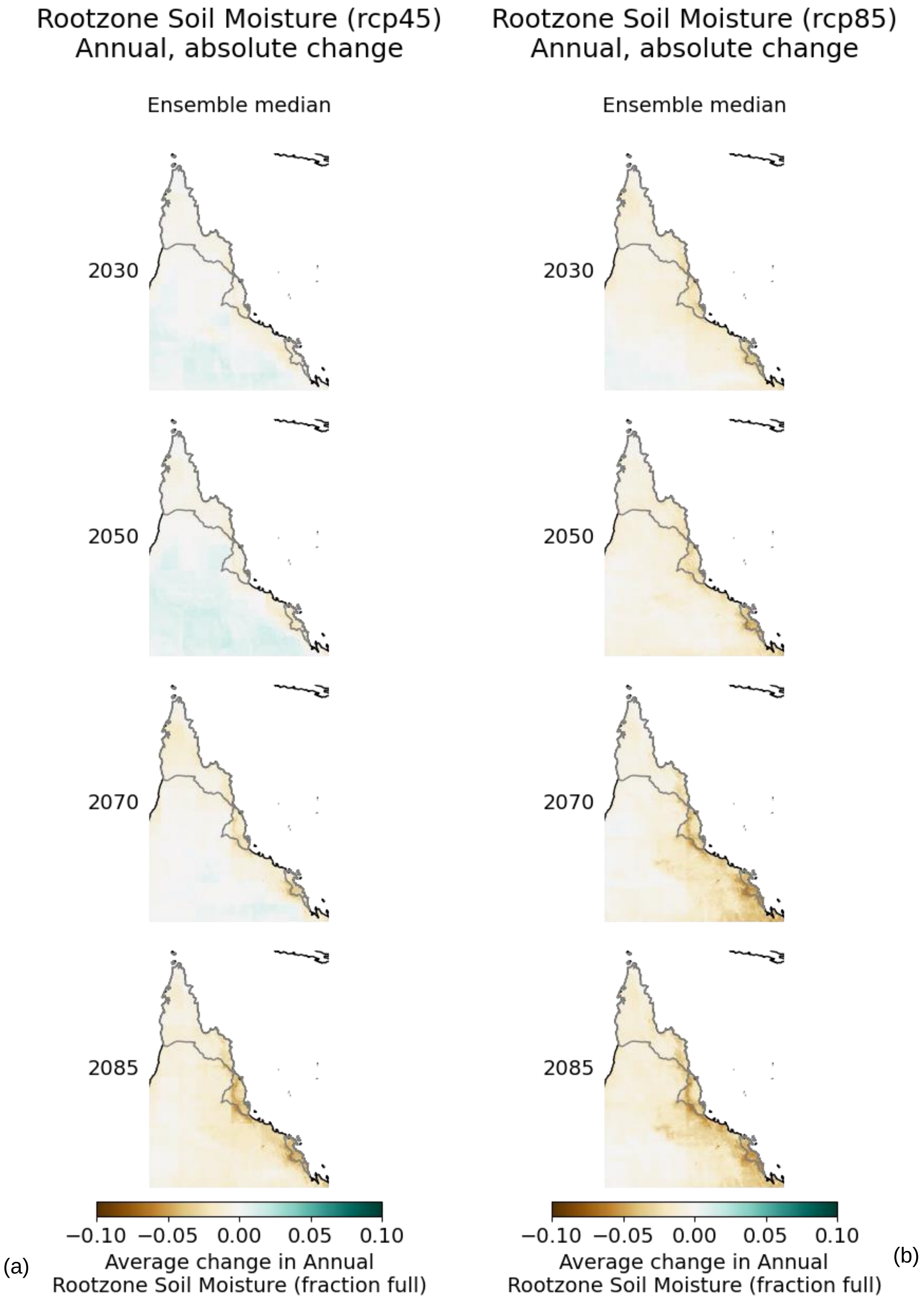

Figure 4.11. Absolute change (fraction full) (ensemble median) in annual modelled root zone soil moisture projected for 2030, 2050, 2070 and 2085 for (a) RCP4.5 and (b) RCP8.5 across the Wet Tropics region. The change is relative to the reference period (1976–2005). Fraction full (scale 0–1) is equivalent to (percentage full)/100 and represents the fraction of available water content in the root zone (0–1 m) soil profile

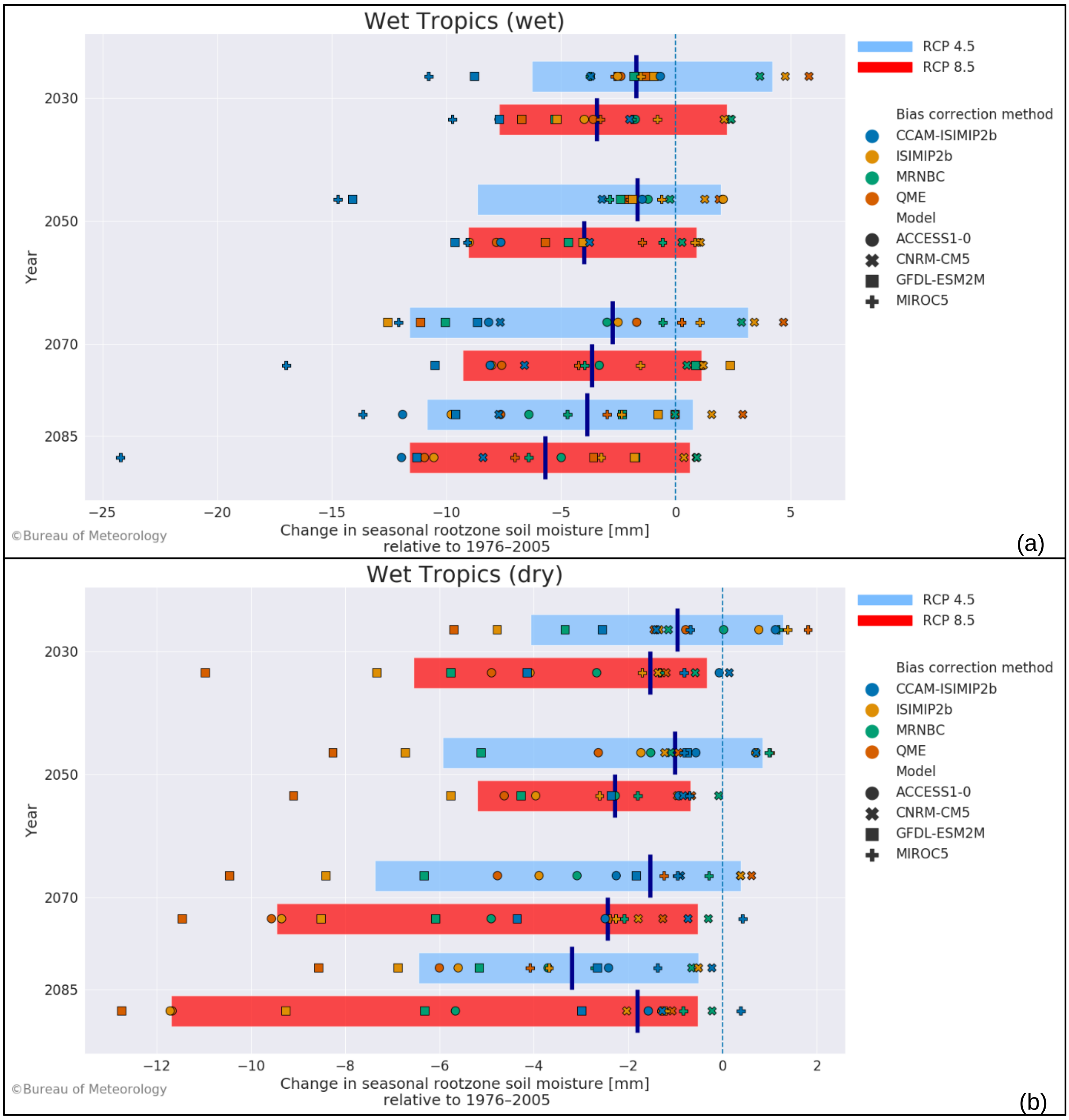

Figure 4.12. Absolute change (as fraction full of soil moisture capacity) projected by each ensemble member for (a) wet season (November–April) and (b) dry season (May–October) root zone soil moisture for 2030, 2050, 2070 and 2085 in the Wet Tropics region. The red bar shows the 10th to 90th percentiles for RCP8.5. The blue bar shows the 10th to 90th percentiles for RCP4.5. The dark blue line shows the ensemble median. The change is relative to the reference period (1976–2005)

The assessment summary for soil moisture is given in Table 4.3.

Table 4.3. Assessment summary for root zone soil moisture in the Wet Tropics region

Feature	Largest plausible range of change (wet season)	Additional evidence: plausible process/model reliability	Summary statement
Annual and wet season soil moisture	RCP4.5 −6 to 2 mm/season (−13% to 5%) RCP8.5 −10 to 1 mm/season (−22 to 2%)	Aligned with increase in evapotranspiration driving a decrease in soil moisture.	Annual and seasonal soil moisture decreases are plausible. The wettest future ensemble member for wet season soil moisture has increases of around 5%; the 16-member ensemble median shows little change for both representative concentration pathways and all future periods. The driest ensemble member features a decrease in soil moisture to mid-century and large decreases in late century with no significant difference between emission pathways.
Dry season soil moisture	RCP4.5 −4 to 0.7 mm/season (−26% to 5%) RCP8.5 −5 to 0.2 mm/season (−33% to 1%)		The wettest future storylines for dry season soil moisture show little change. The median of all storylines projects large decreases (10% to 20%). The driest storyline projects very large decreases (20% to 36%).

4.5 Potential evapotranspiration

In the hydrological cycle, evapotranspiration plays an important role, particularly in soil evaporation and crop transpiration. While precipitation is the key driver of water availability, potential evapotranspiration is an indicator of potential losses in the total water balance for a system, and a limiting factor in the amount of water available for use. While these trends in potential evapotranspiration do not tell us what the projected changes to the actual evapotranspiration rate are, the signal indicates that the region could see impacts including:

- an increase in crop water demand (through higher transpiration of plants)
- increased evaporation from soils following a higher depletion rate of soil moisture
- the potential for greater losses from surface water storages through evaporation.

Increasing temperatures are projected to drive increases in potential evapotranspiration across the Wet Tropics region throughout the century for both prepresentative concentration pathways (Figures 4.13 to 4.16). The rate of increase is greater under RCP8.5 than RCP4.5; the projected increase in potential evapotranspiration by late century (2085) under RCP4.5 is equivalent to the projected increase by 2070 under RCP8.5 (Figure 4.14).

