Office of Environment & Heritage

AdaptNSW

# Heatwaves
# Climate Change Impact Snapshot

# Overview of impacts on heatwaves in **NSW**

NSW has already experienced changes in heatwaves:

- Over the period 1911–2013, heatwaves in parts of NSW have become longer, hotter and occur more often.

Heatwaves in NSW are projected to continue to change:

- Considerable increases in heatwaves are projected in both the near (2020–2039) and far futures (2060–2079).
- In the near future heatwaves over much of NSW are projected to occur more often and to last longer.
- In the far future the changes in heatwaves are larger; across much of the state heatwaves are projected to occur more often, last longer and to become even hotter.
- There will also be more days above 40°C across most of NSW.

# Climate Change Impact Snapshot

## Climate Change Impact Research Program (CCIRP)

This impact report is part of the NSW Climate Change Impact Research Program (CCIRP). The CCIRP aims to understand the biophysical impacts of climate change in NSW using the climate change projections from the NSW and ACT Regional Climate Modelling (NARCliM) project. CCIRP is designed to ensure the research delivered meets the information needs of the NSW community. The CCIRP program is ongoing and will continue to provide updated information on the likely impacts of climate change in NSW.

## NSW and ACT Regional Climate Modelling Project (NARCliM)

The climate change projections in this impact 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 Department of Primary Industries.

The NARCliM project has produced a suite of 12 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. The NARCliM project used a "business as usual" scenario (IPCC A2 scenario) consistent with international modelling approaches. This scenario assumes global development and population continues along current trajectories.

Future climate change projections are compared to the baseline modelled climate (1990–2009). 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.

NARCliM has produced projections for:

1. The **near future** (2020-2039): these projections represent the best estimate of future climate by **2030**, even with significant global mitigation measures.
2. The **far future** (2060-2079): these projections are more sensitive to changes in global emissions but still represent the current best estimate of our future climate by **2070**.

Go to climatechange.environment.nsw.gov.au for more information on the modelling project, methods and technical reports.

## Impact Science Technical Reports

The Climate Change Impact Snapshot reports are based on detailed technical reports. The 'Heatwaves affecting NSW and the ACT: recent trends, future projections and associated impacts on human health-NARCliM Technical Report 5' details the results of the impact science research and can be accessed from the AdaptNSW website: climatechange.environment.nsw.gov.au

The snapshots provide descriptions of climate change projections for two future 20-year periods: near future or 2030, and far future or 2070 and represent the average of the two 20 year periods 2020-2039 and 2060-2079.

The maps in the snapshots represent an **average** of 12 models. The full range of variability is discussed in the technical report.

Help on how to interpret the maps and graphs in this report is provided in Appendix 1.

# Introduction to heatwaves

## What is a heatwave?

### A heatwave is when maximum and minimum temperatures remain unusually high for several days.

Heatwaves represent a significant hazard in Australia for both humans and the environment and have been responsible for more deaths than any other natural hazard, including bushfires, storms, tropical cyclones and floods (Nairn & Fawcett 2015). Human and natural systems have adapted to function best within an expected climate range. Heatwaves are events outside this range which can make systems more vulnerable to impacts.

Excessive heat can lead to hyperthermia, where the body produces or absorbs more heat than it dissipates (Kosaka et al. 2004). The two major types of hyperthermia are heat exhaustion and heat stroke. Symptoms of heat exhaustion include headaches, vomiting and dizziness. If unmanaged, heat exhaustion may progress rapidly to heat stroke, which can result in multiple organ failure and death. In January 2009 an exceptional and devastating heatwave caused 374 deaths in Victoria in three days (Alexander & Tebaldi 2012; Nairn & Fawcett 2015; Victorian DHS 2009).

Extreme heat can also change the probability of occurrence of other extreme events (such as bushfires). The Black Saturday bushfires in Victoria during February 2009 happened during the heatwave mentioned above. In addition to the deaths caused by the heatwave, 173 lives were lost as a direct result of the bushfires (Alexander & Tebaldi 2012; Nairn & Fawcett 2015).

