



Office of  
Environment  
& Heritage

AdaptNSW

# Hunter Climate change snapshot





# Overview of Hunter Region climate change

Based on long-term (1910–2011) observations, temperatures in the Hunter Region have been increasing since about 1960, with higher temperatures experienced in recent decades.

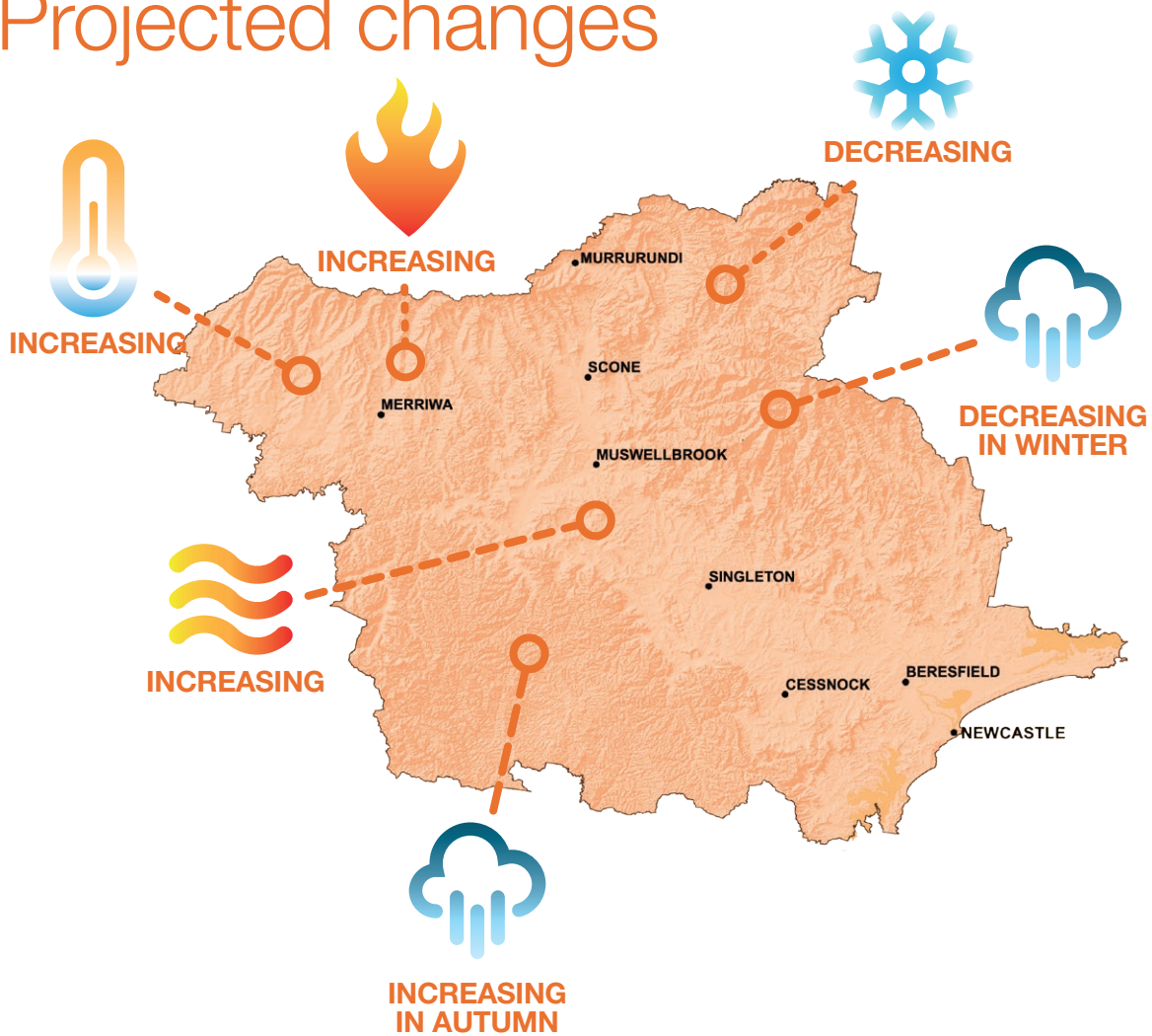
The region is projected to continue to warm during the near future (2020–2039) and far future (2060–2079), compared to recent years (1990–2009). The warming is projected to be on average about 0.7°C in the near future, increasing to about 2°C in the far future. The number of high temperature days is projected to increase in parts of the region, with fewer potential frost risk nights anticipated.

The warming trend projected for the region is large compared to natural variability in temperature and is of a similar order to the rate of warming projected for other regions of NSW.

The Hunter Valley currently experiences considerable rainfall variability across the region, seasons and from year-to-year and this variability is also reflected in the projections. However most models agree that autumn rainfall will increase.

Front Cover: Old building and vineyard in the Hunter Valley. Copyright: Neale Cousland. Page 2: View of Hunter Valley vineyards, NSW, Australia. Copyright: Andrey Bayda. Page 4: Group of Australian kangaroos at Hunter Valley, Australia. Copyright: Andrey Bayda. Page 9: Barrington Tops Thunderbolt lookout view of mountain valley in Blue Mountains with eucalyptus forest under cloudy sky. Copyright: Taras Vyshnya.

# Projected changes



## Projected temperature changes

Maximum temperatures are projected to **increase** in the near future by 0.4–1.0°C

Maximum temperatures are projected to **increase** in the far future by 1.6–2.6°C

Minimum temperatures are projected to **increase** in the near future by 0.5–0.9°C

Minimum temperatures are projected to **increase** in the far future by 1.5–2.5°C

The number of hot days will **increase**

The number of cold nights will **decrease**

## Projected rainfall changes

Rainfall is projected to **decrease** in spring and winter

Rainfall is projected to **increase** in autumn

## Projected Forest Fire Danger Index (FFDI) changes

Average fire weather is projected to **increase** in summer, spring and winter

Severe fire weather is projected to **increase** in summer and spring



# Regional snapshots

## NSW and ACT Regional Climate Modelling project (NARClIM)

The climate change projections in this snapshot are from the NSW and ACT Regional Climate Modelling (NARClIM) project. NARClIM is a multi-agency research partnership between the NSW and ACT governments and the Climate Change Research Centre at the University of NSW. NSW Government funding comes from the Office of Environment and Heritage (OEH), Sydney Catchment Authority, Sydney Water, Hunter Water, NSW Office of Water, Transport for NSW, and the Department of Primary Industries.

The NARClIM project has produced a suite of twelve regional climate projections for south-east Australia spanning the range of likely future changes in climate. NARClIM is explicitly designed to sample a large range of possible future climates.

Over 100 climate variables, including temperature, rainfall and wind are available at fine resolution (10km and hourly intervals). The data can be used in impacts and adaptation research, and by local decision makers. The data is also available to the public and will help to better understand possible changes in NSW climate.

## Modelling overview

The NARClIM modelling was mainly undertaken and supervised at the Climate Change Research Centre. NARClIM takes global climate model outputs and downscales these to provide finer, higher resolution climate projections for a range of meteorological variables. The NARClIM project design and the process for choosing climate models has been peer-reviewed and published in the international scientific literature (Evans et. al. 2014, Evans et. al. 2013, Evans et. al. 2012).

Go to [climatechange.environment.nsw.gov.au](http://climatechange.environment.nsw.gov.au) for more information on the modelling project and methods.

Interpreting climate projections can be challenging due to the complexities of our climate systems. 'Model agreement', that is the number of models that agree on the direction of change (for example increasing or decreasing rainfall) is used to determine the confidence in the projected changes. The more models that agree, the greater the confidence in the direction of change.