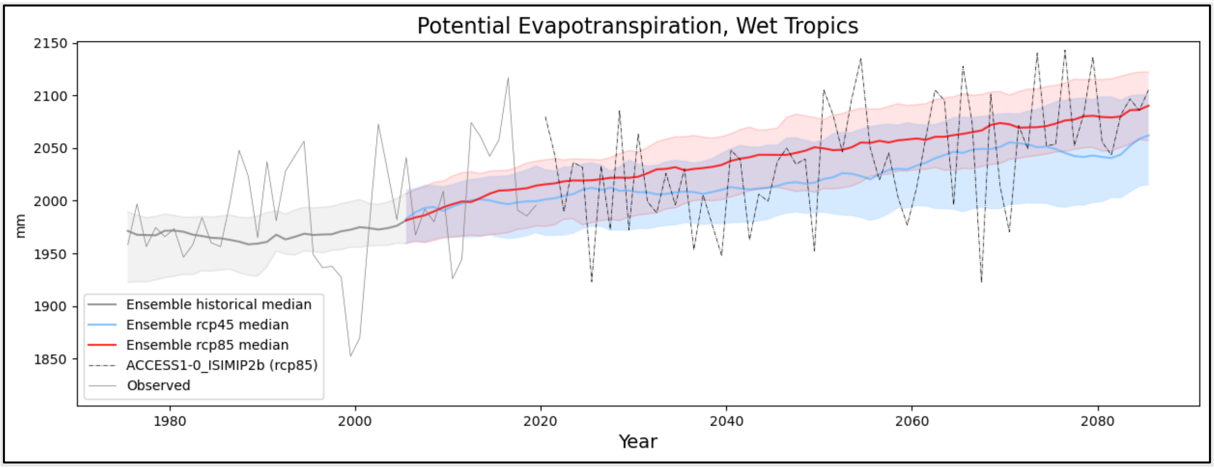

Figure 4.13. Annual modelled potential evapotranspiration (mm) projected to 2099 by ensemble members for RCP4.5 (blue) and RCP8.5 (red) in the Wet Tropics region. The shaded areas represent the 10th to 90th percentile range for all ensemble members in the historical and future time periods. The time series for ACCESS1-0_ISIMIP2b (RCP8.5) is included (dotted line) to show the variability projected for an individual ensemble member. The grey line represents the modelled historical median potential evapotranspiration

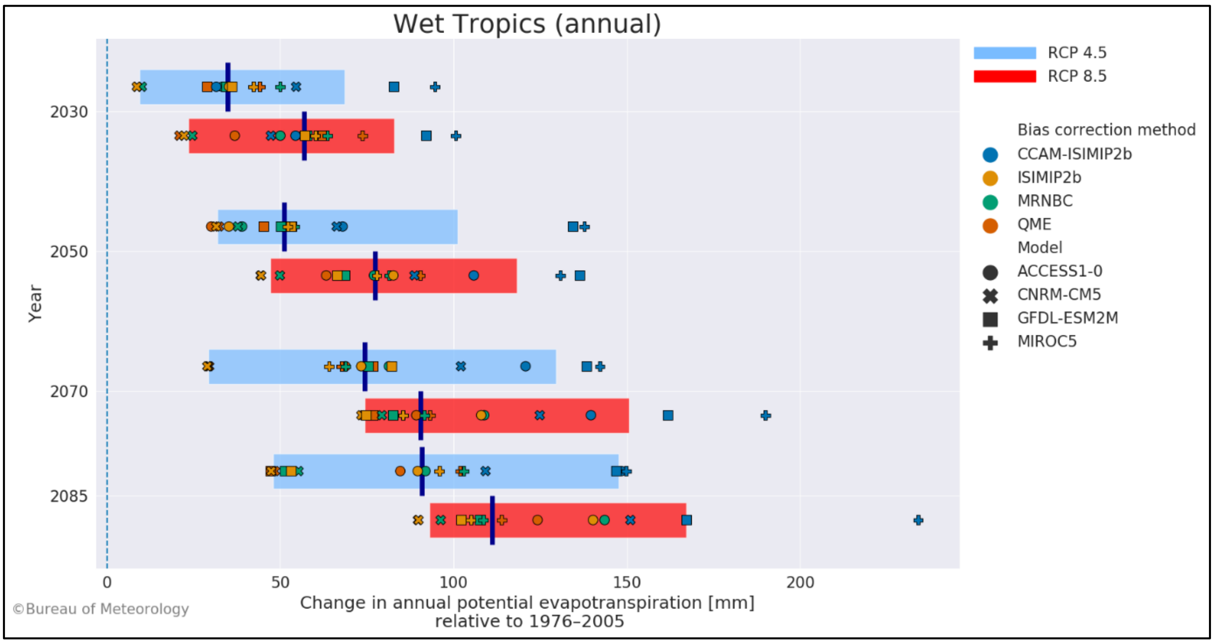

Figure 4.14. Absolute change (mm) in annual potential evapotranspiration projected by each ensemble member for 2030, 2050, 2070 and 2085 in the Wet Tropics region. The red bar shows the 10th to 90th percentiles for RCP8.5. The blue bar shows the 10th to 90th percentiles for RCP4.5. The dark blue line shows the ensemble median. The change is relative to the reference period (1976–2005)

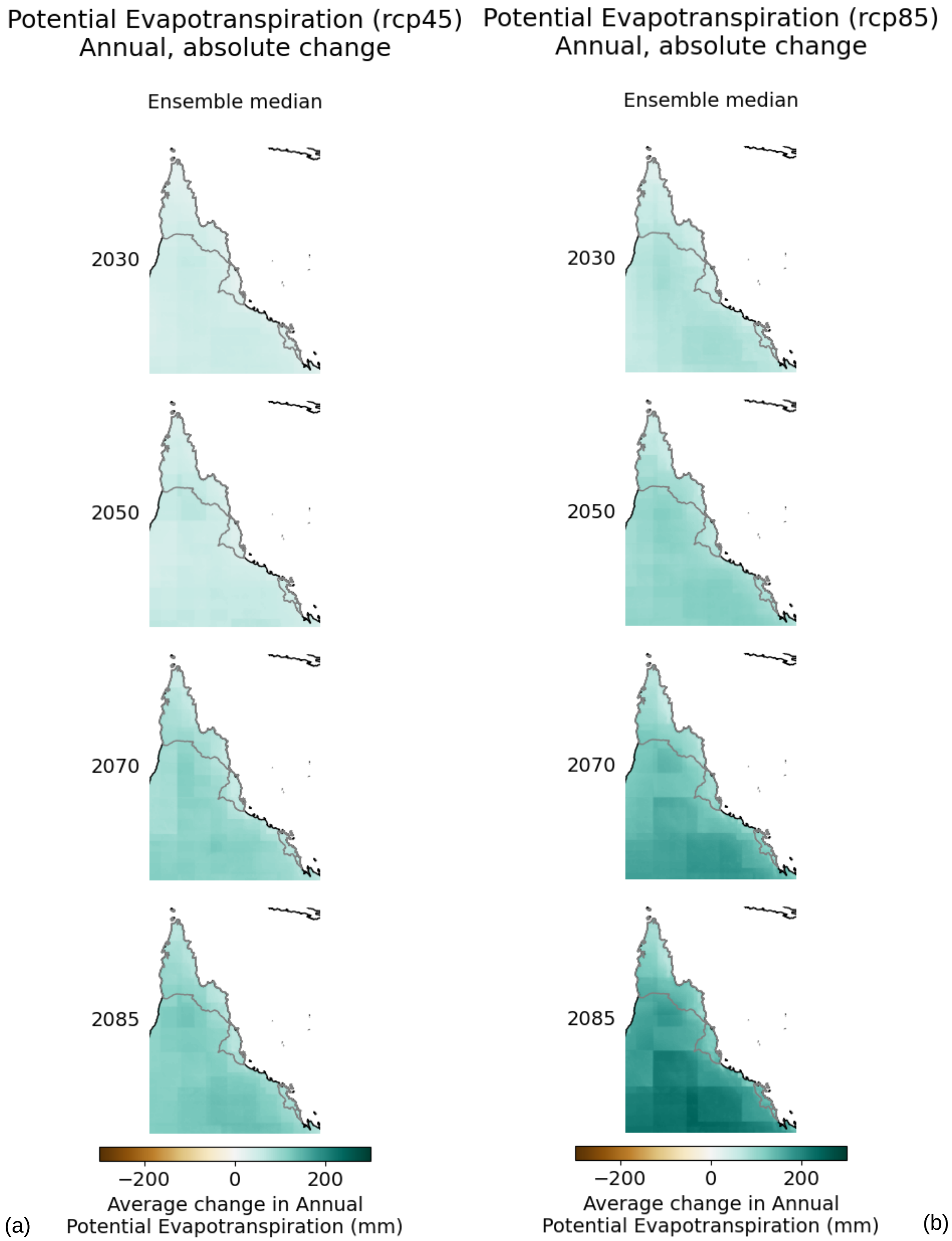

Figure 4.15. Absolute change (mm) (ensemble median) in annual modelled potential evapotranspiration for (a) RCP4.5 and (b) RCP8.5 for 2030, 2050, 2070 and 2085 across the Wet Tropics region. The change is relative to the reference period (1976–2005)

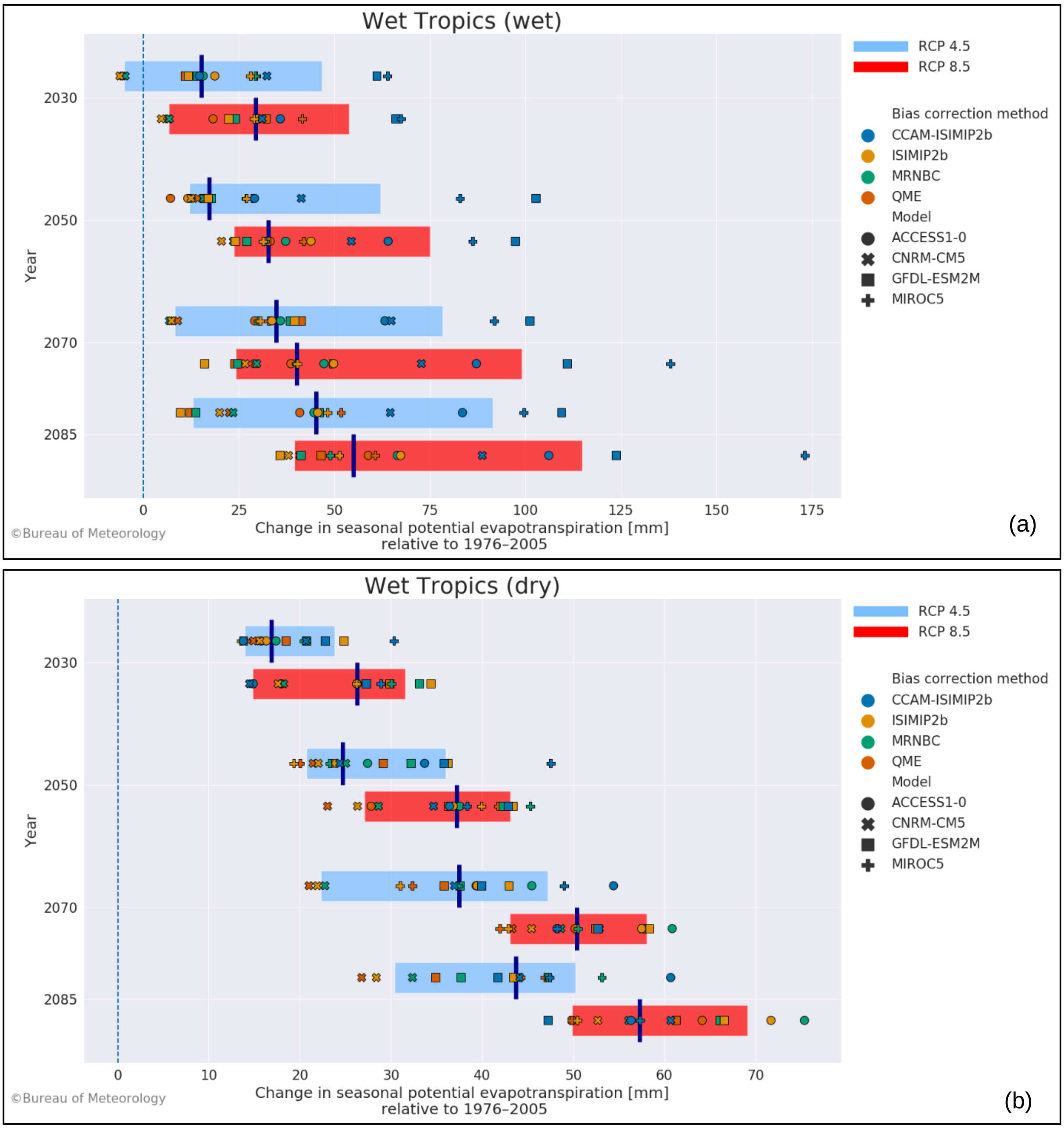

Figure 4.16. Absolute change (mm) in potential evapotranspiration projected by each ensemble member for (a) wet season (November–April) and (b) dry season (May–October) for 2030, 2050, 2070 and 2085 in the Wet Tropics region. The red bar shows the 10th to 90th percentiles for RCP8.5. The blue bar shows the 10th to 90th percentiles for RCP4.5. The dark blue line shows the ensemble median. The change is relative to the reference period (1976–2005)

The assessment summary for evapotranspiration is given in Table 4.4

(b)

Table 4.4. Assessment summary for potential evapotranspiration in the Wet Tropics region

Feature	Largest plausible range of change	Additional evidence: downscaling/consistency of observed trends with projected trends	Additional evidence: plausible process/model reliability	Summary statement
Annual potential evapotranspiration	RPC4.5 -6 to 109 mm/year (0% to 11%) RCP8.5 5 to 173 mm/year (1% to 17%)	Most of the ensembles indicate higher evapotranspiration in both seasons, particularly in the dry season.	The increase in potential evapotranspiration is likely due to higher temperature in the future.	Increase in evapotranspiration for both seasons is highly plausible.

