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Climate change impacts on Australia's dairy regions

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Report for Dairy Australia

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Executive summary

Climate change represents a significant challenge to individuals, communities, governments, businesses and the environment. This report addresses the evidence for past and future climate change, with a focus on projections for Australia's eight dairy regions in the year 2040.

The evidence for global climate change is clear. Increases in greenhouse gases due to human activities have played a role. Human influence has been detected in warming of the global atmosphere and ocean, changes in the global water cycle, reductions in snow and ice, global mean sea level rise, and changes in some climate extremes. It is extremely likely that human influence has been the dominant cause of the observed global warming since the mid-20th century.

The evidence for Australian climate change is also clear. Australian average surface air temperature has increased by around 1°C since 1910, with more hot days and fewer cold days. Annual-total rainfall has increased over northern and inland-western Australia since the 1950s. In contrast, annual-total rainfall in southern and eastern Australia has decreased since the 1950s, particularly in southwest Western Australia. One of the major impacts of the rainfall decline, and associated increases in temperature, has been a reduction in dam inflows.

Further increases in greenhouse gases are expected over the coming decades. A high emission scenario has been assessed for a 20-year period centred on 2040, relative to a 20-year period centred on 1995. Projections based on results from 40 different climate models indicate that Australia will become hotter, with less winter-spring rainfall and more droughts in southern Australia, uncertain rainfall changes in northern Australia, more extreme daily rainfall (except in south-western Australia), higher evapotranspiration and lower soil moisture.

Projected changes in the eight dairy regions by the year 2040 under a high emission scenario

Tasmania

The dairy region in Tasmania is expected to warm by about 0.5-1.5°C by 2040 under the high emission scenario, with slightly greater warming in summer and autumn. Maximum temperatures and minimum temperatures rise by about the same amount, but maxima rise more than minima in spring. Annual total rainfall will continue to have large variability from year to year, superimposed on a decrease of 0-15% by 2040. There are slightly larger decreases in spring and summer with little change in winter. The combination of lower rainfall and higher evapotranspiration means lower soil moisture. The largest median decrease is in summer and the least in winter, with a range of -7 to -3% in summer, -8 to 0% in autumn, -3 to 0% in winter and -5 to 1% in spring.

Gippsland (Victoria)

The Gippsland dairy region will warm by about 1.0-1.7°C by 2040 under the high emission scenario, with greatest warming in summer and least in winter. Maximum temperatures increase more than minimum temperatures. Annual total rainfall will continue to have large variability from year to year, superimposed on a median decrease of about 3% by 2040, with a range of -10 to +5%. There are slightly larger decreases in spring and summer with little change in winter. Soil moisture declines, with a range of -7 to -1% in summer, -10 to -2% in autumn, -14 to -4% in winter and -14 to -10% in spring.

Murray (northern Victoria)

The Murray dairy region will warm by about 1.2-1.8°C by 2040 under the high emission scenario, with greatest warming in summer and least in winter. Maximum temperatures increase more than minimum temperatures. Annual total rainfall will continue to have large variability from year to year, superimposed on a median decrease of about 3% by 2040, with a range of -10 to +5%. The decreases occur in winter and spring with little change in summer and autumn. Soil moisture declines, with a range of -7 to +1% in summer, -10 to -1% in autumn, -10 to -4% in winter and -13 to -6% in spring.

Western Victoria

The western Victorian dairy region will warm by about 1.0-1.6°C by 2040 under the high emission scenario, with greatest warming in summer and least in winter. Maximum temperatures increase more than minimum temperatures in all seasons except autumn. Annual total rainfall will continue to have large variability from year to year, superimposed on a median decrease of about 5% by 2040, with a range of -15 to +3%. The decreases occur in autumn, winter and spring with little change in summer. Soil moisture declines, with a range of -7 to +1% in summer, -10 to -1% in autumn, -10 to -4% in winter and -13 to -6% in spring.

South Australia

The South Australian dairy region will warm by about 1.0-1.6°C by 2040 under the high emission scenario, with greatest warming in summer and least in winter. Maximum temperatures increase more than minimum temperatures in all seasons except autumn. Annual total rainfall will continue to have large variability from year to year, superimposed on a median decrease of about 5% by 2040, with a range of -17 to +3%. The decreases occur in winter and spring with little change in summer and autumn. Soil moisture mostly declines, with a range of 0 to +1% in summer, -3 to 0% in autumn, -10 to -2% in winter and -12 to -3% in spring.

New South Wales

The NSW dairy region will warm by about 1.2-2.0°C by 2040 under the high emission scenario, with greatest warming in summer and least in winter. Maximum temperatures increase more than minimum temperatures. Annual total rainfall will continue to have large variability from year to year, with little change in the median by 2040. A small decrease in winter rainfall is offset by a small increase in summer. Due to increases in evapotranspiration, soil moisture declines, with a range of -7 to +2% in summer, -8 to -1% in autumn, -13 to -7% in winter and -15 to -5% in spring.

Sub-tropical (Queensland and northern NSW)

The sub-tropical dairy region will warm by about 1.0-2.0°C by 2040 under the high emission scenario, with greatest warming in spring and least in autumn. Maximum temperatures increase more than minimum temperatures. Annual total rainfall will continue to have large variability from year to year. When averaged over the north and south sub-regions, the median decreases by around 5% by 2040. However, the decrease is about 10% in the south and only 2% in the north. Decreases occur in all seasons in the south, but only in autumn to spring in the north. Soil moisture declines in most seasons, with a range of -1 to +5% in summer, -10 to 0% in autumn and winter, and -6 to -4% in spring.

South-western Australia

The south-western dairy region will warm by about 1.0-1.7°C by 2040 under the high emission scenario, with greatest warming in summer and least in winter. Maximum temperatures increase more than minimum temperatures. Annual total rainfall will continue to have large variability from year to year, with a 15% decrease in the median by 2040, and a range of -22 to -7%. Decreases occur in all seasons, especially spring. Soil moisture declines in most seasons, with a range of -1 to +1% in summer, -2 to +3% in autumn, -12 to -3% in winter and -12 to -7% in spring.

Projected changes at 24 sites by the year 2040 under a high emission scenario

Projected changes in monthly maximum temperature for 2040 under a high emission scenario have been applied to observed daily maximum temperature data at 24 sites in the dairy regions. The current and future annual-average number of days over 30°C is shown in Table 1. Beyond this temperature threshold, dairy cattle experience heat-stress. At most sites, the increase is 20-50%. Places that currently have an annual-average of 70-80 days over 30°C (e.g. Cowra, Deniliquin, Jerry's Plains, Kerang) would experience an increase of about 13-37 days, although Casino (current average of 80 days) would experience an increase of 30-54 days. Places that currently have an average of 50-60 days (e.g. Donnybrook, Murray Bridge, Tatura) would see an increase of about 10-25 days, and places that currently have an average of 20-30 days (e.g. Ballarat, East Sale, Victor Harbour) would see an increase of about 5-13 days.

Table 1: Annual-average number of days over 30°C for the period 1986-2005 compared with 2030-2049 for the high emission scenario (RCP8.5) at 24 sites in Australian dairy regions.

Site	1986-2005	2030-2049
Ballarat	23.4	29.5-36.0
Burnie	0.2	0.5-0.8
Casino	79.8	111.4-133.7
Corryong	42.0	58.8-73.5
Cowra	74.1	92.8-108.2
Deniliquin	73.1	88.4-100.0
Donnybrook	53.1	61.2-72.8
East Sale	22.5	28.4-33.4
Gatton	103.7	136.2-160.8
Gympie	87.3	121-149.4
Heywood	18.1	20.9-25.8
Jerry's Plains	72.4	93.0-109.5
Kairi	44.6	67.4-104.8
Kerang	73.1	86.3-99.0
Mount Gambier	19.9	23.3-28.1
Murray Bridge	55.8	64.6-75.8
Nowra	22.4	36.4-44.2
Oakey	84.1	114.3-138.0
Olsens Bridge	13.1	16.7-20.0
Scottsdale	1.2	2.2-3.6
Taree	37.8	59.0-78.6
Tatura	52.1	66.6-74.0
Victor Harbour	25.2	30.2-36.5
Wonthaggi	16.2	19.9-23.5

Projected changes in monthly average temperature and rainfall for 2040 under a high emission scenario have been applied to observed monthly data at the same 24 sites. This indicates expected changes in the average seasonal cycle. Since all sites become warmer and drier, the warm season and the dry season become longer, and the cool season and wet season become shorter. At most sites, there is a 1-month shift in temperatures, e.g. the current average temperature for March shifts to April. There is greater uncertainty for rainfall but a 1-month shift is mostly evident, especially in winter and spring.

Implications

A warmer and drier climate poses challenges for the dairy industry in areas such as pasture growth, runoff into dams, viability of shade trees, managing feed, heat stress, pests, weeds, diseases and reproduction. More extreme daily rainfall increases risks for flooding, erosion, water-logging, infrastructure, supply chain and transport.

1 Introduction

Climate change represents a significant challenge to individuals, communities, governments, businesses and the environment. Evidence for global and regional climate change has been well documented in peer-reviewed scientific literature. Increases in greenhouse gases due to human activities such as burning fossil fuels, clearing forests and expansion of agriculture have been linked to climate change. Further increases in greenhouse gases will lead to more climate change. Substantial impacts are expected on water resources, coasts, infrastructure, health, agriculture and biodiversity.

Managing these impacts will require significant reductions in global greenhouse gas emissions over the next few decades. This can reduce climate risks in the 21st century and beyond, increase prospects for effective adaptation, and contribute to climate-resilient pathways for sustainable development (IPCC, 2014).

The UNFCCC Paris Agreement signed in December 2015 aims to keep global warming well below 2°C above pre-industrial levels through nationally determined contributions to emission reductions. It also aims to significantly strengthen national adaptation efforts by enhancing adaptive capacity, strengthening resilience and reducing vulnerability to climate change.

The best mix of emissions reduction policies, change adaptation and resilience-building varies from country to country depending on emissions intensity, the cost of reducing emissions, vulnerability to climate change impacts and tolerance for risk. The National Climate Resilience and Adaptation Strategy (2015) sets out how Australia is managing the risks of a variable and changing climate. It identifies a set of principles to guide effective adaptation and outlines a vision for a climate-resilient future. Australia needs a strong foundation in policies, laws, institutions and investments in research and technology to further reduce greenhouse gas emissions and build the resilience of communities, the economy and the environment.

At the request of Dairy Australia, this report addresses the evidence for past and future climate change, with a focus on projections for Australia's dairy regions around the year 2040. Chapter 2 describes the evidence for observed global and Australian climate change, and Chapter 3 addresses the associated causes of the changes. Chapter 4 covers global and Australia climate projections for the mid-21st century, with a brief summary of possible impacts on the dairy industry. Chapter 5 provides an overview of risk management and dealing with uncertainty. The Appendix gives temperature and rainfall projections for selected sites within the dairy regions.

This work draws upon information and data generated by the CSIRO and Bureau of Meteorology for Climate Change in Australia - see www.climatechangeinaustralia.gov.au.

2 Evidence for observed climate change

Observations of the climate system are based on direct measurement and remote sensing from satellites and other platforms (IPCC, 2013). These observations provide information about variability and long-term changes in the atmosphere, ocean, cryosphere (ice) and land surface.

Since the 1950s, many of the observed changes are unprecedented over decades to millennia. The atmosphere and ocean have warmed, the amounts of snow and ice have diminished, and sea level has risen (IPCC, 2013).

2.1 Global changes

The Intergovernmental Panel on Climate Change (IPCC 2013) assessed past and future climate change. The report concluded that:

- The globally averaged surface warming is 0.85 °C from 1880 to 2012 (Figure 1). It is very likely that the number of cold days and nights has decreased and the number of warm days and nights has increased on the global scale. It is likely that the frequency of heat waves has increased in large parts of Europe, Asia and Australia.
- On a global scale, the ocean warming is largest near the surface, and the upper 75 metres warmed by 0.11°C per decade over the period 1971 to 2010.
- Global-average sea level has risen (Figure 2). The rate of increase is 1.7 mm/year between 1901 and 2010, 2.0 mm/year between 1971 and 2010, and 3.2 mm/year between 1993 and 2010.
- There are likely more land regions where the number of heavy precipitation events has increased than where it has decreased.
- There is low confidence in long-term tropical cyclone trends.
- The atmospheric concentrations of carbon dioxide, methane and nitrous oxide (key greenhouse gases) have increased to levels unprecedented in at least the last 800,000 years. Carbon dioxide concentrations have increased by 40% since the year 1750 (pre-industrial times).
- The ocean has absorbed about 30% of the emitted anthropogenic carbon dioxide, causing ocean acidification.

Since the IPCC (2013) report, a few other notable events have occurred. Firstly, the global-average temperature in 2015 was the highest on record (WMO, 2016; Figure 1). Heatwaves were extremely intense in various part of the world, leading to thousands of deaths in India and Pakistan, partly due to the strong El Niño that developed in the later part of 2015. Secondly, Arctic sea ice has continued shrinking. Ice extent typically increases through autumn and winter, and the maximum usually occurs in mid-March. On 24 March 2016, Arctic sea ice reached a record low maximum extent (NSIDC, 2016). Thirdly, the global-average carbon dioxide concentration set a new record of 404.1 parts per million (ppm) in April 2016 (NOAA, 2016).

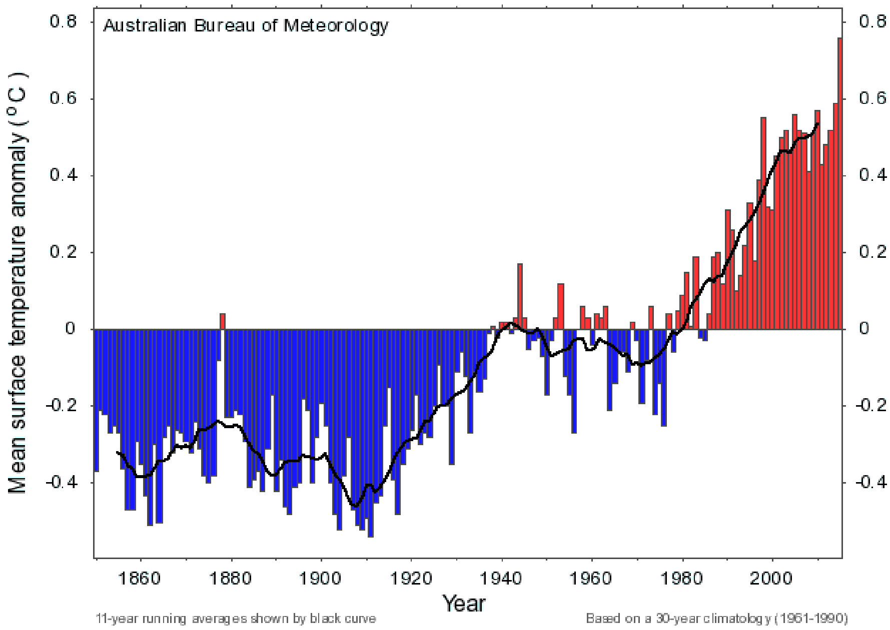

Figure 1: Global-average temperature anomalies from 1850-2015, relative to the period 1961-1990, with an 11-year running average (black line).

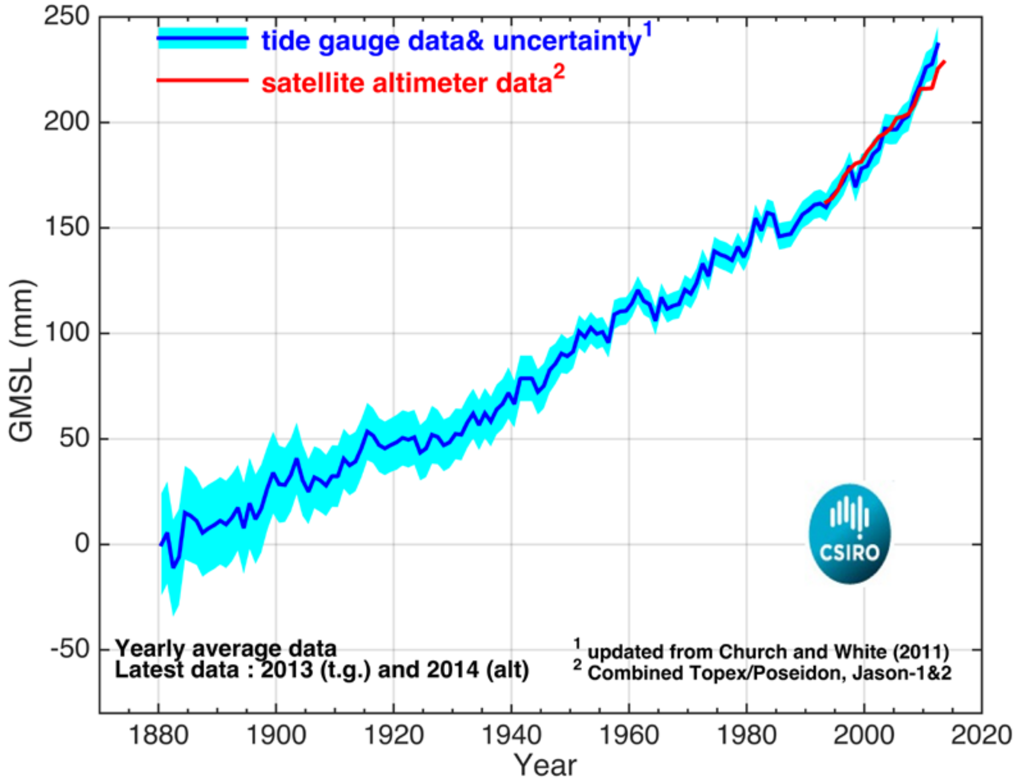

Figure 2: Global-mean sea level (GMSL) rise from 1880-2014.

2.2 Australian changes

Over recent decades, Australia has become warmer, with less rain in the south and east, more droughts in the south west, more rain in the north, unclear changes in evapotranspiration and reduced dam inflows in some regions.

2.2.1 Temperature

Australia has become warmer over the past 100 years. Australian average surface air temperature has increased by around 1°C since 1910 (Figure 3). In recent decades:

- Months warmer than average have occurred more often than months colder than average;
- The number of hot days (over 35°C) has increased and the number of cold days (below 15°C) has decreased (Figure 4).
- Heat waves have increased in duration, frequency, and intensity in many regions;
- Since 2001, the number of extreme heat records in Australia has outnumbered extreme cool records by about 3 to 1 for daytime maximum temperatures and about 5 to 1 for night-time minimum temperatures;
- Many heat extremes have been shown to be much more likely due to human influence, including numerous heat records set from 2013 onwards.

(a) (b)

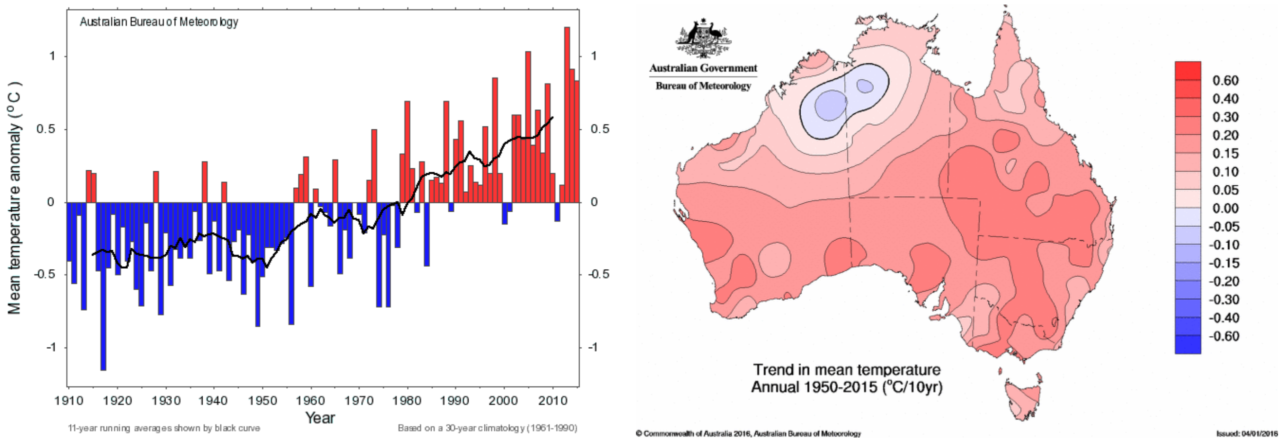

Figure 3: Australian annual average temperatures. (a) Surface air temperature anomalies (bars), shown as the anomaly relative to the 1961-1990 average, with an 11-year running average (black line). (b) Trend in surface air temperatures from 1950-2015.

(a) (b)

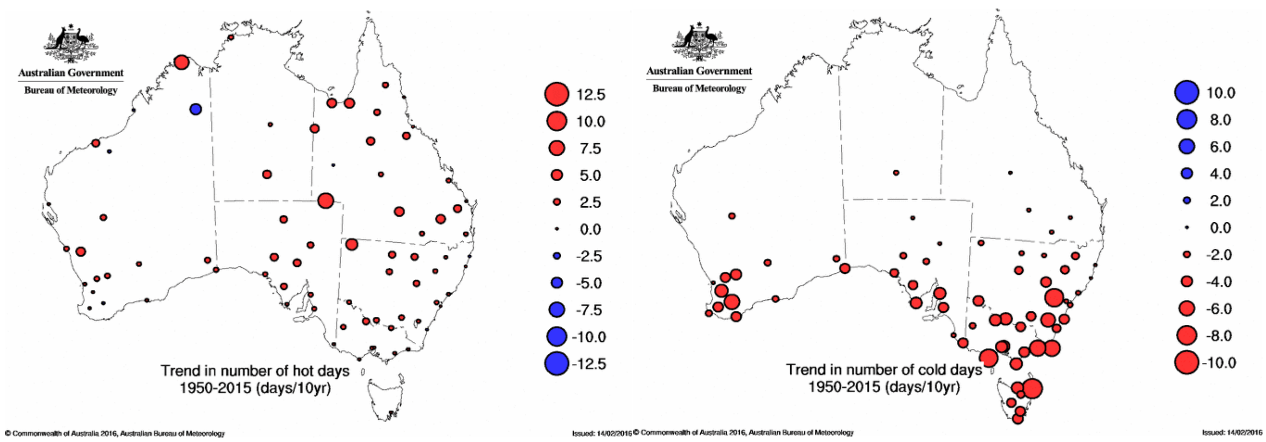

Figure 4: Trend in the decadal number of (a) hot days over 35°C and (b) cold days below 15°C from 1950-2015.

2.2.2 Rainfall

Rainfall over Australia is strongly influenced by large-scale atmospheric circulation patterns such as the El Niño Southern Oscillation, the Indian Ocean Dipole, the monsoon and the Southern Annular Mode. These patterns affect rain-bearing weather systems such as cold fronts, north-west cloud bands, east coast lows, cyclones and other storms.

In recent decades, and in some seasons, the circulation patterns have moved south. In other words, the tropics have expanded. This has produced changes in Australian rainfall.

- Annual-total rainfall in southern and eastern Australia has decreased since the 1950s, particularly in south-western Australia (Figure 5a), partly driven by human influence.
- Annual-total rainfall has increased over northern and inland-western Australia since the 1950s (Figure 5a).
- Very heavy rain-days have generally decreased in southern and eastern Australia, while increases have occurred in northern Australia (Figure 5b).
- There is large variability from year-to-year and decade-to-decade (Figure 6).
- Drought frequency and extent (defined as the area with annual-total rainfall in the lowest 10% on record) has increased in the south-west since the 1960s (Figure 7).

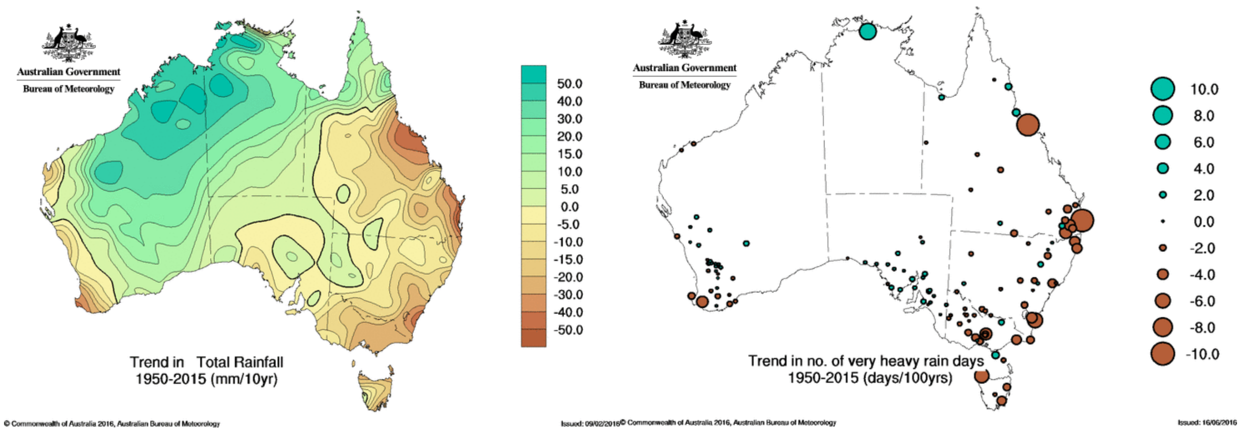

Figure 5: (a) Trend in annual total rainfall and (b) trend in the number of very heavy rain days (over 30 mm/day) from 1950-2015.