In this report care should be taken when interpreting changes in rainfall that are presented as the average of all of the climate change projections, especially when the model outputs show changes of both wetting and drying. To understand the spread of potential changes in rainfall the bar charts should be considered along with the maps provided in this document. Help on how to interpret the maps and graphs in this report is provided in Appendix 1.

Summary documents for each of the state planning regions of NSW are available and provide climate change information specific to each region.

The snapshots provide descriptions of climate change projections for two future 20-year time periods: 2020–2039 and 2060–2079.

1. The climate projections for 2020–2039 are described in the snapshots as **NEAR FUTURE, or as 2030**, the latter representing the average for the 20-year period.
2. The climate projections for 2060–2079 are described in the snapshots as **FAR FUTURE, or as 2070**, the latter representing the average of the 20-year period.

Further information about the regions will be released in 2015.

# Introduction

This snapshot presents climate change projections for the Hunter region of NSW. It outlines some key characteristics of the region, including its current climate, before detailing the projected changes to the region's climate in the near and far future.

## Location and topography

Famous for its world-class vineyards and wines, the Hunter Region covers an area of 26,100 km<sup>2</sup> with the Hunter River a dominant feature. The region extends from west of Murrurundi and Merriwa to Newcastle on the NSW east coast.

The Hunter River catchment is 21,500 km<sup>2</sup> in extent, with the Hunter River flowing 460 km from its headwaters in Barrington Tops to the Tasman Sea at Newcastle. Some of the more significant natural areas include Barrington Tops, the Wollemi–Yengo region, the Tomago Sands and the Ramsar-listed Hunter Estuary Wetlands.

## Population and settlements

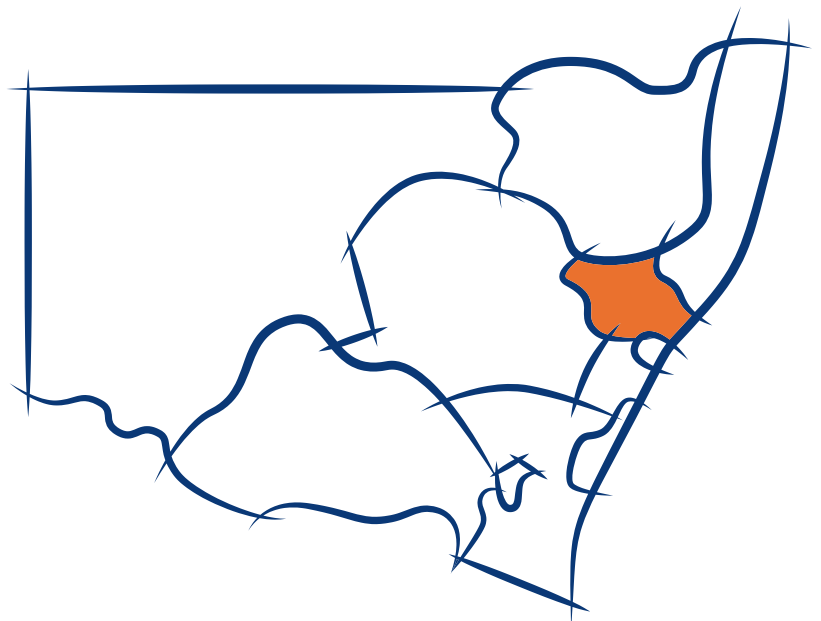
The population of the Hunter Region is approximately 604,600, with the largest cities in the region including Newcastle, Maitland, Lake Macquarie and Cessnock in the lower Hunter, and Singleton, Muswellbrook and Scone in the upper Hunter. The majority of the population lives near the coast or near the Hunter River.

With about 261,500 people employed in the region, the largest employers by sector include hospitality, retail and professional and scientific services. Coal mining is also a significant industry, with the export of coal representing 90 per cent of all shipping tonnage leaving Newcastle Port, making it one of the largest coal terminals in the world. By 2031, the population of the Hunter region is projected to reach about 734,850.

## Natural ecosystems

The region is a convergence zone for ecosystems that are characteristic of the north coast, western slopes and Sydney Basin. Large areas of the coast, escarpment and sandstone plateau are protected in the Barrington Tops, Yengo, Wollemi and other national parks. Extensive areas on the lowlands have been cleared and much of the remaining vegetation in these areas is fragmented.

The region contains several estuaries and large lake systems including Port Stephens and Lake Macquarie. The Hunter Estuary Wetlands (Kooragang Nature Reserve and Shortland Wetlands) are of international significance (Ramsar site) and Barrington Tops National Park forms part of the Gondwana Rainforests of Australia's World Heritage Areas.



# Climate of the region

The climate of the Hunter region is subtropical to temperate, with annual rainfall across the region averaging about 870 mm. Rainfall varies as you move from the coast inland, ranging from more than 1100 mm per year on the coast and on the Barrington Tops, down to less than 600 mm per year in parts of the upper Hunter. Rainfall is greatest in summer and autumn, with a higher proportion of winter rainfall on the coast than inland. It is mild to warm in summer throughout much of the region, however winters are cool in more elevated parts of the region and as you move inland. Milder conditions occur along the coast, which typically experiences the warmest average winter temperatures and lower summer maximum temperatures in the region.

## Temperature

The upper Hunter experiences distinct seasonal variations in temperature, with temperatures varying less in the lower Hunter closer to the coast. In summer, average temperatures range from 22–24°C throughout much of the region, with cooler temperatures (16–22°C) in the Barrington Tops. In winter, average temperatures range from 12–14°C along the coast to 4–8°C in the Barrington Tops and along the Liverpool Range.

In summer the highest average maximum temperatures (30–32°C) occur in the upper Hunter valley, with cooler conditions along the coast and in the Barrington Tops and Liverpool Ranges. In winter, the lowest average minimum temperatures range from 0–2°C on the Barrington Tops and along the Liverpool Range to 8–10°C near the coast.

Figure 1 shows seasonal variations in average, minimum and maximum monthly temperatures, averaged across the entire region.

Long-term records indicate a gradual increase in temperatures in the Hunter since the 1960s. More sustained warming has occurred over the most recent decades.

## Temperature extremes

Temperature extremes, both hot and cold, occur infrequently but can have considerable impacts on health, infrastructure and our environment. Changes to temperature extremes often result in greater impacts than changes to average temperatures.

## Hot days

Much of the Hunter Valley experiences 10–20 days each year with a maximum temperature greater than 35°C. Along the Liverpool Range, in the Barrington Tops and near the coast there are fewer hot days per year.

## Cold nights

The number of cold nights per year (minimum temperatures below 2°C) ranges from only a few near the coast to over 50 nights per year along the Liverpool Range and on the Barrington Tops.