4.6 Extreme events

Hydrological extremes, including floods and droughts, are among the costliest natural disasters in the world (Wasko & Nathan 2019). They pose risks to life, food security, infrastructure and energy supply. Future climate change is expected to bring a more variable precipitation pattern with longer dry spells and more frequent extreme events, such as flood-producing rain and cyclones (Easterling et al. 2000; Johnson & Murray 2004; Milly et al. 2002; Palmer & Räisänen 2002; Walsh & Ryan 2000). On the extreme dry end of the spectrum, prolonged absence of precipitation, for example, through a failure of the monsoon, may result in increasing dry spells. On the extreme wet end of the spectrum, an increase in extreme rains can exacerbate flooding events. Changes in the frequency, amount and duration of precipitation have serious impacts on sectors such as agriculture, water management and flood control (Alam et al. 2018). The ability to project future climate can help improve irrigation planning, flood planning, and design and management of hydraulic structures such as dams and stormwater drainage systems. This knowledge will also help us identify Australia's vulnerability to future droughts and improve resilience through mitigation actions.

4.6.1 Extreme precipitation and runoff

Earlier studies using observations and projections have shown an increase in the frequency of extreme precipitation events in the Australian region (Alexander & Arblaster 2009; Rafter & Abbs 2009). In a warming climate, heavy precipitation events are likely to increase in magnitude due to the increased moisture-holding capacity of a warmer atmosphere (Sherwood et al. 2010; Yin et al. 2020). Such excessive precipitation events may enhance the potential risk of flooding, depending on antecedent conditions. However, Wasko and Nathan (2019) found that, in Australia as in many other parts of the world, soil moisture deficits that are first re-filled during precipitation events commonly reduce flood magnitudes, despite increasing precipitation extremes. Therefore, in this project, we estimated projected future flood scenarios based on both precipitation and runoff.

Characterising changes in flood frequency and intensity at a large spatial and temporal scale is challenging; flood risk often depends on local topography, sub-daily precipitation intensity and antecedent conditions. We calculated a set of threshold-based indicators using precipitation and runoff to capture changes in flood risk on a broad scale. The changes on the extreme wet end of the spectrum are determined using 3 indicators: the projected annual mean and maximum daily precipitation and runoff, and the 20-year return period precipitation and runoff estimated using the generalised extreme value (GEV) distribution. The GEV distribution is generally used to represent the rare events (Bali 2003), which are indicative of the occurrence of floods.

Both precipitation and runoff analyses project an increase in the maximum 1-day and 20-year return period for two 30-year periods (2030, and 2070) and both presentative concentration pathways (RCP4.5 and RCP8.5) (Figures 4.17 and 4.18). In comparison, the trends in the annual mean precipitation and runoff clearly show that the median of the storylines for mean daily precipitation and runoff tend towards little change or decrease. This pattern (little change or decrease in annual mean relative to increase in extremes) is found in almost all other National Hydrological Projections assessment regions and is supported by the results from other studies (Abbs & Rafter 2009; IPCC 2012; Wasko & Sharma 2017; Rafter & Abbs 2009; Alexander & Arblaster 2009). The magnitudes of the modelled changes in extreme precipitation and runoff indicators depend on the representative concentration pathway, the given ensemble member, and the time period in question. The magnitudes of the simulated changes in extreme precipitation indicators depend heavily on the representative concentration pathways, the given ensemble member and the time period in question. Therefore, the magnitude of change is uncertain. This could be because smaller-scale systems that generate extreme precipitation are not well represented by GCMs (Fowler & Ekström 2009). Our analysis shows that the far future (2070) has much wider spread in ensembles than the near future (2030). This is evident for estimated change in extreme wet conditions based on both precipitation (Figure 4.17) and runoff (Figure 4.18), in which the spread in the runoff indicators is higher than the spread in the precipitation indicators.

In summary, the results suggest that the intensity of extreme events is projected to increase over the century in Wet Tropics region. This finding concurs with other studies carried out for this region (Rosenzweig et al. 2007; McInnes et al. 2015) and is also supported by studies from the Wet Tropics Management Authority (Wet Tropics Management Authority 2020) and Australian National University (2009). However, the magnitude and timing of the future change in intensity of wet extremes from natural climate variability of the region, cannot be projected.

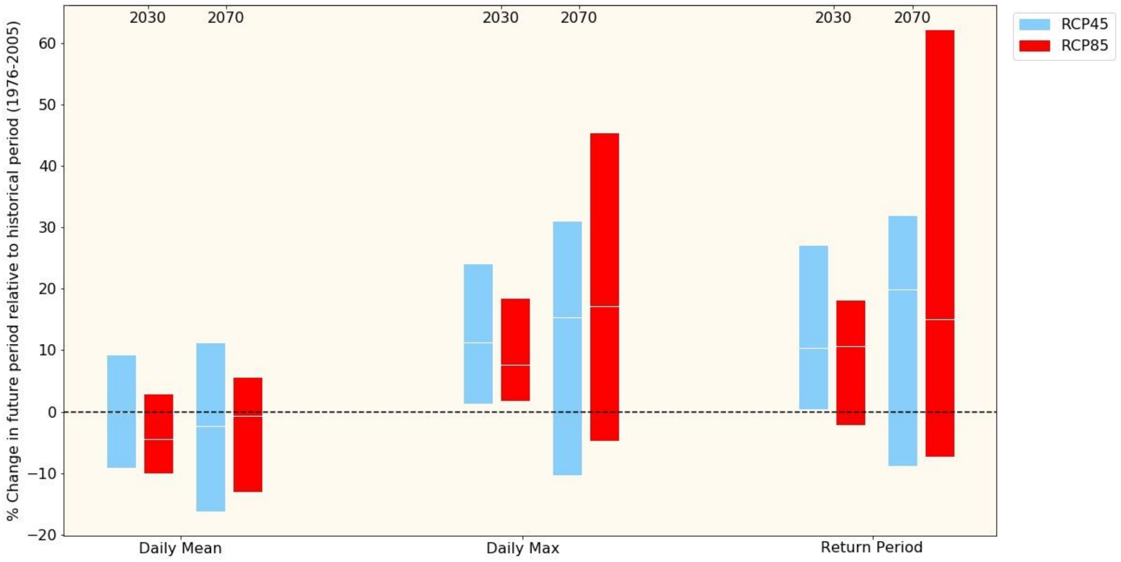

Figure 4.17. Future extreme wet analysis based on modelled precipitation shown by changes (%) in mean daily precipitation, maximum daily precipitation and 20-year return period of the annual maximum precipitation for 2030 and 2070 in the Wet Tropics region. The red bars show the 10th to 90th percentiles for RCP8.5. The blue bars show the 10th to 90th percentiles for RCP4.5. The white lines show the ensemble median. The change is relative to the reference period (1976–2005)

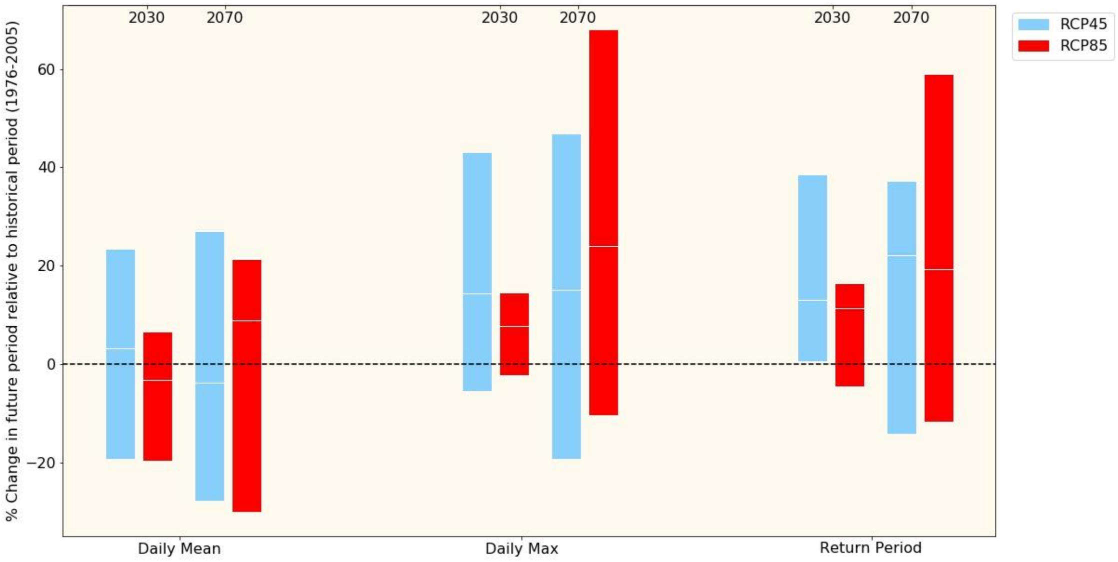

Figure 4.18. Future extreme wet analysis based on modelled runoff shown by changes (%) in mean daily runoff, maximum daily runoff and 20-year return period of the annual maximum runoff for 2030 and 2070 in the Wet Tropics region. The red bars show the 10th to 90th percentiles for RCP8.5. The blue bars show the 10th to 90th percentiles for RCP4.5. The white lines show the ensemble median. The change is relative to the reference period (1976–2005)

4.6.2 Dry landscape conditions

To gain a greater understanding of future extreme dry conditions or droughts and the range of socioeconomic impacts, it is important to combine multiple lines of evidence encompassing climatological and hydrological extreme dry states. Projected extreme meteorological, hydrological and agricultural dry conditions were investigated using 3 separate indicators. A meteorological extreme dry state refers to when an area is subject to below-average precipitation that results in dry landscape conditions. A hydrological extreme dry state refers to when water resources are insufficient, for example, in rivers and water storages. An agricultural extreme dry state is determined through the impacts of soil moisture deficits on crops and vegetation and its subsequent effect on livestock. Analysis of future conditions must also take into account different time frames, as hydrological dry states arise over a longer time period than meteorological and agricultural extreme dry periods (which can include ‘flash droughts’). Hydrological dry states result from prolonged spells of below-average precipitation and the subsequent below-average runoff. However, a reduction in precipitation may result in a decrease in water available for stock or a depletion of topsoil moisture needed to grow crops. This will impact agriculturalists sooner than it will cause disruption to the whole hydrological system.

In this study, projected precipitation, runoff and soil moisture data was used to represent these 3 types of droughts: meteorological, hydrological and agricultural. This lets us capture the potential impacts on key sectors of agricultural and water-sensitive industries. The indicators are used as a proxy for drought, noting that they should be taken as an indicative estimate of drought conditions because many other factors involved in determining whether a region is in drought have not been included in this analysis.

As the various types of extreme dry conditions or droughts arise over different time frames, our analysis addresses short-term to long-term durations by calculating the median extreme dry condition duration (short, moderate, long or prolonged). An extreme dry condition is defined by applying a threshold quantile of 15% of the historical period to future projections. We use percentile thresholds to determine drought periods as this method involves no assumptions about the data distribution. Using the 15th percentile as the drought threshold means that any month below this threshold is classified as being in drought. The 15th percentile corresponds approximately to a threshold of −1 for the widely used Standardised Precipitation Index (SPI) (McKee et al. 1993) and is commonly used to characterise ‘moderate’ droughts (McKee et al. 1993). We use this threshold to ensure we have a sufficient number of drought events to infer trends in drought metrics reliably. Previous work has shown that while simulated drought characteristics can be somewhat sensitive to the choice of threshold, inter-model differences represent a much greater source of uncertainty (Ukkola et al. 2018). The 15% threshold definition is applied separately for each indicator and for each different time period. Figure 4.19 and Table 4.5 show that various characteristics of the extreme dry condition were evaluated, namely, the future change in the cumulative duration of the short, moderate, long and prolonged extreme dry spells and the change in the spatial extent of the area undergoing short, moderate, long, and prolonged extreme dry conditions compared to the historical reference period (1976–2005). Using the defined drought metrics, the average percentage of time spent in drought in the future was also calculated, and the results are presented in Table 4.5.