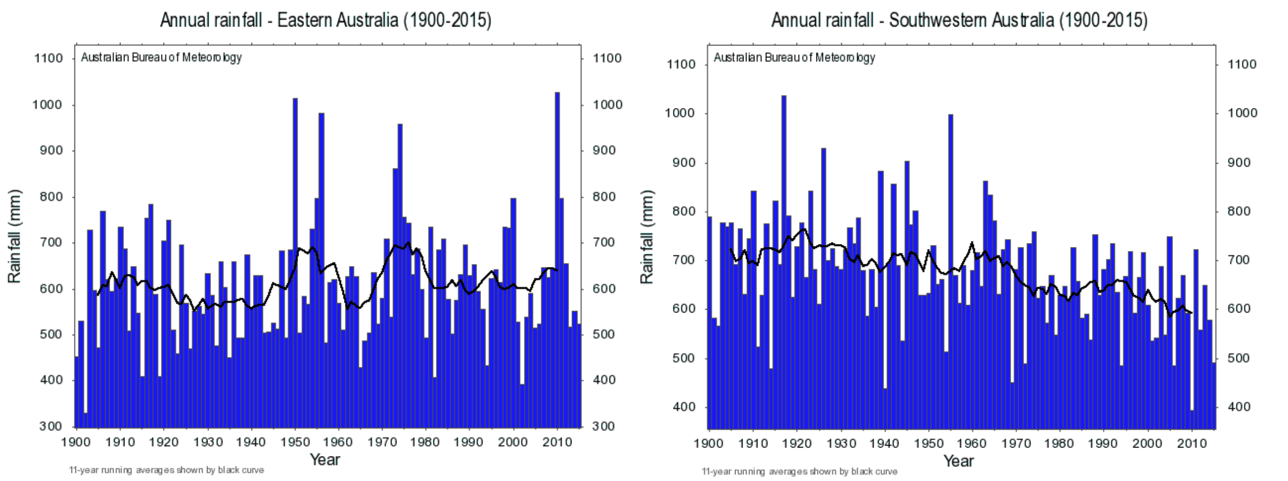

Figure 6: Annual total rainfall for (a) eastern Australia (Qld, NSW, Vic and Tas) and (b) south-western Australia from 1900-2015 with an 11-year running mean (black line).

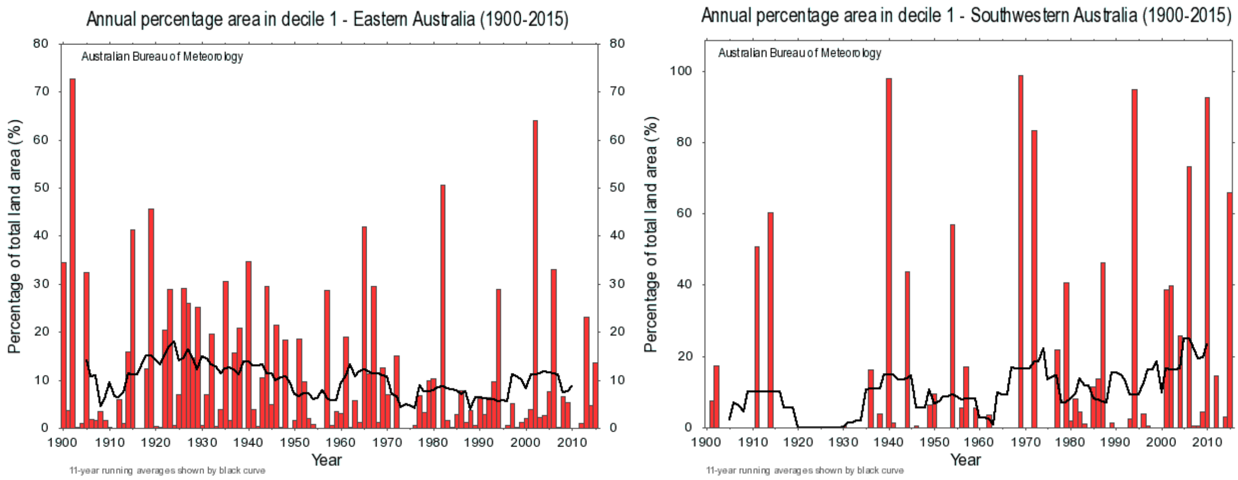

Figure 7: Annual percentage area in decile 1 (driest 10% of years) for (a) eastern Australia (Qld, NSW, Vic and Tas) and (b) south-western Australia from 1900-2015 with an 11-year running mean (black line).

2.2.3 Evapotranspiration

Pan evapotranspiration is a direct measurement of the evaporative loss from a uniform (standard) small body of water placed within the environment at the surface. Pan evapotranspiration is mostly utilized for estimating evapotranspiration, or the transfer of water vapour from vegetation and the land surface. There are no clear changes observed in pan evapotranspiration across Australia in data available from over 60 high-quality sites from 1970-2005 (Jovanovic et al. 2008). Uncertainties in pan evapotranspiration changes over time are largely due to sensitivity to wind speed at pan height, which in turn is highly sensitive to changes in site exposure. There is a broad-scale pattern of decreases in pan evapotranspiration across northern Australia in regions which have seen recent increases in monsoonal rainfall (CSIRO and BoM, 2015).

2.2.4 Dam inflows

One of the major impacts of the rainfall decline, and associated increases in temperature, in southern and eastern Australia has been a reduction in dam inflows.

Run-off has declined significantly in south-western Australia. Annual (May to April) inflow to Perth dams over the period 1911 to 1974 was 338 gigalitres (GL), which is almost twice the average of 177 GL/yr over the period 1975 to 2000 (Figure 8). Average inflow from 2001 to 2005 was even less, at 93 GL/yr. From 2006-2013 the average was only 70 GL/yr. Inflow in 2015 was 11.4 GL, setting a new record for the lowest amount (WA Water Corporation, 2016).

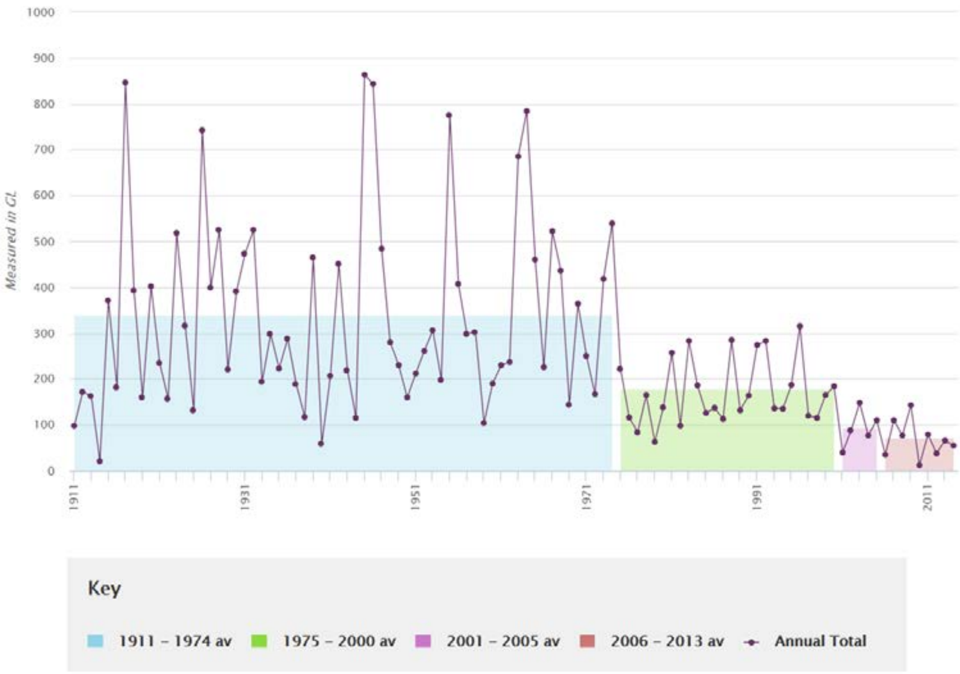

Figure 8: Yearly (May-April) inflow to Perth dams from 1911-2014. In order to provide an accurate historical comparison, streamflow from Stirling, Wokalup and Samson Brook Dams are not included as these dams only came online in 2001. Inflow is therefore modelled on Perth dams pre-2001. Source (WA Water Corporation, 2016).

Other regions of Australia have also experienced declines in dam inflows. In Victoria, inflow to Melbourne's main dams dropped from an average of 615 GL/yr from 1913-1996 to 376 GL/yr from 1997-2009, but recovered to 503 GL/yr from 2010-2015 (Melbourne Water, 2016; Figure 9). In New South Wales, average inflows to the Hawkesbury-Nepean dams were 951 GL/yr from 1909-1948, increasing to 2153 GL/yr from 1949-1990, and dropping to 763 GL/yr from 1991-2012 (WSAA, 2013; Figure 10). Data for dams servicing other capital cities are shown in Table 1.

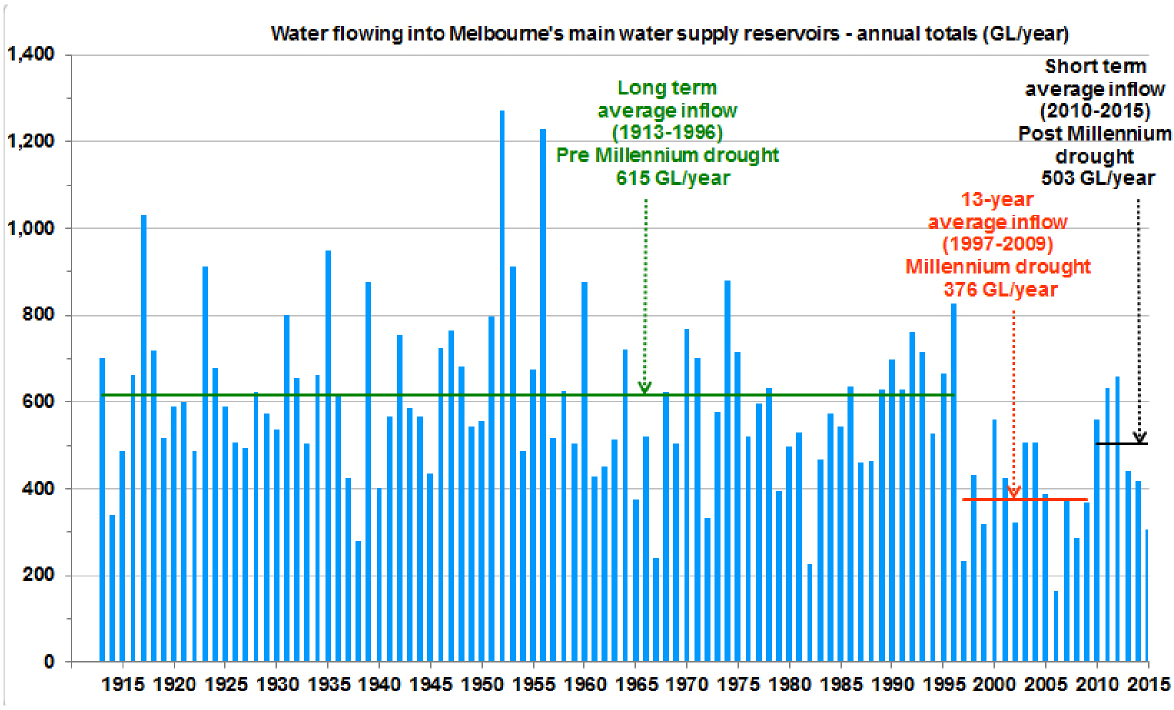

Figure 9: Yearly streamflow into Melbourne's major dams from 1913 to 2015. Source: Melbourne Water (2016).

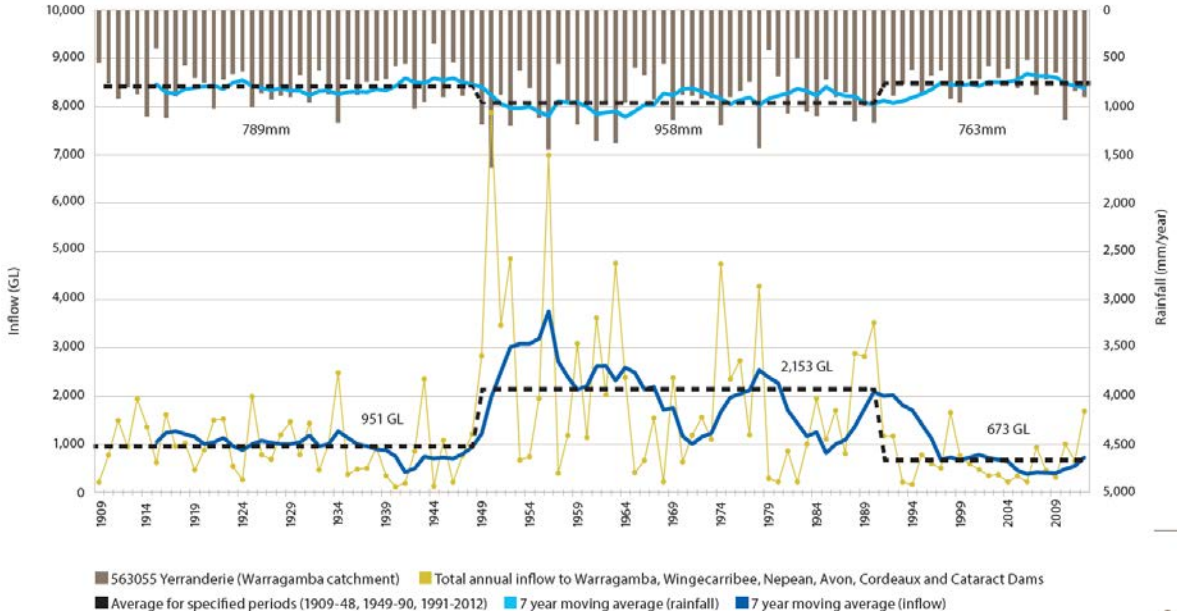

Figure 10: Total annual catchment inflow to Hawkesbury-Nepean dams and rainfall at Yerranderie in NSW from 1909-2012. Source: WSAA (2013).

Table 1: Average inflows to major dams servicing Australian capital cities.

CITY	AVERAGE INFLOW FOR SELECTED PERIODS (GL/YEAR)
Adelaide	Mt Lofty Ranges Dams 1892-1990 (177) 1997-2007 (113) Murray River 1891-2007 (11,100) 1996-2007 (5,700)
Brisbane	Wivenhoe Dam 1984-2001 (572) 2001-2009 (100)
Melbourne	Upper Yarra, Thomson, Maroondah and O'Shannassy Dams Pre-1996 (615) 1997-2009 (376)
Sydney	Warragamba and Upper Nepean Dams 1909-1948 (951) 1948-1990 (2153) 1991-2012 (673)
Perth	1911-1974 (338) 1975-2000 (177) 2001-2005 (93) 2006-2012 (66)
Canberra	Pre-1996 (202) 1997-2009 95)

Source: WSAA (2013)

3 Causes of observed climate change

Natural factors that affect our climate include the Earth's rotations that produce diurnal and seasonal cycles, variations in the amount of radiant energy emitted by the Sun (e.g. the 11-year sunspot cycle), large volcanic eruptions (which can cause a slight cooling for 2-3 years) and changes in the Earth's orbital parameters (e.g. the 100,000 year Milankovic cycle which causes Ice Ages).

Human activities also influence climate. For example:

- Changes in atmospheric composition (e.g. stratospheric ozone and greenhouse gases).
- Release of atmospheric particulates (e.g. sulfate aerosols and soot).
- Modification of the terrestrial ecosystems (e.g. land clearance).

Human influence has been detected in warming of the global atmosphere and ocean, changes in the global water cycle, reductions in snow and ice, global mean sea level rise, and changes in some climate extremes. It is extremely likely that human influence has been the dominant cause of the observed global warming since the mid-20th century.

Regional climate change attribution studies have shown significant consistency between observed increases in Australian temperatures and those from climate models driven by increasing greenhouse gases. By extension, many aspects of warming over Australia are also attributable to the enhanced greenhouse effect (CSIRO and BoM, 2015). Increasing greenhouse gases lead to a five-fold increase in the odds of Australia recording the extremely high temperatures experienced in January 2013 (Lewis and Karoly, 2013; 2014).

Attributing observed regional rainfall changes is a more difficult task than attributing temperature changes. This is especially so in the Australian region, where intrinsic rainfall variability on year to year and decade to decade timescales is large. It seems likely from the literature to date that drying across southern Australia cannot be explained by natural variability alone. The basic dynamical reasoning for changes in the Southern Hemisphere circulation is that warming expands the tropics. A shift of mid-latitude weather systems toward the pole, associated with a more positive Southern Annular Mode, has been attributed to both increases in greenhouse gases and springtime Antarctic stratospheric ozone depletion (CSIRO and BoM, 2015). Modelling studies (Cai and Cowan, 2006) show the possibility that a SAM-south-west Western Australia relationship exists in winter, with anthropogenic forcing contributing to about 50 % of the observed rainfall decline since the late 1960s. It is not yet possible to attribute rainfall decreases in eastern Australia, and rainfall increases in north-western Australia, to human activities.

4 Climate projections for 2040

4.1 Global projections

Global climate projections use the latest climate science to provide detailed information about plausible future climates. They illustrate the effect of different scenarios of greenhouse gas and aerosol emissions due to human activity.

The climate experienced for a given future period depends on three main factors:

1. Natural climate variability - this is always present year-to-year (e.g. the El Niño Southern Oscillation) and decade-to-decade, and this will continue as the underlying climate changes.
2. Greenhouse gas and aerosol emissions – explored using Representative Concentration Pathways (RCPs). The RCP number refers to the amount of extra radiative impact (W/m^2) on the climate system by the end of the century. All the RCPs are quite similar up to 2030, but grow increasingly different after that, depending on demographic change, economic development and technological advances (Figure 11):
   - High - little global action to reduce greenhouse gas emissions (RCP8.5)
   - Medium – strong global action to reduce emissions towards end of century (RCP4.5)
   - Low - ambitious global action to quickly reduce emissions (RCP2.6)
3. Climate response – the range of possible changes in the climate system to each RCP given our current understanding of how processes and feedbacks react to emissions. Scientists use computer models of the climate system to simulate the climate response to different RCPs. These global climate models are mathematical representations of the climate system, based on the laws of physics, and are assessed against historical climate records. Simulations from 40 different models give a range of possible climate responses.

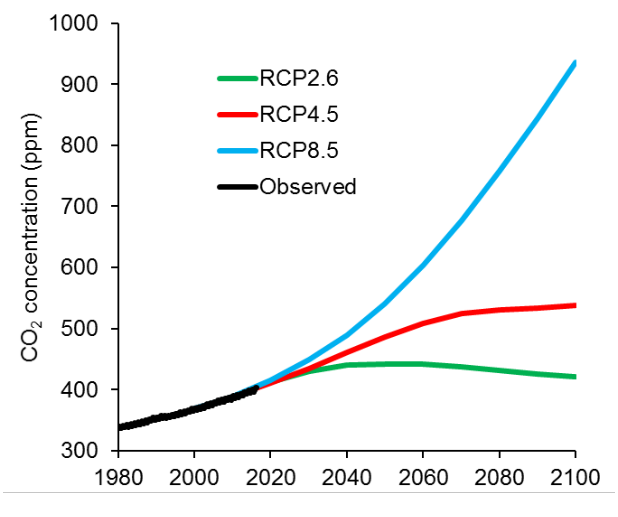

Figure 11: Concentrations of a carbon dioxide from global observations and for three future scenarios (RCPs) in the 21st Century. Adapted from van Vuuren et al (2011).

Taking these three factors into account, the IPCC (2013) concluded that:

- There will be further global warming. By 2046-2065, a warming of 0.4°C–1.6°C relative to 1986-2005 is expected under the low emissions scenario, 0.9°C–2.0°C under the medium scenario and 1.4°C–2.6°C under the high scenario.
- It is virtually certain that there will be more extremely hot days/seasons and fewer extremely cold days/seasons.
- It is very likely that heat waves will occur with a higher frequency and duration.
- Changes in the global water cycle in response to the warming over the 21st century will not be uniform. In many mid-latitude and sub-tropical dry regions, mean precipitation will likely decrease, while in many mid-latitude wet regions, mean precipitation will likely increase.
- Extreme rainfall over most of the mid-latitude land masses and over wet tropical regions will very likely become more intense and more frequent.
- It is very likely that the Arctic sea ice cover will continue to shrink and thin, and that Northern Hemisphere spring snow cover will decrease during the 21st century.
- Global mean sea level will continue to rise during the 21st century. By 2046-2065, a rise of 17-32 cm relative to 1986-2005 is expected under the low emissions scenario, 19-33 cm under the medium scenario and 22-38 cm under the high scenario.

4.2 Australian projections

Australian climate projections for the 21st century have been produced by CSIRO and BoM (2015). Various reports, brochures, guidance material, web-tools, data and animations are available from the Climate Change in Australia website: http://www.climatechangeinaustralia.gov.au. Confidence ratings for projected changes were derived from assessment of multiple lines of evidence, consistent with the IPCC guidelines. This includes physical theory, past climate changes and climate model simulations. The assessment considers the evidence (type, amount, quality and consistency), and agreement between those lines of evidence to assign a confidence rating using calibrated language based on expert judgement. Confidence is expressed using the qualifiers 'very high', 'high', 'medium' and 'low'. Key findings with relevance to the dairy industry are summarised below.

Temperature

- Australia's average temperature will increase, with more hot extremes and fewer cold extremes (very high confidence).

Rainfall

- In southern Australia, winter and spring rainfall is projected to decrease (high confidence), although increases are projected for Tasmania in winter (medium confidence).
- In northern Australia, substantial changes to wet-season and annual rainfall are possible, but the direction of change is uncertain (low confidence).
- Extreme rainfall events are likely to become more intense (high confidence).

Drought

- The time in drought is expected to increase over southern Australia, with a greater frequency of severe droughts (high confidence).

Evapotranspiration and soil moisture

- A projected increase in evapotranspiration rates will contribute to a reduction in soil moisture in southern Australia (high confidence).

Humidity

- Inland humidity is expected to decrease in winter and spring as well as annually (high confidence), and humidity in summer and autumn is expected to also decrease (medium confidence).

Tropical cyclones

- The number of tropical cyclones is projected to decrease (with high year-to-year variability) but with a greater proportion of intense cyclones (medium confidence). Higher sea levels and rainfall intensity will affect their impact.

4.3 Australian dairy region projections

In this section, projections have been averaged over the eight dairy regions shown in Figure 12. These regions were defined by Dairy Australia. Results for each region are presented for a 20-year period centred on 2040 (2030-2049) relative to a 20-year period centred on 1995 (1986-2005) for the high emission scenario (RCP 8.5). The projections cover: temperature, rainfall, drought (based on Standardised Precipitation Index, SPI), evapotranspiration (Morton potential wet areal evapotranspiration) and soil moisture (using the Budyko method).