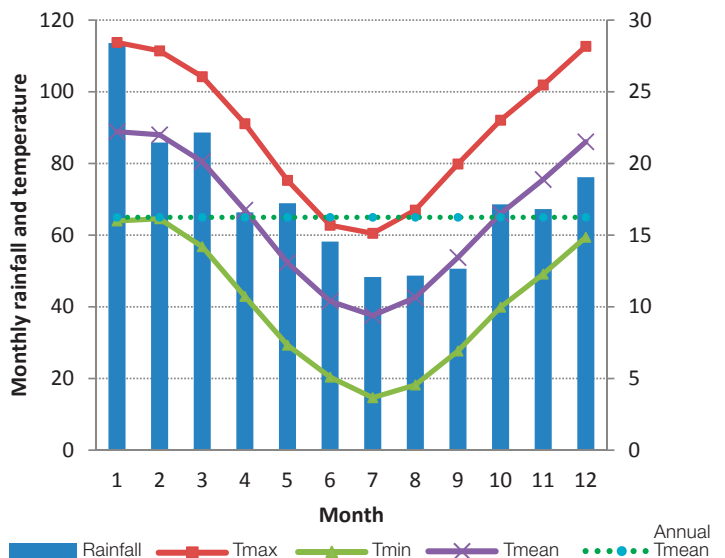
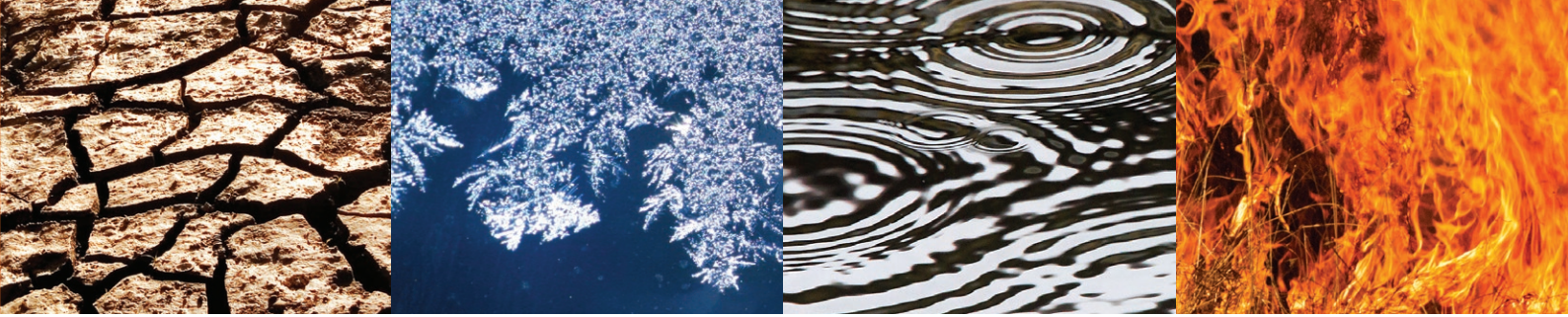


Figure 1: Seasonal rainfall and temperature variations (AWAP<sup>1</sup> data for 1960–1991).

1. Australian Water Availability Project, see [www.csiro.au/awap/](http://www.csiro.au/awap/).



## Rainfall

Rainfall varies considerably across the Hunter. This variability is due to the complex interactions between weather patterns in the region, the influence of larger-scale climate patterns such as El Niño Southern Oscillation, the topography of the valley, including the Liverpool Range and the Barrington Tops and the influence of sea surface temperature near the coast.

Rainfall generally decreases with distance from the coast, with average annual rainfall ranging from 800–1600 mm along the coast to 400–800 mm in the upper Hunter. More rainfall occurs during summer and autumn, with lower rainfall in winter and spring. Average monthly rainfall for the region as a whole shows more rainfall in the warmer months (Figure 1).

The long term rainfall record (1900-2013) shows that the Hunter has experienced considerable variation in rainfall with periods of both wetter and drier conditions. During much of the first half of the 20<sup>th</sup> century the region experienced drier conditions. From the 1950s to the 1990s there was more inter-annual variability with many wet years and many dry years. The first decade of the 21<sup>st</sup> century saw a long period of below average rainfall during the Millennium Drought. This dry period ended with two of the wettest years on record for Australia (2010-2011), with 2010 being the third wettest year on record for NSW

## Fire weather

The risk of bushfire in any given region depends on four ‘switches’. There needs to be enough vegetation (fuel), the fuel needs to be dry enough to burn, the weather needs to be favourable for fire to spread, and there needs to be an ignition source (Bradstock 2010). All four of these switches must be on for a fire to occur. The Forest Fire Danger Index (FFDI) is used in NSW to quantify fire weather. The FFDI combines observations of temperature, humidity and wind speed with an estimate of the fuel state.

Long-term observations of FFDI come from daily measurements of temperature, rainfall, humidity and wind speed at only a small number of weather stations in Australia, with 17 stations located in NSW and the ACT (Lucas 2010).

Long-term FFDI estimates are available for one station in the Hunter, Williamtown near the coast north of Newcastle. The average annual FFDI estimated for Williamtown for the period 1990–2009 is 5.4. The highest average FFDI occurs in spring and summer, and the lowest in autumn and winter.

Fire weather is classified as ‘severe’ when the FFDI is above 50, and most of the property loss from major fires in Australia has occurred when the FFDI reached this level (Blanchi et al. 2010). FFDI values below 12 indicate low to moderate fire weather, 12-25 high, 25-49 very high, 50-74 severe, 75-99 extreme and above 100 catastrophic.

Severe fire weather conditions are estimated to occur one day per year on average at Williamtown, and are more likely to occur in summer and spring.

Mean FFDI					
Station	Annual	Summer	Autumn	Winter	Spring
Williamtown	5.4	6.7	3.4	4.1	7.4
Number of severe fire weather days (FFDI>50)					
Williamtown	1.4	0.7	0	0	0.7

Table 1: Baseline FFDI values for meteorological stations within the Hunter Region.

# Temperature

Climate change projections are presented for the near future (2030) and far future (2070), compared to the baseline climate (1990–2009). The projections are based on simulations from a suite of twelve climate models run to provide detailed future climate information for NSW and the ACT.

Temperature is the most reliable indicator of climate change. Across the Hunter Region all of the models agree that average, minimum and maximum temperatures are all increasing.

## Summary temperature

Maximum temperatures are projected to increase in the near future by 0.7°C

Maximum temperatures are projected to increase in the far future by 2.0°C

Minimum temperatures are projected to increase by near future by 0.7°C

Minimum temperatures are projected to increase by far future by 2.1°C

There are projected to be more hot days and fewer cold nights

## Projected regional climate changes

The Hunter is expected to experience an **increase in all temperature variables** (average, maximum and minimum) for the near future and the far future (Figure 2).

Maximum temperatures are projected to increase by 0.7°C in the near future and by 2.0°C in the far future (Figure 2b). Summer and spring will experience the greatest changes in temperatures, with maximum temperatures increasing by 2.3°C by 2070 (Figure 2b). Increased maximum temperatures are known to impact human health through heat stress and increasing the numbers of heatwave events.

Minimum temperatures are projected to increase by 0.7°C in the near future and by 2.1°C in the far future (Figure 2c). Increased overnight temperatures (minimum temperatures) can have a considerable effect on human health.

These increases are projected to occur across the region, with a slightly greater increase in the upper Hunter (Figures 3–6).



The long-term temperature trend indicates that temperatures in the Hunter Valley have been increasing since approximately 1960, with the largest increase in temperature in the most recent decades.