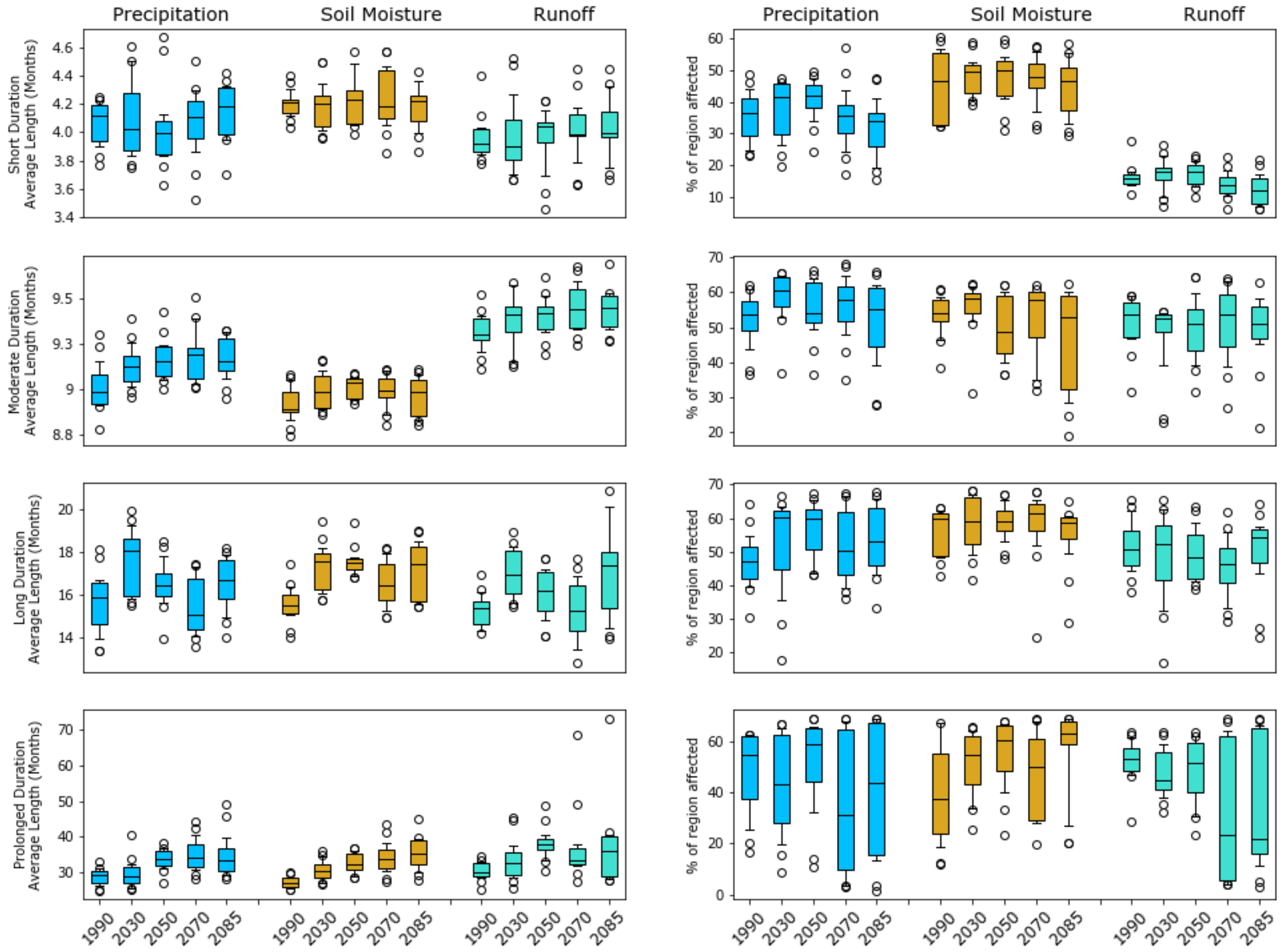

Figure 4.19. Change in projected median drought lengths (left) and percentage of total area affected by extreme dry conditions (right) for modelled precipitation (meteorological drought indicator), modelled soil moisture (agricultural drought indicator) and modelled runoff (hydrological drought indicator) in the Wet Tropics region. The box plots show the median, 10th and 90th percentiles and outliers. They are presented for short-term, moderate, long-term and prolonged drought durations. The change is relative to the reference period (1976–2005)

Table 4.5. Summary of the primary results shown in Figure 4.19

Duration	Drought type	Projected result	Impact
Short (3–6 months)	All types	Little change on average projected for all drought types but a wide spread in ensemble members means that both increases and decreases are plausible.	Projected flash droughts (as represented by 3–6 months duration), important for the agricultural growing seasons, remain similar on average compared to the historical reference period. Higher variability is plausible. The area affected by short-term drought decreases as moderate- to longer- and prolonged term droughts increase.
Moderate (7–11 months)	All types	Little change on average projected for all drought types, but a wide spread in ensemble members means that both increases and decreases are plausible.	Projected moderate droughts remain similar to the historical reference period. Higher variability is plausible. Hydrological droughts are projected to increase.
Long-term (12–23 months)	All types	Increases projected to varying degrees across the future time periods. Areas under drought are projected to increase for meteorological droughts.	Projected long-term droughts to increase, which could have negative implications for river health, water-dependent industries and agricultural systems in the future. Water management in this region depends on annual infills of storages, which are at risk of becoming less reliable (see Chapter 5).
Prolonged (>24 months)	Meteorological dry conditions	Projected 10% increase in time in drought by 2050 and remaining at this level until the end of the century. However, projected decrease in area under meteorological drought.	Projected increases in prolonged periods of low precipitation are plausible with an intensification of precipitation-deficient areas in the future.
	Hydrological dry conditions	Projected 20% increase in time in drought by 2050 followed by a decline to levels similar to the historical period. Area under hydrological drought is projected to decline.	Projected increase in prolonged periods of low-runoff states, which could impact on surface water supply and insufficient environmental flows in the future (see Chapter 5).
	Agricultural dry conditions	Projected increase of between 8% and 15% in time in drought towards the end of the century, followed by a 30% increase in prolonged dry conditions by 2085. The area under agricultural drought is projected to increase.	Projected increases in prolonged soil moisture deficits and states are plausible, which can lead to future impacts on crop and pasture growth and natural vegetation growth.

Overall, the Wet Tropics region is projected to have increased long-term to prolonged meteorological, hydrological and agricultural dry conditions (Table 4.5), with a larger spread towards the end of the century (Figure 4.19 left). However, the area of the region undergoing prolonged meteorological and hydrological dry conditions is projected to decrease. In contrast, the area undergoing prolonged agricultural dry conditions is projected to increase. This possibly relates back to the location of the decrease in median precipitation versus the increase in extreme precipitation, although there is a large spread in results (Figure 4.17 and Figure 4.18). The socioeconomic implications of these results mean that water-sensitive industries, agriculture and water management in this region would need to prepare for drier conditions during crop growing seasons and an unreliable year-to-year water supply brought about by an increase in long-term to prolonged dry spells. The environmental implications for ecosystems and river health could be significant as these results project reduced availability of water for plants and less surface water leading to more variable environmental flows.

5 Exploring future water resource impacts: applying selected storylines to the Wet Tropics region

Projection results feature many sources of uncertainty, including uncertainty over future trajectories of atmospheric greenhouse gas concentrations, how a warmer climate will lead to changes in hydroclimatic features and feedback loops, and how well climate models will represent those features. Acknowledging these uncertainties, the National Hydrological Projections 16-member ensemble provides a unique opportunity to examine the impacts of plausible future changes on Australia's hydroclimate and its water resources. Projections provide a collection of possible future storylines rather than a forecast or likelihood of a specific outcome.

While the National Hydrological Projections 16-member ensemble does not represent every possible future outcome (e.g. of the CMIP5 climate models) for every possible future emissions profile, the ensemble members do represent a selection of internally consistent plausible hydroclimatic futures, or storylines, that let us investigate hydrological responses and inform adaptation planning. Storylines can be used to tie the projections results to a specific impact (Shepherd et al. 2018). We have selected single ensemble members that represent changes to hydrological features that define a selection of storylines for the Wet Tropics region.

5.1 Exploring water-sensitive impacts

Changes to water supply and demand storylines are explored in the storylines below. In the Wet Tropics region, the key climate features that relate to water resource impacts are runoff in the wet season and changes to soil moisture in the dry season.

Almost all inflow to water storages occurs during the wet season in this region. Furthermore, the results in Chapter 4 show that, in absolute terms, very little change to dry season runoff is projected under any storyline. Therefore, changes in dry season runoff are not considered significant when discussing changes to annual water availability, and only changes in wet season runoff are used as an indicator for changes to water availability in these storylines.

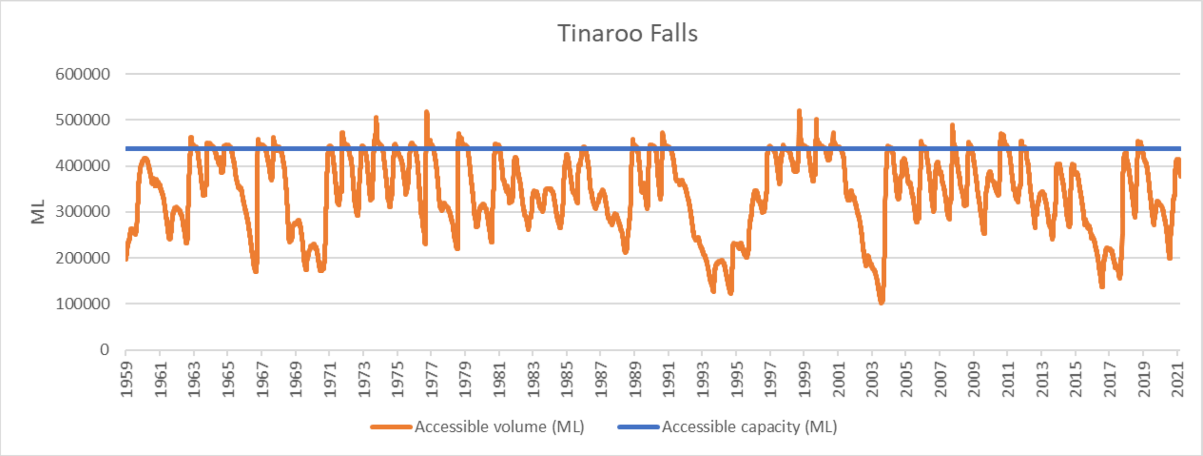

Figure 5.1. Daily storage data in Tinaroo Falls Dam from 1959 to 2021. Water in Tinaroo Falls is captured in the Barron River and diverted west, over the Great Dividing Range, to the Walsh River catchment for use in the Mareeba–Dimbulah Irrigation Scheme.

Daily storage data highlights the seasonal dynamics and the reliability of wet season refilling (Figure 5.1). Historical data highlights the storage's susceptibility to poor wet seasons or extended dry periods. Soil moisture is an indicator of changes to demand. In periods of low soil moisture, population centres are likely to use more water for domestic uses, and irrigated crops require more water to compensate for the reduced water available naturally from the soils. Therefore, it is assumed that decreases in soil moisture correlate with stored water being depleted at faster rates. While soil moisture is a useful indicator for changes to demand pressure year-round, the water security of a system is particularly sensitive to changes during the dry season. This is because stored water depleted during the wet season still has scope to be replenished, and water storages in this region typically receive far larger inflows than capacity in the wet season. On the other hand, the negligible streamflow during the dry season means there is almost no scope to replenish stored water depleted during this period – at the sub-annual scale, a region could become water scarce due to increased pressure on demand. Dry season soil moisture is also a crucial indicator of the water demands for pastural agriculture such as the beef industry.