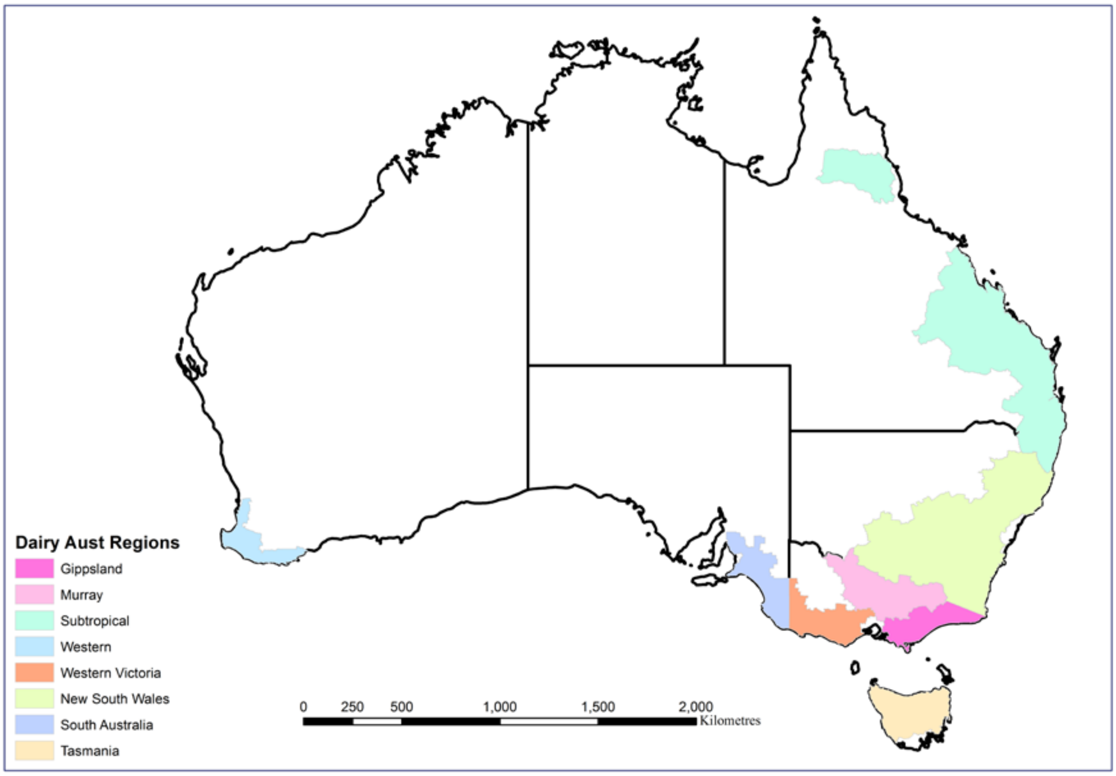

Figure 12: Eight Australian dairy regions used in this report.

4.3.1 Tasmania

Temperature

The dairy region in Tasmania will warm by about 0.5-1.5°C by 2040 under the high emission scenario (Figure 13), with slightly greater warming in summer and autumn (Figure 14). Maximum temperatures and minimum temperatures rise by about the same amount, but maxima rise more than minima in spring. Warmer conditions with higher CO2 concentrations may enhance pasture growth, although the effects are complex and dependent on grass type, rainfall and soil moisture. More extremely hot days will cause greater heat stress for dairy cows, with implications for reproduction and milk yield.

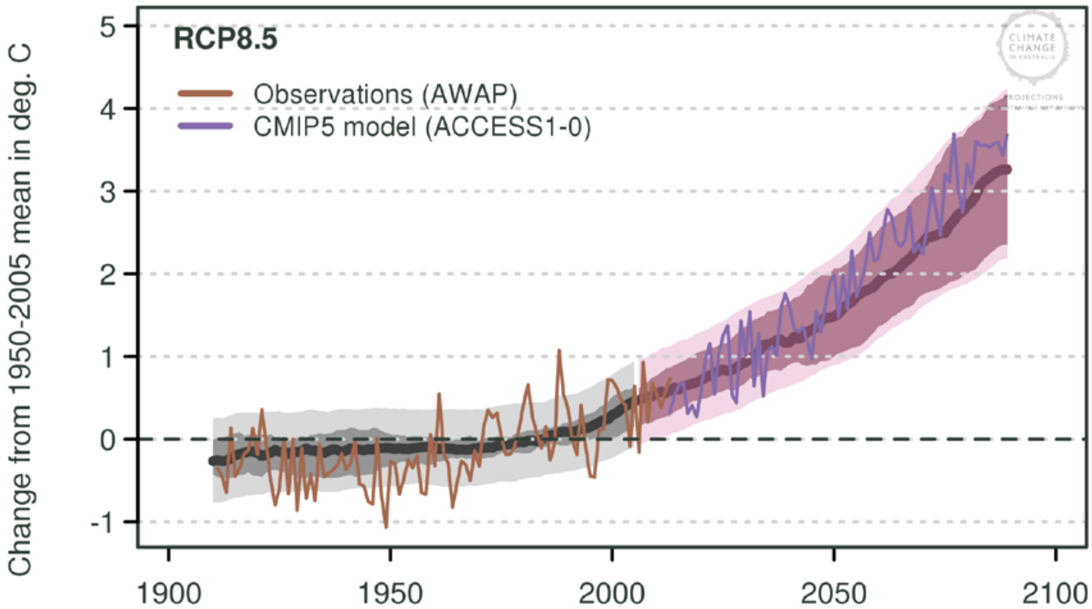

Figure 13: Change in annual-average temperature for 1910-2090, relative to 1950-2005, simulated by global climate models. The thick line is the median (50th percentile) value. The shading is the 10th to 90th percentile range of the 20-year running means (inner) and single-year values (outer). The grey shading is for the historical period, while the purple shading is for the high emission scenario (RCP8.5). The brown line shows observed data, while the purple line shows data from one climate model (ACCESS1-0).

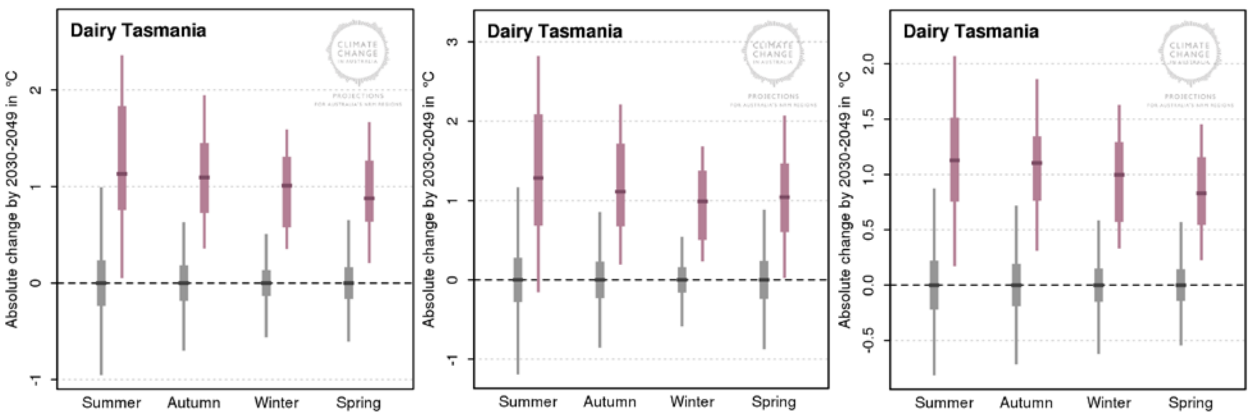

Figure 14: Projected changes in seasonal mean (left), maximum (centre) and minimum (right) temperatures by 2030-2049 (purple bars) for the high emission scenario (RCP8.5) relative to 1986-2005 (grey bars). The thick horizontal line is the median (50th percentile) value. Each bar shows the 10th to 90th percentile range of the 20-year running means (thick) and single-year values (thin).

Rainfall

Annual total rainfall will continue to have large variability from year to year, superimposed on a decrease of 0-15% by 2040 (Figure 15). There are slightly larger decreases in spring and summer with little change in winter (Figure 16). This would have implications for pasture productivity.

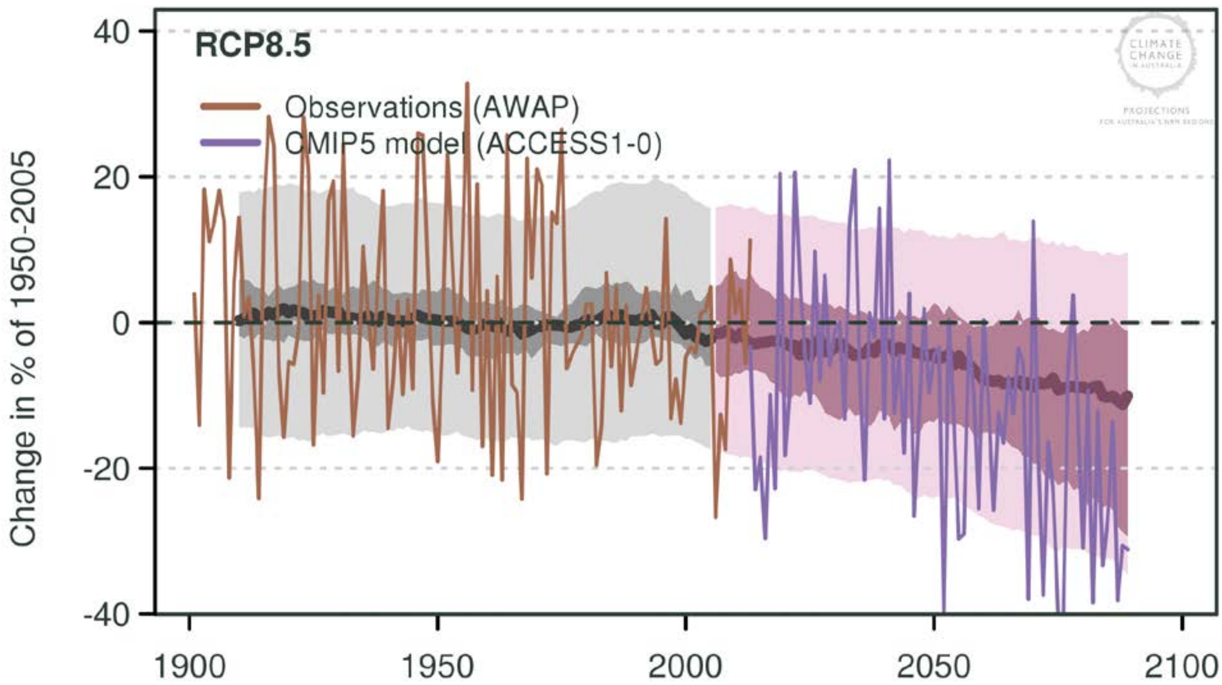

Figure 15: Change in annual-average rainfall for 1910-2090, relative to 1950-2005, simulated by global climate models. The thick line is the median (50th percentile) value. The shading is the 10th to 90th percentile range of the 20-year running means (inner) and single-year values (outer). The grey shading is for the historical period, while the purple shading is for the high emission scenario (RCP8.5). The brown line shows observed data, while the purple line shows data from one climate model (ACCESS1-0).

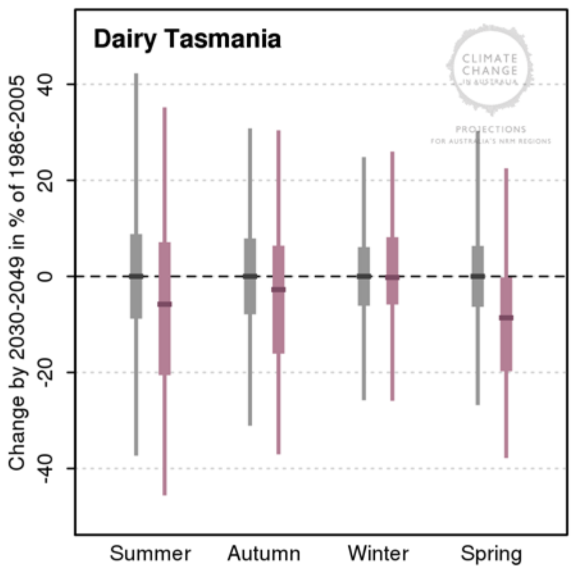

Figure 16: Projected changes in seasonal mean rainfall by 2030-2049 (purple) for the high emission scenario (RCP8.5), relative to 1986-2005 (grey). The thick horizontal line is the median (50th percentile) value. Each bar shows the 10th to 90th percentile range of the 20-year running means (thick) and single-year values (thin).

Despite projected decreases in annual-mean rainfall, extreme daily rainfall intensity is expected to increase (high confidence; Figure 17). The annual maximum 1-day rainfall intensity changes by -10 to +23%, with a median of +7%. The 1-in-20-year maximum 1-day rainfall intensity changes by -10 to +33%, with a median of +10%. This has implications for flooding, erosion, infrastructure, transport and water-logging.

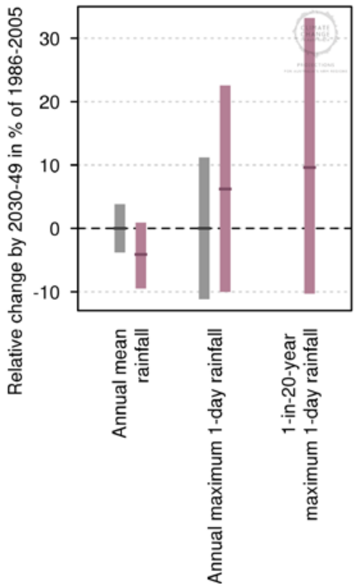

Figure 17: Projected changes in annual mean rainfall, annual maximum 1-day rainfall intensity and 1-in-20-year maximum 1-day rainfall intensity by 2030-2049 (purple) for the high emission scenario (RCP8.5), relative to 1986-2005 (grey).

Drought

Consistent with the projected decrease in average rainfall, more time in drought is expected (Figure 18). The percentage of time in drought (SPI<-1) increases from a current median of 33% to a median of 53%. This has implications for managing feed, water and heat stress during hot, dry conditions.

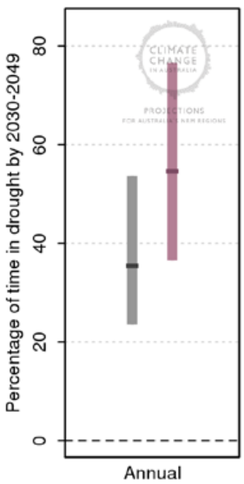

Figure 18: Projected changes in annual-average time in drought by 2030-2049 (purple) for the high emission scenario (RCP8.5), relative to 1986-2005 (grey). The thick horizontal line is the median (50th percentile) value. Each bar shows the 10th to 90th percentile range of the 20-year running means (thick) and single-year values (thin).

Evapotranspiration

Consistent with the increase in temperature, an increase in evapotranspiration is expected. The median increase by 2040 is about 6% for the high emission scenario in all seasons, with a range of 3 to 12% in summer, 4 to 14% in autumn, -5 to 16% in winter and 4 to 9% in spring (Figure 19).

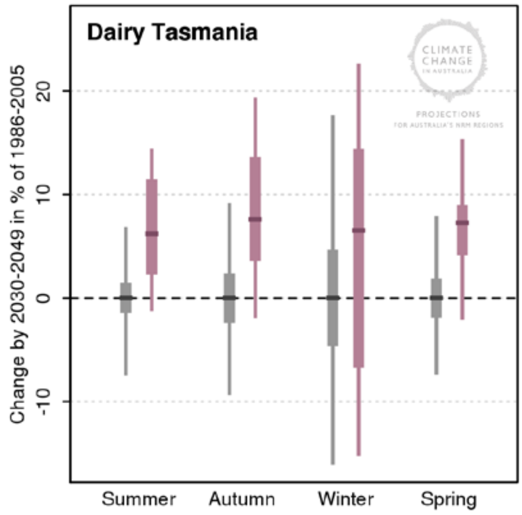

Figure 19: Projected changes in seasonal mean evapotranspiration by 2030-2049 (purple) for the high emission scenario (RCP8.5), relative to 1986-2005 (grey). The thick horizontal line is the median (50th percentile) value. Each bar shows the 10th to 90th percentile range of the 20-year running means (thick) and single-year values (thin).

Soil moisture

The projected combination of lower rainfall and higher evapotranspiration means lower soil moisture. The largest median decrease is in summer and the least in winter, with a range of -7 to -3% in summer, -8 to 0% in autumn, -3 to 0% in winter and -5 to 1% in spring (Figure 20). This will have implications for pasture growth, runoff into dams and viability of shade trees.

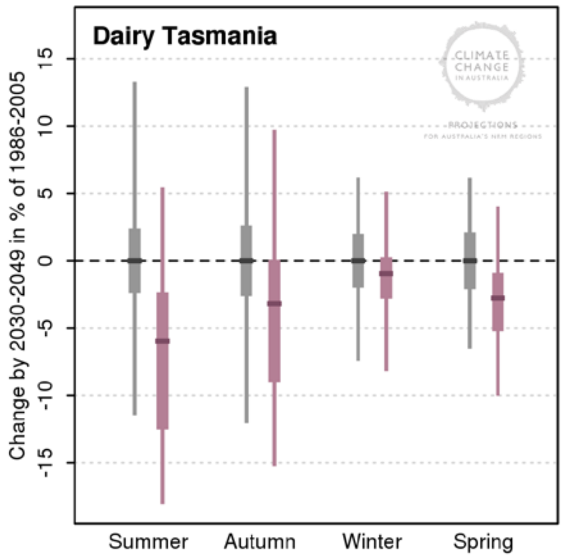

Figure 20: Projected changes in seasonal mean soil moisture by 2030-2049 (purple) for the high emission scenario (RCP8.5), relative to 1986-2005 (grey). The thick horizontal line is the median (50th percentile) value. Each bar shows the 10th to 90th percentile range of the 20-year running means (thick) and single-year values (thin).

4.3.2 Gippsland (Victoria)

Temperature

The Gippsland dairy region will warm by about 1.0-1.7°C by 2040 under the high emission scenario (Figure 21), with greatest warming in summer and least in winter (Figure 22). Maximum temperatures increase more than minimum temperatures. Warmer conditions with higher CO2 concentrations may enhance pasture growth, although the effects are complex and dependent on grass type, rainfall and soil moisture. More extremely hot days will cause greater heat stress for dairy cows, with implications for reproduction and milk yield.

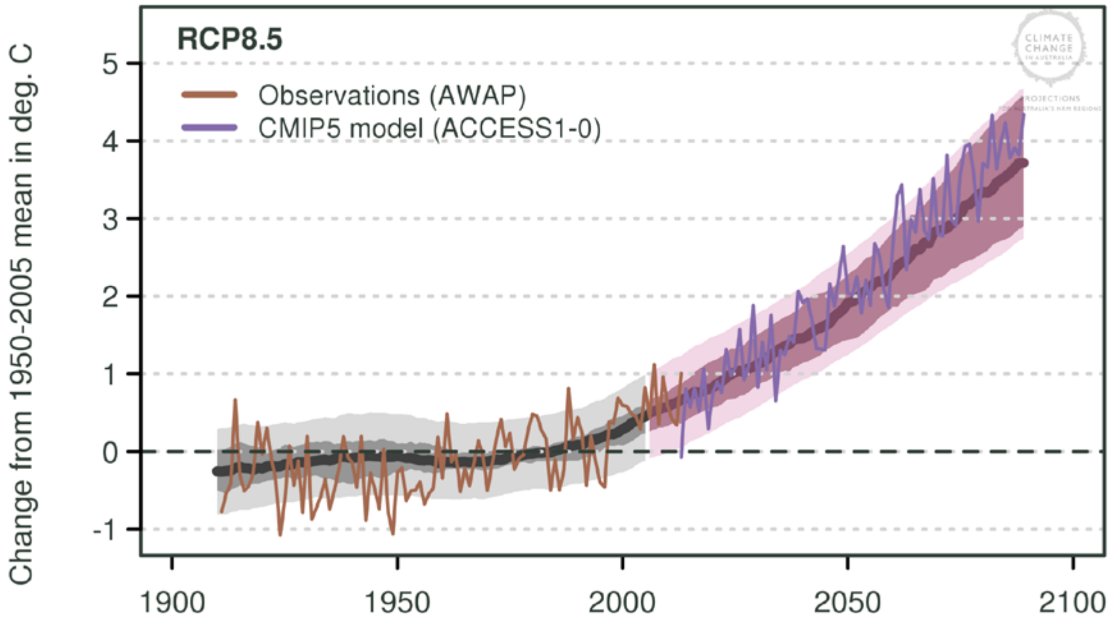

Figure 21: Change in annual-average temperature for 1910-2090, relative to 1950-2005, simulated by global climate models. The thick line is the median (50th percentile) value. The shading is the 10th to 90th percentile range of the 20-year running means (inner) and single-year values (outer). The grey shading is for the historical period, while the purple shading is for the high emission scenario (RCP8.5). The brown line shows observed data, while the purple line shows data from one climate model (ACCESS1-0).

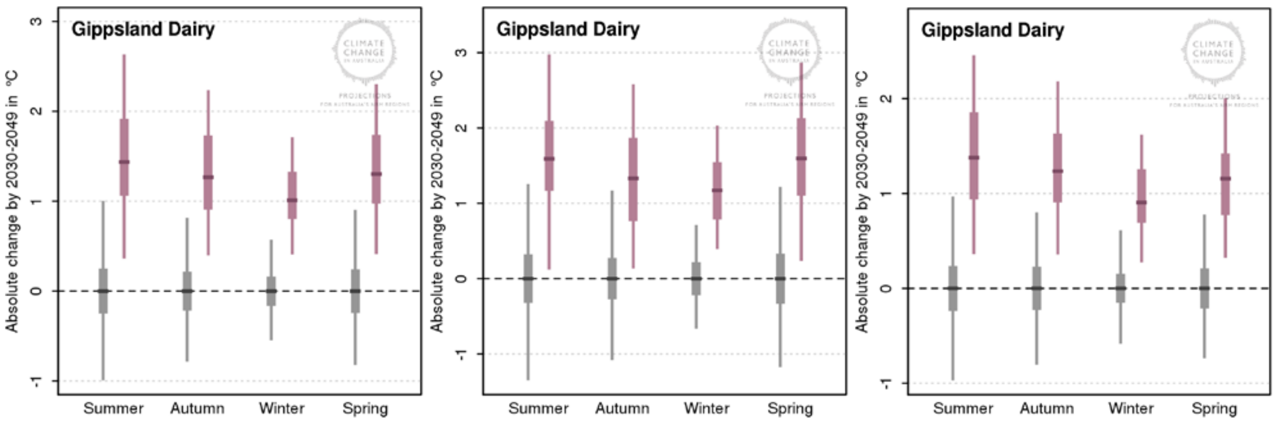

Figure 22: Projected changes in seasonal mean (left), maximum (centre) and minimum (right) temperatures by 2030-2049 (purple bars) for the high emission scenario (RCP8.5) relative to 1986-2005 (grey bars). The thick horizontal line is the median (50th percentile) value. Each bar shows the 10th to 90th percentile range of the 20-year running means (thick) and single-year values (thin).

Rainfall

Annual total rainfall will continue to have large variability from year to year, superimposed on a median decrease of about 3% by 2040, with a range of -10 to +5% (Figure 23). There are slightly larger decreases in winter and spring with little change in summer (Figure 24). This would have implications for pasture productivity.

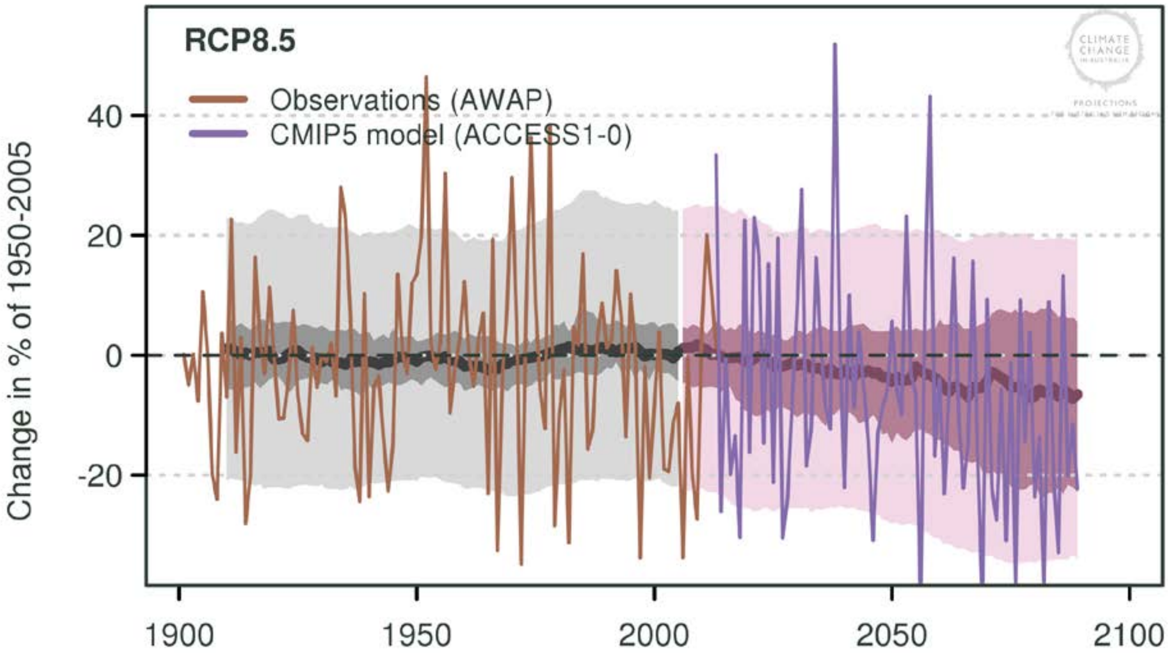

Figure 23: Change in annual-average rainfall for 1910-2090, relative to 1950-2005, simulated by global climate models. The thick line is the median (50th percentile) value. The shading is the 10th to 90th percentile range of the 20-year running means (inner) and single-year values (outer). The grey shading is for the historical period, while the purple shading is for the high emission scenario (RCP8.5). The brown line shows observed data, while the purple line shows data from one climate model (ACCESS1-0).