Heatwaves also affect other living creatures. For example, in January 2002 extreme temperatures above 42°C caused the deaths of over 3500 flying foxes in NSW (Welbergen et al. 2008). Excess heat can also affect agriculture. For example, wheat, barley and canola yields were forecast to drop by 14%, 22% and 12% respectively as result of the extreme heat over winter and spring in 2014 (Voice 2015). Changes in extreme heat may affect production in the Murray–Darling Basin, where 40% of Australia's agricultural income is produced (ABS 2013).

As well as the direct and immediate impacts from excessive heat, heatwaves can also have flow-on effects, such as increases in the national health burden and insurance losses. It is estimated that extreme temperatures contribute to the deaths of over 1000 people aged over 65 each year across Australia (McMichael et al. 2003). Some estimates suggest that 85% of all deaths in Australia due to natural hazards since 1900 are related to extreme heat. In terms of insurance, the economic cost of a bushfire disaster such as the one associated with the 2009 heatwave is estimated to be US$1.3 billion (BMA 2014).

Despite the obvious importance of understanding heatwave characteristics there is currently no universally accepted definition of heatwave. In order to identify heatwaves, this snapshot uses the excess heat factor index derived by the Collaboration for Australian Weather and Climate Research (Nairn & Fawcett 2013) (See Appendix 1). This index is used by the Bureau of Meteorology to operationally define and monitor heatwaves, and has also been found to be a good predictor of the implications of heatwaves for health services (Scalley et al. 2015).

Once heatwaves are identified, a range of metrics are used to describe heatwaves based on their duration (at least three days), frequency (how often they occur) and their intensity (how hot they are). When discussing heatwave intensity, two measures are used, one referring to the average temperature across all heatwave events of the year (heatwave magnitude), another referring to the hottest day of the hottest heatwave of the year (heatwave amplitude). Heatwave frequency is described in terms of both the number of heatwave events each year (heatwave number) and the number of days in the year classed as heatwave days as a percentage of all days (heatwave frequency). Appendix 1 provides a more detailed description of the various metrics used to represent the nature of heatwaves, and further detailed discussion on the methods used is available in the Heatwave Technical Report at climatechange.environment.nsw.gov.au.

## Recent heatwave observations

For the period 1990–2009, the hottest heatwaves in NSW occurred in the south-west of the state, based on both the average temperature across all heatwave events (Figure 1a), and the magnitude of the hottest day across all heatwave events (Figure 1b). East of the Great Dividing Range and along the coast, heatwaves have relatively less extreme temperatures.

Because they are defined in relation to local conditions, there is not much variation in the average number of heatwaves experienced each year across the state: around two heatwaves, or about 10 to 15 days each year that are classed as heatwave days. In any given year, the longest heatwave in NSW lasts between five and eight days, with longer heatwaves occurring in central NSW and shorter ones along the central and south coasts (Figure 2a).

An alternative measure of extreme heat is the number of days per year with maximum temperatures over 40°C. The far north-west of the state records over 20 such days a year on average, compared to fewer than five for most of the eastern half of NSW (Figure 2b).

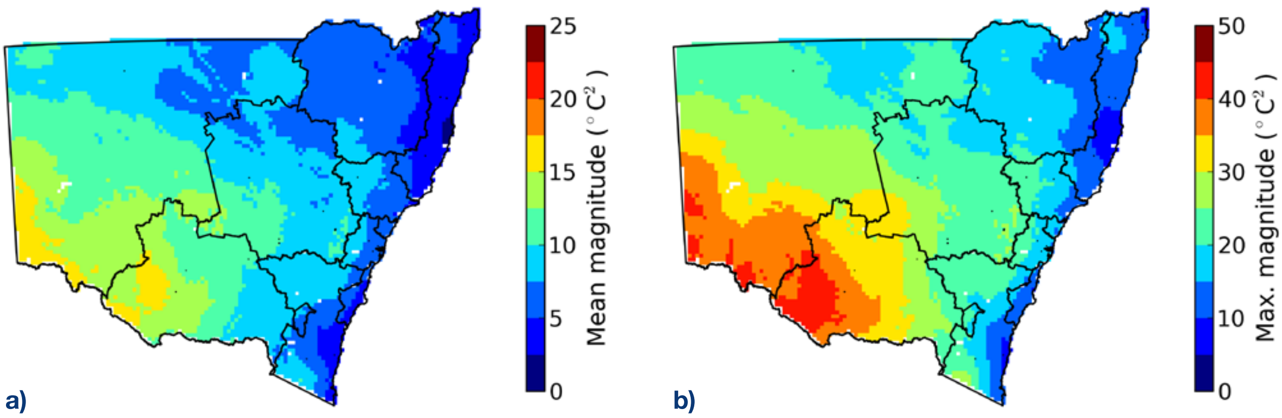



Figure 1: Heatwave events across NSW, 1990–2009; a) mean magnitude (°C2) across all heatwave events (heatwave magnitude), b) magnitude (°C2) of hottest day across all heatwave events (heatwave amplitude)