5.2 Establishing representative storylines

To determine plausible storylines reflecting a range of changes to water availability, changes to wet season runoff are plotted against changes to dry season soil moisture for each ensemble member (Figure 5.2).

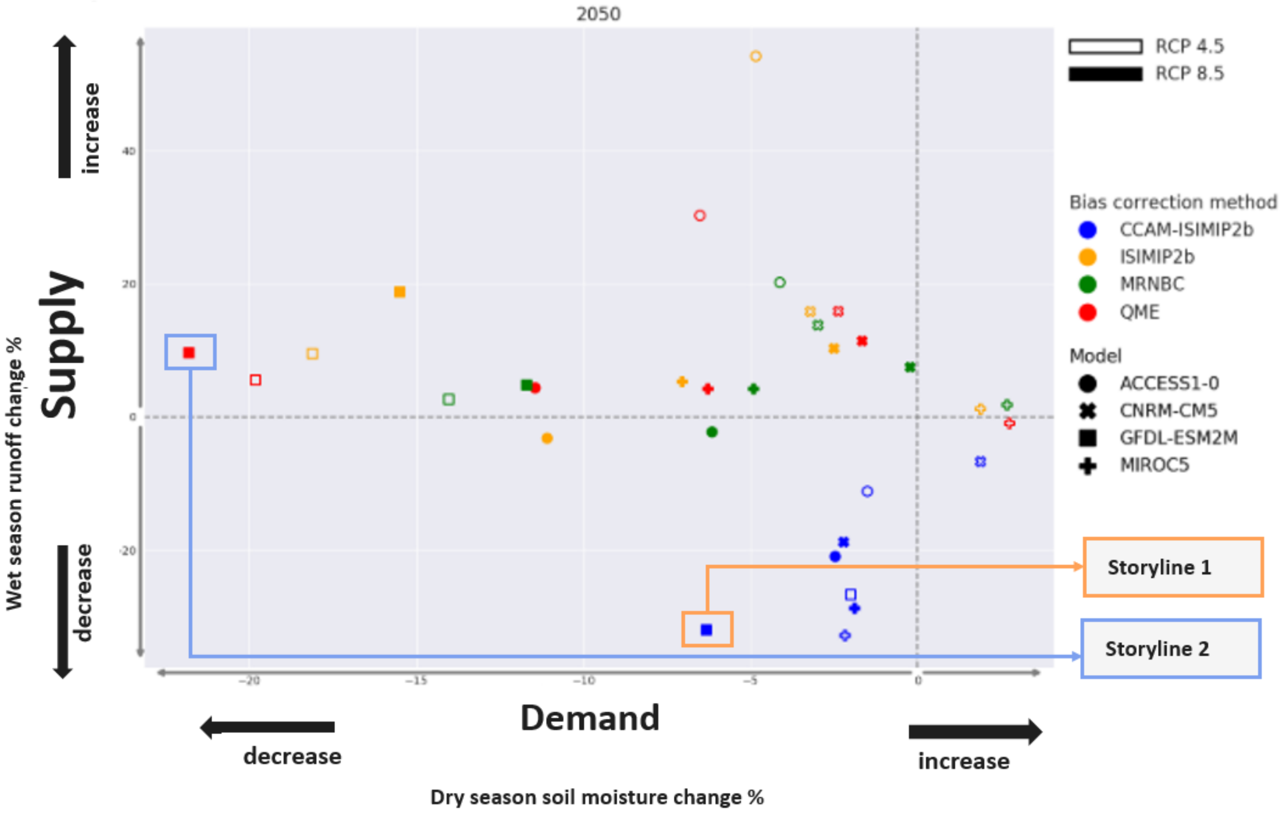

Figure 5.2. Projected changes to wet season runoff vs projected changes to dry season soil moisture. Wet season runoff is used as a proxy for changes to water supply and dry season soil moisture for changes to demand

This plot shows that a number of storylines can be established that represent the extreme conditions from the perspective to changes in water supply and drivers of demand (Table 5.1).

Table 5.1. Storylines for exploring changes in water supply and drivers of demand

Storyline	Impacts to be explored
Large decrease in wet season runoff, decrease in dry season soil moisture (GFDL-ESM2M_CCAM_ISIMIP2b RCP8.5)	All storylines showing large decreases in wet season runoff result from ensemble members downscaled and bias corrected with CCAM_ISIMIP2b. Most of these ensemble members feature little change to dry season soil moisture; however, GFDL-ESM2M_CCAM_ISIMIP2b projects a decrease in dry season soil moisture under RCP8.5.
Very large decreases in dry season soil moisture, some increases in wet season runoff (GFDL-ESM2M_QME and GFDL-ESM2M_ISIMIP2b)	Some ensemble members project decreases in dry season soil moisture of around 15% to 20%. The largest decrease is projected by GFDL-ESM2M_QME; therefore, this storyline projects the largest increases to dry season demand.
Little change in dry season soil moisture and wet season runoff (MIROC5 bias-corrected with QME, ISIMIP2b and MRNBC RCP4.5)	All ensemble members project little change in wet season runoff and in dry season soil moisture. This suggests that there are no storylines where significant favourable increases in dry season soil moisture are likely to occur, and the best-case storyline is little change, in both dry season soil moisture and wet season runoff.
Large increase in wet season runoff, little change in dry season soil moisture (ACCESS1-0_ISIMIP2b RCP4.5)	This storyline, which sees large increases in wet season runoff, is more favourable to water managers than are other storylines. Dry season soil moisture is projected to decrease by around 5%, which is classified as little change. This is represented by ACCESS1-0_ISIMIP2b under RCP4.5.

The first 2 storylines are discussed in more detail below. The relationship between changes to variables and impacts associated with increases in wet season runoff are discussed in these 2 storylines, which give a picture of how the other storylines would also describe impacts.

All but one of selected storylines feature little change in dry season soil moisture (less than 5%). GFDL-ESM2M–CCAM_ISIMIP2b is the only exception, with decreases around 6%. GFDL-ESM2M–CCAM_ISIMIP2b is selected as the storyline that has the largest decreases in wet season runoff and dry season soil moisture.

5.2.1 Storyline 1: Large decreases to wet season runoff and decreases to dry season soil moisture (GFDL-ESM2M–CCAM_ISIMIP2b RCP8.5)

This storyline represents a large decrease in wet season runoff (32%) and therefore the largest projected decrease to water supplies based on seasonal totals. This storyline is produced by the GFDL climate model downscaled by the CCAM_ISIMIP2b bias-correction method (GFDL-ESM2M–CCAM_ISIMIP2b). Ensemble members downscaled with CCAM_ISIMIP2b project larger increases in potential evapotranspiration than do other ensemble groups; they also project the largest decreases to wet season precipitation and soil moisture, which drive the decreased runoff.

Only one other ensemble member (MIROC5–CCAM_ISIMIP2b) projects a comparable decrease (28%) in wet season runoff. However, GFDL-ESM2M–CCAM_ISIMIP2b projects a much larger decrease in dry season soil moisture (6% decrease compared with 2%), so it represents a more extreme water management storyline and reflects the compounding issues of decreases to supply and increases to demand. This storyline is around the 75th percentile of all ensemble results for changes to dry season soil moisture. Changes to dry season soil moisture are plausible as these are driven largely by increases to evapotranspiration (about 9%).

A decrease of 32% in wet season runoff could result in less-reliable filling of storages in the wet season and could mean a vulnerability for water supply under this future storyline. A decrease in soil moisture, an indication of larger demands through the dry season, would compound the issue of decreased water availability under this storyline compared to current conditions.

Spatial distribution of median changes show that the wet season runoff decreases are largest along the Gulf of Carpentaria and also around Cairns (in the Herbert, Tully and Johnston river catchments) and Mackay. The largest dry season soil moisture decreases are also around Mackay; there is little change in most of the other areas. The median change maps (Figure 4.7) show that the Mackay part of this region is projected to experience both a decrease in water supply and an increase in demand, making it the area vulnerable for future water availability.

The projected decrease in dry season soil moisture will also reduce water availability for pasture growth, making industries like beef cattle less viable and increasing fire risk in the region.

Many surface water and groundwater stores in northern Australia are characterised by a cycle of annual filling and replenishment in the wet season followed by depletion from consumptive and irrigation use or natural draining into waterways during the dry season. Despite large inter-annual variability of precipitation characteristic of northern Australia (particularly in the early wet season), surface water storages and groundwater tend to fill reliably. This is due to the typically high intensity of precipitation events, which generate significant volumes of runoff and fill many water storages within the first few precipitation events of the season. While current physical water availability consistently exceeds water demand in this part of Australia, future surface water supplies under this storyline could face dual and compounding pressures from a less-reliable source of water (lower wet season runoff) and faster depletion of stored water (as indicated by decreases in soil moisture). With the water resources depending heavily on annual filling for some storages, several years of below-average precipitation could indicate vulnerabilities to water supply scarcity.

The results here do not assess changes to reliability of the area's surface water supply arising from changes in year-to-year variability. However, noting the large natural variability in precipitation for the region, this storyline would also result in more frequent years of extreme dry, and these extreme dry periods would be more intense in terms of water deficits. Projected year-round increased evapotranspiration means greater direct losses from stored water, increasing the vulnerability for existing water storages.

5.2.2 Storyline 2: Very large decrease in dry season soil moisture, increase in wet season runoff (GFDL-ESM2M_QME RCP8.5)

This storyline describes the largest decrease in dry season soil moisture (about 22%). It is therefore the storyline that demonstrates the largest dry season water demand. The large decreases are driven partly by increases in potential evapotranspiration for this storyline (4% at 2050), which is related to increases in temperature. Projected decreases in dry season precipitation from this storyline (about 40%) are the largest of any of the 16 storylines.

In this storyline, wet season runoff is projected to increase by 9.5%. Despite increased wet season runoff, the storyline is unlikely to result in increases to water availability. Storages in northern Australia already reliably fill in most wet seasons, so a storyline describing increases to wet season runoff would not increase water availability without increases to storage capacity. However, increases in surface storage capacity, which results in decreased flow to streams and recharge to groundwater, would be counterbalanced by the projected large increases in potential evaporation throughout the year. Similarly, the increased runoff is not likely to increase the recharge of some groundwater systems, particularly those which have limited capacity to replenish. However, karstic aquifers (typically of porous limestone) have the potential to recharge greater amounts in the storylines that project increases in runoff.

Runoff in all seasons is projected to be increasingly experienced as higher-intensity events, which will result in more frequent and more severe inundation. An increase in runoff could also mean more frequent spill over of dams, which must be managed. The projected increase in runoff despite little change to wet season precipitation and a decrease in dry season soil moisture for this storyline suggests the projected increases may be driven by higher-intensity events generating more quick runoff due to infiltration runoff. In low-lying areas, this will result in road closures and impacts on, for example, pastoralists, who could find their fodder supply chain cut off.

Dry season soil moisture decreases are largest around the Cairns and Mackay areas (Figure 4.11), which are the most developed in terms of population and irrigation districts. Hence, decreases in soil moisture would more readily convert to faster depletion of stored water. Cape York Peninsula features decreases at the start of the dry season months but little change in the middle and end of the dry season. Pastoral activities in these regions would be mostly affected by decreases in soil moisture during the early part of the dry season.

Wet season runoff increases are focused on the north-west tip of Cape York, river basins south of Cairns and also the Mackay area. The increases are constrained to the summer months (December–February), and decreases are projected in autumn for the Cairns area river basins.

5.3 Conclusions

National Hydrological Projections for changes to precipitation, soil moisture, runoff and evapotranspiration can be useful indicators for a range of water-sensitive impacts, such as water availability for the environment and human consumption, inflows and demands on water storages, and soil moisture for rain-fed agriculture or as a risk factor for bushfires. Using a storylines approach, we have used the National Hydrological Projections to interrogate potential changes to water security as an example of how impact risks can be assessed with these data. Each of the 16 ensemble members represents a plausible future storyline with respect to future changes to water security. Results from other projections are discussed to contextualise where these storylines fit in a broader understanding of plausible futures.