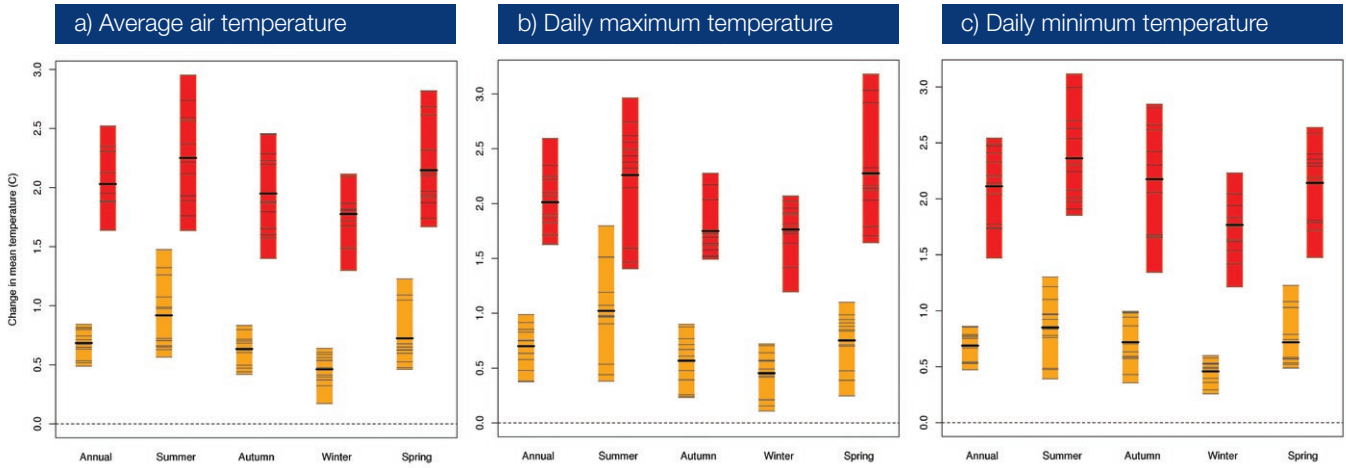


Figure 2: Projected air temperature changes for the Hunter Region, annually and by season (2030 yellow; 2070 red): a) average, b) daily maximum, and c) daily minimum. (Appendix 1 provides help with how to read and interpret these graphs).

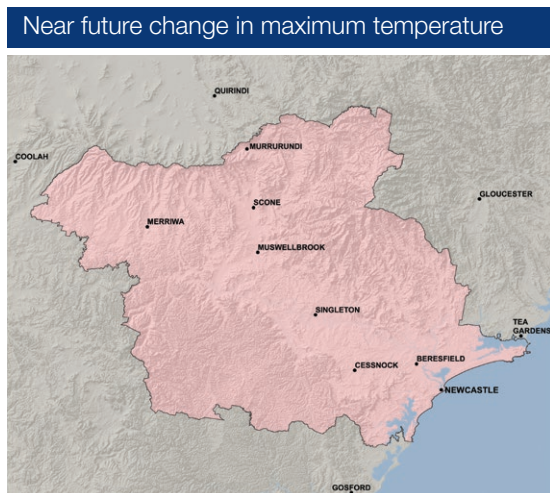


Figure 3: Near future (2020–2039) change in annual mean maximum temperature, compared to the baseline period (1990–2009).

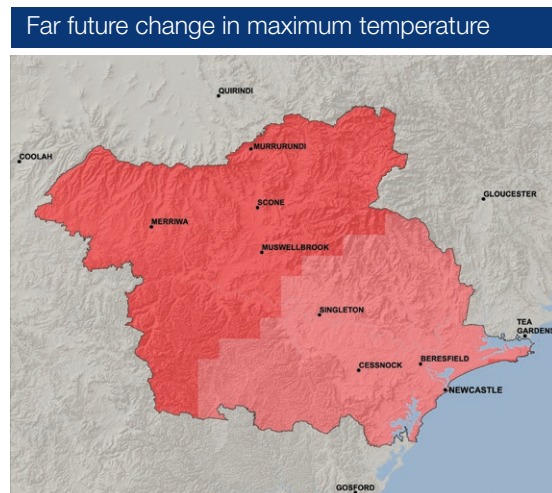


Figure 4: Far future (2060–2079) change in annual mean maximum temperature, compared to the baseline period (1990–2009).

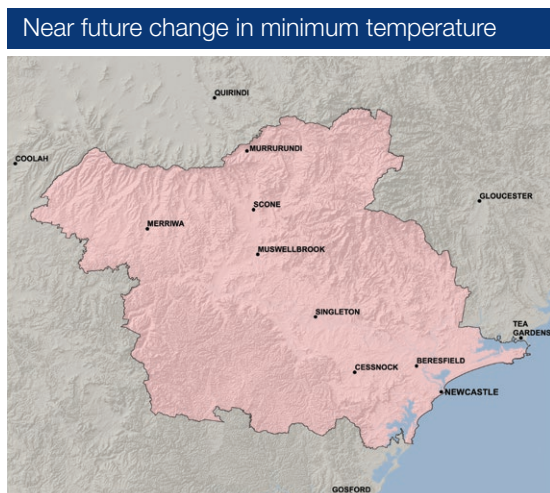


Figure 5: Near future (2020–2039) change in annual mean minimum temperature, compared to the baseline period (1990–2009).

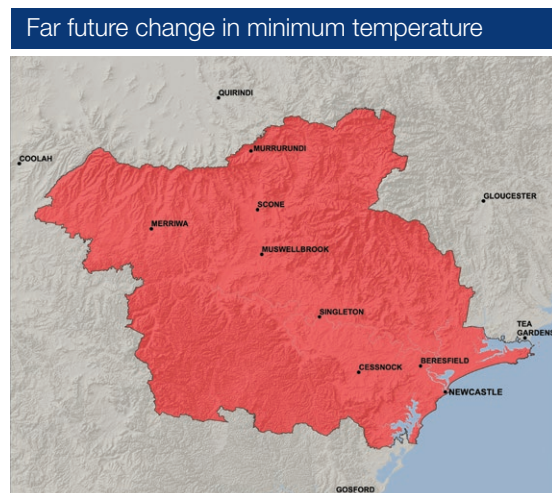
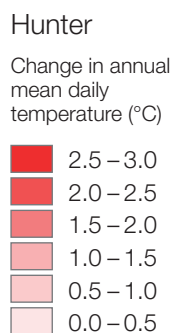


Figure 6: Far future (2060–2079) change in annual mean minimum temperature, compared to the baseline period (1990–2009).



# Hot days

## DAYS PER YEAR ABOVE 35°C

Currently the Hunter Region experiences an average of 10–20 days above 35°C each year, although areas near Muswellbrook and Denman within the upper Hunter valley have recorded 20–30 hot days per year. International and Australian experiences show that prolonged hot days increase the incidence of illness and death – particularly among vulnerable population groups such as people who are older, have a pre-existing medical condition or who have a disability. Seasonal changes are likely to have considerable impacts on bushfire danger, infrastructure development and native species diversity.

### Projected regional climate changes

**The Hunter is expected to experience more hot days in the near future and the far future (Figure 7).**

**The greatest increase in hot days is projected for the upper Hunter with an additional 5–10 days in the near future (Figure 8) and over 20 additional hot days by 2070 (Figure 9).**

**Averaging across the region as a whole there are projected to be an additional five hot days in the near future (ranging from 0–7 days across the 12 models) and 14 more hot days in the far future (5–19 days across the 12 models) (Figure 7).**

**These increases are projected to occur mainly in spring and summer, although in the far future a small increase in the number of hot days is also projected to extend into autumn (Figure 7).**

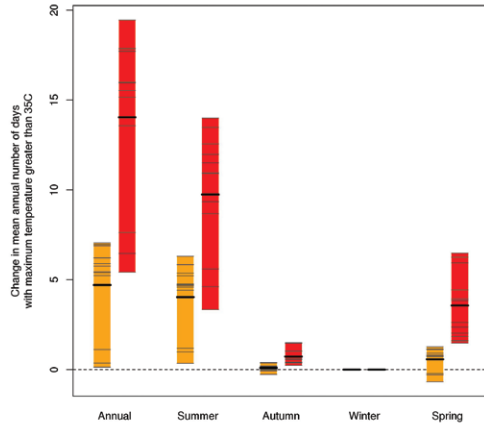


Figure 7: Projected changes in the number of hot days (with daily maximum temperature of above 35°C) for the Hunter Region, annually and by season (2030 yellow; 2070 red). (Appendix 1 provides help with how to read and interpret these graphs).