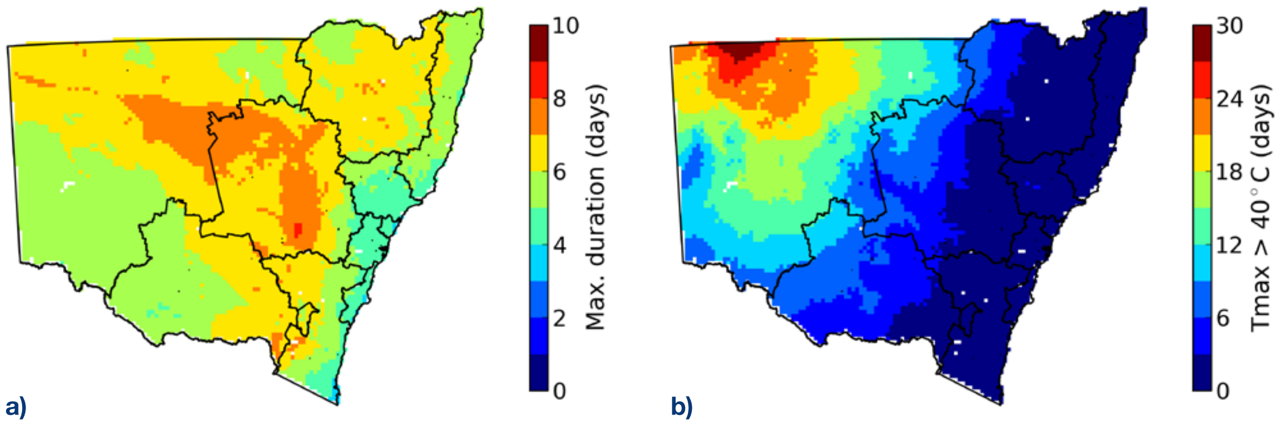



Figure 2: Heatwave events across NSW, 1990–2009; a) maximum duration (days) across all heatwave events, b) number of days above 40°C

# Long-term trends

## Long-term trends in heatwaves

Heatwaves have increased in intensity, duration and frequency in parts of NSW and the ACT since 1911. The most significant increases in intensity have occurred along the Great Dividing Range and in parts of the far west of the state. Virtually the entire eastern seaboard and parts of the far west of the state have experienced increases in the number of heatwaves each year and the frequency of occurrence of heatwave days each year. Significant increases in the duration of heatwaves are apparent for the southern coastal areas and parts of the far west. For example, in the south-east of NSW there are about 18 more heatwave days now compared to the beginning of the 20th century. Other parts of the state are experiencing about 4-11 more heatwave days every year when compared to the beginning of the 20th century.

More and better climate data available since 1958 means that trends in heatwave events since that time can be more accurately identified. It has been observed that greater and more widespread increases in heatwaves have occurred since the late 1950s than over the longer-term record described above. These increases have occurred over most of the state and include heatwave intensity, frequency and duration, as well as the number of days each year over 40°C.

One exception is along the eastern seaboard from the south coast to the mid north coast, where there have been declines since the late 1950s in the average intensity across each heatwave event and, to a lesser extent, in the intensity of the hottest day of each heatwave event. No such declines occurred in the number or duration of heatwaves in this area. It is worth noting that the Great Dividing Range is a significant physical and climatological barrier between the eastern seaboard and the rest of NSW.