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8 Appendix: Evaluation of bias-correction methods

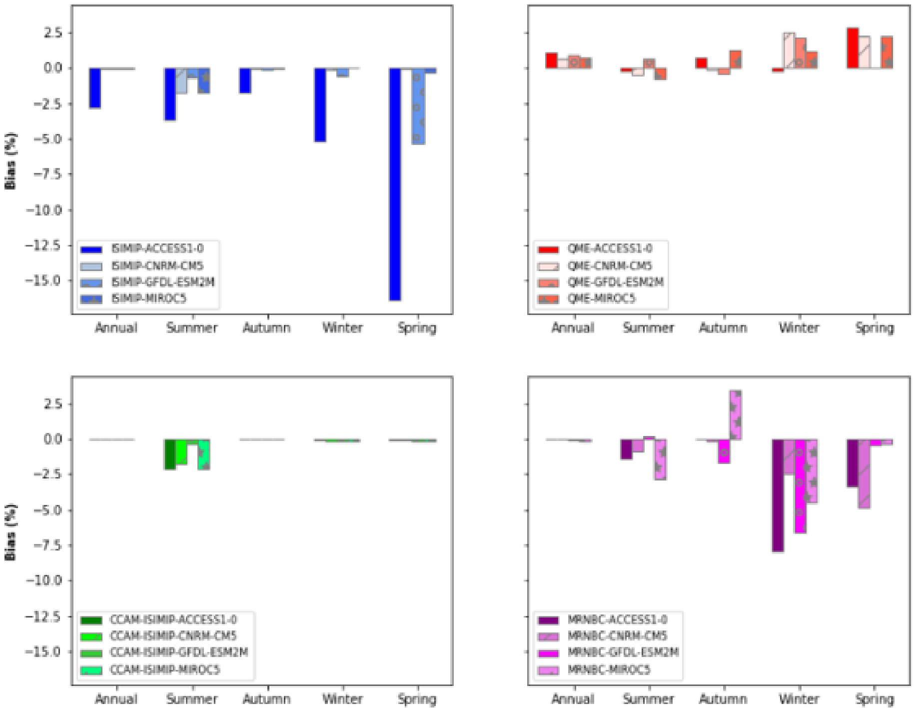

Figure 8.1. Bias (%) in mean annual and seasonal precipitation for the Wet Tropics region

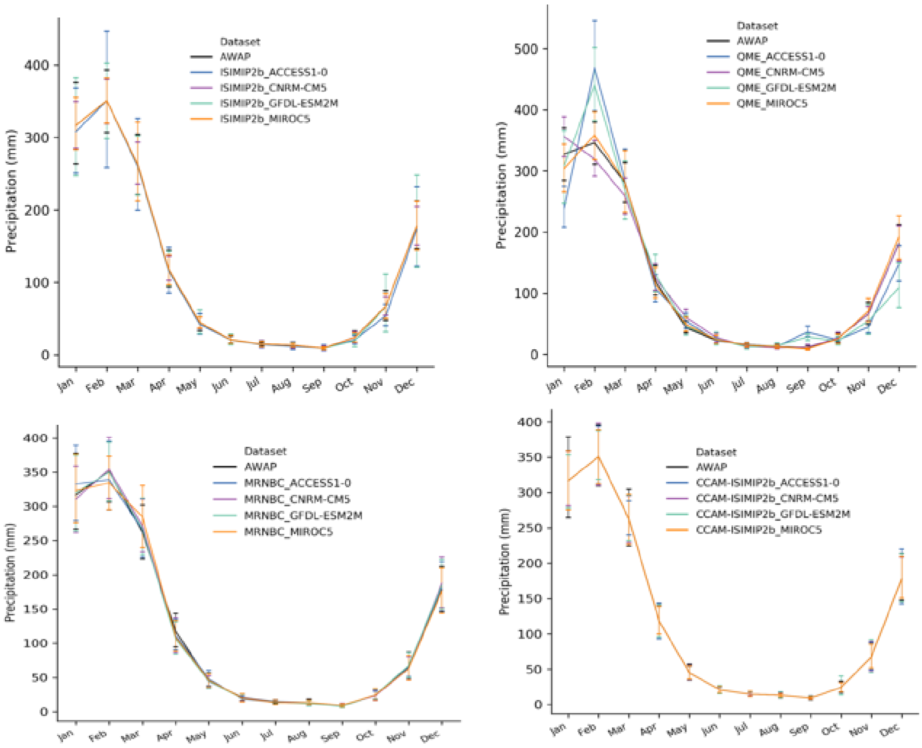

Figure 8.2. Comparison of the mean monthly precipitation (mm) for the 16-member ensemble and observed (AWAP) data for the Wet Tropics region (1976–2005)

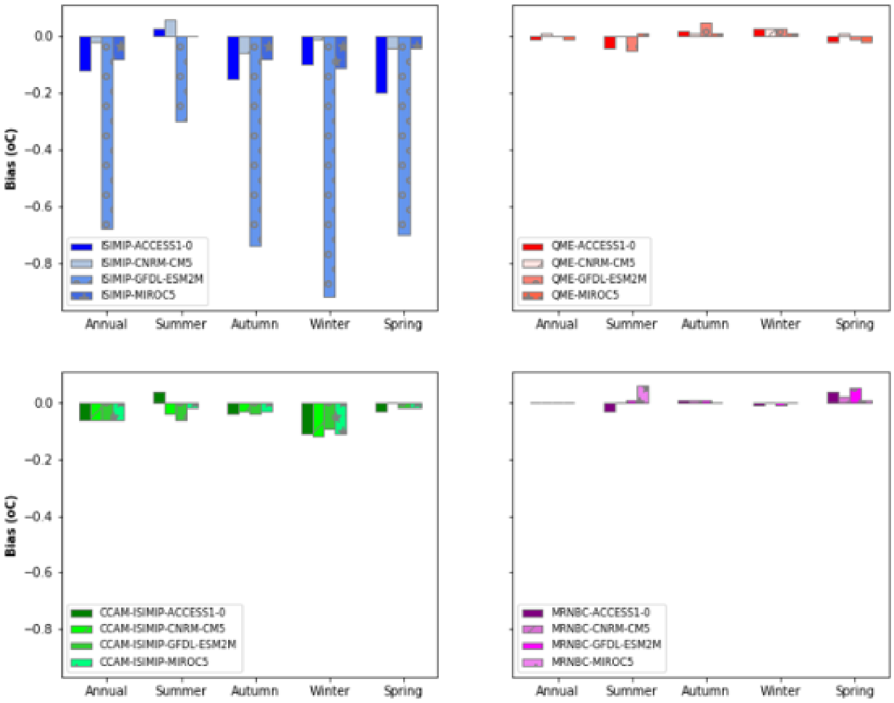

Figure 8.3. Bias (°C) in mean annual and seasonal maximum temperature for the Wet Tropics region

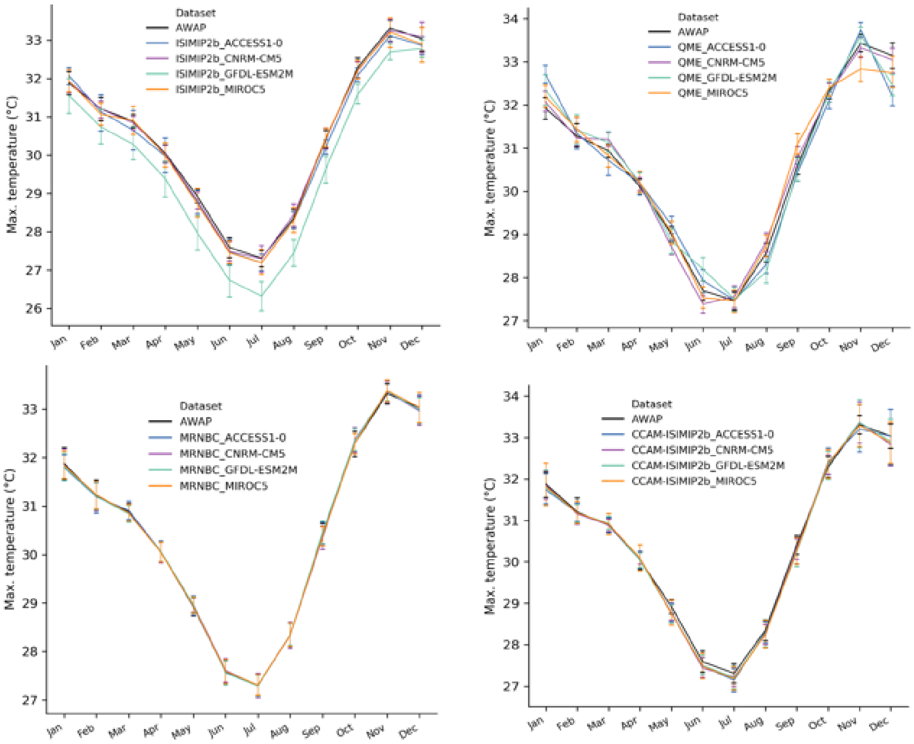

Figure 8.4. Comparison of the mean monthly maximum temperature (°C) for the 16-member ensemble and observed (AWAP) data for the Wet Tropics region (1976–2005)

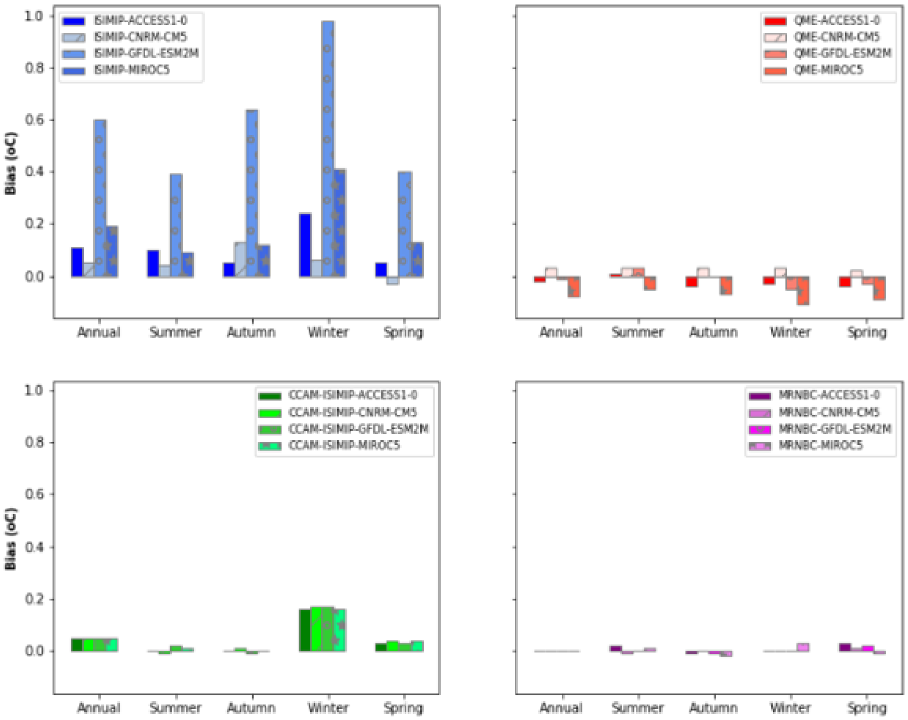

Figure 8.5. Bias (°C) in mean annual and seasonal minimum temperature for the Wet Tropics region