### Near future change in days per year above 35°C

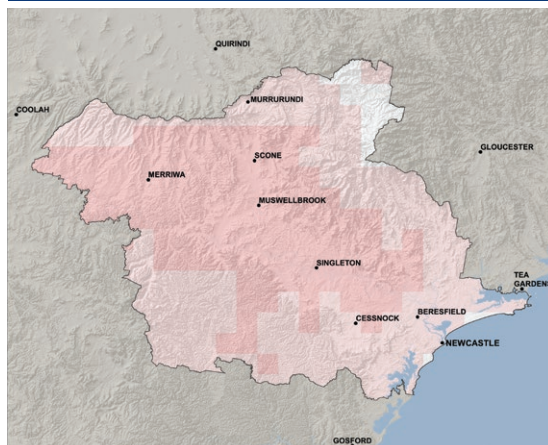


Figure 8: Near future (2020–2039) projected changes in the number of days per year with maximum temperatures above 35°C.

### Far future change in days per year above 35°C

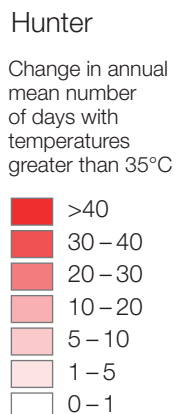
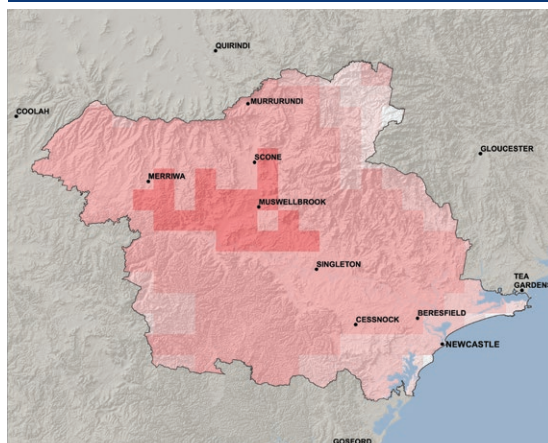


Figure 9: Far future (2060–2079) projected changes in the number of days per year with maximum temperatures above 35°C.

# Cold nights

## DAYS PER YEAR BELOW 2°C

Most of the emphasis on changes in temperatures from climate change has been on hot days and maximum temperatures, but changes in cold nights are equally important in the maintenance of our natural ecosystems and agricultural/horticultural industries; for example, some common temperate fruit species require sufficiently cold winters to produce flower buds.

### Projected regional climate changes

All models agree that the Hunter is expected to experience fewer cold nights in the near future and the far future (Figure 10).

The greatest decreases are projected to occur in the upper Hunter where there could be a decrease of 30–40 cold nights per year by 2070 along the Liverpool Range and the Barrington Tops. There are no projected changes for the coastal areas where there are already very few cold nights (Figures 11 and 12).

Averaging across the region as a whole, there are projected to be approximately six fewer cold nights per year by 2030 (ranging from 4–8 nights across the individual models). The decrease in cold nights is projected to be even greater by 2070, with an average decrease of 15 nights per year (ranging from 12–19 nights across the models) (Figure 10).

A decrease in the number of cold nights is projected for all seasons, dominated by decreases winter and spring (Figure 10).

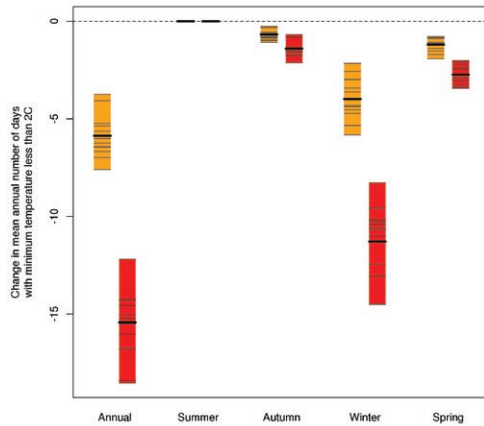


Figure 10: Projected changes in the number of low temperature nights for the Hunter Region, annually and by season (2030 yellow; 2070 red). (Appendix 1 provides help with how to read and interpret these graphs).

### Near future change in number of cold nights (below 2°C) per year

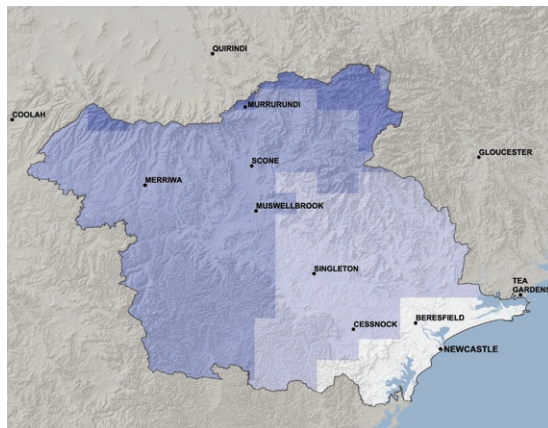


Figure 11: Near future (2020–2039) change in the number of days per year with minimum temperatures below 2°C, compared to the baseline period (1990–2009).

### Far future change in number of cold nights (below 2°C) per year

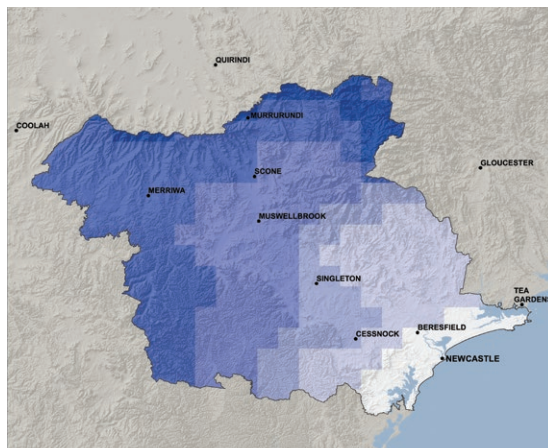
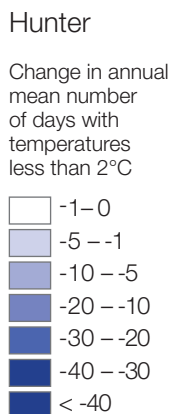


Figure 12: Far future (2060–2079) change in the number of days per year with minimum temperatures below 2°C, compared to the baseline period (1990–2009).



# Rainfall

Changes in rainfall patterns have the potential for widespread impacts. Seasonal shifts in rainfall can impact native species' reproductive cycles as well as impacting agricultural productivity; for example crops that are reliant on winter rains for peak growth.

Rainfall changes are also associated with changes in the extremes, such as floods and droughts, as well as secondary impacts such as water quality and soil erosion that occur as a result of changes to rainfall intensity.

Modelling rainfall is challenging due to the complexities of the weather systems that generate rain. 'Model agreement', that is the number of models that agree on the direction of change (increasing or decreasing rainfall) is used to determine the confidence in the projected change. The more models that agree, the greater the confidence in the direction of change.

Care should be taken when interpreting changes in rainfall from averaging climate change projections when the model outputs project changes of both wetting and drying. To understand the spread of potential changes in rainfall the bar charts should be considered along with the maps provided in this document.