## How well do the NARCliM modelled heatwaves compare with observed heatwaves?

To assess how well NARCliM temperature projections are able to account for heatwaves, projected heatwaves calculated based on temperature projections for the 1990-2009 period were compared to projected heatwaves calculated based on temperatures from the Bureau of Meteorology's AWAP gridded temperature data set for the same period. Very few biases between the NARCliM ensemble and AWAP heatwave characteristics are statistically significant, indicating very good simulations of heatwaves. The NARCliM projections have a tendency to underestimate the frequency and maximum duration of heatwaves, particularly in the south-east of NSW. On average this underestimate occurs in January and February.

## Projected changes in heatwaves

All of the NARCliM models agree that temperatures will increase across all of NSW. Maximum, minimum and average temperatures are all projected to increase. These increases happen in both the near and far futures, with the greatest increases in the far future. The number of hot days is also projected to increase, while there will be fewer cold nights. More information about these projected changes can be found on the AdaptNSW website: climatechange.environment.nsw.gov.au.

These projected changes in temperatures are also expected to lead to changes in the nature of heatwaves. Because heatwaves are defined by consecutive stretches of unusually hot temperatures compared to more usual temperatures experienced at that location, their properties are slightly different to those of daily maximum and minimum temperatures. This section explores changes in heatwave intensity, frequency and duration, as well as in the number of days over 40°C.

# Projected changes

## Heatwave intensity

Two measures of heatwave intensity are used, one referring to the average temperature across all heatwave events of the year (heatwave magnitude), another referring to the hottest day of the hottest heatwave of the year (heatwave amplitude).

The hottest day of the hottest heatwave (heatwave amplitude) is projected to increase across the state in both the near and far futures, although it is only in the western regions of NSW in the far future that most models project statistically significant increases (Figure 3).

In contrast, for the average temperature across all heatwave events of the year (heatwave magnitude), there are areas of projected increase, no change and, particularly for the south-east and the far future, decrease (Figure 4). However, none of these changes are statistically significant for a majority of models. Importantly, because this measure draws on every heatwave day of the year, it is possible to get an increase in the intensity of the hottest heatwave and in the number of heatwaves but a decrease in the average intensity across heatwaves. For more information see the Heatwave Technical Report at climatechange.environment.nsw.gov.au.

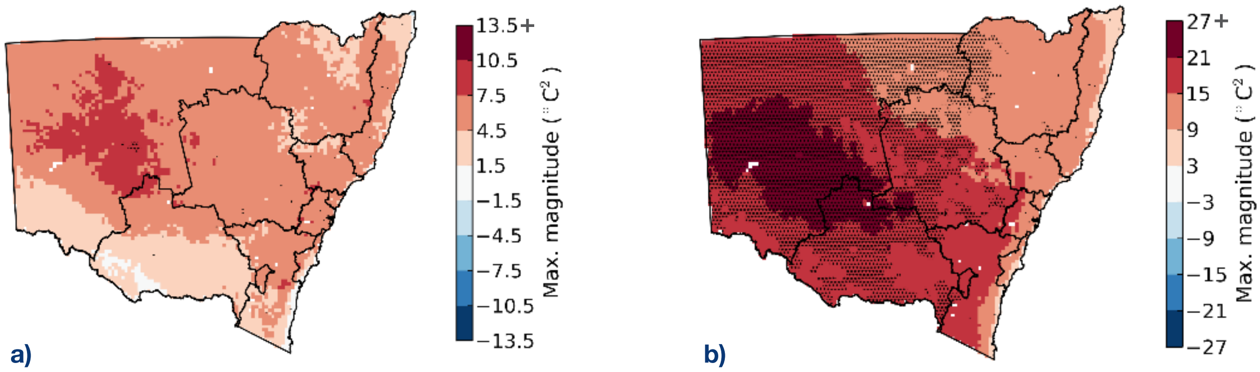



Figure 3: Projected changes to the hottest day of the hottest heatwave of the year across NSW or heatwave amplitude (HWA), a) near future (2030), b) far future (2070)

