Earth Systems and Climate Change Hub

National Environmental Science Programme

Our changing climate

Southern Australia rainfall: long-term trends and future projections

Based on projections of future climate, the general drying trend over southern Australia over the past 50 or so years is likely to continue in the future.

The seasonal cycle of rainfall is also likely to change because trends in warm and cool seasons differ. These factors have important implications for many sectors including water management, industry, transport, infrastructure planning, agriculture and natural resource management.

Building on Australia's national climate change projections released in 2015, we have continued to develop our understanding of the processes driving southern Australia's rainfall, so we now know more about the causes of our declining winter rainfall, the seasonality of rainfall, and the occurrence of extreme rainfall in southern Australia.

With this information, we are in a better position to use projections of future rainfall as a tool to help identify and minimise exposure to climate-related risk and make climate-smart decisions for the future.

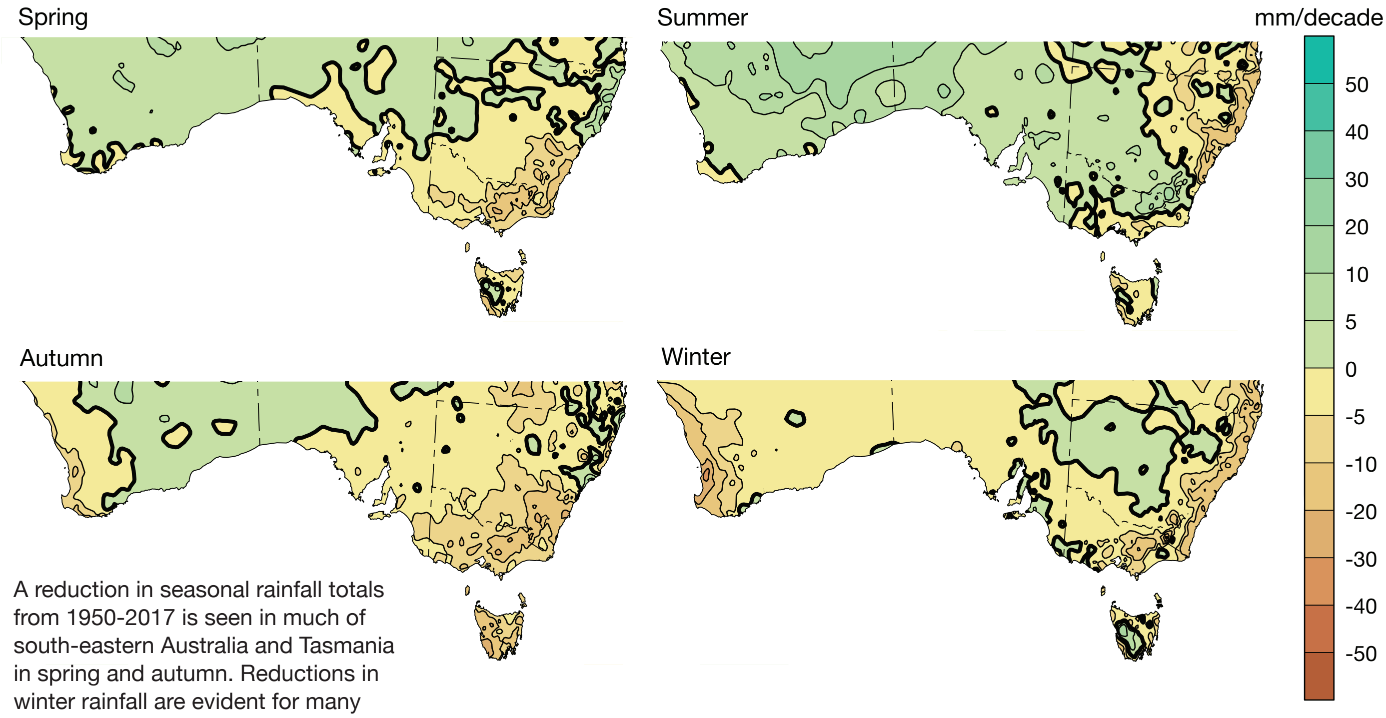
Observed rainfall trends

Rainfall in southern Australian can vary greatly from year to year. This variability is influenced by a range of climate drivers. On top of the strong year-to-year variability, trends over time are apparent. In recent decades there has been a generally drier climate than the long-term average, particularly in winter, generally tracking at the lower end of the range of climate projections in key agricultural regions.