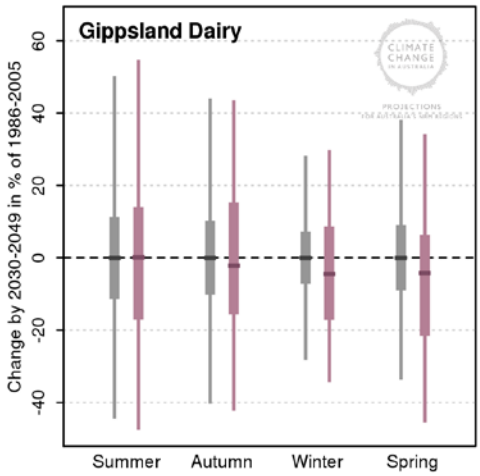

Figure 24: Projected changes in seasonal mean rainfall by 2030-2049 (purple) for the high emission scenario (RCP8.5), relative to 1986-2005 (grey). The thick horizontal line is the median (50th percentile) value. Each bar shows the 10th to 90th percentile range of the 20-year running means (thick) and single-year values (thin).

Despite projected decreases in annual-mean rainfall, extreme daily rainfall intensity is expected to increase (high confidence; Figure 25). The annual maximum 1-day rainfall intensity changes by -6 to +20%, with a median of +8%. The 1-in-20-year maximum 1-day rainfall intensity changes by -10 to +33%, with a median of +11%. This has implications for flooding, erosion, infrastructure, transport and water-logging.

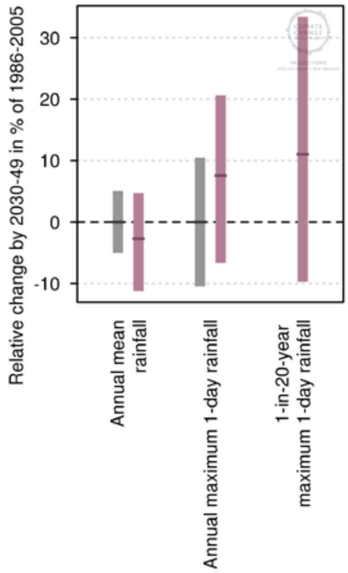

Figure 25: Projected changes in annual mean rainfall, annual maximum 1-day rainfall intensity and 1-in-20-year maximum 1-day rainfall intensity by 2030-2049 (purple) for the high emission scenario (RCP8.5), relative to 1986-2005 (grey).

Drought

Consistent with the projected decrease in average rainfall, more time in drought is expected (Figure 26). The percentage of time in drought (SPI<-1) increases from a current median of 33% to a median of 45%. This has implications for managing feed, water and heat stress during hot, dry conditions.

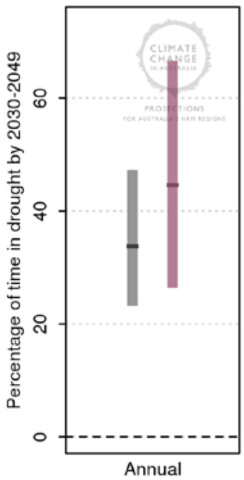

Figure 26: Projected changes in annual-average time in drought by 2030-2049 (purple) for the high emission scenario (RCP8.5), relative to 1986-2005 (grey). The thick horizontal line is the median (50th percentile) value. Each bar shows the 10th to 90th percentile range of the 20-year running means (thick) and single-year values (thin).

Evapotranspiration

Consistent with the increase in temperature, an increase in evapotranspiration is expected. The median increase by 2040 is about 7% in all seasons, with a range of 2 to 7% in summer, 4 to 10% in autumn, 5 to 20% in winter and 2 to 9% in spring (Figure 27).

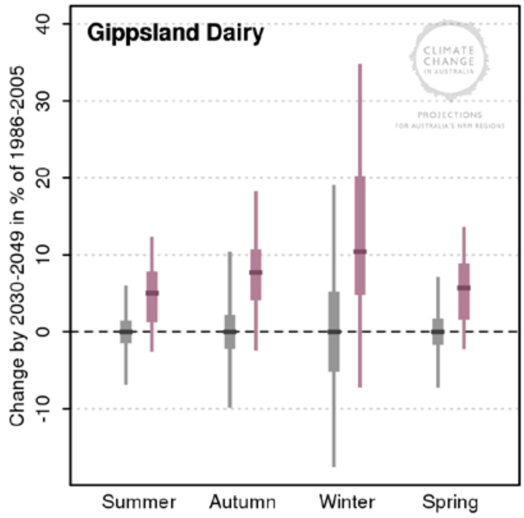

Figure 27: Projected changes in seasonal mean evapotranspiration by 2030-2049 (purple) for the high emission scenario (RCP8.5), relative to 1986-2005 (grey). The thick horizontal line is the median (50th percentile) value. Each bar shows the 10th to 90th percentile range of the 20-year running means (thick) and single-year values (thin).

Soil moisture

The projected combination of lower rainfall and higher evapotranspiration means lower soil moisture. The largest median decrease is in spring and the least in summer, with a range of -7 to -1% in summer, -10 to -2% in autumn, -14 to -4% in winter and -14 to -10% in spring (Figure 28). This will have implications for pasture growth, runoff into dams and viability of shade trees.

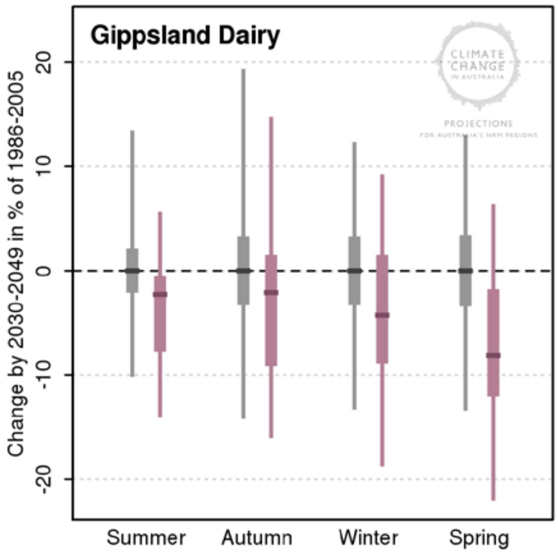

Figure 28: Projected changes in seasonal mean soil moisture by 2030-2049 (purple) for the high emission scenario (RCP8.5), relative to 1986-2005 (grey). The thick horizontal line is the median (50th percentile) value. Each bar shows the 10th to 90th percentile range of the 20-year running means (thick) and single-year values (thin).

4.3.3 Murray (northern Victoria)

Temperature

The Murray dairy region will warm by about 1.2-1.8°C by 2040 under the high emission scenario (Figure 29), with greatest warming in summer and least in winter (Figure 30). Maximum temperatures increase more than minimum temperatures. Warmer conditions with higher CO2 concentrations may enhance pasture growth, although the effects are complex and dependent on grass type, rainfall and soil moisture. More extremely hot days will cause greater heat stress for dairy cows, with implications for reproduction and milk yield.

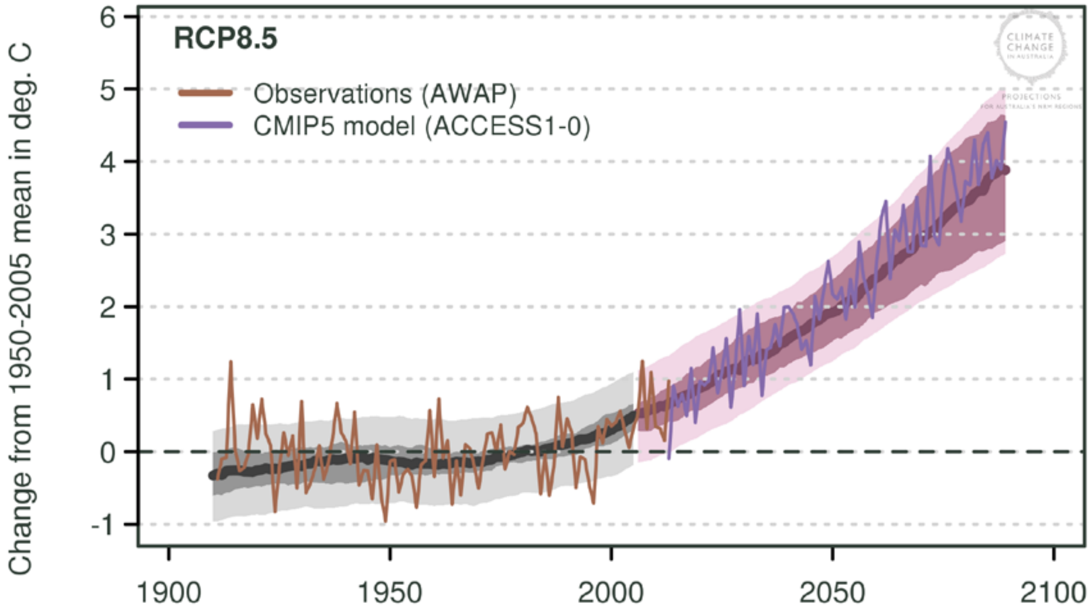

Figure 29: Change in annual-average temperature for 1910-2090, relative to 1950-2005, simulated by global climate models. The thick line is the median (50th percentile) value. The shading is the 10th to 90th percentile range of the 20-year running means (inner) and single-year values (outer). The grey shading is for the historical period, while the purple shading is for the high emission scenario (RCP8.5). The brown line shows observed data, while the purple line shows data from one climate model (ACCESS1-0).

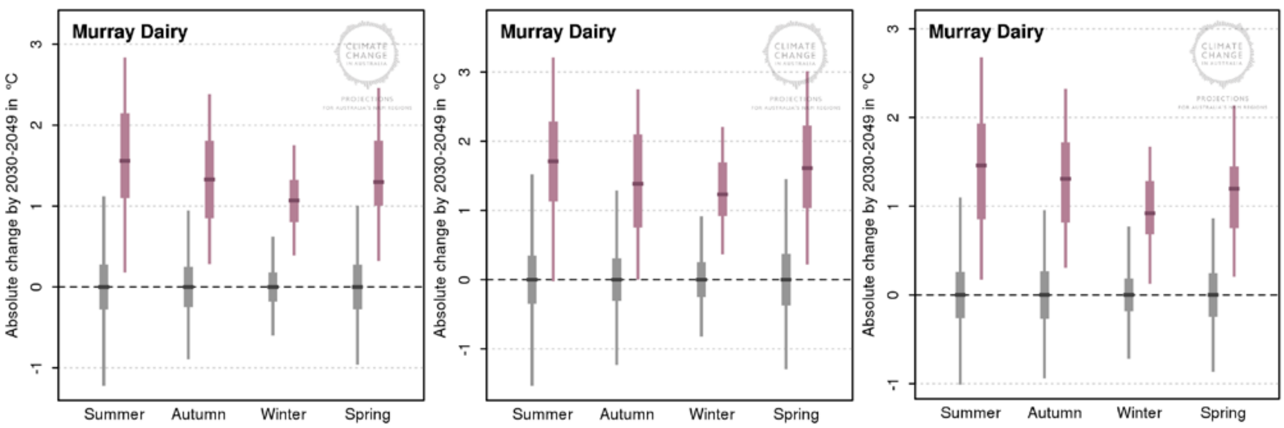

Figure 30: Projected changes in seasonal mean (left), maximum (centre) and minimum (right) temperatures by 2030-2049 (purple bars) for the high emission scenario (RCP8.5) relative to 1986-2005 (grey bars). The thick horizontal line is the median (50th percentile) value. Each bar shows the 10th to 90th percentile range of the 20-year running means (thick) and single-year values (thin).

Rainfall

Annual total rainfall will continue to have large variability from year to year, superimposed on a median decrease of about 3% by 2040, with a range of -10 to +5% (Figure 31). The decreases occur in winter and spring with little change in summer and autumn (Figure 32). This would have implications for pasture productivity.

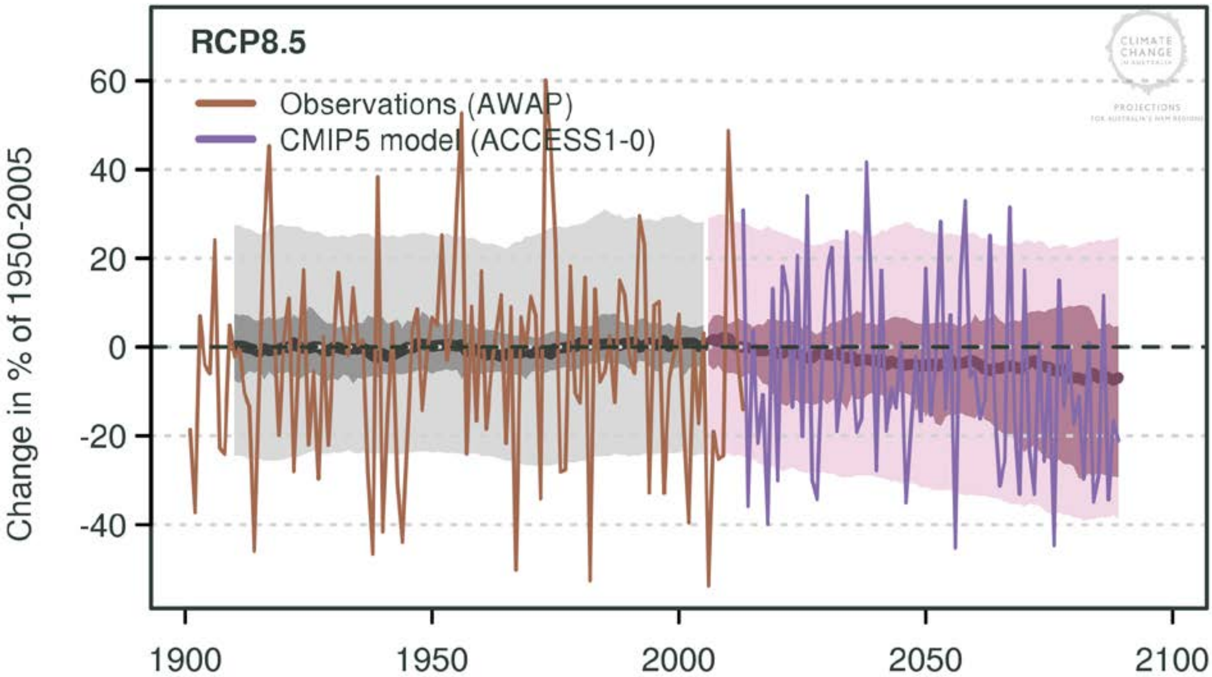

Figure 31: Change in annual-average rainfall for 1910-2090, relative to 1950-2005, simulated by global climate models. The thick line is the median (50th percentile) value. The shading is the 10th to 90th percentile range of the 20-year running means (inner) and single-year values (outer). The grey shading is for the historical period, while the purple shading is for the high emission scenario (RCP8.5). The brown line shows observed data, while the purple line shows data from one climate model (ACCESS1-0).

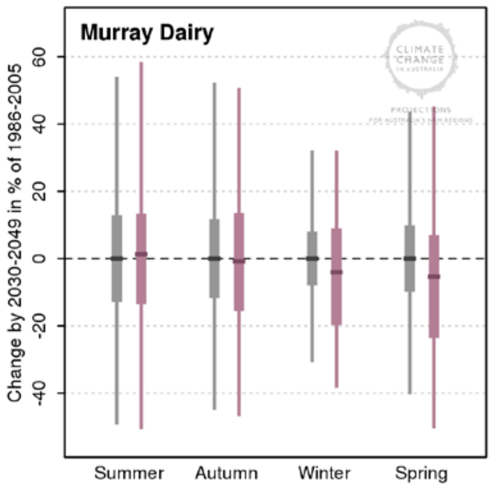

Figure 32: Projected changes in seasonal mean rainfall by 2030-2049 (purple) for the high emission scenario (RCP8.5), relative to 1986-2005 (grey). The thick horizontal line is the median (50th percentile) value. Each bar shows the 10th to 90th percentile range of the 20-year running means (thick) and single-year values (thin).

Despite projected decreases in annual-mean rainfall, extreme daily rainfall intensity is expected to increase (high confidence; Figure 33). The annual maximum 1-day rainfall intensity changes by -5 to +13%, with a median of +8%. The 1-in-20-year maximum 1-day rainfall intensity changes by -10 to +31%, with a median of +9%. This has implications for flooding, erosion, infrastructure, transport and water-logging.

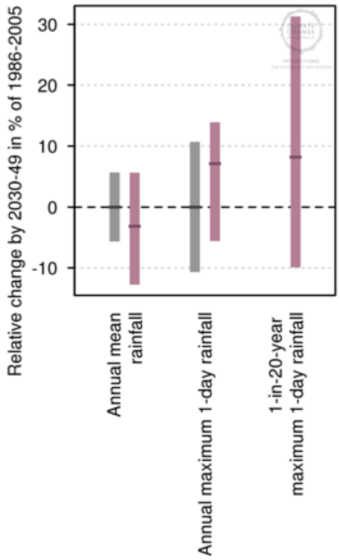

Figure 33: Projected changes in annual mean rainfall, annual maximum 1-day rainfall intensity and 1-in-20-year maximum 1-day rainfall intensity by 2030-2049 (purple) for the high emission scenario (RCP8.5), relative to 1986-2005 (grey).

Drought

Consistent with the projected decrease in average rainfall, more time in drought is expected (Figure 34). The percentage of time in drought (SPI<-1) increases from a current median of 33% to a median of 46%. This has implications for managing feed, water and heat stress during hot, dry conditions.

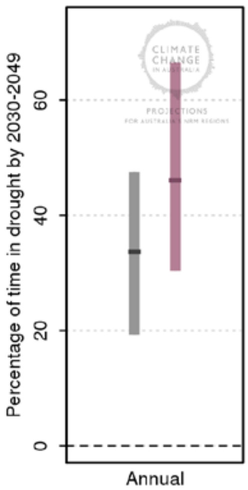

Figure 34: Projected changes in annual-average time in drought by 2030-2049 (purple) for the high emission scenario (RCP8.5), relative to 1986-2005 (grey). The thick horizontal line is the median (50th percentile) value. Each bar shows the 10th to 90th percentile range of the 20-year running means (thick) and single-year values (thin).

Evapotranspiration

Consistent with the increase in temperature, an increase in evapotranspiration is expected. The median increase by 2040 is about 5% in spring, summer and autumn, and 10% in winter (Figure 35). The ranges are 0 to 7% in spring and summer, 3 to 10% in autumn, and 5 to 17% in winter.

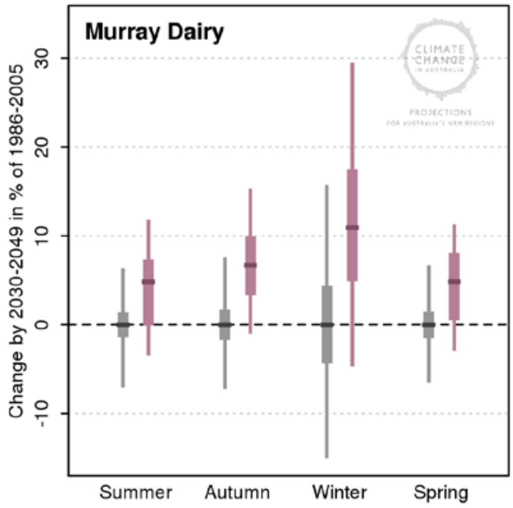

Figure 35: Projected changes in seasonal mean evapotranspiration by 2030-2049 (purple) for the high emission scenario (RCP8.5), relative to 1986-2005 (grey). The thick horizontal line is the median (50th percentile) value. Each bar shows the 10th to 90th percentile range of the 20-year running means (thick) and single-year values (thin).

Soil moisture

The projected combination of lower rainfall and higher evapotranspiration means lower soil moisture. The largest median decrease is in spring and the least in summer, with a range of -7 to +1% in summer, -10 to -1% in autumn, -10 to -4% in winter and -13 to -6% in spring (Figure 36). This will have implications for pasture growth, runoff into dams and viability of shade trees.

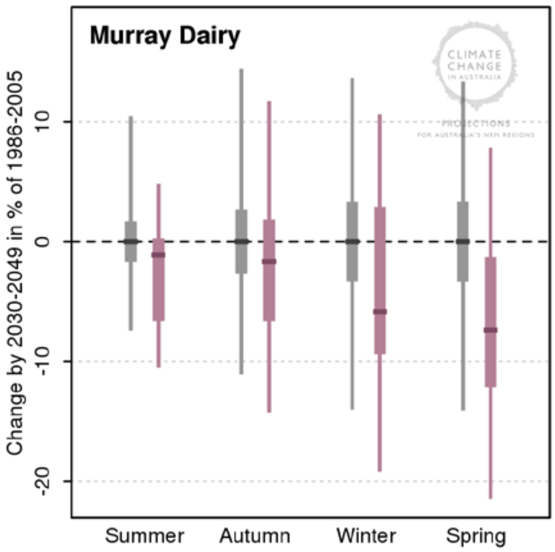

Figure 36: Projected changes in seasonal mean soil moisture by 2030-2049 (purple) for the high emission scenario (RCP8.5), relative to 1986-2005 (grey). The thick horizontal line is the median (50th percentile) value. Each bar shows the 10th to 90th percentile range of the 20-year running means (thick) and single-year values (thin).

4.3.4 Western Victoria

Temperature

The western Victorian dairy region will warm by about 1.0-1.6°C by 2040 under the high emission scenario (Figure 37), with greatest warming in summer and least in winter (Figure 38). Maximum temperatures increase more than minimum temperatures in all seasons except autumn. Warmer conditions with higher CO_2 concentrations may enhance pasture growth, although the effects are complex and dependent on grass type, rainfall and soil moisture. More extremely hot days will cause greater heat stress for dairy cows, with implications for reproduction and milk yield.

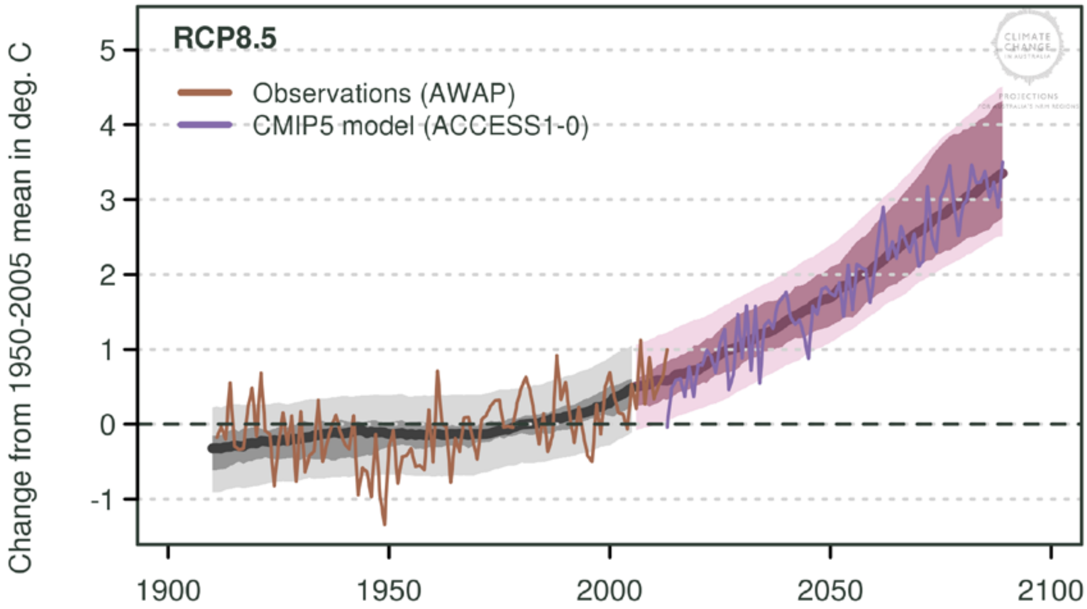

Figure 37: Change in annual-average temperature for 1910-2090, relative to 1950-2005, simulated by global climate models. The thick line is the median (50th percentile) value. The shading is the 10th to 90th percentile range of the 20-year running means (inner) and single-year values (outer). The grey shading is for the historical period, while the purple shading is for the high emission scenario (RCP8.5). The brown line shows observed data, while the purple line shows data from one climate model (ACCESS1-0).