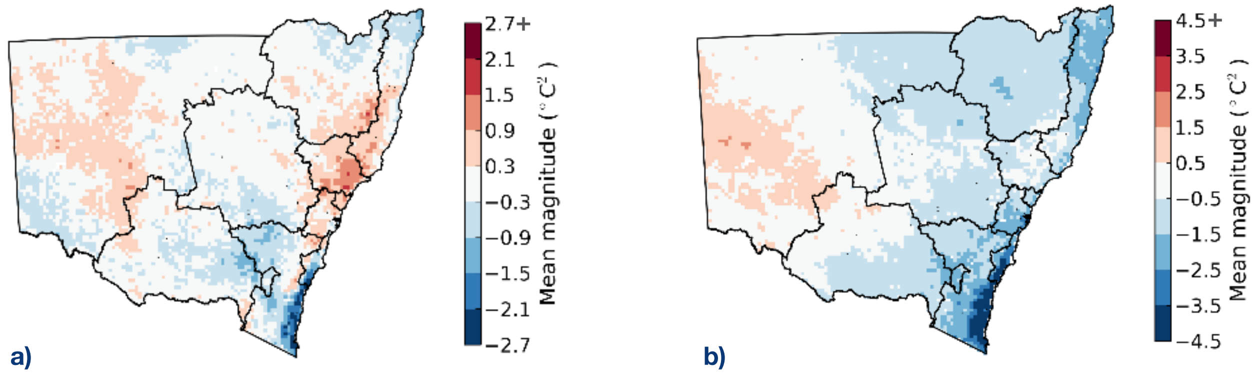



Figure 4: Projected changes to the average conditions of all heatwaves across NSW or heatwave magnitude (HWM), a) near future (2030), b) far future (2070)

Stippling indicates where future changes are stastically significant for at least half the models and where at least 80% of them agree on the direction of change.

# Projected changes

## Heatwave frequency

Statistically significant increases in the number of heatwave events are projected for most of NSW and the ACT in the near future, with even bigger increases projected for the far future (Figure 5a and b). In the near future, an extra 1–1.5 heatwave events each year is projected almost everywhere in NSW with the exception of the south-western interior and the northern coast (Figure 5a). By the far future, the number of heatwaves is projected to increase by 2.5–4.5 events per year, with somewhat larger increases in the central and northern parts of NSW (Figure 5b).

The number of 'heatwave days' is a slightly different measure to heatwave events. Based on the index used the shortest heatwave event lasts three days, resulting in three heatwave days. It is possible to have a large number of heatwave days spread across a small number of heatwaves, and vice versa.

Statistically significant increases in the number of heatwave days are projected for most of NSW and the ACT in the near and far futures (Figures 6a and b). In the near future, all regions except the north coast and parts of the New England Northwest show statistically significant increases (Figure 6a). The largest increases are projected in the northern interior, equivalent to 7.5–10 more heatwave days per year. In the far future these increases are much larger, and follow a clear north-south trend (Figure 6b). The largest increases are projected for the north of the state (around 26–33 more heatwave days per year) and smaller, but still significant increases of around 7 extra heatwave days a year are projected in the south-west and south-east of NSW.

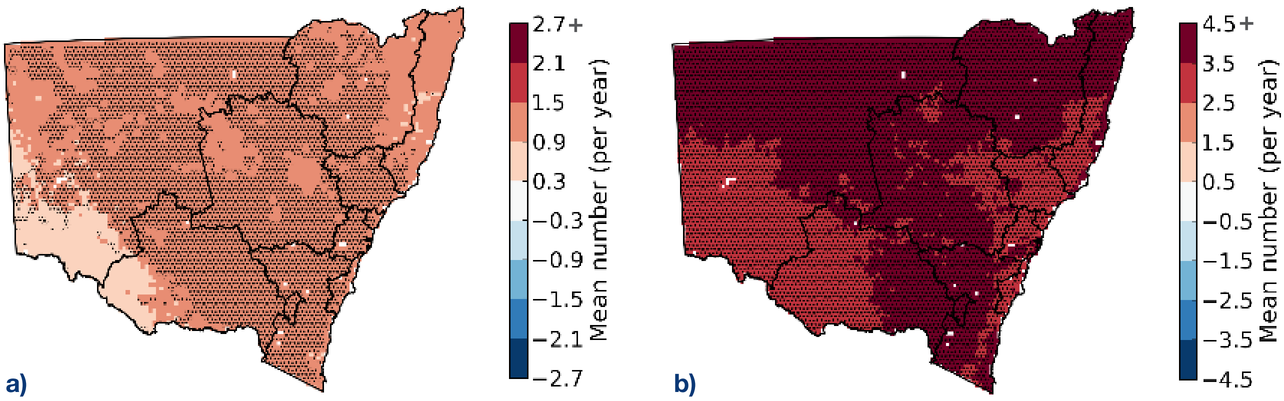



Figure 5: Projected changes to the average number of heatwaves each year across NSW or heatwave number (HWN), a) near future (2030), b) far future (2070)