## Rainfall is projected to decrease in spring and winter and to increase in autumn

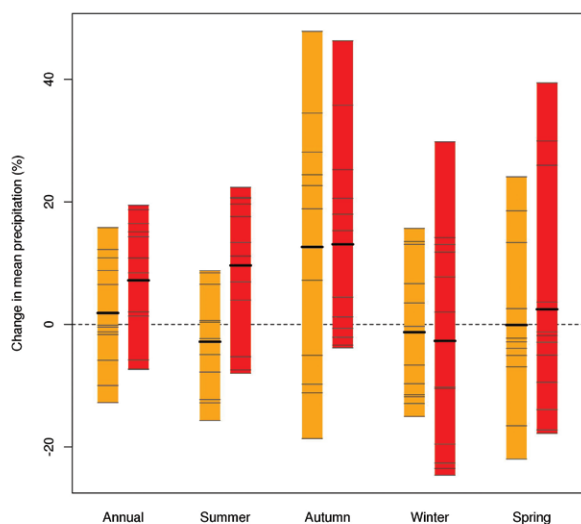


Figure 13: Projected changes in average rainfall for the Hunter Region, annually and by season (2030 yellow; 2070 red). (Appendix 1 provides help with how to read and interpret these graphs).

## Projected regional climate changes

In the Hunter the majority of models (8 out of 12) agree that **autumn rainfall will increase in the near future and far future (Figure 13, 14 and 15).**

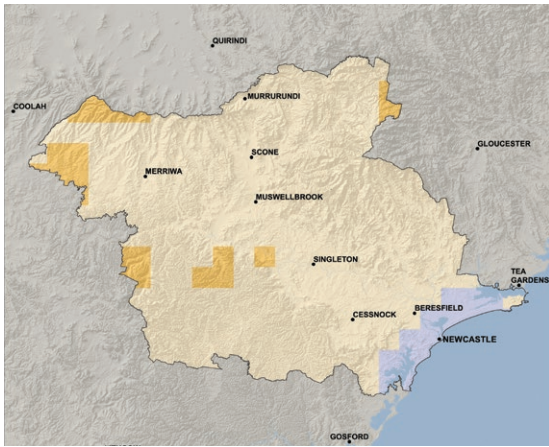
The majority of models (8 out of 12) also agree that **spring rainfall will decrease in the near future (Figure 13, 14 and 15).**

During winter seven out of 12 models project a decrease in rainfall in the near future but projections for the far future are less clear (Figure 13, 14 and 15).

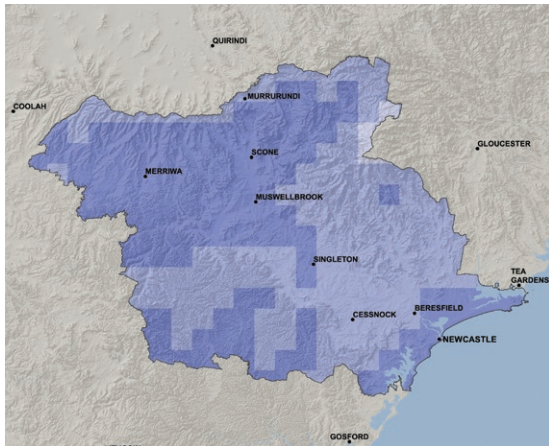
Seasonal rainfall projections for the near future and far future span both drying and wetting scenarios. In the near future the range of changes are: summer -16% to +9%, autumn -19% to +48%, winter -15% to +16%, and spring -22% to 24%; in the far future the range of projected changes are: summer -8% to +22%, autumn -4% to +46%, winter -25% to +30%, and spring -18% to +39% (Figure 13).

Projections for the region's annual average rainfall range from a decrease (drying) of 13% to an increase (wetting) of 16% by 2030 and still span both drying and wetting scenarios (-7% to +19%) by 2070.

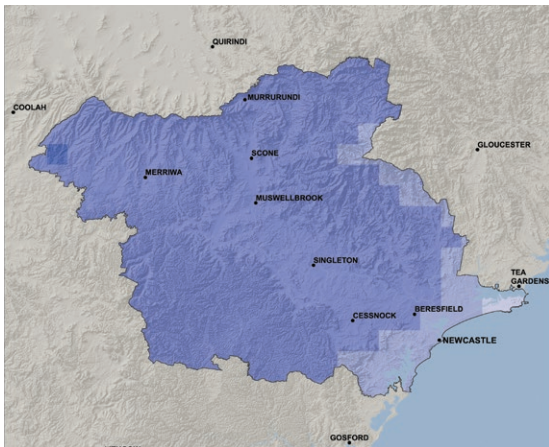
Summer 2020–2039



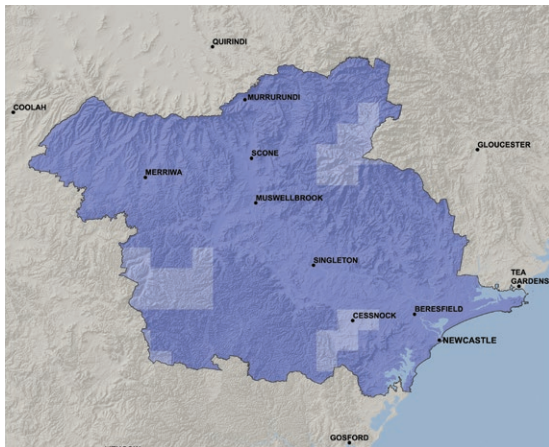
Summer 2060–2079



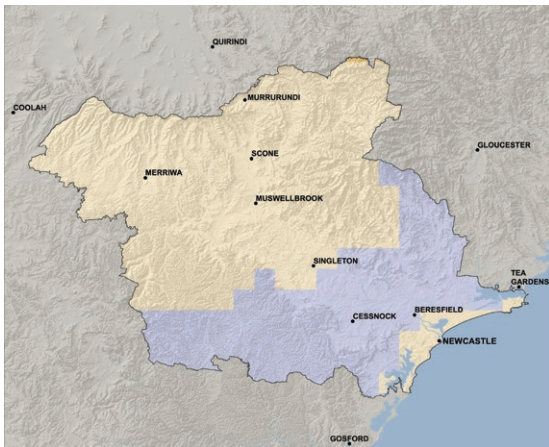
Autumn 2020–2039



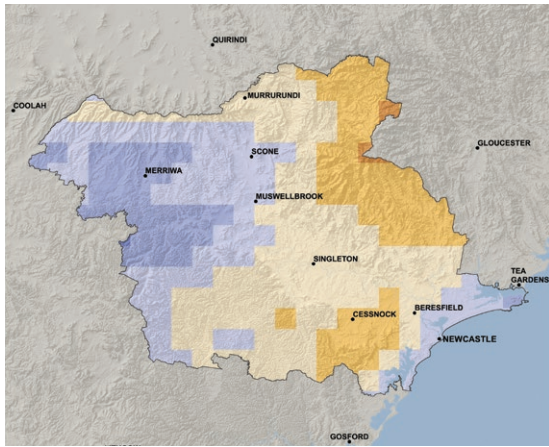
Autumn 2060–2079



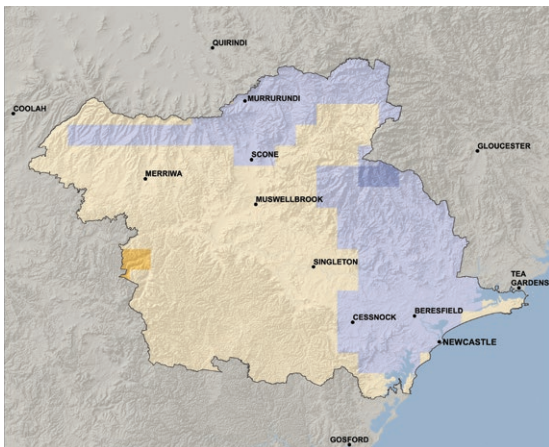
Winter 2020–2039



Winter 2060–2079



Spring 2020–2039



Spring 2060–2079

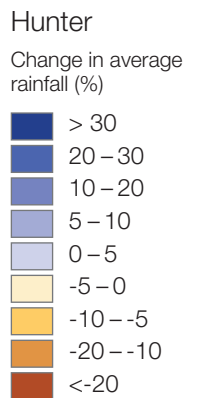
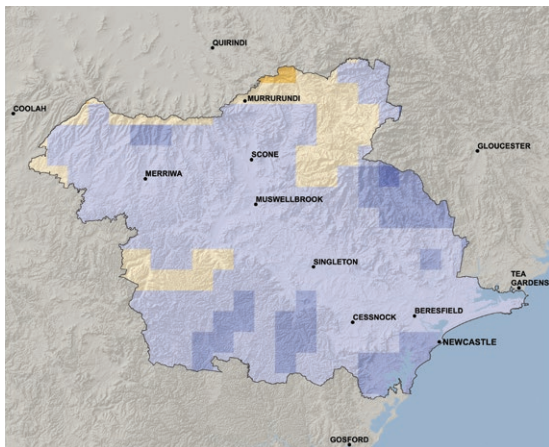


Figure 14: Near future (2020–2039) projected changes in average rainfall by season.