In south-west Western Australia, the trend to drier conditions has been accompanied by large reductions in inflows into the main storage systems, seriously impacting the total amount of water held in Perth's major dams, and reducing groundwater levels in some catchments (Smith and Power 2014). The desalination plant near Perth, operating since 2006, now provides 18% of Perth's water supply, with a second desalination plant completed in 2011 at Binningup capable of providing 33% of Perth's total water needs. Two further desalination plants for Perth are under consideration.

Similarly, in south-eastern Australia, many catchments have experienced a 50% decline in streamflow in recent years (1997–2014 compared to 1975–1996) (Hope *et al*. 2017), which has had serious implications for urban water supply, environmental flows, and agriculture/horticulture including dairy, stone fruit, and grapes. While this recent period included the Millennium drought, there is some evidence that climate change has played a role in the decline in rainfall in recent decades across southern Australia.

Trend in rainfall 1950–2017



A reduction in seasonal rainfall totals from 1950-2017 is seen in much of south-eastern Australia and Tasmania in spring and autumn. Reductions in winter rainfall are evident for many parts of southern Australia.

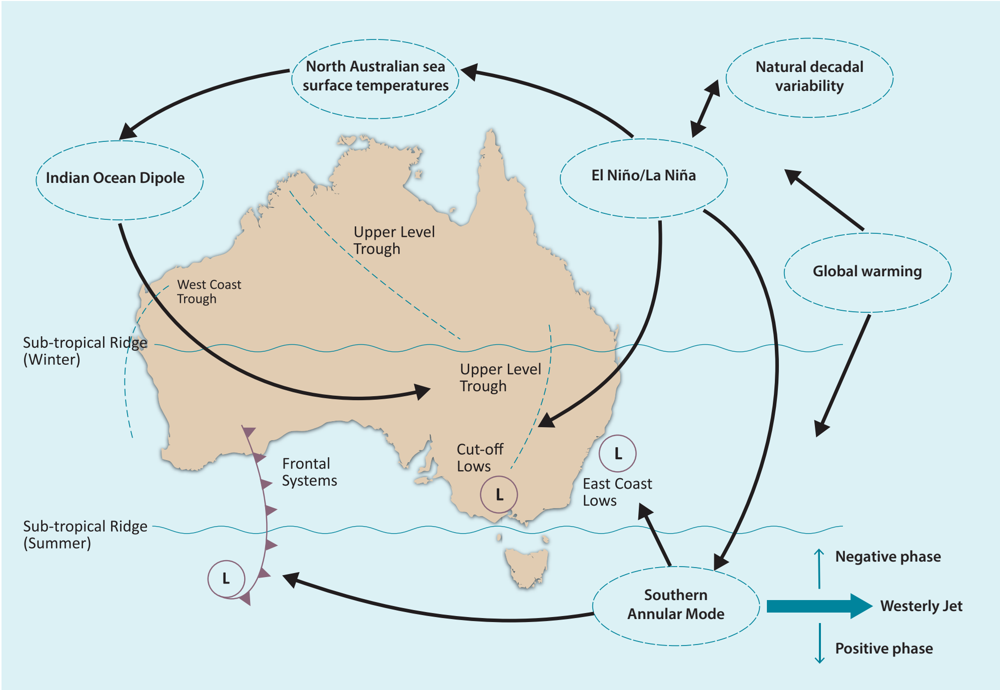
(Source: Australian Bureau of Meteorology)

1. https://www.watercorporation.com.au/water-supply/our-water-sources/desalination

What influences rainfall in southern Australia?

The main rain-bearing weather systems for most of southern Australia, particularly the west-facing regions, are cold fronts and troughs coming from the west. These regions are often dominated by cool-season rainfall, with drier summers. Cut-off lows, including east coast lows (intense lows that develop periodically along the southern coast of NSW), are also important, particularly for eastern parts of Victoria and Tasmania.

During summer, for Western Australia, the west coast trough (a long north-south band of coastal low pressure) is important for sea-breezes and showery rainfall, but tropical influences such as the southward passage of ex-tropical cyclones can bring stronger downpours. In the south-east, moist tropical airmasses can interact with other weather features such as an upper-level trough or cold front to bring heavy summer rainfall. Thunderstorms are also important in bringing rainfall (Dowdy and Catto 2017).



Rainfall influences on southern Australia.