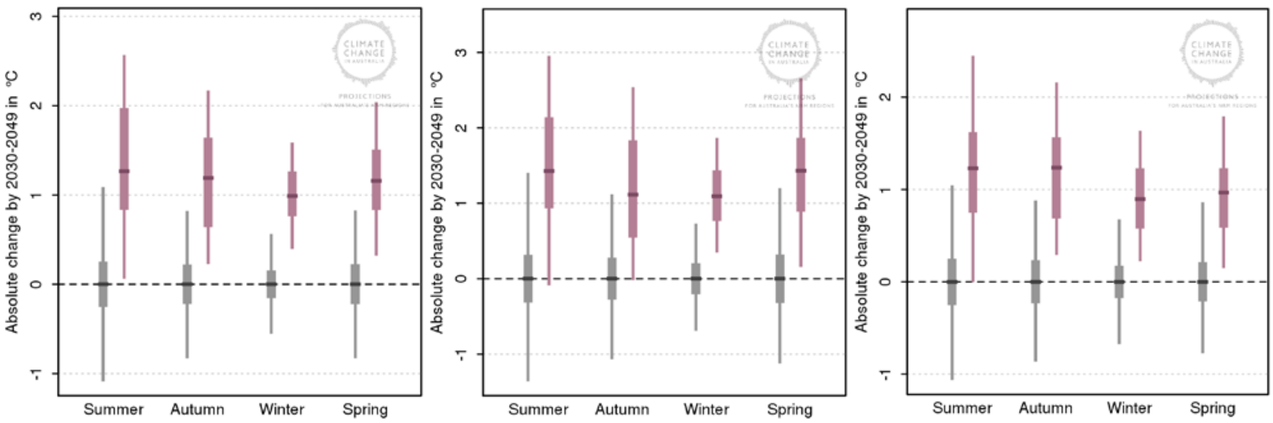

Figure 38: Projected changes in seasonal mean (left), maximum (centre) and minimum (right) temperatures by 2030-2049 (purple bars) for the high emission scenario (RCP8.5) relative to 1986-2005 (grey bars). The thick horizontal line is the median (50th percentile) value. Each bar shows the 10th to 90th percentile range of the 20-year running means (thick) and single-year values (thin).

Rainfall

Annual total rainfall will continue to have large variability from year to year, superimposed on a median decrease of about 5% by 2040, with a range of -15 to +3% (Figure 39). The decreases occur in autumn, winter and spring with little change in summer (Figure 40). This would have implications for pasture productivity.

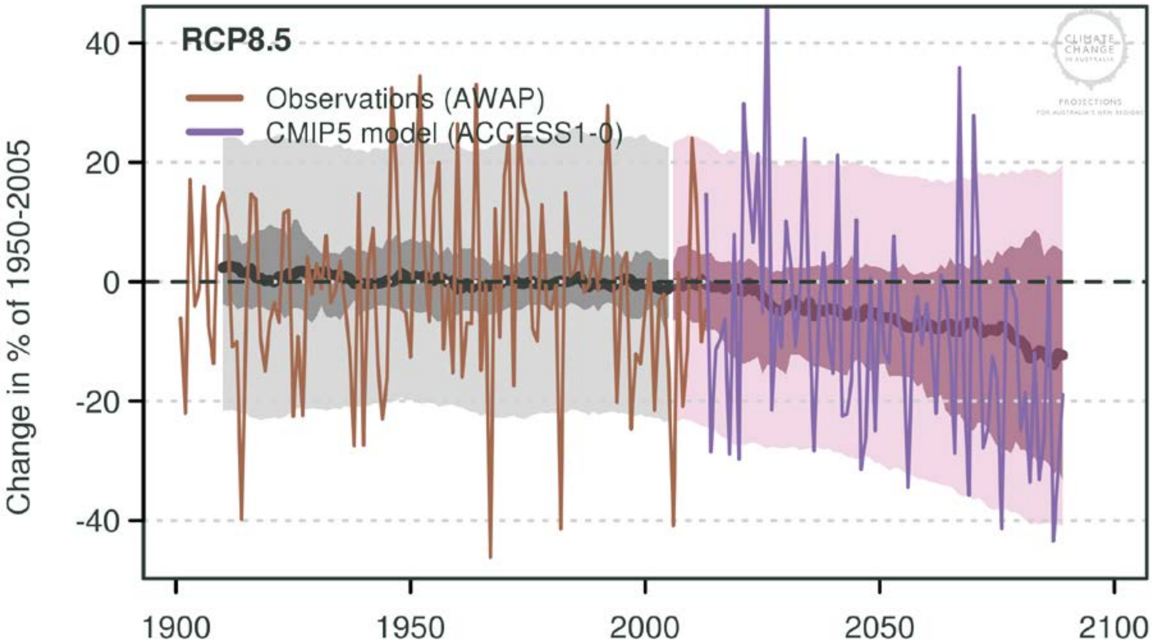

Figure 39: Change in annual-average rainfall for 1910-2090, relative to 1950-2005, simulated by global climate models. The thick line is the median (50th percentile) value. The shading is the 10th to 90th percentile range of the 20-year running means (inner) and single-year values (outer). The grey shading is for the historical period, while the purple shading is for the high emission scenario (RCP8.5). The brown line shows observed data, while the purple line shows data from one climate model (ACCESS1-0).

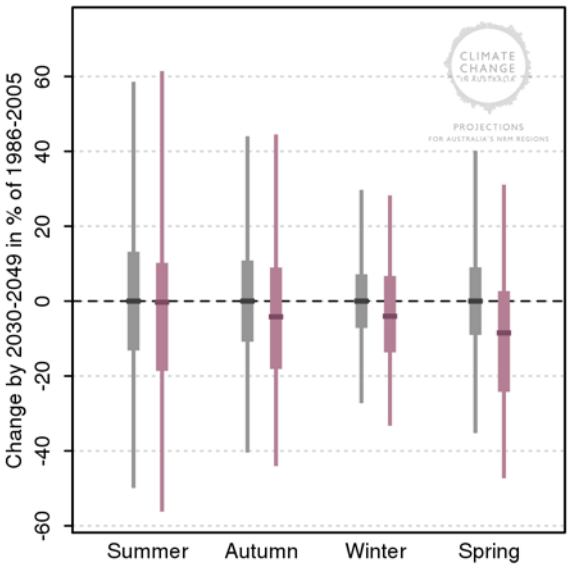

Figure 40: Projected changes in seasonal mean rainfall by 2030-2049 (purple) for the high emission scenario (RCP8.5), relative to 1986-2005 (grey). The thick horizontal line is the median (50th percentile) value. Each bar shows the 10th to 90th percentile range of the 20-year running means (thick) and single-year values (thin).

Despite projected decreases in annual-mean rainfall, extreme daily rainfall intensity is expected to increase (high confidence; Figure 41). The annual maximum 1-day rainfall intensity changes by -7 to +16%, with a median of +7%. The 1-in-20-year maximum 1-day rainfall intensity changes by -3 to +24%, with a median of +10%. This has implications for flooding, erosion, infrastructure, transport and water-logging.

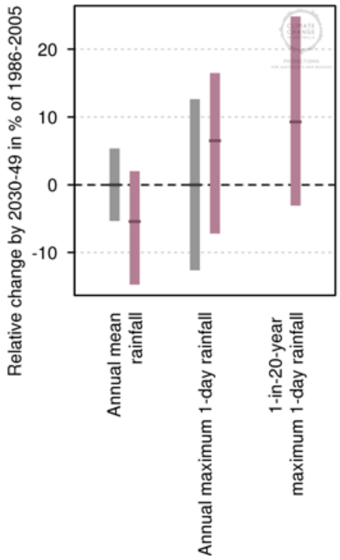

Figure 41: Projected changes in annual mean rainfall, annual maximum 1-day rainfall intensity and 1-in-20-year maximum 1-day rainfall intensity by 2030-2049 (purple) for the high emission scenario (RCP8.5), relative to 1986-2005 (grey).

Drought

Consistent with the projected decrease in average rainfall, more time in drought is expected (Figure 42). The percentage of time in drought (SPI<-1) increases from a current median of 38% to a median of 55%. This has implications for managing feed, water and heat stress during hot, dry conditions.

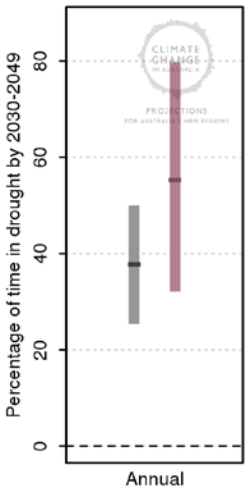

Figure 42: Projected changes in annual-average time in drought by 2030-2049 (purple) for the high emission scenario (RCP8.5), relative to 1986-2005 (grey). The thick horizontal line is the median (50th percentile) value. Each bar shows the 10th to 90th percentile range of the 20-year running means (thick) and single-year values (thin).

Evapotranspiration

Consistent with the increase in temperature, an increase in evapotranspiration is expected. The median increase by 2040 is about 5% in spring, summer and autumn, and 10% in winter (Figure 43). The ranges are 0 to 7% in spring and summer, 3 to 10% in autumn, and 5 to 17% in winter.

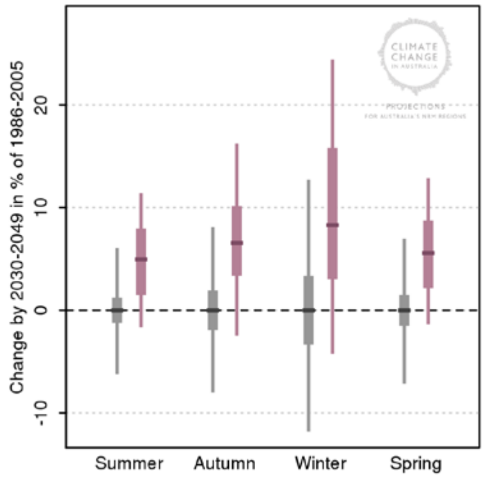

Figure 43: Projected changes in seasonal mean evapotranspiration by 2030-2049 (purple) for the high emission scenario (RCP8.5), relative to 1986-2005 (grey). The thick horizontal line is the median (50th percentile) value. Each bar shows the 10th to 90th percentile range of the 20-year running means (thick) and single-year values (thin).

Soil moisture

The projected combination of lower rainfall and higher evapotranspiration means lower soil moisture. The largest median decrease is in spring and the least in summer, with a range of -7 to +1% in summer, -10 to -1% in autumn, -10 to -4% in winter and -13 to -6% in spring (Figure 44). This will have implications for pasture growth, runoff into dams and viability of shade trees.

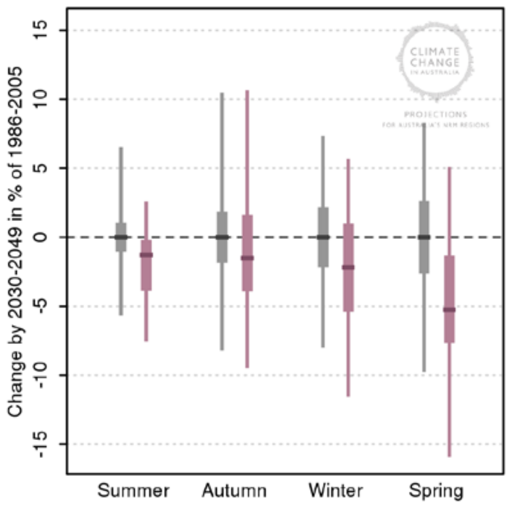

Figure 44: Projected changes in seasonal mean soil moisture by 2030-2049 (purple) for the high emission scenario (RCP8.5), relative to 1986-2005 (grey). The thick horizontal line is the median (50th percentile) value. Each bar shows the 10th to 90th percentile range of the 20-year running means (thick) and single-year values (thin).

4.3.5 South Australia

Temperature

The South Australian dairy region will warm by about 1.0-1.6°C by 2040 under the high emission scenario (Figure 45), with greatest warming in summer and least in winter (Figure 46). Maximum temperatures increase more than minimum temperatures in all seasons except autumn. Warmer conditions with higher CO2 concentrations may enhance pasture growth, although the effects are complex and dependent on grass type, rainfall and soil moisture. More extremely hot days will cause greater heat stress for dairy cows, with implications for reproduction and milk yield.

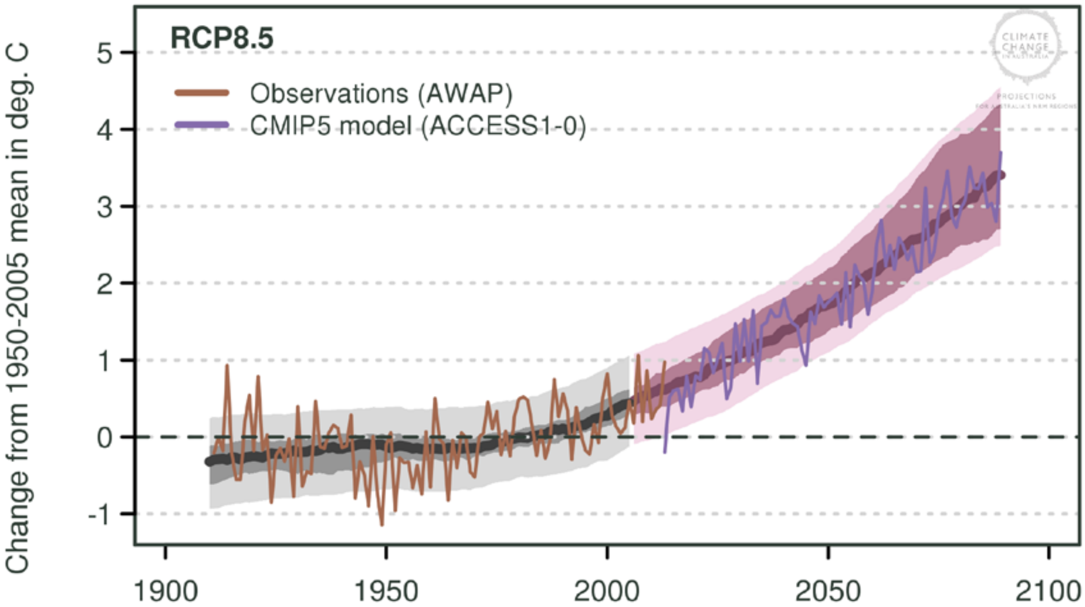

Figure 45: Change in annual-average temperature for 1910-2090, relative to 1950-2005, simulated by global climate models. The thick line is the median (50th percentile) value. The shading is the 10th to 90th percentile range of the 20-year running means (inner) and single-year values (outer). The grey shading is for the historical period, while the purple shading is for the high emission scenario (RCP8.5). The brown line shows observed data, while the purple line shows data from one climate model (ACCESS1-0).

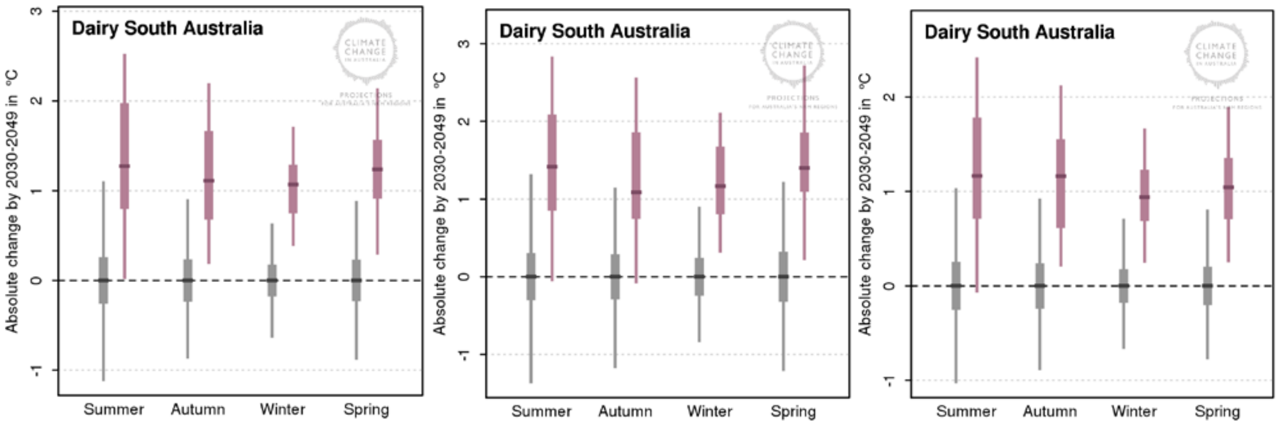

Figure 46: Projected changes in seasonal mean (left), maximum (centre) and minimum (right) temperatures by 2030-2049 (purple bars) for the high emission scenario (RCP8.5) relative to 1986-2005 (grey bars). The thick horizontal line is the median (50th percentile) value. Each bar shows the 10th to 90th percentile range of the 20-year running means (thick) and single-year values (thin).

Rainfall

Annual total rainfall will continue to have large variability from year to year, superimposed on a median decrease of about 5% by 2040, with a range of -17 to +3% (Figure 47). The decreases occur in winter and spring with little change in summer and autumn (Figure 48). This would have implications for pasture productivity.

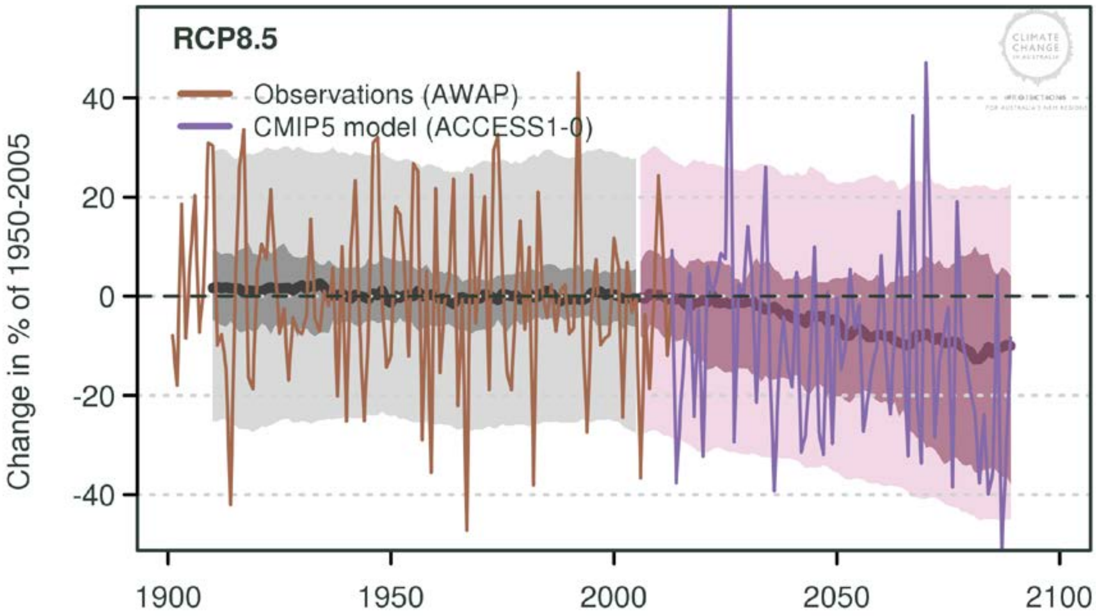

Figure 47: Change in annual-average rainfall for 1910-2090, relative to 1950-2005, simulated by global climate models. The thick line is the median (50th percentile) value. The shading is the 10th to 90th percentile range of the 20-year running means (inner) and single-year values (outer). The grey shading is for the historical period, while the purple shading is for the high emission scenario (RCP8.5). The brown line shows observed data, while the purple line shows data from one climate model (ACCESS1-0).

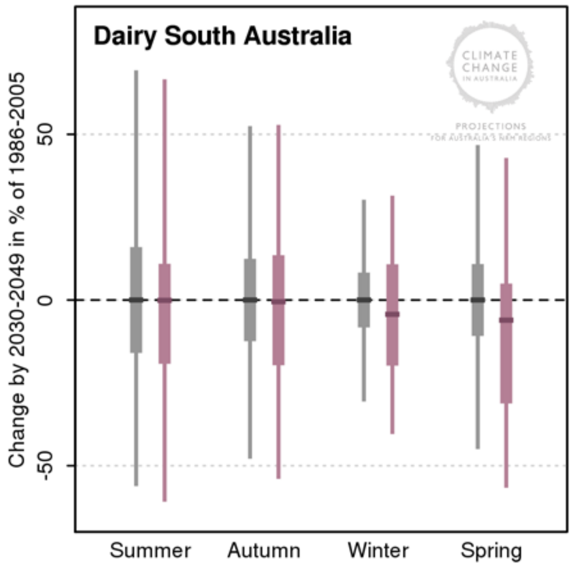

Figure 48: Projected changes in seasonal mean rainfall by 2030-2049 (purple) for the high emission scenario (RCP8.5), relative to 1986-2005 (grey). The thick horizontal line is the median (50th percentile) value. Each bar shows the 10th to 90th percentile range of the 20-year running means (thick) and single-year values (thin).

Despite projected decreases in annual-mean rainfall, extreme daily rainfall intensity is expected to increase (high confidence; Figure 49). The annual maximum 1-day rainfall intensity changes by -13 to +28%, with a median of +4%. The 1-in-20-year maximum 1-day rainfall intensity changes by -18 to +25%, with a median of +8%. This has implications for flooding, erosion, infrastructure, transport and water-logging.

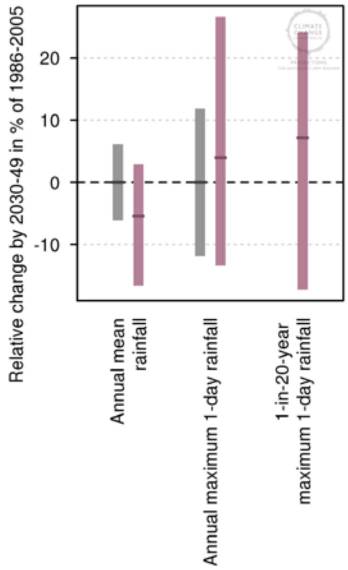

Figure 49: Projected changes in annual mean rainfall, annual maximum 1-day rainfall intensity and 1-in-20-year maximum 1-day rainfall intensity by 2030-2049 (purple) for the high emission scenario (RCP8.5), relative to 1986-2005 (grey).

Drought

Consistent with the projected decrease in average rainfall, more time in drought is expected (Figure 50). The percentage of time in drought (SPI<-1) increases from a current median of 40% to a median of 50%. This has implications for managing feed, water and heat stress during hot, dry conditions.

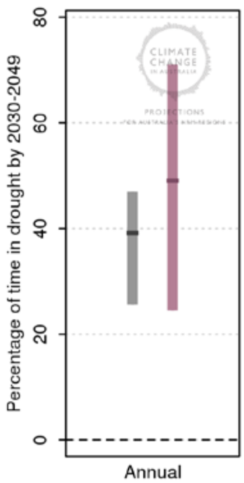

Figure 50: Projected changes in annual-average time in drought by 2030-2049 (purple) for the high emission scenario (RCP8.5), relative to 1986-2005 (grey). The thick horizontal line is the median (50th percentile) value. Each bar shows the 10th to 90th percentile range of the 20-year running means (thick) and single-year values (thin).

Evapotranspiration

Consistent with the increase in temperature, an increase in evapotranspiration is expected. The median increase by 2040 is 3-5% in spring, summer and autumn, and 8% in winter (Figure 51). The ranges are 1 to 7% in spring, 2-6% in summer, 3 to 8% in autumn, and 4 to 14% in winter.

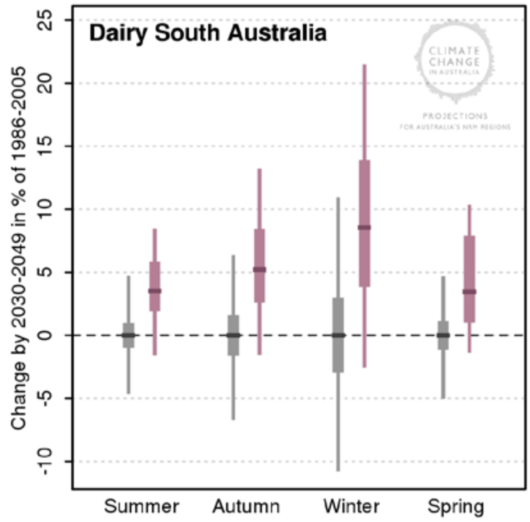

Figure 51: Projected changes in seasonal mean evapotranspiration by 2030-2049 (purple) for the high emission scenario (RCP8.5), relative to 1986-2005 (grey). The thick horizontal line is the median (50th percentile) value. Each bar shows the 10th to 90th percentile range of the 20-year running means (thick) and single-year values (thin).

Soil moisture

The projected combination of lower rainfall and higher evapotranspiration means lower soil moisture. The largest median decrease is in winter and the least in summer, with a range of 0 to +1% in summer, -3 to 0% in autumn, -10 to -2% in winter and -12 to -3% in spring (Figure 52). This will have implications for pasture growth, runoff into dams and viability of shade trees.