Figure 15: Far future (2060–2079) projected changes in average rainfall by season.

# Fire weather

The Bureau of Meteorology issues Fire Weather Warnings when the FFDI is forecast to be over 50. High FFDI values are also considered by the Rural Fire Service when declaring a Total Fire Ban.

Average FFDI values are often used to track the status of fire risk. These values can be used when planning for prescribed burns and help fire agencies to better understand the seasonal fire risk. The FFDI is also considered an indication of the consequences of a fire if one was to start – the higher the FFDI value the more dangerous the fire could be.

FFDI values below 12 indicate low to moderate fire weather, 12-25 high, 25-49 very high, 50-74 severe, 75-99 extreme and above 100 catastrophic.

**Severe and average fire weather is projected to increase in summer and spring**

**Severe fire weather is projected to decrease in autumn**

## Projected regional climate changes

**The Hunter Region is projected to experience an increase in average and severe fire weather in the near future and the far future (Figures 16 and 17).**

**Increases in severe fire weather are projected in summer and spring. Although these changes are relatively small in magnitude (up to two more days per year on average) they are projected in prescribed burning periods (spring) and the peak fire risk season (summer) (Figure 19).**

Average fire weather risk is projected to increase in all seasons in the far future except for autumn (figure 18). The increases are in prescribed burning periods (spring) and the peak fire risk (summer), reducing the ability for preventative works.

Autumn is projected to have a decrease in severe fire weather along parts of the Liverpool Range and the Barrington Tops. As fire weather measurements take into account rainfall, it is likely that the decrease in autumn FFDI is due to projected increases in autumn rainfall across the region (compare Figures 14 and 15 with Figures 18 and 19).

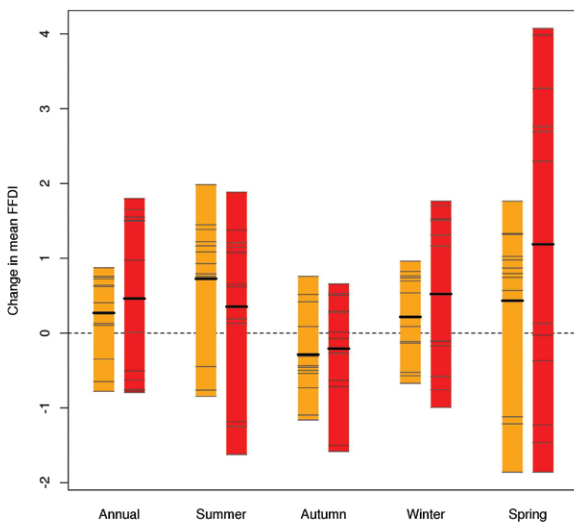


Figure 16: Projected changes in the average daily forest fire danger index (FFDI) for the Hunter Region, annually and by season (2030 yellow; 2070 red). (Appendix 1 provides help with how to read and interpret these graphs).

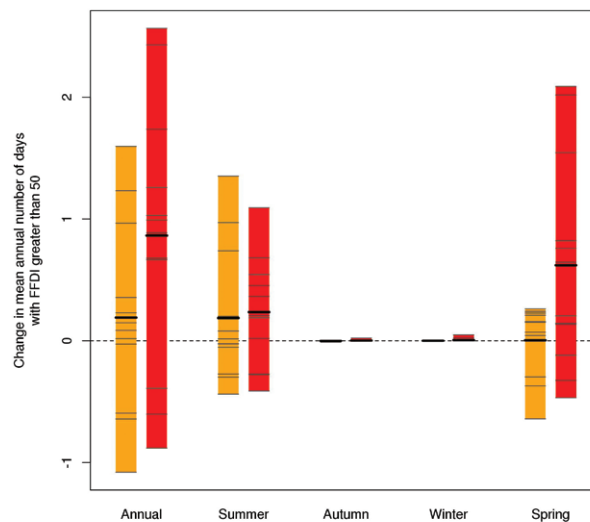


Figure 17: Projected changes in average annual number of days with a forest fire danger index (FFDI) greater than 50 for the Hunter Region, annually and by season (2030 yellow; 2070 red). (Appendix 1 provides help with how to read and interpret these graphs).

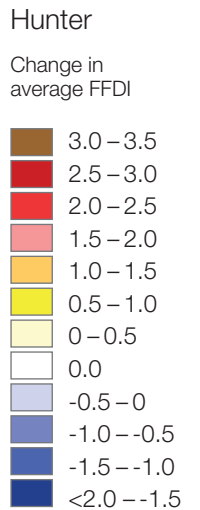
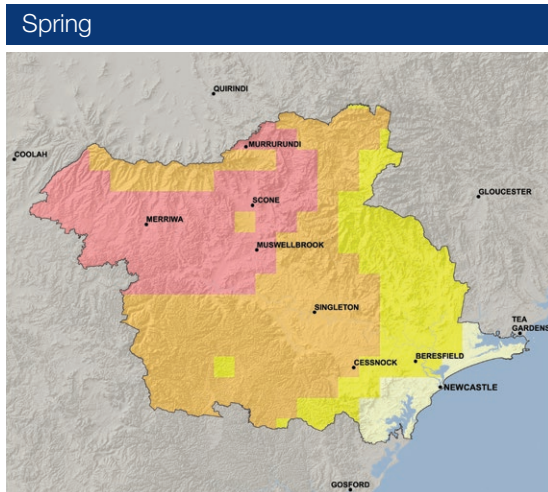
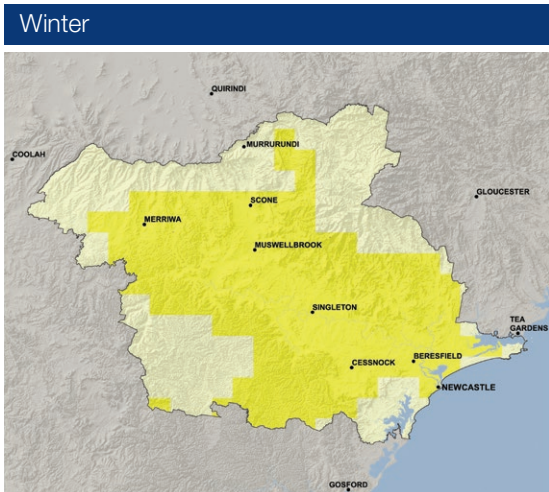
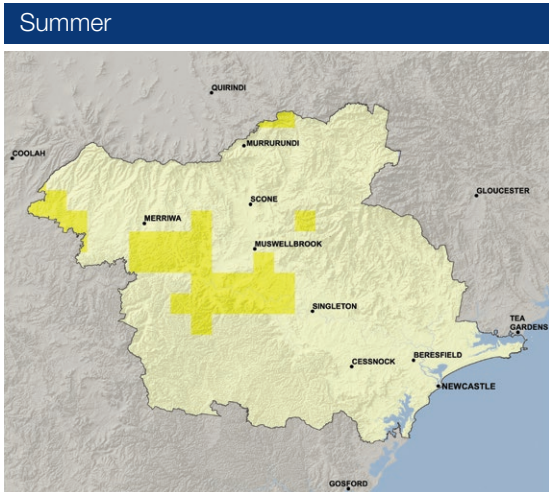