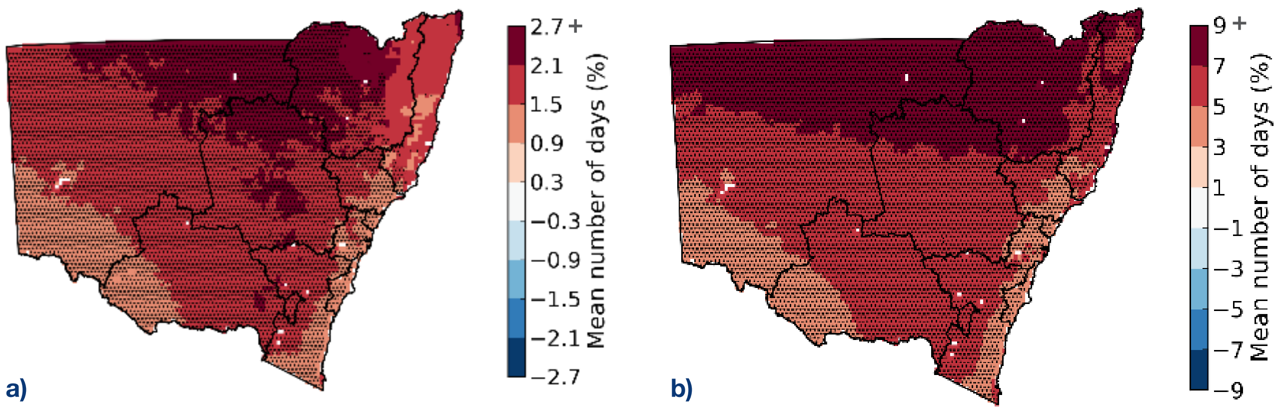



Figure 6: Projected changes to the number of days classed as heatwaves each year across NSW or heatwave frequency (HWF), a) near future (2030), b) far future (2070)

Stippling indicates where future changes are stastically significant for at least half the models and where at least 80% of them agree on the direction of change.

## Heatwave duration

Heatwave duration is measured here by the length of the longest heatwave of the year. In the near future the longest heatwave of the year will last 1.5–3.5 more days on average over most regions, with exceptions along the coast and in the south-west of the state (Figure 7a). These increases are statistically significant over most areas. Increases are even greater in the far future, with the longest heatwave of the year projected to be 2–11 days longer on average, with the largest increases in the north-east and the smallest changes in the southern part of NSW (Figure 7b).

## Extreme heat days

The number of days of extreme heat, defined as days with temperatures above 40°C, is projected to significantly increase over the interior half of NSW by 2030, with changes in the range of 1.5–7.5 additional days per year on average (Figure 8a). In the very north-west of the state, changes are larger, up to 10.5 more extreme heat days a year. In the eastern half of NSW, changes are not statistically significant and are smaller than 1.5 days per year. The number of extreme heat days is projected to rise further in the far future (Figure 8b). Increases of over 30 days are projected in far north-western NSW by 2070, while in the eastern part of the state, changes are generally smaller than three days a year and are not statistically significant.