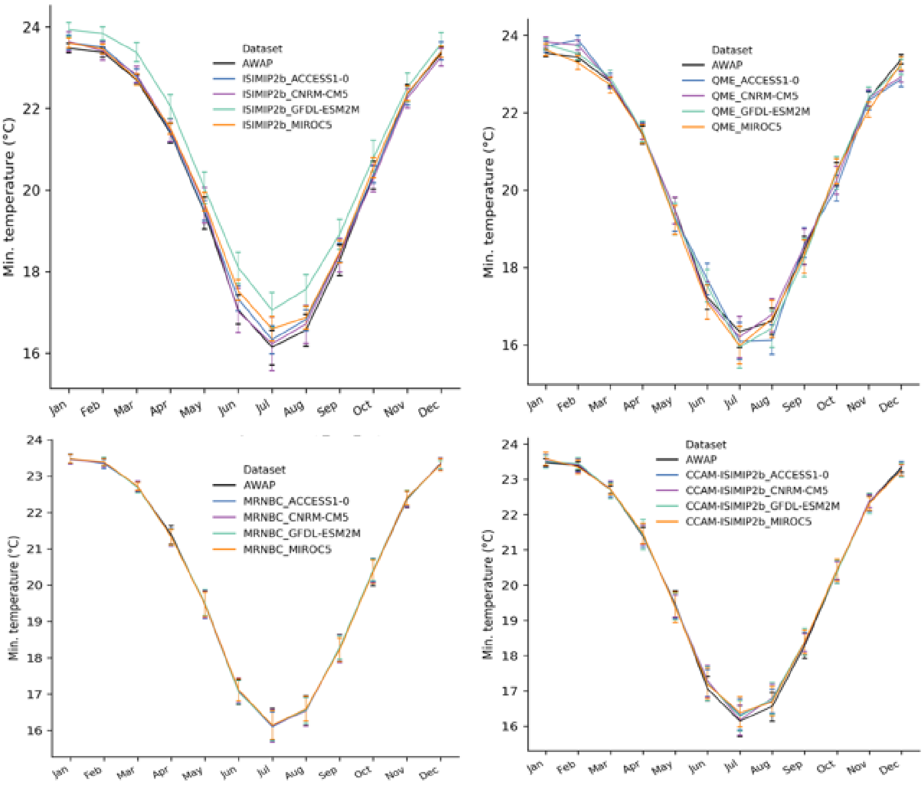

Figure 8.6. Comparison of the mean monthly minimum temperature (°C) for the 16-member ensemble and observed (AWAP) data for the Wet Tropics region (1976–2005)

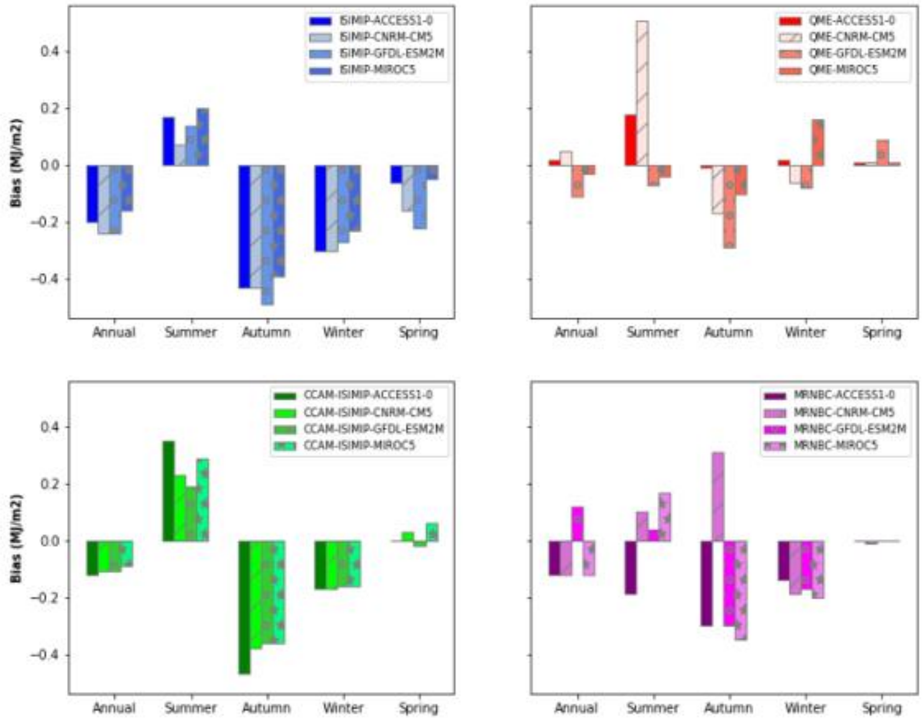

Figure 8.7. Bias (megajoules per square metre, MJ/m^2) in mean annual and seasonal solar radiation for the Wet Tropics region

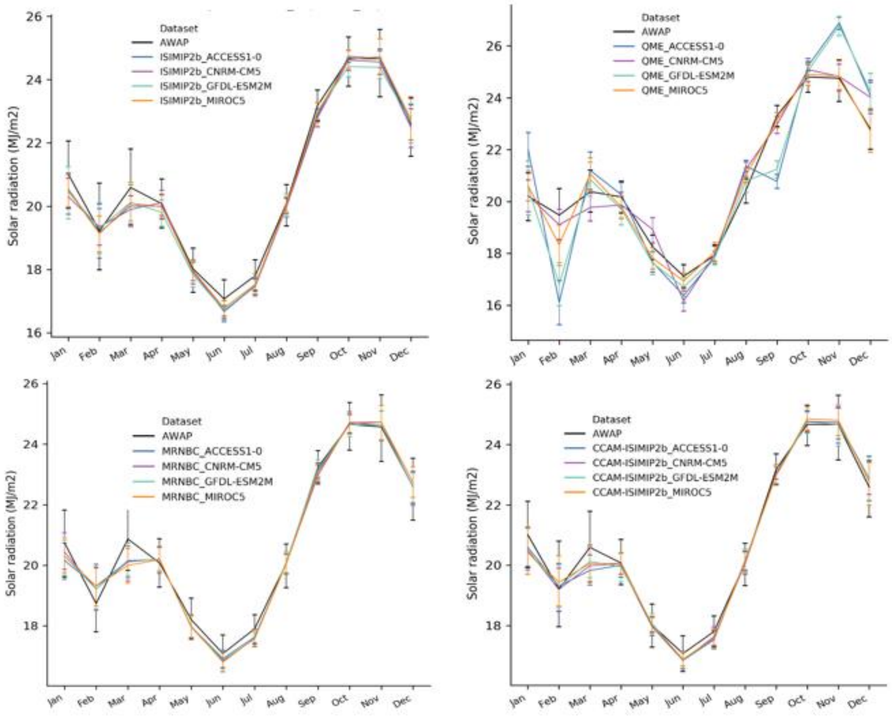

Figure 8.8. Comparison of the mean monthly solar radiation (MJ/m^2) for the 16-member ensemble and observed (AWAP) data for the Wet Tropics region (1976–2005)

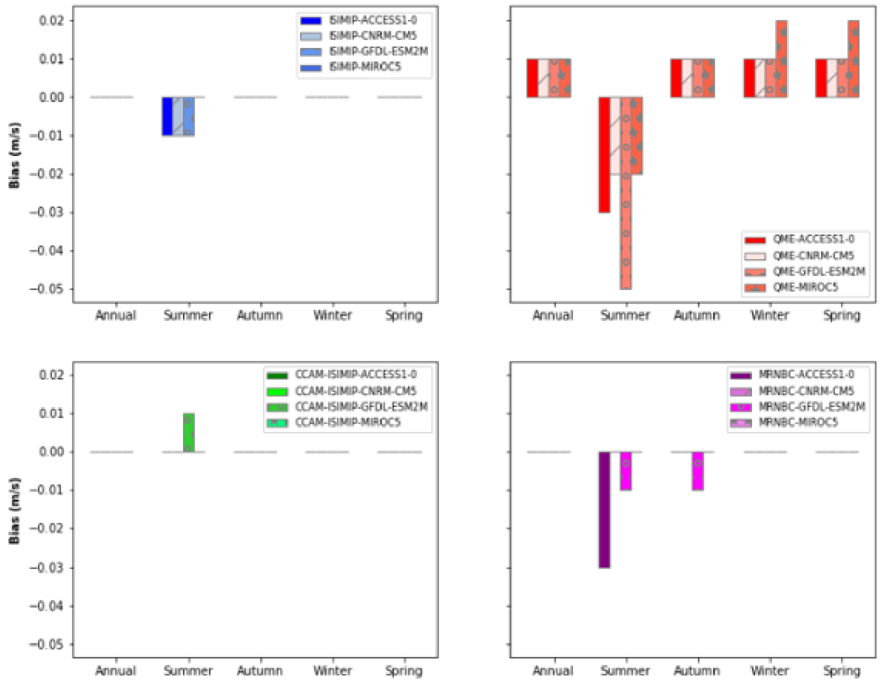

Figure 8.9. Bias (m/s) in mean annual and seasonal wind speed for the Wet Tropics region

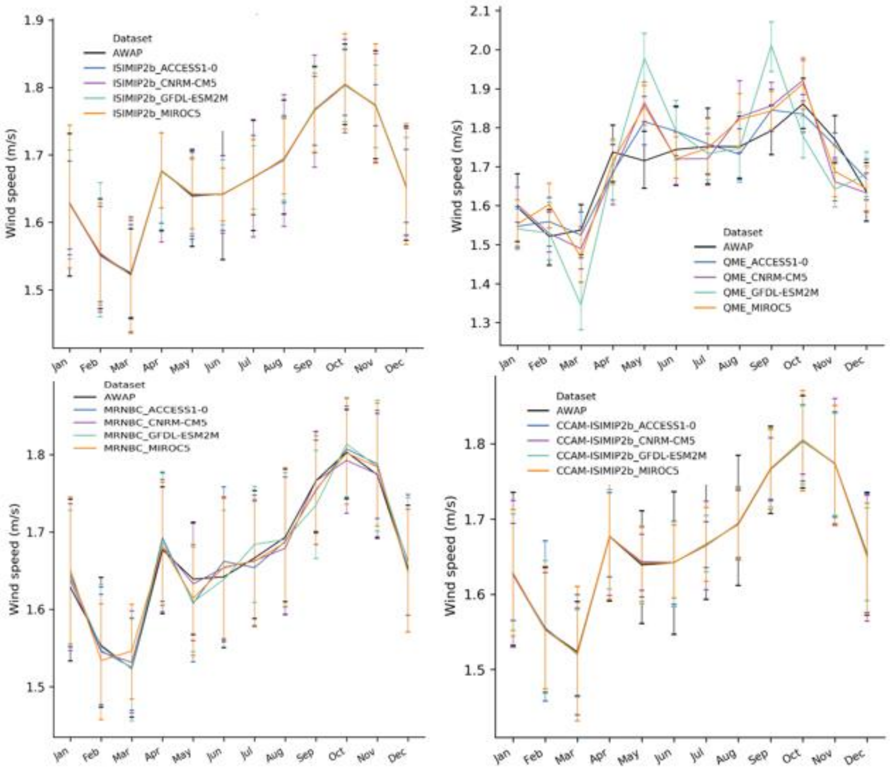

Figure 8.10. Comparison of the mean monthly wind speed (m/s) for the 16-member ensemble and observed (AWAP) data for the Wet Tropics region (1976–2005)

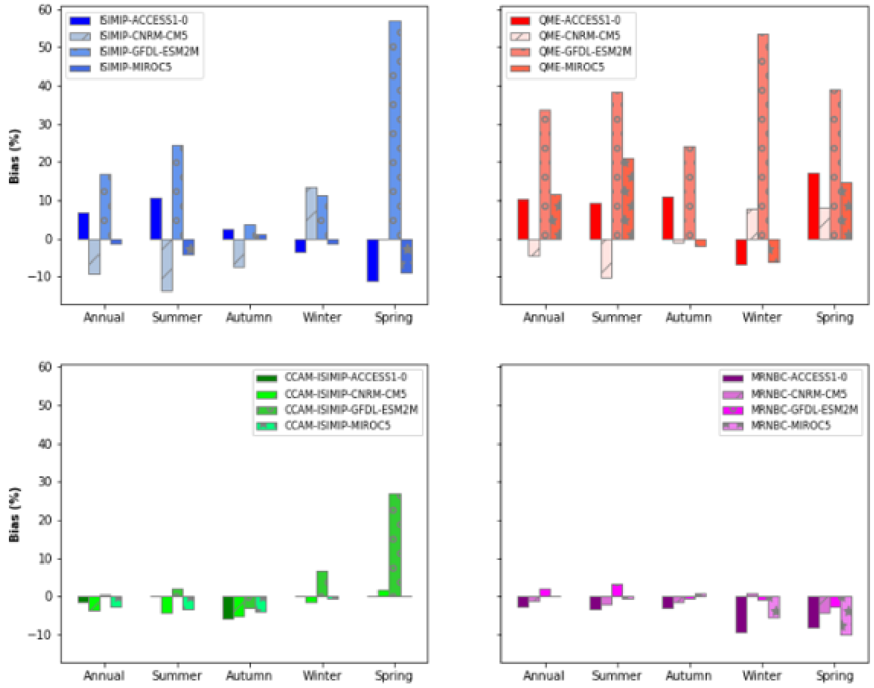

Figure 8.11. Bias (%) in mean annual and seasonal runoff for the Wet Tropics region