Figure 18: Far future (2060–2079) projected changes in average daily FFDI, compared to the baseline period (1990–2009)

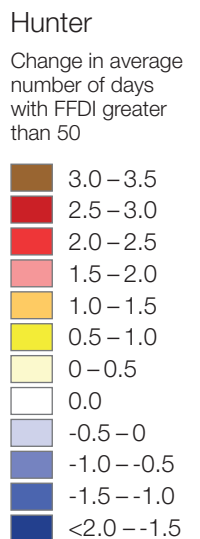
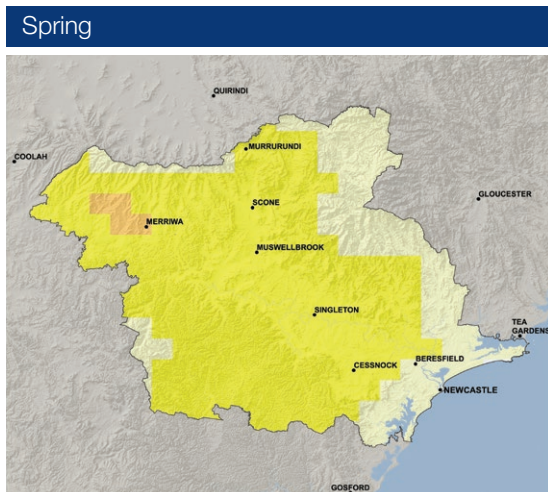
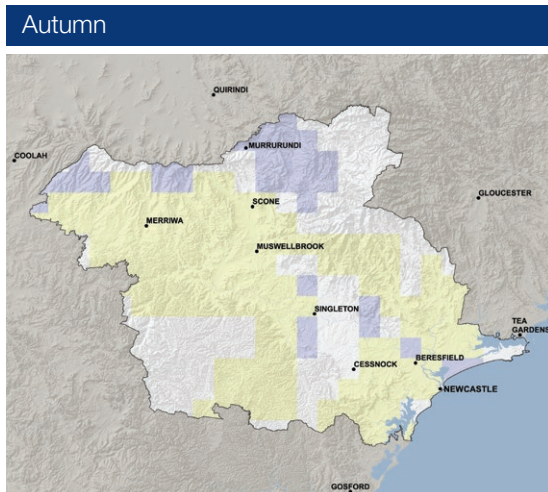


Figure 19: Far future (2060–2079) projected changes in average annual number of days with a FFDI greater than 50, compared to the baseline period (1990–2009)

## Appendix 1 Guide to reading the maps and graphs

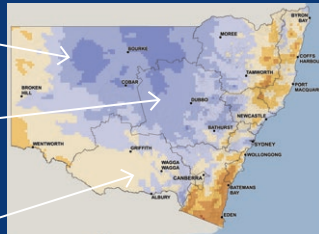
This document contains maps and bar graphs of the climate change projections. The maps present the results of the twelve models as an average of all twelve models. The bar graphs show projections averaged across the entire state and do not represent any particular location within the state. The bar graphs also show results from each individual model. See below for more information on what is displayed in the maps and bar graphs..

### How to read the maps

The maps display a **10km grid**.

NSW has been divided into State Planning Regions and each region has a Local Snapshot report.

The colour of each grid is the average of all **12 models** outputs for that grid.



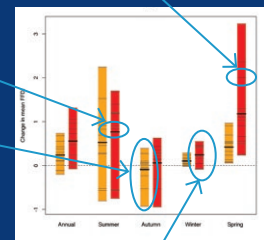
### How to read the bar graphs

The thin grey lines are the **individual models**. There are 12 thin lines for each bar.

The thick line is the **average of all 12 models** for the region.

The length of the bar shows the **spread of the 12 model values** for the region

Each line is the **average for the region**. They do not represent a single location in the region.



Note: The yellow bars represent near future scenarios (2020–2039), while the red bars represent far future scenarios (2060–2079).

## References

Blanchi, R, Lucas, C, Leonard, F and Finkele, K (2010), 'Meteorological conditions and wildfire-related house loss in Australia', *International Journal of Wildland Fire*, vol. 19, pp. 914–926.

Bradstock, R (2010), 'A biogeographic model of fire regimes in Australia: current and future implications', *Global Ecology and Biogeography*, vol. 19, pp. 145–158.

Department of Planning & Environment (2014), *NSW Statewide Profile 2014*, NSW Department of Planning & Environment, Sydney, available at [www.planning.nsw.gov.au/Portals/0/PlanningYourRegion/2014\\_NSW\\_StatewideProfile.pdf](http://www.planning.nsw.gov.au/Portals/0/PlanningYourRegion/2014_NSW_StatewideProfile.pdf).

Evans, J. P., Ji, F., Lee, C., Smith, P., Argüeso, D., and Fita, L. (2014) A regional climate modelling projection ensemble experiment – NARCLIM, *Geoscientific Model Development*, 7(2), 621-629, doi: 10.5194/gmd-7-621-2014.

Evans, J.P., F. Ji, G. Abramowitz and M. Ekström (2013) Optimally choosing small ensemble members to produce robust climate simulations. *Environmental Research Letters* 8, 044050, DOI: 10.1088/1748-9326/8/4/044050.

Evans, J. P., M. Ekström, and F. Ji (2012) Evaluating the performance of a WRF physics ensemble over South-East Australia. *Climate Dynamics*, 39(6), 1241-1258, DOI: 10.1007/s00382-011-1244-5.

**Disclaimer:** OEH has prepared this report in good faith, exercising all due care and attention, but no representation or warranty, express or implied, is made as to the relevance, accuracy, completeness or fitness for purpose of this information in respect of any particular user's circumstances. With respect to the content of this report, it should also be noted that some projections currently involve a considerable degree of uncertainty.

This material may be reproduced for educational or non-commercial purposes, in whole or in part, provided the meaning is unchanged and the source is acknowledged. © Copyright State of NSW and the NSW Office of Environment and Heritage.

**Published by:**  
Office of Environment and Heritage  
59–61 Goulburn Street  
PO Box A290  
Sydney South 1232  
Report pollution and environmental incidents  
Environment Line: 131 555 (NSW only) or  
[info@environment.nsw.gov.au](mailto:info@environment.nsw.gov.au)  
See also [www.environment.nsw.gov.au](http://www.environment.nsw.gov.au)

Phone: (02) 9995 5000 (switchboard)  
Phone: 131 555 (environment information and publications requests)  
Phone: 1300 361 967 (national parks, climate change and energy efficiency information and publications requests)  
Fax: (02) 9995 5999  
TTY users: phone 133 677 then ask for 131 555  
Speak and Listen users: phone 1300 555 727 then ask for 131 555  
Email: [info@environment.nsw.gov.au](mailto:info@environment.nsw.gov.au)  
Website: [www.environment.nsw.gov.au](http://www.environment.nsw.gov.au)

OEH 2014/0828 – 978 1 74359 828 3  
ISSN 1837–5650

November 2014

Printed on environmentally sustainable paper