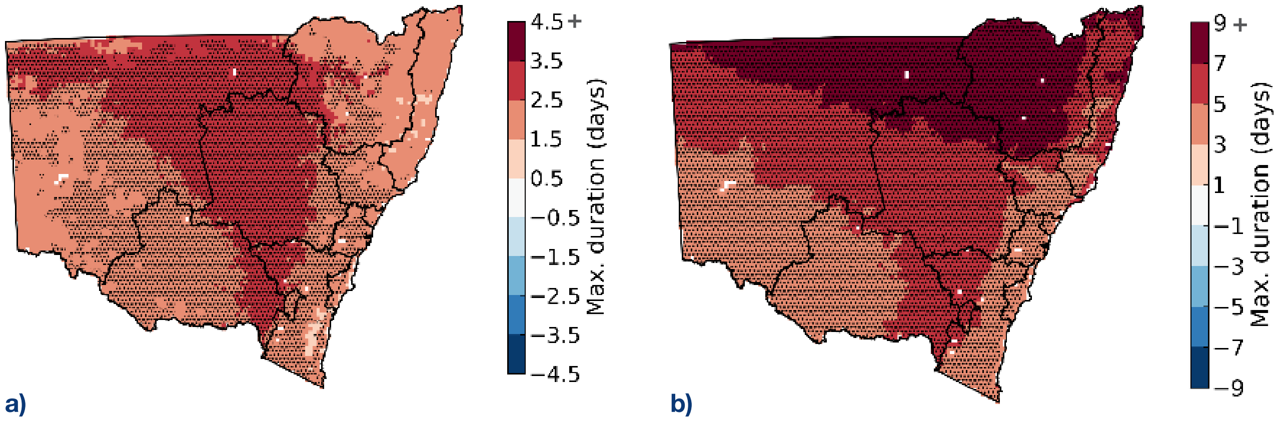



Figure 7: Projected changes to the duration of the longest heatwave each year across NSW, a) near future (2030), b) far future (2070)

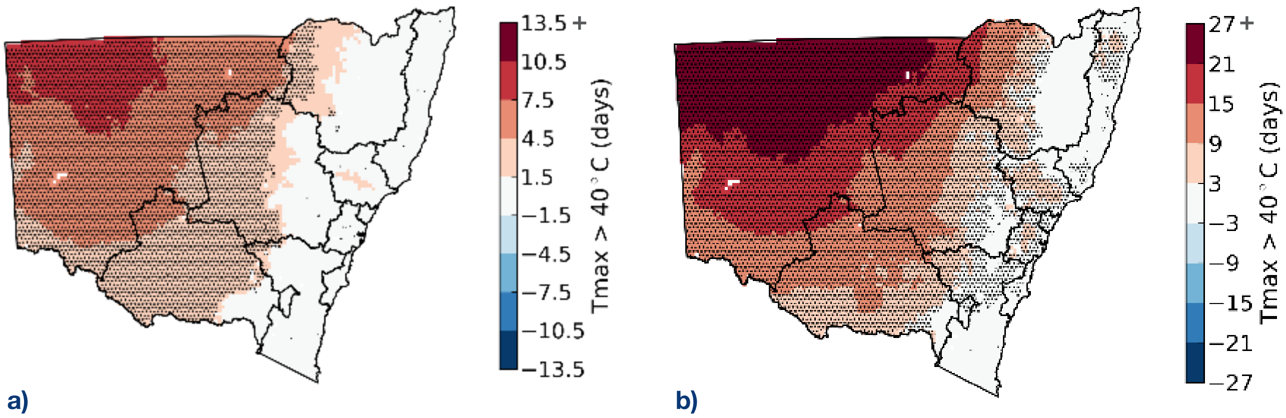



Figure 8: Projected changes to the number of days with temperatures above 40°C each year across NSW, a) near future (2030), b) far future (2070)

Stippling indicates where future changes are statistically significant for at least half the models and where at least 80% of them agree on the direction of change.

# Implications

## Implications for human health

In general, studies of future heat-related deaths using various scenarios and climate models have predicted an increase in the mortality rate (Knowlton et al. 2007; Peng et al. 2011). The health effects that may be coupled with increases in heatwave duration, frequency and intensity depend on a number of factors. Such factors include the health status, spatial distribution and age of the future population, the mean temperature range and urban structure of each region, and the magnitudes of increases in heatwave duration, frequency and intensity.

The frequency and duration of heatwaves are projected to significantly increase over large areas in NSW and the ACT by 2030. By 2070, the frequency, duration and intensity of heatwaves are project to significantly increase over the whole of NSW and ACT. Although it is currently known that the intensity of a heatwave affects mortality and morbidity levels, it is unknown how this particular heatwave characteristic would combine with the projected increases in the other characteristics (i.e. frequency and duration) to affect human health.

As discussed, regions of NSW will see the number of days above 40°C increase significantly. These projections are particularly important for human health outcomes, as single hot days, not just heatwaves, can result in significant short-term increases in mortality and morbidity.