These rain-bearing weather systems are influenced by large scale atmospheric circulations that act, and interact, on various space and time scales. A major feature is the seasonal progression of the subtropical ridge, a band of high surface pressure that marks the boundary of mean westerly winds to the south and easterly winds to the north. The subtropical ridge ranges in latitude from around 40°S in summer to 30°S in winter, and has intensified (i.e. pressures have increased) in recent decades due to an increase in the number of high pressure systems (Pepler *et al*. 2018). These changes are contributing to the observed cool-season drying (Timbal and Drosdowsky 2013).

To the south of Australia, the band of strong westerly winds that encircle the hemisphere impact the behaviour of the weather systems that affect Australia. The expansion and contraction of this band is called the Southern Annular Mode (SAM). Contraction of these winds closer to Antarctica (positive SAM) is linked to reduced winter rainfall for southern mainland Australia, though in summer positive SAM is often linked to higher than average rainfall. In its negative phase, when the strong westerly winds shift equatorward, SAM is associated with wetter than normal conditions in winter, but drier in spring and summer.

Large-scale circulations in the tropics also influence southern Australian rainfall variability. The Indian Ocean Dipole (IOD) is a basin wide 'see-sawing' of temperatures across the Indian Ocean. In its 'negative' phase, where there are anomalously warm waters off the north-west of Australia, the IOD is associated with more rainfall than average over south-eastern Australia, primarily in late winter through spring. A 'positive' IOD is associated with relatively reduced rainfall over this period.

In the Pacific Ocean, the El Niño-Southern Oscillation (ENSO) also has a significant influence on Australia's rainfall. An El Niño event is often associated with drier conditions during winter and spring across eastern Australia, while La Niña generally brings wet conditions, sometimes extending into summer. In contrast, for south-western Australia La Niña can mean very dry conditions due to linkages with SAM (Lim *et al*. 2016), although overall the influence of ENSO is weaker in the west.

Each of the above climate 'drivers' interact with each other and are influenced by global warming. For instance, SAM is projected to shift towards its more positive phase, resulting in higher atmospheric pressures over southern Australia and thus less favourable conditions for winter rainfall across the mainland. Tasmania, being further south, will be less affected. Very severe ENSO and IOD events are expected to become more common and result in greater impacts, including enhanced rainfall variability (Power and Delage 2018; Wang *et al*. 2017ab).

More drying to come...

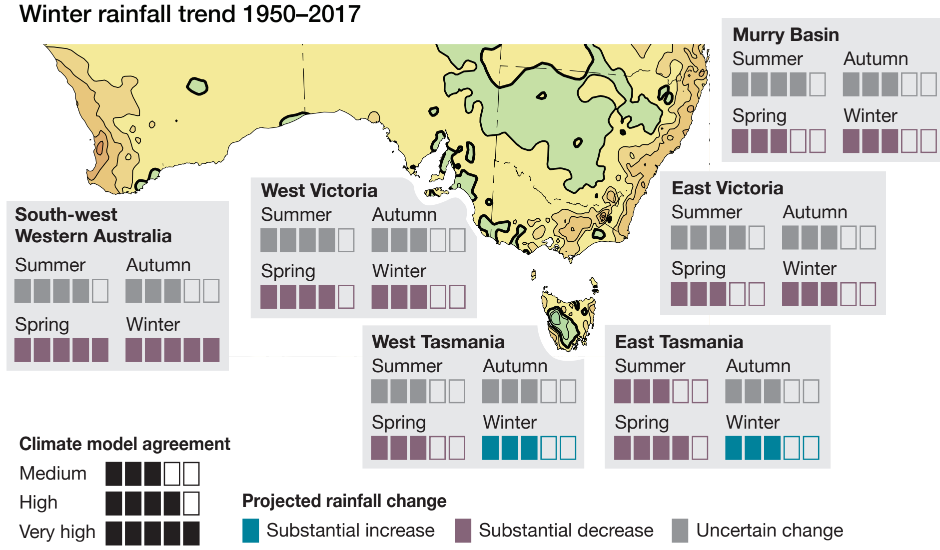
Rainfall projections for the end of the century (2080–2099) show that as the concentration of global atmospheric greenhouse gases increases, we can expect an increasing decline in winter rainfall across much of southern Australia. This is particularly evident for south-western Western Australia where there is very high agreement among climate model simulations of a substantial decline in winter and spring rainfall. This may be as great as 50% by the end of the century (compared with the reference period 1986–2005) under a high greenhouse gas emissions scenario (RCP 8.5; note that the progression of greenhouse gas emissions will determine the extent of the rainfall change, and our future might follow a different emissions pathway). An exception is Tasmania, where there is medium model agreement of an increase in winter rainfall (of up to 20%) in association with projected increases in the strength of the westerlies.