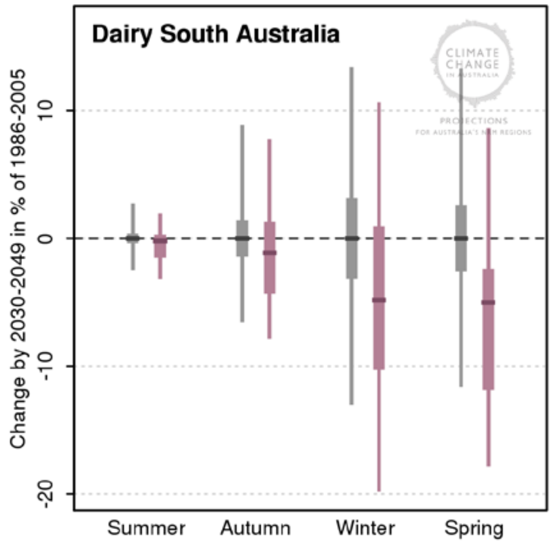

Figure 52: Projected changes in seasonal mean soil moisture by 2030-2049 (purple) for the high emission scenario (RCP8.5), relative to 1986-2005 (grey). The thick horizontal line is the median (50th percentile) value. Each bar shows the 10th to 90th percentile range of the 20-year running means (thick) and single-year values (thin).

4.3.6 New South Wales

Temperature

The NSW dairy region will warm by about 1.2-2.0°C by 2040 under the high emission scenario (Figure 53), with greatest warming in summer and least in winter (Figure 54). Maximum temperatures increase more than minimum temperatures. Warmer conditions with higher CO2 concentrations may enhance pasture growth, although the effects are complex and dependent on grass type, rainfall and soil moisture. More extremely hot days will cause greater heat stress for dairy cows, with implications for reproduction and milk yield.

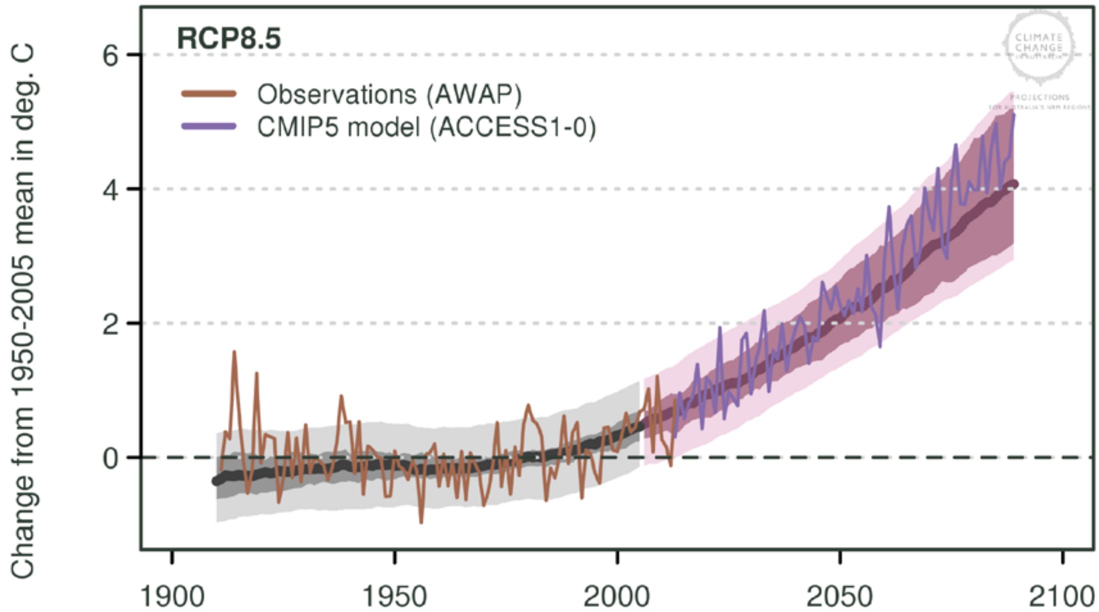

Figure 53: Change in annual-average temperature for 1910-2090, relative to 1950-2005, simulated by global climate models. The thick line is the median (50th percentile) value. The shading is the 10th to 90th percentile range of the 20-year running means (inner) and single-year values (outer). The grey shading is for the historical period, while the purple shading is for the high emission scenario (RCP8.5). The brown line shows observed data, while the purple line shows data from one climate model (ACCESS1-0).

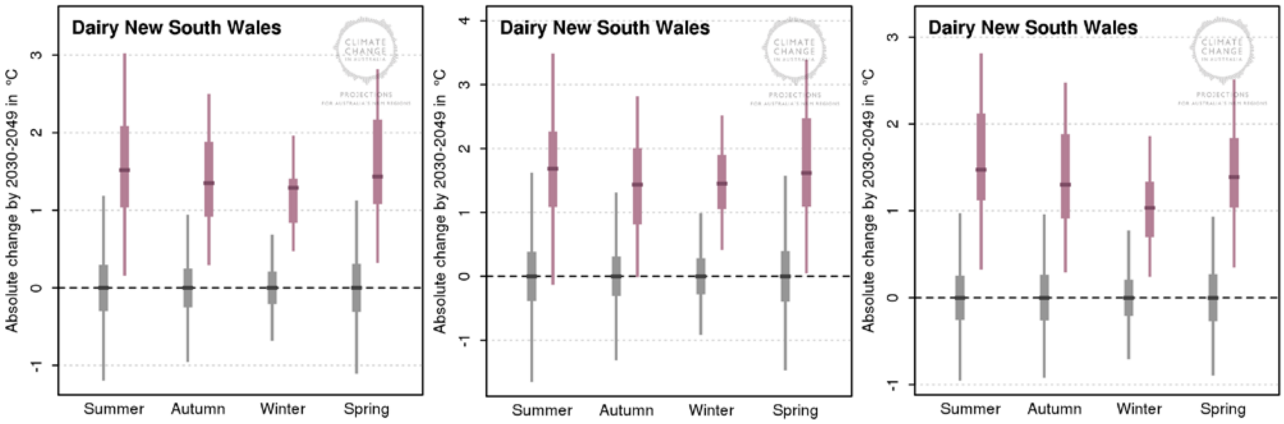

Figure 54: Projected changes in seasonal mean (left), maximum (centre) and minimum (right) temperatures by 2030-2049 (purple bars) for the high emission scenario (RCP8.5) relative to 1986-2005 (grey bars). The thick horizontal line is the median (50th percentile) value. Each bar shows the 10th to 90th percentile range of the 20-year running means (thick) and single-year values (thin).

Rainfall

Annual total rainfall will continue to have large variability from year to year, with little change in the median by 2040 (Figure 55). A small decrease in winter is offset by a small increase in summer (Figure 56). This may have implications for pasture productivity.

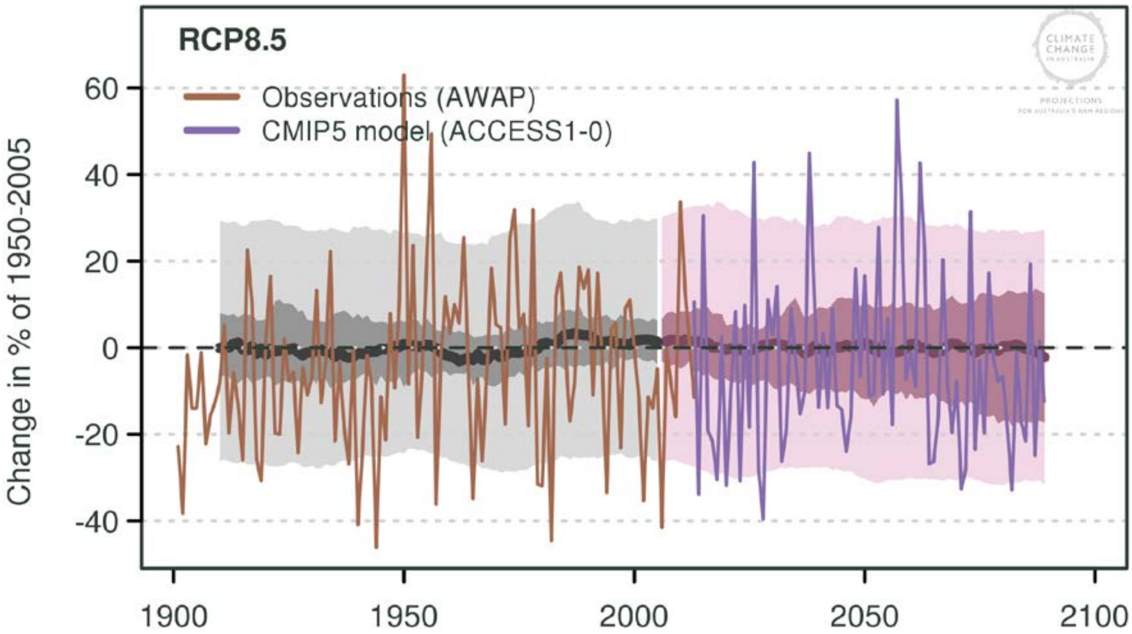

Figure 55: Change in annual-average rainfall for 1910-2090, relative to 1950-2005, simulated by global climate models. The thick line is the median (50th percentile) value. The shading is the 10th to 90th percentile range of the 20-year running means (inner) and single-year values (outer). The grey shading is for the historical period, while the purple shading is for the high emission scenario (RCP8.5). The brown line shows observed data, while the purple line shows data from one climate model (ACCESS1-0).

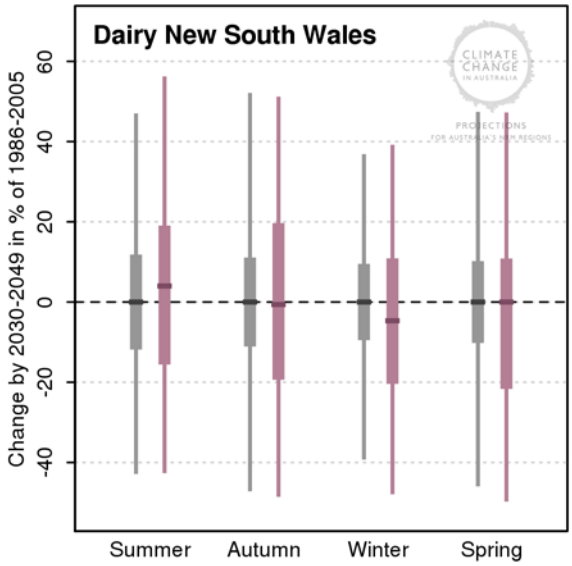

Figure 56: Projected changes in seasonal mean rainfall by 2030-2049 (purple) for the high emission scenario (RCP8.5), relative to 1986-2005 (grey). The thick horizontal line is the median (50th percentile) value. Each bar shows the 10th to 90th percentile range of the 20-year running means (thick) and single-year values (thin).

Despite little projected change in annual-mean rainfall, extreme daily rainfall intensity tends to increase (Figure 57). The annual maximum 1-day rainfall intensity changes by -5 to +16%, with a median of +8%. The 1-in-20-year maximum 1-day rainfall intensity changes by -2 to +28%, with a median of +10%. This has implications for flooding, erosion, infrastructure, transport and water-logging.

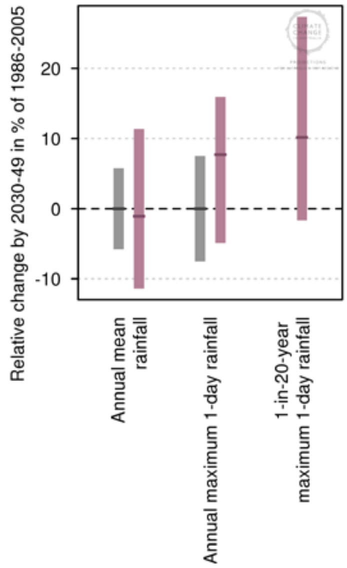

Figure 57: Projected changes in annual mean rainfall, annual maximum 1-day rainfall intensity and 1-in-20-year maximum 1-day rainfall intensity by 2030-2049 (purple) for the high emission scenario (RCP8.5), relative to 1986-2005 (grey).

Drought

Consistent with little projected change in average rainfall, little change in drought frequency is expected (Figure 58). The percentage of time in drought (SPI<-1) increases from a current median of 35% to a median of 38%.

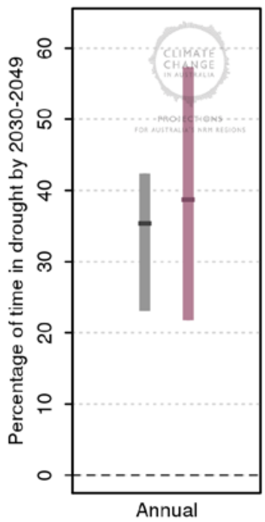

Figure 58: Projected changes in annual-average time in drought by 2030-2049 (purple) for the high emission scenario (RCP8.5), relative to 1986-2005 (grey). The thick horizontal line is the median (50th percentile) value. Each bar shows the 10th to 90th percentile range of the 20-year running means (thick) and single-year values (thin).

Evapotranspiration

Consistent with the increase in temperature, an increase in evapotranspiration is expected. The median increase by 2040 is 5-6% in summer and autumn, 8% in winter and 3% in spring (Figure 59). The ranges are 1 to 6% in spring, 2-7% in summer, 3 to 10% in autumn, and 6 to 14% in winter.

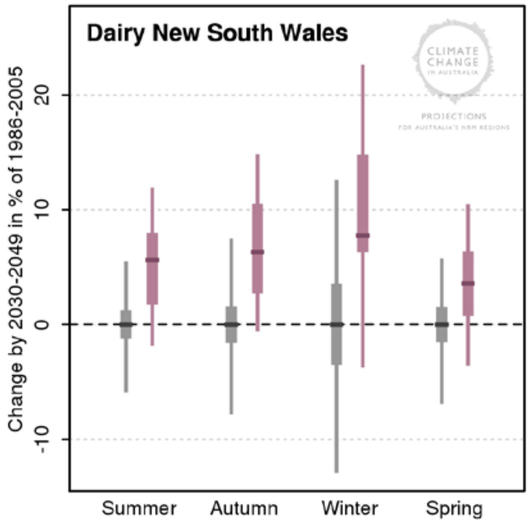

Figure 59: Projected changes in seasonal mean evapotranspiration by 2030-2049 (purple) for the high emission scenario (RCP8.5), relative to 1986-2005 (grey). The thick horizontal line is the median (50th percentile) value. Each bar shows the 10th to 90th percentile range of the 20-year running means (thick) and single-year values (thin).

Soil moisture

The projected combination of little change in rainfall and higher evapotranspiration means lower soil moisture. The largest median decrease is in spring and the least in summer, with a range of -7 to +2% in summer, -8 to -1% in autumn, -13 to -7% in winter and -15 to -5% in spring (Figure 60). This will have implications for pasture growth, runoff into dams and viability of shade trees.

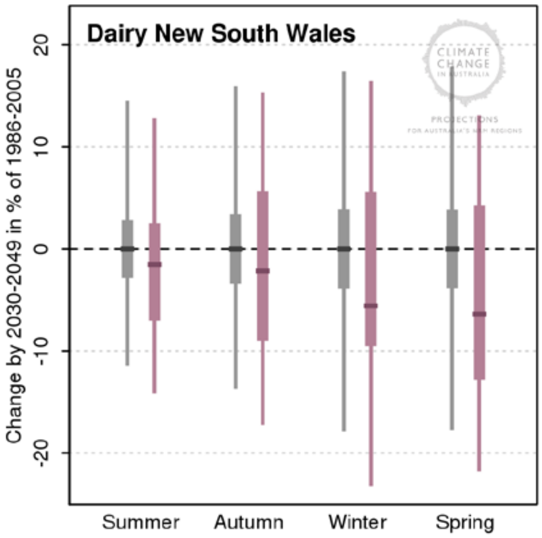

Figure 60: Projected changes in seasonal mean soil moisture by 2030-2049 (purple) for the high emission scenario (RCP8.5), relative to 1986-2005 (grey). The thick horizontal line is the median (50th percentile) value. Each bar shows the 10th to 90th percentile range of the 20-year running means (thick) and single-year values (thin).

4.3.7 Sub-tropical (Queensland and northern New South Wales)

Temperature

The sub-tropical dairy region will warm by about 1.0-2.0°C by 2040 under the high emission scenario (Figure 61), with greatest warming in spring and least in autumn (Figure 62). Maximum temperatures increase more than minimum temperatures. Warmer conditions with higher CO2 concentrations may enhance pasture growth, although the effects are complex and dependent on grass type, rainfall and soil moisture. More extremely hot days will cause greater heat stress for dairy cows, with implications for reproduction and milk yield.

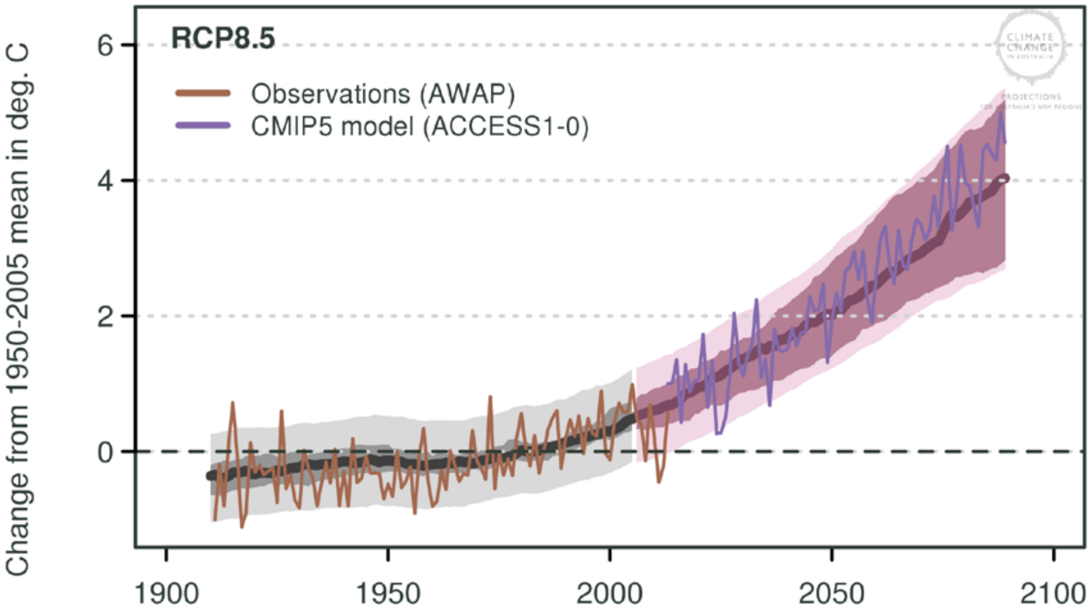

Figure 61: Change in annual-average temperature for 1910-2090, relative to 1950-2005, simulated by global climate models. The thick line is the median (50th percentile) value. The shading is the 10th to 90th percentile range of the 20-year running means (inner) and single-year values (outer). The grey shading is for the historical period, while the purple shading is for the high emission scenario (RCP8.5). The brown line shows observed data, while the purple line shows data from one climate model (ACCESS1-0).

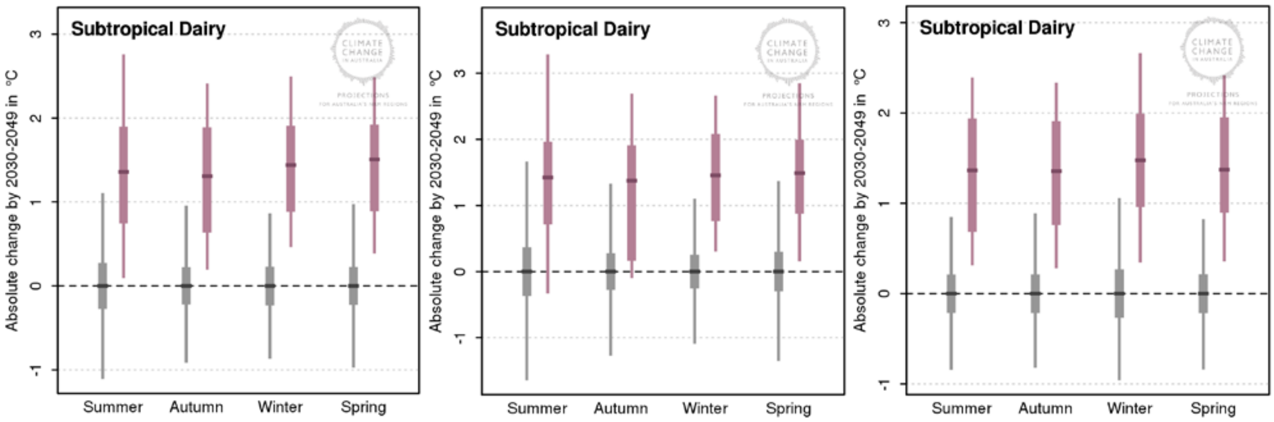

Figure 62: Projected changes in seasonal mean (left), maximum (centre) and minimum (right) temperatures by 2030-2049 (purple bars) for the high emission scenario (RCP8.5) relative to 1986-2005 (grey bars). The thick horizontal line is the median (50th percentile) value. Each bar shows the 10th to 90th percentile range of the 20-year running means (thick) and single-year values (thin).

Rainfall

Annual total rainfall will continue to have large variability from year to year. When averaged over the north and south sub-regions, the median decreases by around 5% by 2040 (Figure 63). However, the decrease is about 10% in the south and only 2% in the north. Decreases occur in all seasons in the south, but only in autumn to spring in the north (Figure 64). This may have implications for pasture productivity.

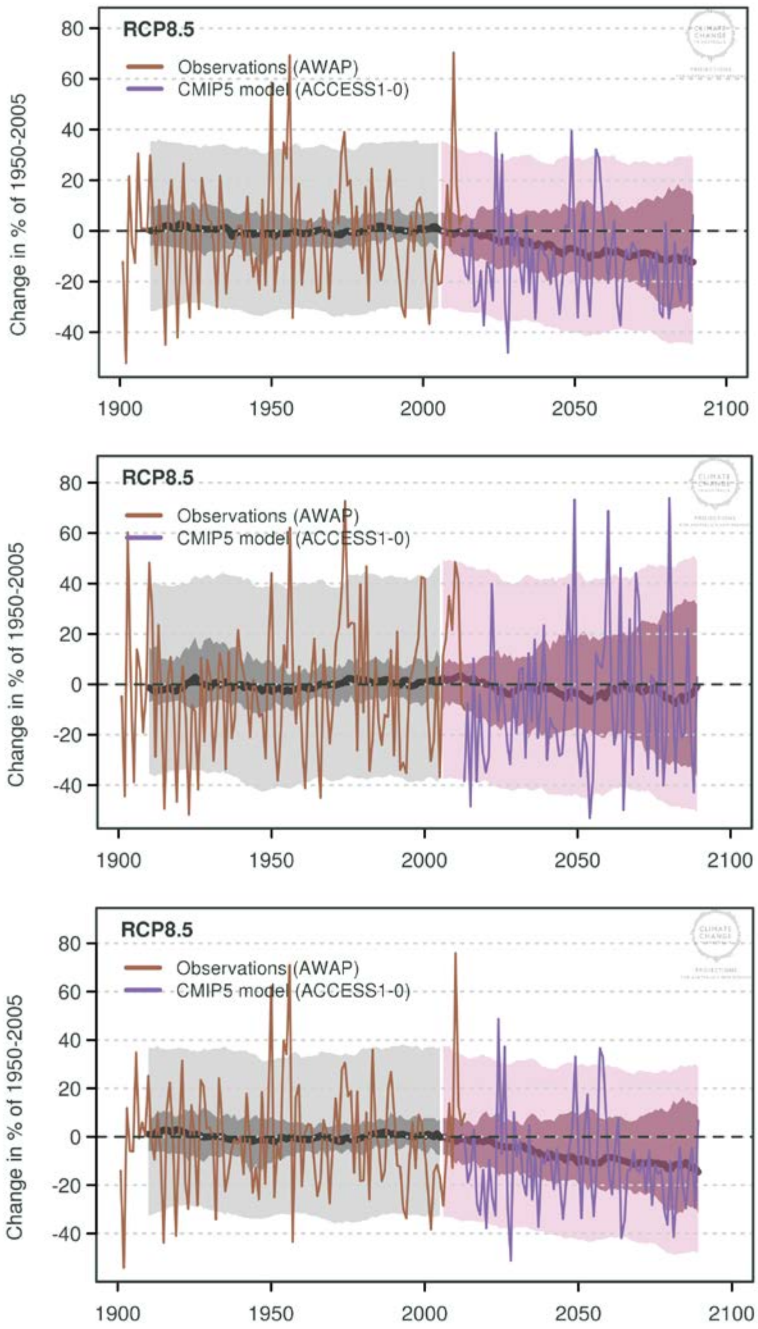

Figure 63: Change in annual-average rainfall for 1910-2090, relative to 1950-2005, simulated by global climate models. The thick line is the median (50th percentile) value. The shading is the 10th to 90th percentile range of the 20-year running means (inner) and single-year values (outer). The grey shading is for the historical period, while the purple shading is for the high emission scenario (RCP8.5). The brown line shows observed data, while the purple line shows data from one climate model (ACCESS1-0). The top panel shows the average over the whole region, the middle panel is for the northern region and the bottom panel is for the southern region (see Figure 12).