Most studies have shown the existence of temperature thresholds; that is, a particular daily temperature (usually maximum temperature) above which there are marked increases in mortality and morbidity (Loughnan et al. 2010; Williams et al. 2012). These temperature thresholds vary significantly across regions and climatic zones due to the population's ability to acclimatise. For example, the temperature threshold for Sydney appears to be within the range of 26–27°C for daily maximum temperature (Bambrick & Dear 2008; Gosling et al. 2007). Therefore, increases in the number of hot days exceeding 40°C will likely lead to increases in mortality and morbidity.

# Appendix 1

## Description of heatwave indices

This report uses the Excess Heat Factor index derived by the Collaboration for Australian Weather and Climate Research (CAWCR) to identify heatwaves (Nairn & Fawcett 2013).

## Excess heat factor

To determine whether a heatwave occurs, the EHF metric is calculated. This metric is calculated from daily mean temperature. It aims to capture how unusual the last three days of heat have been compared to two reference points:

1. the last 30 days
2. the very hottest days on record.

When EHF is greater than 1 on three or more consecutive days, it is classed as a heatwave. Because of this definition, it is not enough to be 'very hot' to get a heatwave. It must be very hot compared to usual conditions at the given location, which means you can get heatwaves in cool alpine or coastal areas as well as in arid, inland areas. The EHF is calculated with reference to not one, but two different measures of temperature, so it has the unit of measure °C$^2$.

Once a heatwave is identified, the EHF provides information on the characteristics of such heatwaves as described below.

## Heatwave amplitude

Heatwave amplitude, or HWA, refers to the hottest day of the hottest heatwave of the year. The hottest heatwave is the one with the highest average EHF across all days of the heatwave. The hottest day of this heatwave is also selected, based on the day within the heatwave with the highest EHF. Because HWA is based on EHF, it has the unit of measure °C$^2$.

## Heatwave magnitude

Heatwave magnitude, or HWM, refers to the average conditions of all heatwaves of the year. It is simply the sum of EHF on all days classed as heatwave days, divided by the number of such days. Because HWM is based on EHF, it has the unit of measure °C$^2$.

Heatwave amplitude and magnitude refer to the hottest, or most intense days, but it is important to remember that for these indices heat or intensity is measured in heatwave units, not simple degrees Celsius.

## Heatwave number

Heatwave number, or HWN, is simply the average number of separate heatwave events occurring each year. Remember, based on the definition used each heatwave event is at least three days long.

## Heatwave frequency

Heatwave frequency, or HWF, is a count of the number of days in the year classed as heatwave days. This is a slightly different measure from HWN. The shortest heatwave lasts three days, resulting in three heatwave days. It is possible to have a large number of heatwave days spread across a small number of heatwaves, and vice versa. HWF is measured as a percentage of the total days of the year. If 10 days of the year are classed as heatwave days, the HWF is 10/365, or a little under 3%. An HWF of 10% implies that about 37 days a year are heatwave days.

## Heatwave duration

Heatwave duration refers to the longest heatwave in a year, expressed as days.

For a full description and definition of the EHF index and metrics used to describe heatwave characteristics, see NARCliM Technical Note 5, Heatwaves affecting NSW and the ACT – recent trends, future projections and associated impacts on human health (Argueso et al. 2015).

# Appendix 2 Guide to reading the maps and graphs

This document contains maps and bar graphs of the climate change projections, which are used to present the twelve model outputs as a central estimate calculated by averaging the results from the twelve models.
The bar graphs show future projections averaged across the entire region and are not representative of any particular location within the region. For more detailed spatial information, maps are presented showing the central estimates of future projections. Below is information on what is displayed in the bar graphs and maps.

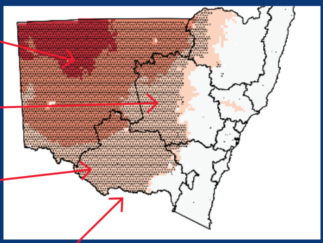
## How to read the maps

The map displays modelled data in grids across NSW.

The colour of each grid is the AVERAGE of 12 models for that grid.

The State is divided into NSW State Planning Regions.

Stippling indicates where future changes are stastically significant for at least half the models and where at least 80% of them agree on the direction of change.



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