Projected rainfall changes for summer and autumn are less clear, with less model agreement, which we attribute to the complex interplay between tropical and mid-latitude rain-bearing processes at that time of year. Western Tasmania is an exception, with most climate models projecting a decrease in summer rainfall.

As both observed and projected trends in winter can differ from those in summer for any given location, the seasonal cycle is likely to change over time, with implications for ecosystems, agriculture and water supply.

Near-term projections (2030s, 2050s) show less pronounced trends in rainfall change and less difference between high and low emissions scenarios than for later in the century (2070s, 2090s).

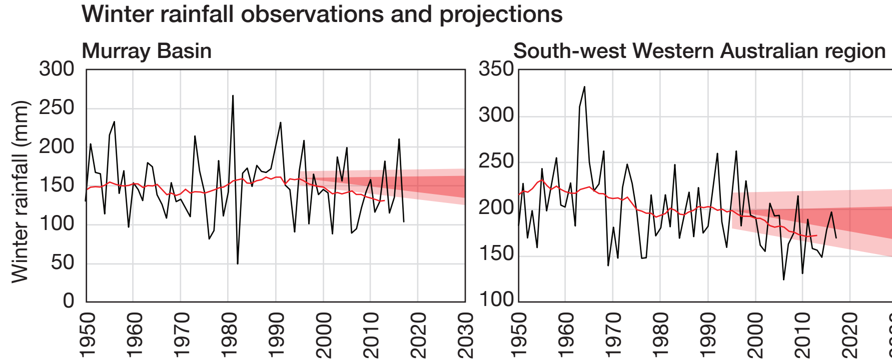
Winter rainfall trend 1950–2017



The map illustrates the long-term (1950-2017) winter rainfall trend, while the boxes show the regional projected changes in seasonal rainfall by 2090, relative to a reference period of 1986-2005 under RCP8.5. Colours show direction of change, where "Substantial" indicates the projected change is outside the 10-90% range of model natural variability, and fill shows the extent of climate model agreement (medium: >60% of models agree; high: >75%; very high: >90%). Source: data obtained from CSIRO and Bureau of Meteorology (2015)

For short-term projections (to 2030s), observed winter rainfall declines are tracking at or below the dry end of the winter projections for many regions of southern Australia (see below). This suggests either large multi-decadal variability or that the projections underestimate the observed rainfall decline. Thus, climate models that project a drier future would agree better with the recent observed rainfall trends in these regions.

Winter rainfall observations and projections



Across the Murray basin and the south-west Australian region observed winter rainfall has been tracking towards the drier end of the near-term projections. Shown are observed rainfall (AWAP; black line) plus the 10-year running average (red line), and the projected rainfall change to 2030 across climate models and emissions scenarios (relative to a 1986–2005 baseline period) (dark pink shading) plus an indication of decadal variability (light pink shading; one standard deviation of 10-year running average from the observations). (For more details on the method, see Grose *et al*. 2017b)

… but flooding is still possible!

While southern Australia is expected to get less total rainfall in general in the future, extreme rainfall is projected to intensify (CSIRO and Bureau of Meteorology 2015; Westra *et al*. 2014), even in regions where mean rainfall decreases. Increases in rainfall extremes have already been observed for short duration (3-hour or less) rainfall (Chen *et al*. 2013; Guerreiro *et al*. 2018), however these changes can vary dependent on season and geography.

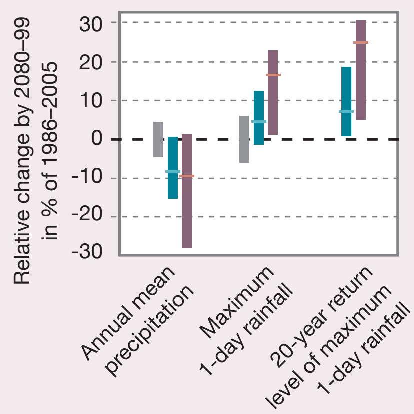
Short-duration extremes can have major impacts, such as flash flooding – particularly in urban environments – which holds significant implications for infrastructure. While intense rainfall may also contribute to large-scale riverine flooding, other factors such as the level of saturation of the catchment prior to the rainfall event (Johnson *et al*. 2016) will determine the extent of the impacts.