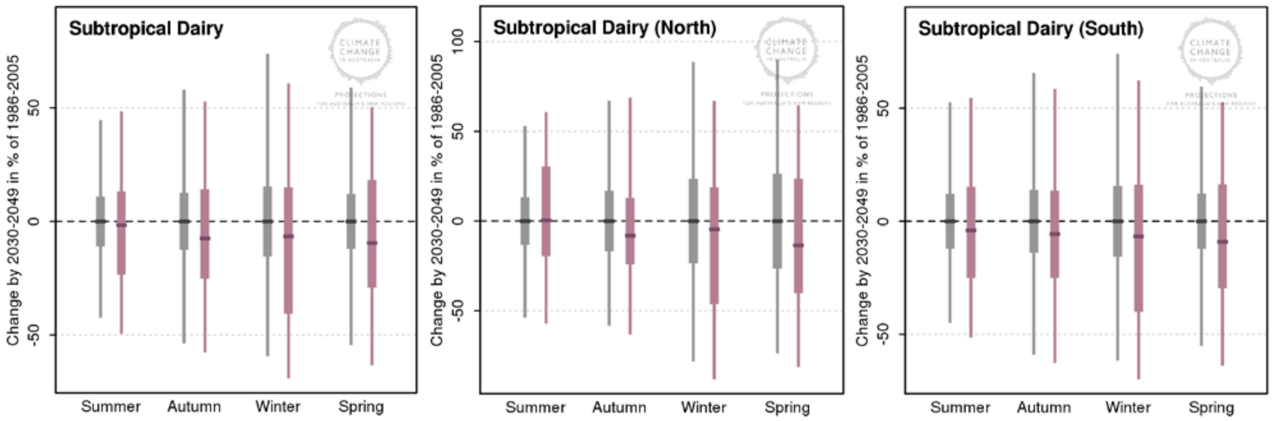

Figure 64: Projected changes in seasonal mean rainfall by 2030-2049 (purple) for the high emission scenario (RCP8.5), relative to 1986-2005 (grey). The thick horizontal line is the median (50th percentile) value. Each bar shows the 10th to 90th percentile range of the 20-year running means (thick) and single-year values (thin). The left panel shows the average over the whole region, the middle panel is for the northern region and the right panel is for the southern region (see Figure 12).

Despite projected decreases in annual-mean rainfall, extreme daily rainfall intensity is expected to increase (high confidence; Figure 65). The annual maximum 1-day rainfall intensity changes by -12 to +20%, with a median of +3%. The 1-in-20-year maximum 1-day rainfall intensity changes by -2 to +30%, with a median of +9%. This has implications for flooding, erosion, infrastructure, transport and water-logging.

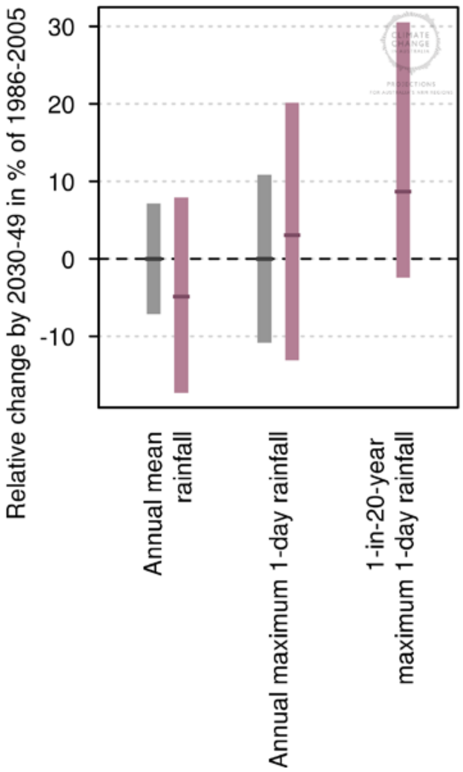

Figure 65: Projected changes in annual mean rainfall, annual maximum 1-day rainfall intensity and 1-in-20-year maximum 1-day rainfall intensity by 2030-2049 (purple) for the high emission scenario (RCP8.5), relative to 1986-2005 (grey).

Drought

Consistent with a small decrease in average rainfall, a small increase in drought frequency is expected (Figure 66). Averaged over the whole region, The percentage of time in drought (SPI<-1) increases from a current median of 35% to a median of 43%. Averaged over the northern region, The percentage of time in drought (SPI<-1) increases from a current median of 32% to a median of 35%. Averaged over the southern region, The percentage of time in drought (SPI<-1) increases from a current median of 36% to a median of 44%.

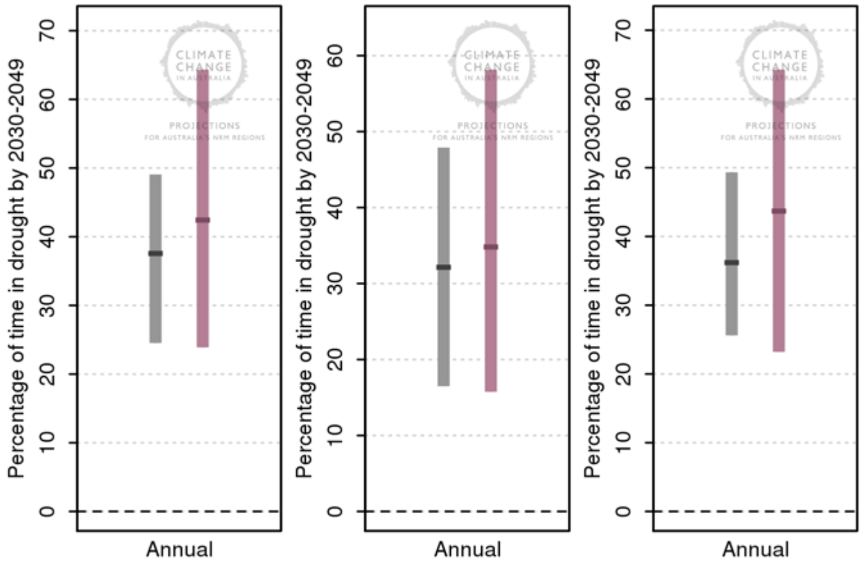

Figure 66: Projected changes in annual-average time in drought by 2030-2049 (purple) for the high emission scenario (RCP8.5), relative to 1986-2005 (grey). The thick horizontal line is the median (50th percentile). Each bar shows the 10th to 90th percentile range of the 20-year running means. The left panel shows the average over the whole region, the middle panel is for the northern region and the right panel is for the southern region (see Figure 12).

Evapotranspiration

Consistent with the increase in temperature, an increase in evapotranspiration is expected. The median increase by 2040 is 4% in spring and summer, 6% in autumn and 5% in winter (Figure 67). The ranges are 3 to 5% in spring, 2-8% in summer, 4 to 9% in autumn, and 3 to 5% in winter.

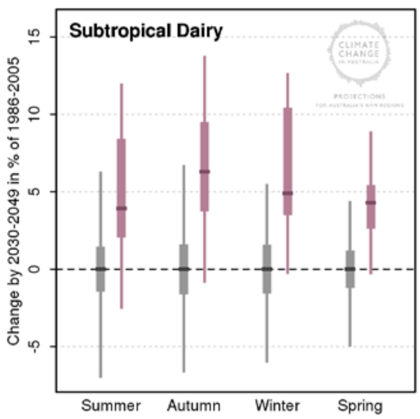

Figure 67: Projected changes in seasonal mean evapotranspiration by 2030-2049 (purple) for the high emission scenario (RCP8.5), relative to 1986-2005 (grey). The thick horizontal line is the median (50th percentile) value. Each bar shows the 10th to 90th percentile range of the 20-year running means (thick) and single-year values (thin).

Soil moisture

The projected combination of less rainfall and higher evapotranspiration means lower soil moisture. The largest median decrease is in winter and the least in summer, with a range of -1 to +5% in summer, -10 to 0% in autumn and winter, and -6 to -4% in spring (Figure 68). This will have implications for pasture growth, runoff into dams and viability of shade trees.

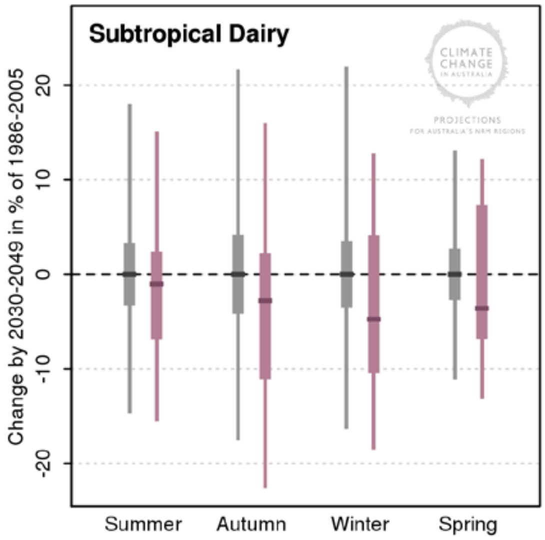

Figure 68: Projected changes in seasonal mean soil moisture by 2030-2049 (purple) for the high emission scenario (RCP8.5), relative to 1986-2005 (grey). The thick horizontal line is the median (50th percentile) value. Each bar shows the 10th to 90th percentile range of the 20-year running means (thick) and single-year values (thin).

4.3.8 South-western Australia

Temperature

The Western dairy region will warm by about 1.0-1.7°C by 2040 under the high emission scenario (Figure 69), with greatest warming in summer and least in winter (Figure 70). Maximum temperatures increase more than minimum temperatures. Warmer conditions with higher CO2 concentrations may enhance pasture growth, although the effects are complex and dependent on grass type, rainfall and soil moisture. More extremely hot days will cause greater heat stress for dairy cows, with implications for reproduction and milk yield.

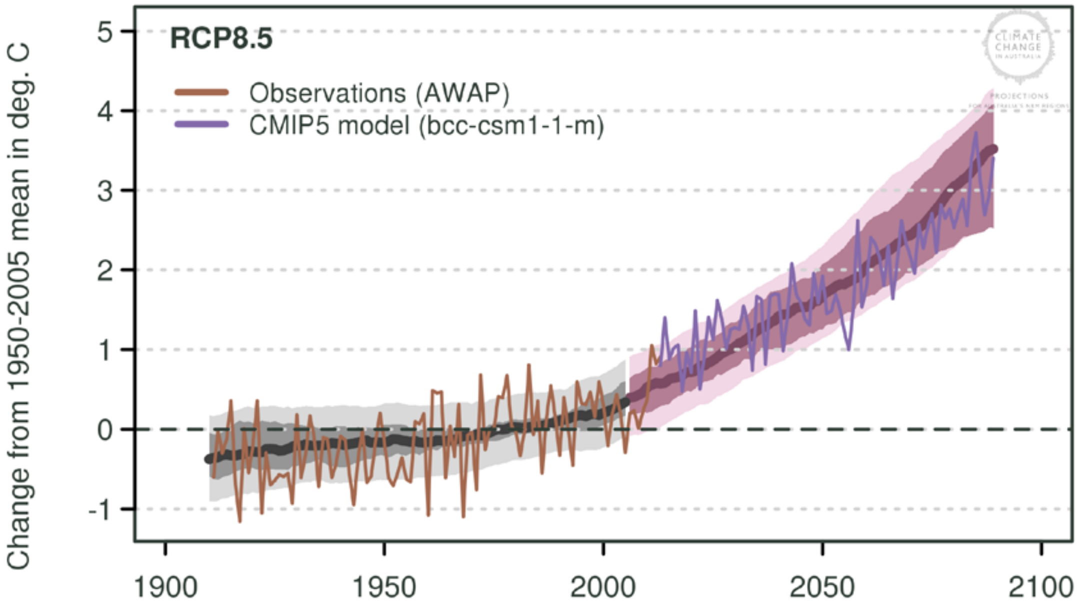

Figure 69: Change in annual-average temperature for 1910-2090, relative to 1950-2005, simulated by global climate models. The thick line is the median (50th percentile) value. The shading is the 10th to 90th percentile range of the 20-year running means (inner) and single-year values (outer). The grey shading is for the historical period, while the purple shading is for the high emission scenario (RCP8.5). The brown line shows observed data, while the purple line shows data from one climate model (BCC-CSM1-1-M).

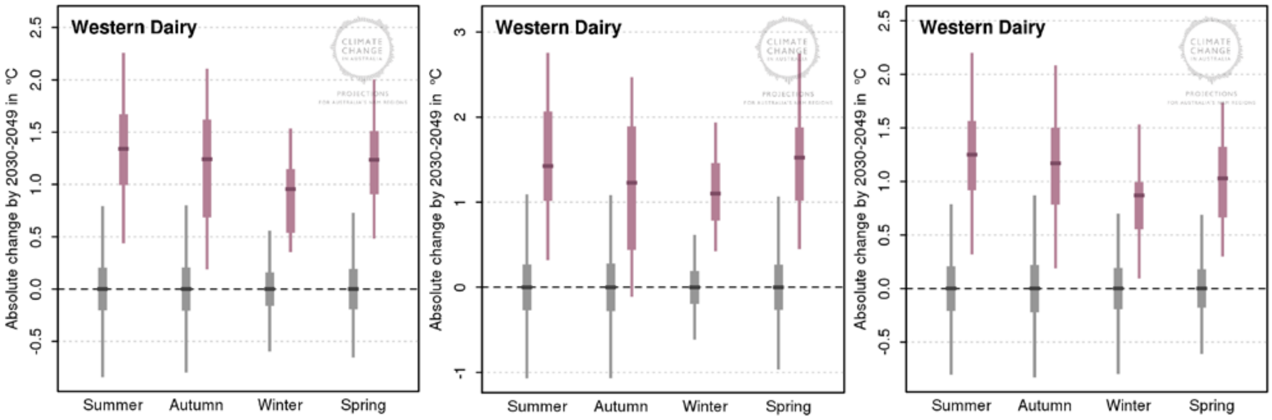

Figure 70: Projected changes in seasonal mean (left), maximum (centre) and minimum (right) temperatures by 2030-2049 (purple bars) for the high emission scenario (RCP8.5) relative to 1986-2005 (grey bars). The thick horizontal line is the median (50th percentile) value. Each bar shows the 10th to 90th percentile range of the 20-year running means (thick) and single-year values (thin).

Rainfall

Annual total rainfall will continue to have large variability from year to year, with a 15% decrease in the median by 2040, and a range of -22 to -7% (Figure 71). Decreases occur in all seasons, especially spring (Figure 72). This will have major implications for pasture productivity.

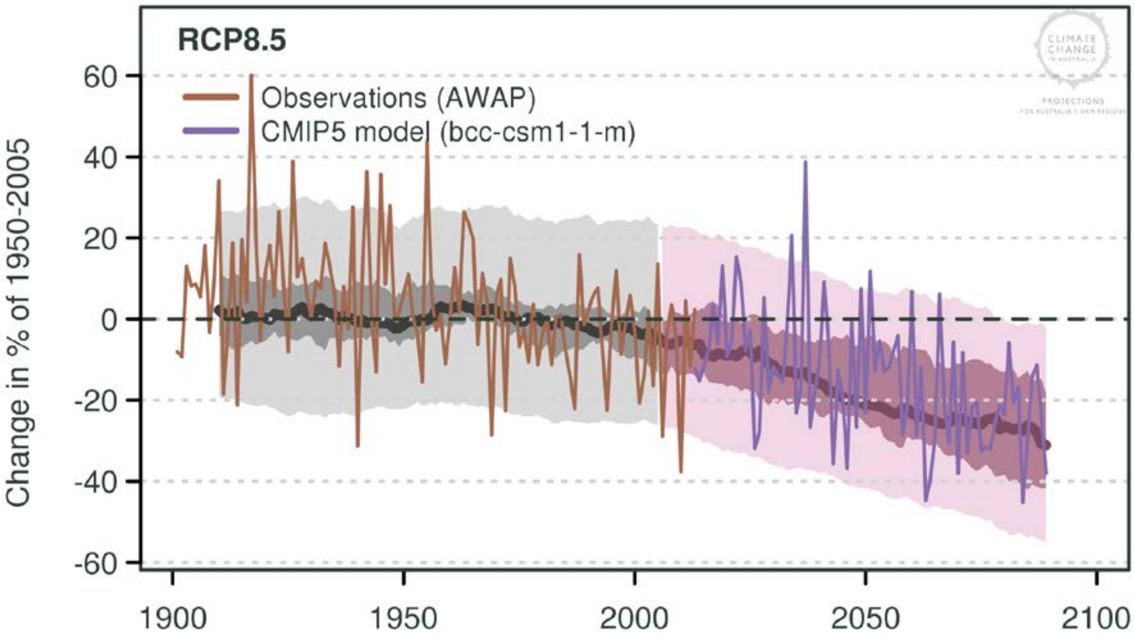

Figure 71: Change in annual-average rainfall for 1910-2090, relative to 1950-2005, simulated by global climate models. The thick line is the median (50th percentile) value. The shading is the 10th to 90th percentile range of the 20-year running means (inner) and single-year values (outer). The grey shading is for the historical period, while the purple shading is for the high emission scenario (RCP8.5). The brown line shows observed data, while the purple line shows data from one climate model (BCC-CSM1-1-M).

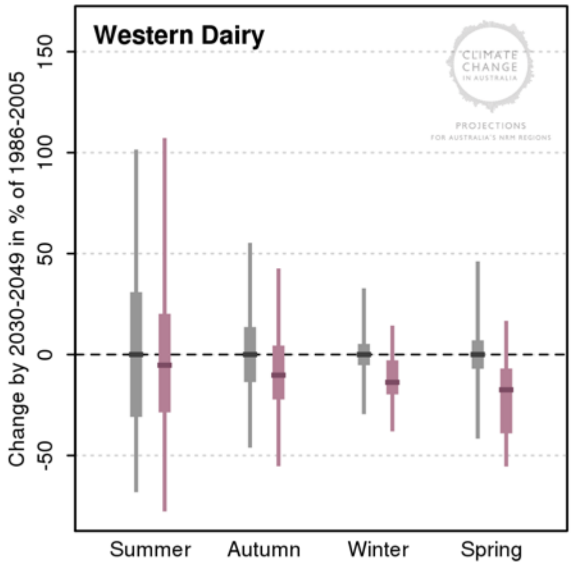

Figure 72: Projected changes in seasonal mean rainfall by 2030-2049 (purple) for the high emission scenario (RCP8.5), relative to 1986-2005 (grey). The thick horizontal line is the median (50th percentile) value. Each bar shows the 10th to 90th percentile range of the 20-year running means (thick) and single-year values (thin).

Despite the large projected decrease in annual-mean rainfall, extreme daily rainfall intensity tends to decrease slightly (Figure 73). The annual maximum 1-day rainfall intensity changes by -60 to +16%, with a median of -4%. The 1-in-20-year maximum 1-day rainfall intensity changes by -20 to +20%, with a median of -4%. This has implications for flooding, erosion, infrastructure, transport and water-logging.

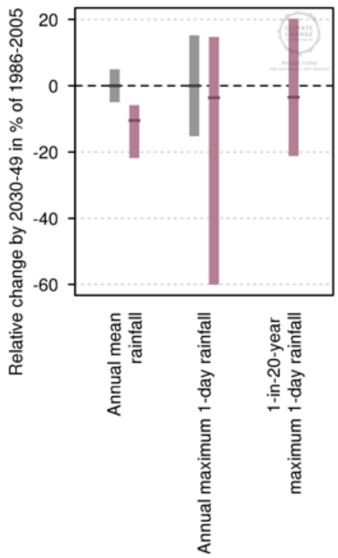

Figure 73: Projected changes in annual mean rainfall, annual maximum 1-day rainfall intensity and 1-in-20-year maximum 1-day rainfall intensity by 2030-2049 (purple) for the high emission scenario (RCP8.5), relative to 1986-2005 (grey).

Drought

Consistent with large projected decreases in average rainfall, a large increase in drought frequency is expected (Figure 74). The percentage of time in drought (SPI<-1) increases from a current median of 45% to a median of 62%. This has implications for managing feed, water and heat stress during hot, dry conditions.

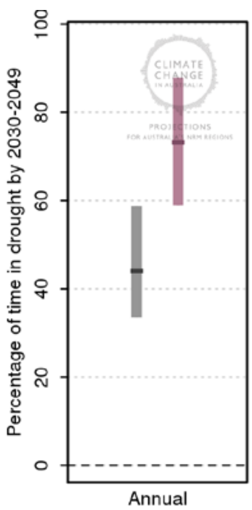

Figure 74: Projected changes in annual-average time in drought by 2030-2049 (purple) for the high emission scenario (RCP8.5), relative to 1986-2005 (grey). The thick horizontal line is the median (50th percentile) value. Each bar shows the 10th to 90th percentile range of the 20-year running means (thick) and single-year values (thin).

Evapotranspiration

Consistent with the increase in temperature, an increase in evapotranspiration is expected. The median increase by 2040 is 4% in summer, 6% in autumn and spring, and 7% in winter (Figure 75). The ranges are 2-7% in summer, 3 to 10% in autumn, 4 to 14% in winter and 3 to 8% in spring.

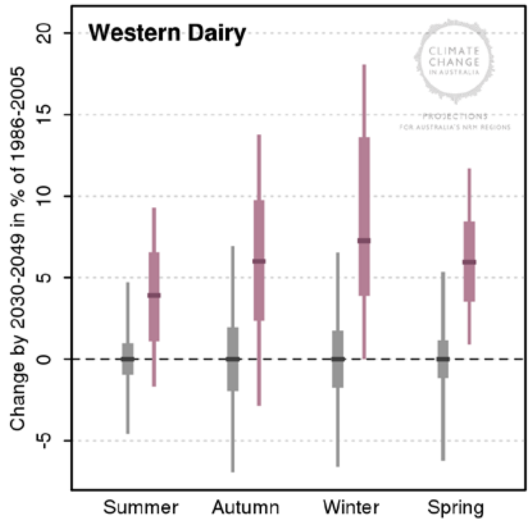

Figure 75: Projected changes in seasonal mean evapotranspiration by 2030-2049 (purple) for the high emission scenario (RCP8.5), relative to 1986-2005 (grey). The thick horizontal line is the median (50th percentile) value. Each bar shows the 10th to 90th percentile range of the 20-year running means (thick) and single-year values (thin).

Soil moisture

The projected combination of less rainfall and higher evapotranspiration means lower soil moisture. The largest median decrease is in spring and the least in summer, with a range of -1 to +1% in summer, -2 to +3% in autumn, -12 to -3% in winter and -12 to -7% in spring (Figure 76). This will have implications for pasture growth, runoff into dams and viability of shade trees.

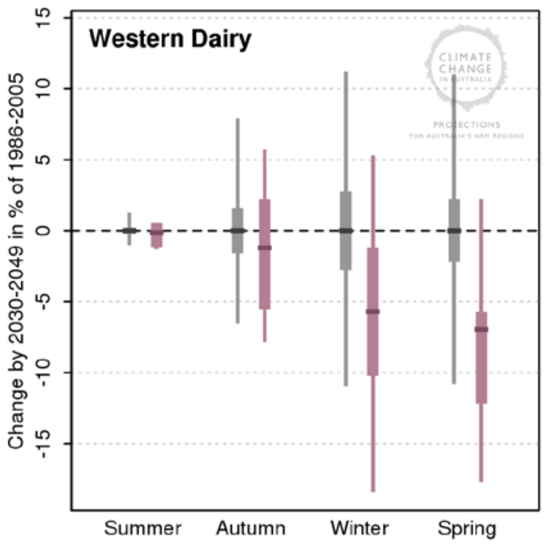

Figure 76: Projected changes in seasonal mean soil moisture by 2030-2049 (purple) for the high emission scenario (RCP8.5), relative to 1986-2005 (grey). The thick horizontal line is the median (50th percentile) value. Each bar shows the 10th to 90th percentile range of the 20-year running means (thick) and single-year values (thin).

5 Risk management, uncertainty and the Climate Futures approach

Projections of future climate are essential to understanding the likely impacts of a changing climate on business, industry, communities and natural systems.

A robust approach to undertaking a climate change impact assessment is illustrated in Figure 77. The first three stages of this process (establishing the context, identifying the known risks, and risk analysis) require climate information as inputs. Other frameworks exist, but have many similarities to this simple process.

While some understanding of likely impact can be derived from a broad understanding of expected future climate, many assessments require detailed datasets representing multiple climatic variables.

Such detailed datasets should:

- Be internally consistent
- Adequately represent the uncertainty range
- Be manageable (in size, format and complexity of analysis)
- Help inform an understanding of likelihood.