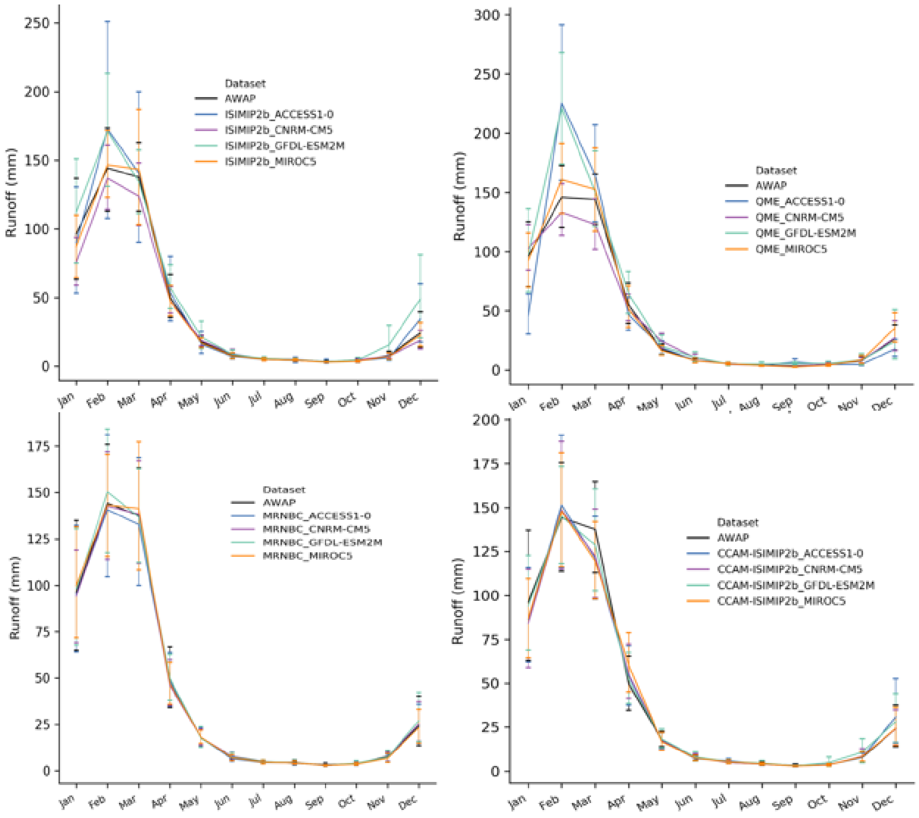

Figure 8.12. Comparison of the mean monthly runoff (mm) for the 16-member ensemble and observed (AWAP) data for the Wet Tropics region (1976–2005)

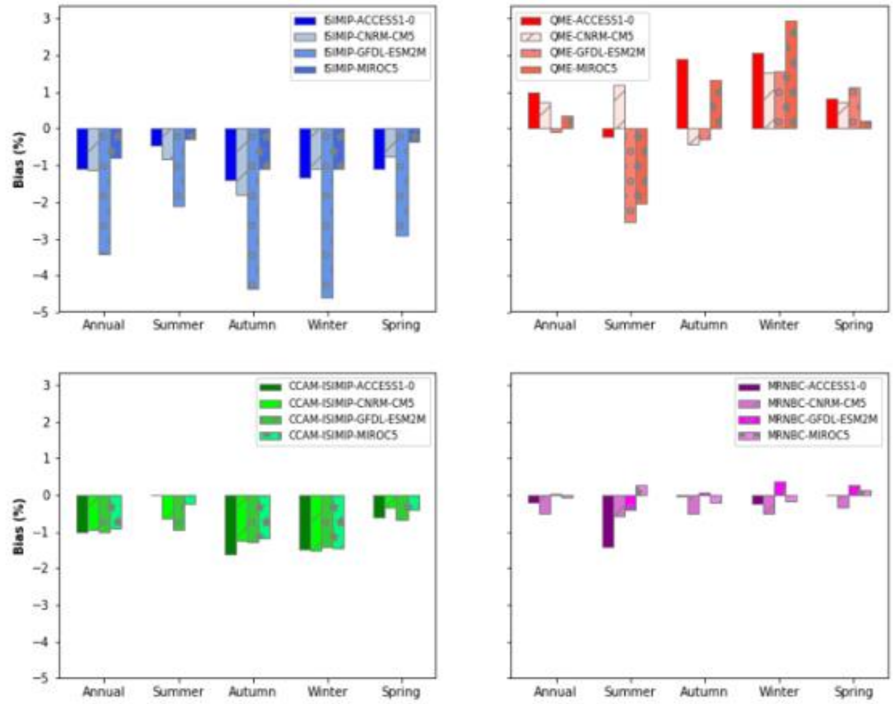

Figure 8.13. Bias (%) in mean annual and seasonal potential evapotranspiration for the Wet Tropics region

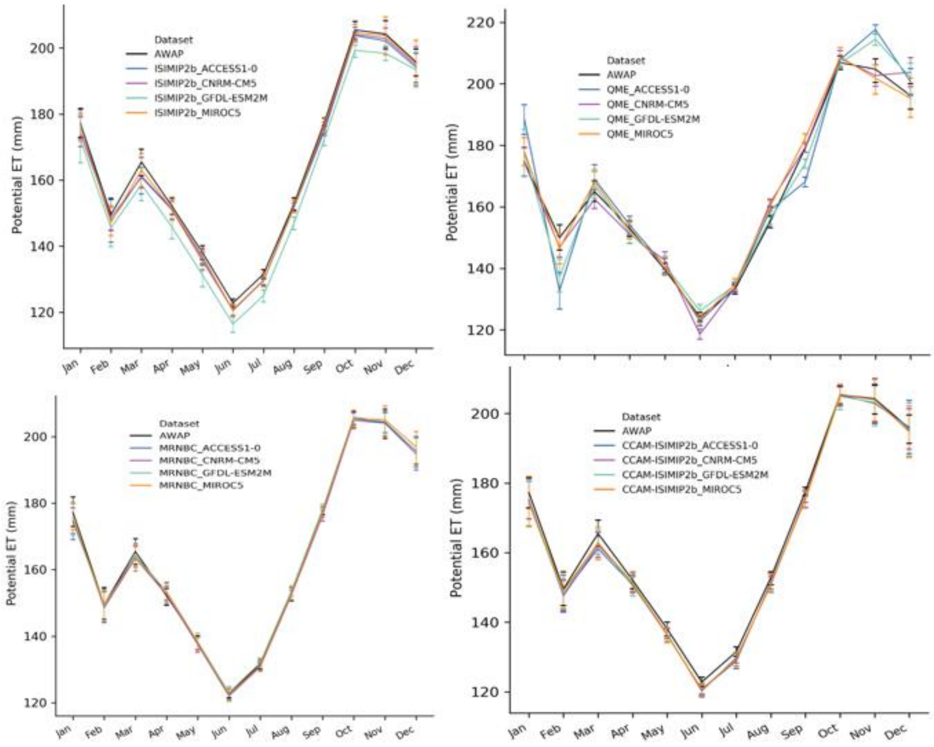

Figure 8.14. Comparison of the mean monthly potential evapotranspiration (mm) for the 16-member ensemble and observed (AWAP) data for the Wet Tropics region (1976–2005)

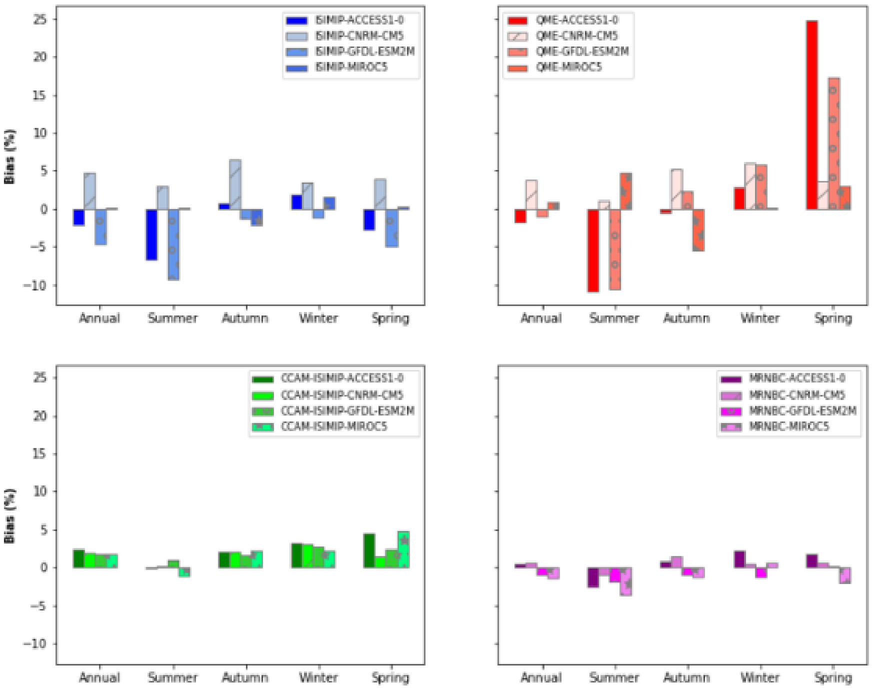

Figure 8.15. Bias (%) in mean annual and seasonal soil moisture for the Wet Tropics region

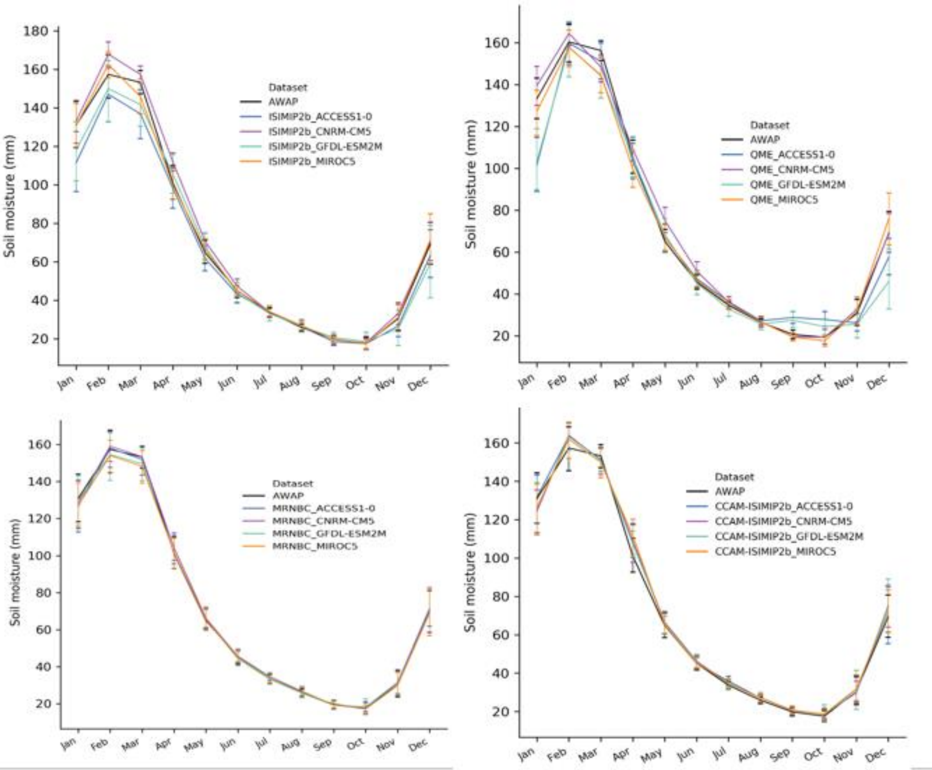

Figure 8.16. Comparison of the mean monthly soil moisture (mm) for the 16-member ensemble and observed (AWAP) data for the Wet Tropics region (1976–2005)