For low-lying coastal communities, future flooding risk is also exacerbated by rising sea levels.

Why will extreme rainfall increase?

As temperature rises, the capacity of the air to hold water vapour also increases, providing a greater potential source of moisture for rain to fall under the right conditions: for each 1°C increase in temperature, the water-holding capacity of air increases by approximately 7%. The increase in intense rainfall can be even greater when the increased moisture in the air provides more energy for storms. This is already evident in the most extreme hourly rainfall, particularly in summer storms. While intense, short-duration rainfall might increase in intensity, circulation changes mean that there are likely to be changes in the number of storms and weather systems, which will more strongly drive trends in total rainfall.

Even though average rainfall in southern Australia is projected to decrease by the end of the century under both high (pink bars) and mid-level (blue bars) emissions scenarios, almost all models agree that the wettest day of the year will get wetter, regardless of the emissions scenario. The grey bars show the year-to year variability and the dark horizontal line on each bar shows the median value of the model simulations (20-year moving average climate) – half the model results fall above and half below this line.



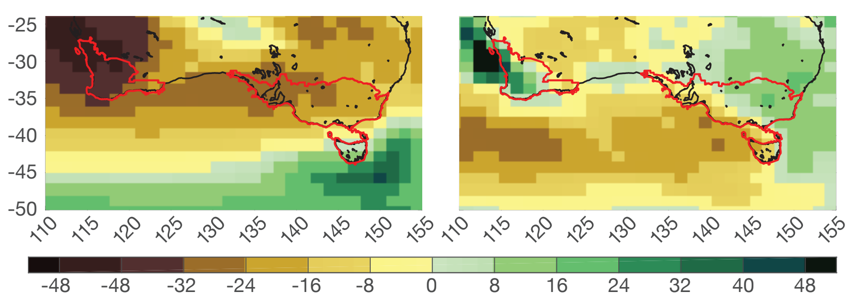
(Source: CSIRO and Bureau of Meteorology, 2015)

Confidence in rainfall projections for southern Australia

Global climate models differ in their configuration and their ability to simulate rain-bearing features in the region of interest. This can lead to a wide spread in the magnitude and direction of projected change, as is the case with summer rainfall.

Researchers are confident in the projected decrease of winter rainfall in south-western Australia because the drying projection is highly consistent across all global climate models, and the physical basis for the projection – intensification and poleward progression of the local subtropical ridge and a positive trend in the SAM (Hope *et al*. 2015) – is compelling.

Confidence in projections can be improved by selecting only climate models that best simulate the weather and climate features that have a strong influence on Australian rainfall. Grose *et al*. (2017a) adopted this approach and found that 15 climate models passed tests on their representation of local circulation features. The resulting projected change in rainfall (%) for 2080–2099 (relative to 1986–2005) supported the wet winter projections for Tasmania, and suggested that the expected winter drying by the end of the century is even stronger in July in the south-west and the south-east of the continent than previously indicated using the full group of climate models. This is consistent with the observed rainfall declines in winter over the last several decades being at the drier end of model projections to 2030. Using this subset of models that best represents rainfall in southern Australia also increases confidence in projections of more summer rainfall in south-west and eastern Australia.



Change in rainfall (%) between 1986–2005 and 2080–2099 for July (left) and January (right) drawn from only the sub-set of climate models that best represent the drivers of southern Australian rainfall (from Grose *et al*. 2017a).

Climate change science to improve rainfall projections

The Earth Systems and Climate Change Hub's research is improving our confidence in climate change projections and is increasing our understanding of how the climate system works by:

- improving simulations of important climate processes in the Australasian region in Australia's global climate model, ACCESS,
- analysing past climate variability and extremes to enhance our understanding of the underpinning climate drivers
- improving our physical understanding of the effects of climate change on those drivers, and their impact on southern Australian rainfall.

The Hub is also developing methods to deliver new projections of future water availability and hydrologic variables or metrics important to the water sector, and working to make climate change information more user-friendly, so it can more easily be applied to risk assessment and adaptation activities.

For information on these projects and other research conducted by the Hub, please visit **www.nespclimate.com.au**

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