The Climate Futures framework has been developed by CSIRO to assist decision-makers in understanding the range and likelihood of future climates when conducting their impact assessment (Whetton et al. 2012). The associated Australian Climate Futures web-tool (http://www.climatechangeinaustralia.gov.au/en/climate-projections/climate-futures-tool/) facilitates application of the framework through a user-friendly interface. The web-tool allows the user to explore climate projections in terms of the expected changes in two variables (e.g. temperature and rainfall) simultaneously. A two-way classification 'matrix' is shown in Figure 78.

Each cell in the matrix shows the number of global climate models (GCMs) or regional climate models (RCMs) that give climate projections within a specified range of change (indicated on the axis labels). The number of models gives an indication of likelihood. In this example, three 'key cases' of interest have been identified: 'best case', 'worst case' and 'maximum consensus case' (detailed in Clarke et al. 2011). The tool then facilitates identification of a representative GCM or RCM from each key case. Each model has data that are internally consistent. The impact assessment can then be undertaken for each key case using data from each representative model. Using data from only three models instead of over 40 models makes the assessment more manageable, while covering most of the uncertainty range.

A more complete description of the Climate Futures Framework and its application to risk assessment can be found in Chapter 9 of the Climate Change in Australia Technical Report (CSIRO and BoM, 2015).

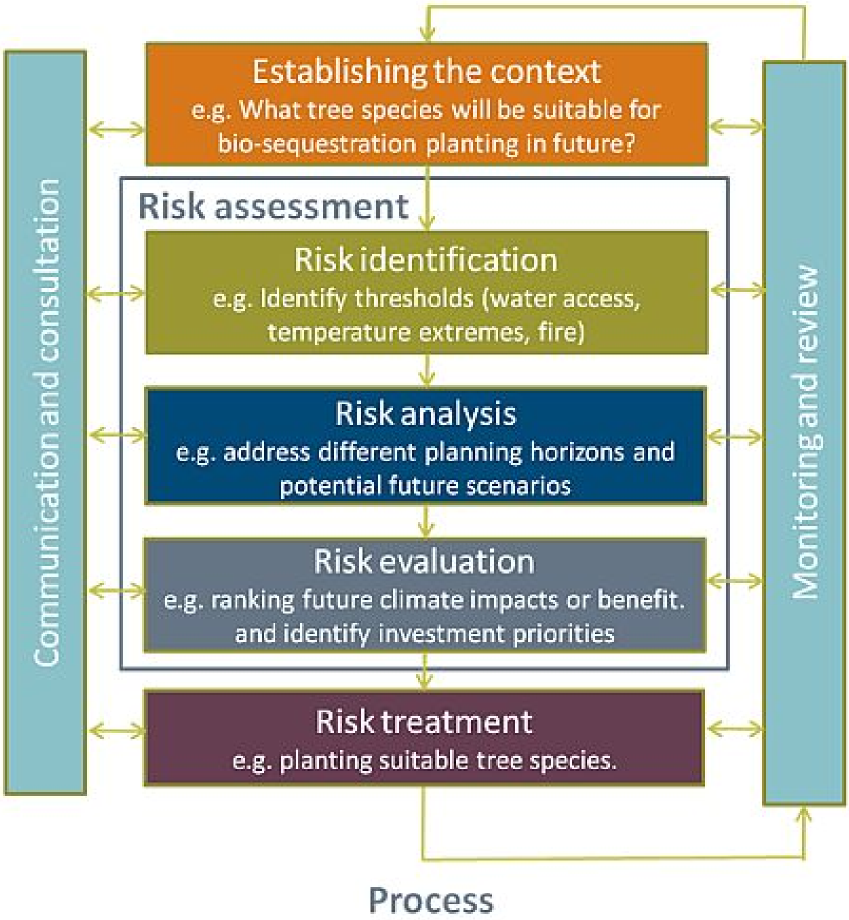

Figure 77 Steps involved in undertaking a climate risk assessment (adapted from Standards Australia, 2009).

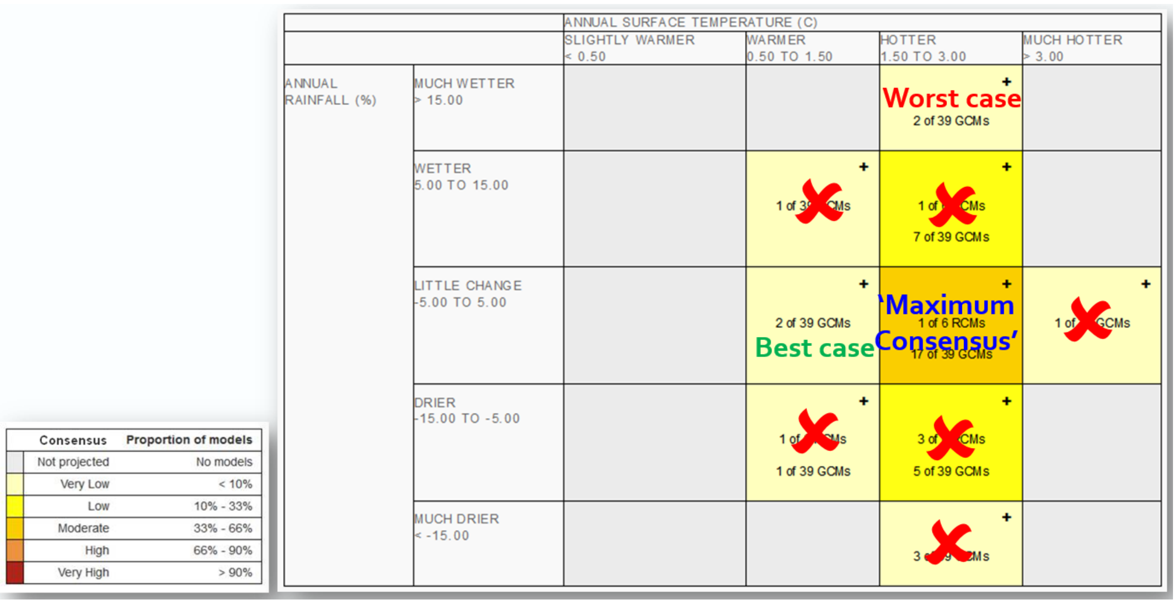

Figure 78: Climate Futures Matrix for a particular region, emission scenario and year, with example key cases illustrated.

Appendix A Projections for selected locations

Projected changes in monthly-mean maximum daily temperature for 2040 under a high emission scenario have been applied to observed daily maximum temperature data at 24 sites in the dairy regions. The current and future annual-average number of days over 30°C is shown in Table 1. At most sites, the increase is 20-50%. Places that currently have an annual-average of 70-80 days over 30°C (e.g. Cowra, Deniliquin, Jerry's Plains, Kerang) would experience an increase of about 13-37 days, although Casino (current average of 80 days) would experience an increase of 30-54 days. Places that currently have an average of 50-60 days (e.g. Donnybrook, Murray Bridge, Tatura) would see an increase of about 10-25 days. Places that currently have an average of 20-30 days (e.g. Ballarat, East Sale, Victor Harbour) would see an increase of about 5-13 days.

Table A1: Annual-average number of days over 30°C for the period 1986-2005 compared with 2030-2049 for the high emission scenario (RCP8.5) at 24 sites in Australian dairy regions. The range of future days is derived from eight climate models that span most of the range of possibilities from 40 climate models.

Site	1986-2005	2030-2049
Ballarat	23.4	29.5-36.0
Burnie	0.2	0.5-0.8
Casino	79.8	111.4-133.7
Corryong	42.0	58.8-73.5
Cowra	74.1	92.8-108.2
Deniliquin	73.1	88.4-100.0
Donnybrook	53.1	61.2-72.8
East Sale	22.5	28.4-33.4
Gatton	103.7	136.2-160.8
Gympie	87.3	121-149.4
Heywood	18.1	20.9-25.8
Jerry's Plains	72.4	93.0-109.5
Kairi	44.6	67.4-104.8
Kerang	73.1	86.3-99.0
Mount Gambier	19.9	23.3-28.1
Murray Bridge	55.8	64.6-75.8
Nowra	22.4	36.4-44.2
Oakey	84.1	114.3-138.0
Olsens Bridge	13.1	16.7-20.0
Scottsdale	1.2	2.2-3.6
Taree	37.8	59.0-78.6
Tatura	52.1	66.6-74.0
Victor Harbour	25.2	30.2-36.5
Wonthaggi	16.2	19.9-23.5

Projected changes in monthly average temperature and rainfall for 2040 under a high emission scenario have been applied to observed monthly data at the same 24 sites. This indicates expected changes in the average seasonal cycle. That is: all sites becoming warmer and drier, the warm season and the dry season becoming longer, and the cool season and wet season becoming shorter. At most sites, there is an expected 1-month shift in temperatures, e.g. the current average temperature for March shifts to April. There is greater uncertainty for rainfall but a 1-month shift is mostly evident, especially in winter and spring.

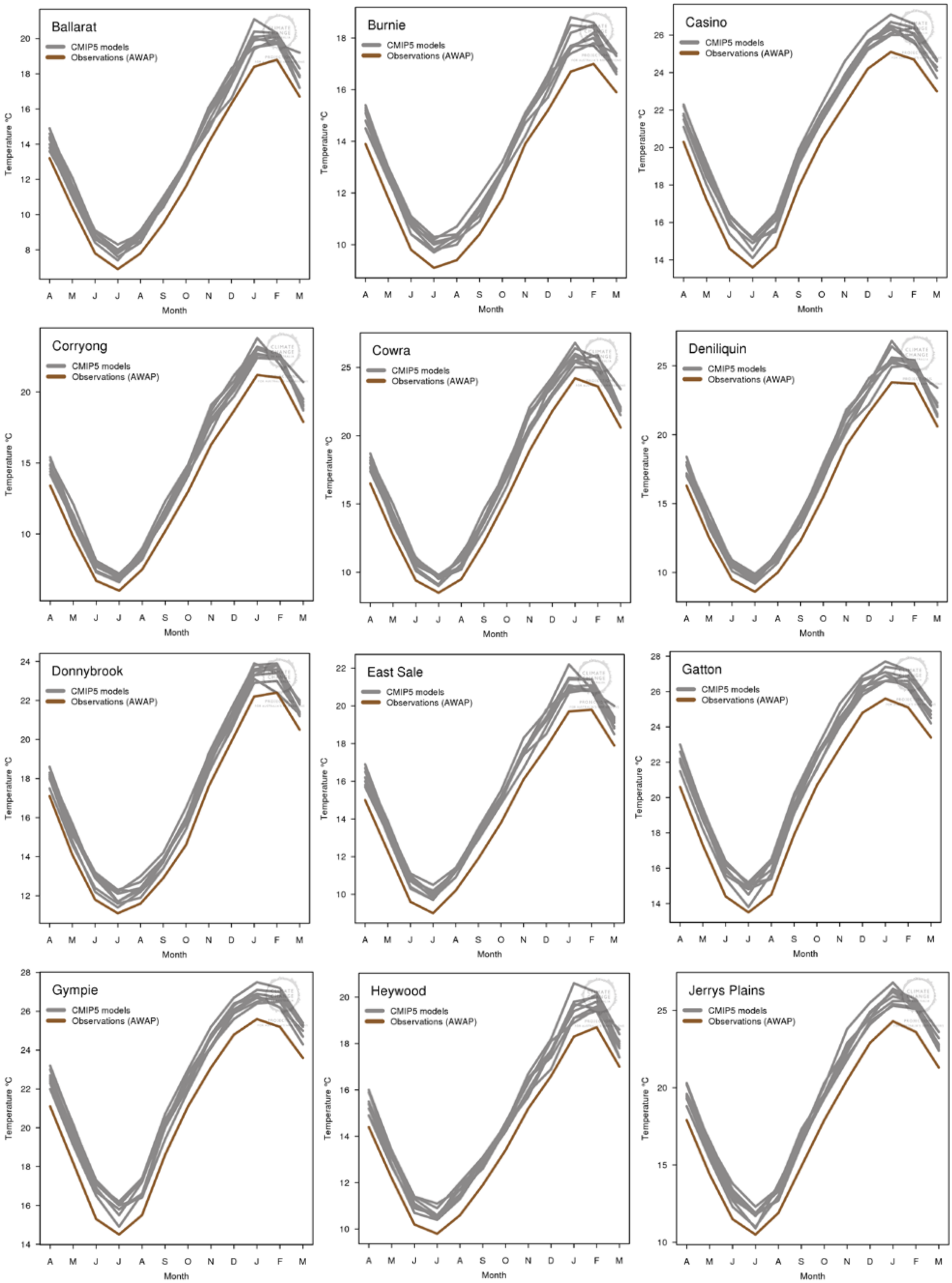

Figure A1: Observed (1985-2005; brown line) and projected (2030-2049, high emissions; grey lines) monthly-average temperature for 12 sites in dairy regions. The projected temperatures are derived from eight CMIP5 climate models that span most of the range of possibilities from 40 CMIP5 climate models.

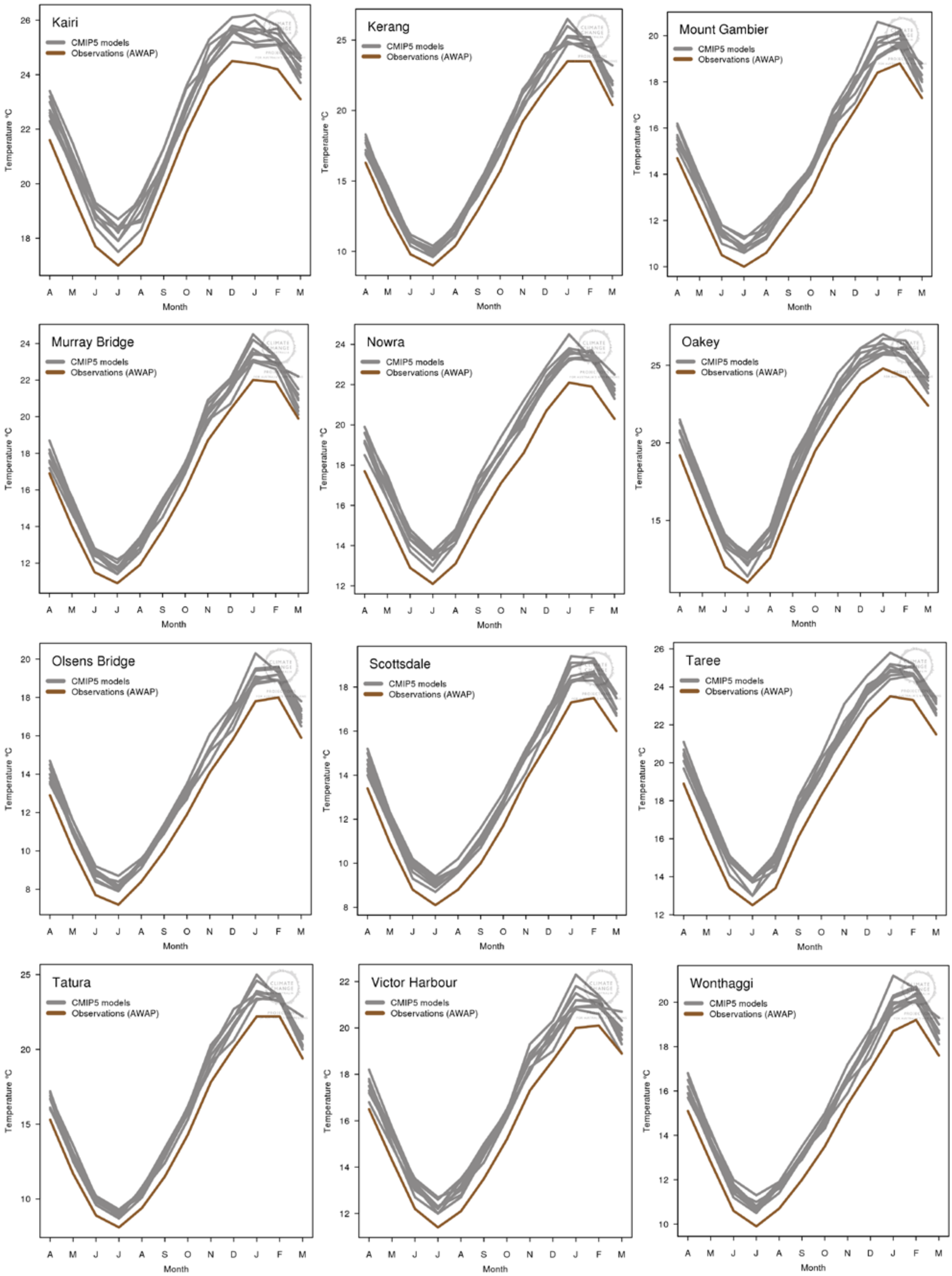

Figure A2: Observed (1985-2005; brown line) and projected (2030-2049, high emissions; grey lines) monthly-average temperature for 12 sites in dairy regions. The projected temperatures are derived from eight CMIP5 climate models that span most of the range of possibilities from 40 CMIP5 climate models.

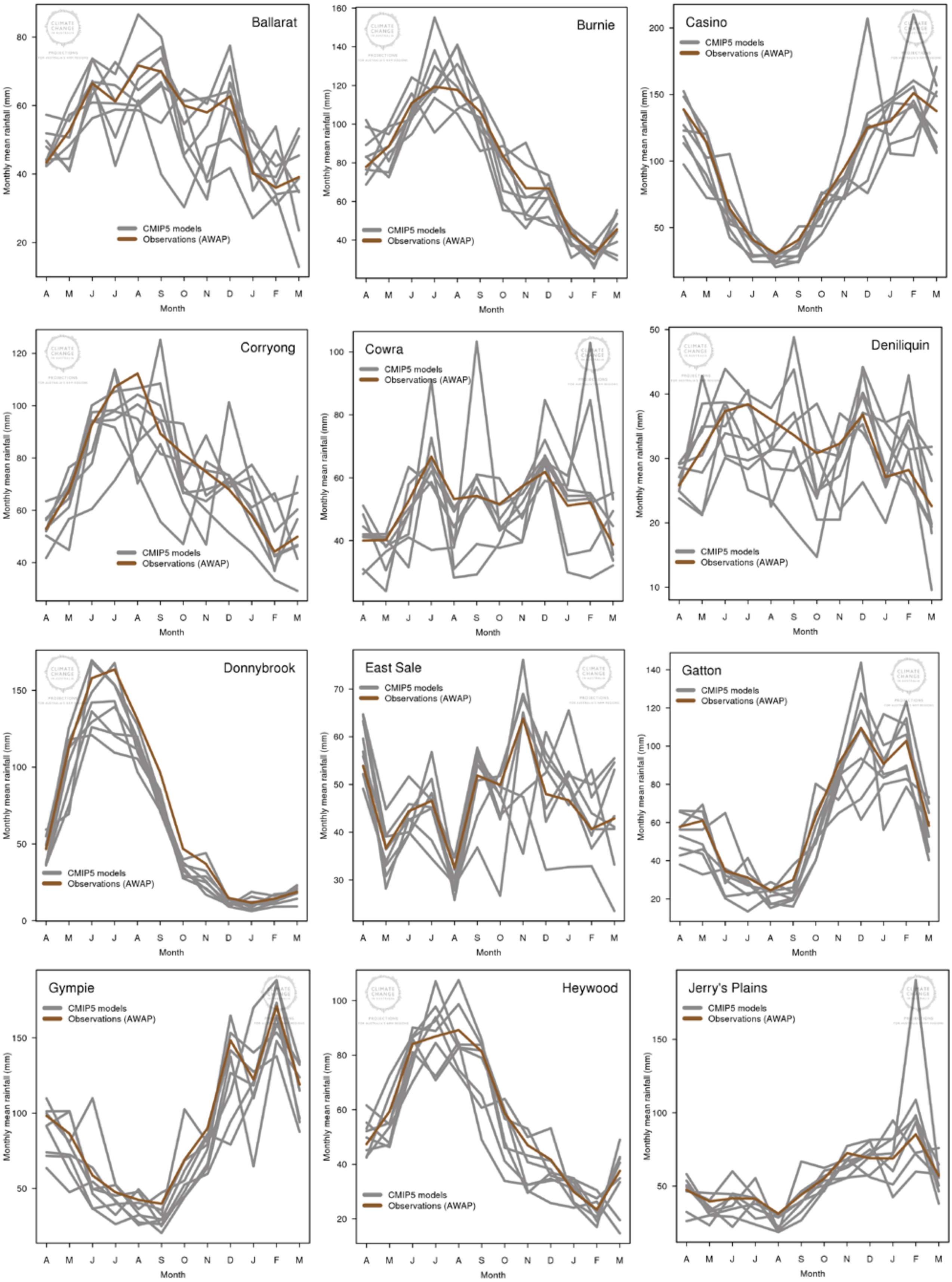

Figure A3: Observed (1985-2005; brown line) and projected (2030-2049, high emissions; grey lines) monthly-average rainfall for 12 sites in dairy regions. The projected rainfall is derived from eight CMIP5 climate models that span most of the range of possibilities from 40 CMIP5 climate models.

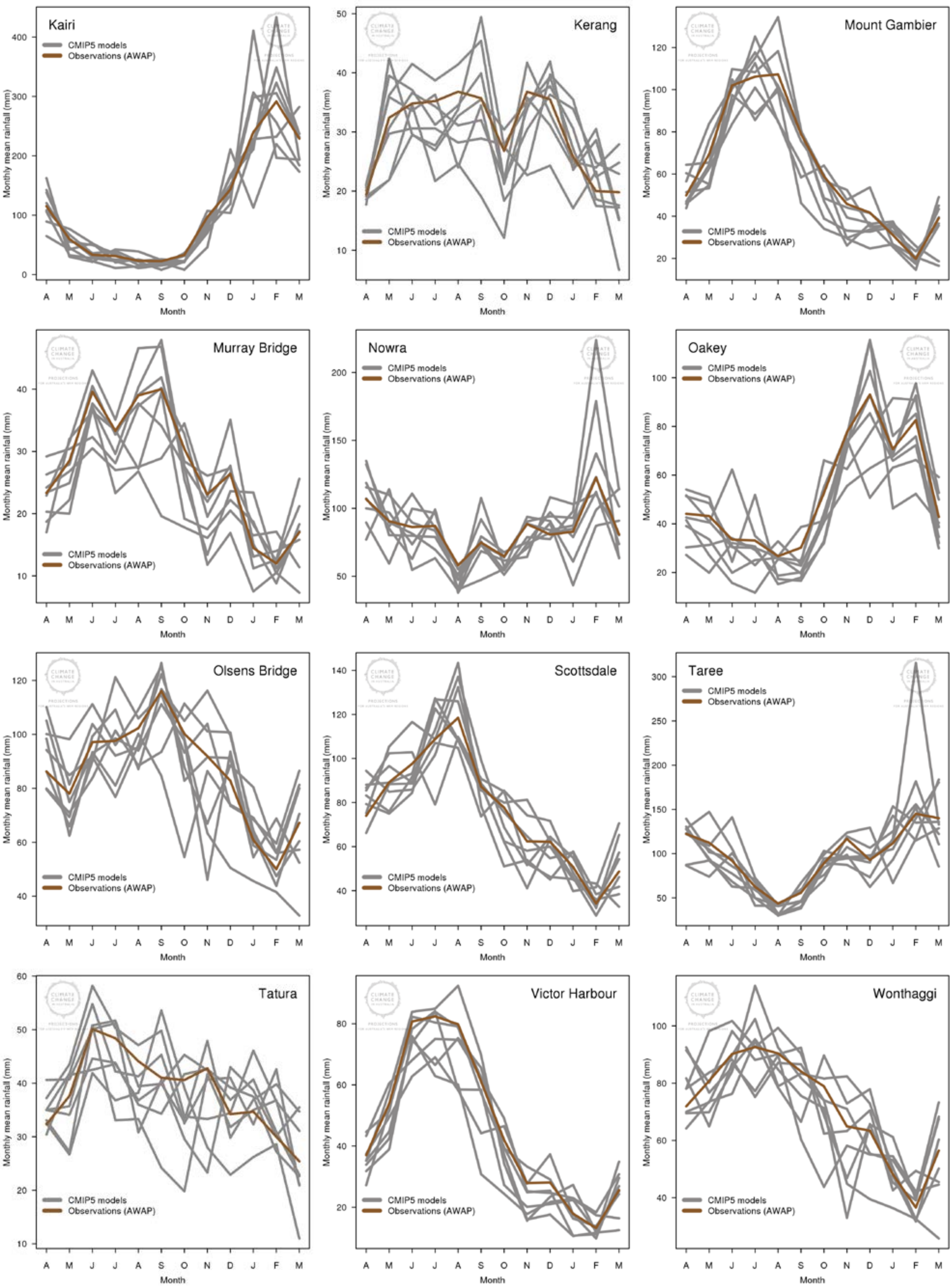

Figure A4: Observed (1985-2005; brown line) and projected (2030-2049, high emissions; grey lines) monthly-average rainfall for 12 sites in dairy regions. The projected rainfall is derived from eight CMIP5 climate models that span most of the range of possibilities from 40 CMIP5 climate models.

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