Western Australian climate projections

Summary

September 2021

Department of Water and Environmental Regulation

Prime House, 8 Davidson Terrace
Joondalup Western Australia 6027

Telephone +61 8 6364 7000
Facsimile +61 8 6364 7001
National Relay Service 13 36 77

dwer.wa.gov.au

FIRST 115943

Disclaimer

This document has been published by the Department of Water and Environmental Regulation. Any representation, statement, opinion or advice expressed or implied in this publication is made in good faith and on the basis that the Department of Water and Environmental Regulation and its employees are not liable for any damage or loss whatsoever which may occur as a result of action taken or not taken, as the case may be in respect of any representation, statement, opinion or advice referred to herein. Professional advice should be obtained before applying the information contained in this document to particular circumstances.

The Department of Water and Environmental Regulation was established by the Government of Western Australia on 1 July 2017. It is a result of the amalgamation of the Department of Environment Regulation, Department of Water and the Office of the Environmental Protection Authority. This publication may contain references to previous government departments and programs.

Please email the Department of Water and Environmental Regulation to clarify any specific information.

This publication is available on our website or for those with special needs it can be made available in alternative formats such as audio, large print, or Braille.

Acknowledgements

The Department of Water and Environmental Regulation (the department) acknowledges the use of data from the Commonwealth Scientific and Industrial Research Organisation and the Bureau of Meteorology Climate Change in Australia website (www.climatechangeinaustralia.gov.au).

Cover image: Z Bend Lookout, Kalbarri National Park, Source: Tourism Western Australia

21220065

We acknowledge the traditional custodians of the land upon which we live and work, and pay our respects to their elders past and present. We recognise the practice of intergenerational care for country and its relevance to our work.

We seek to listen, learn and build strong partnerships. We aim to provide genuine opportunities for Aboriginal people within our workforce and through our business.

Contents

Climate change in Western Australia

In August 2021, the world's leading climate scientists delivered their starkest warning on climate change yet, with some changes now considered inevitable and irreversible. Australia remains a notable hotspot, with temperatures and sea levels rising faster than the global average.

The findings from Working Group I's contribution to the sixth Assessment Report (AR6) of the Intergovernmental Panel on Climate Change (IPCC) is the first of four reports, with subsequent reports coming in 2022. For more information see www.ipcc.ch.

The latest IPCC report confirms climate change poses a serious risk to Western Australia under all emissions scenarios, requiring every sector of society to adapt. It also provides hope for the future and sets out how the most serious risks can be averted with immediate, rapid and large-scale cuts to greenhouse gas emissions.

This document provides a summary of the changes in climate and sea levels likely to occur over the coming decades based on models from the previous 2014 IPCC Report. This guide will continue to be improved and enhanced as scientists work to understand how the latest global trends from AR6 translate to local and regional specific impacts. Some of this work will be delivered under the Climate Science Initiative.

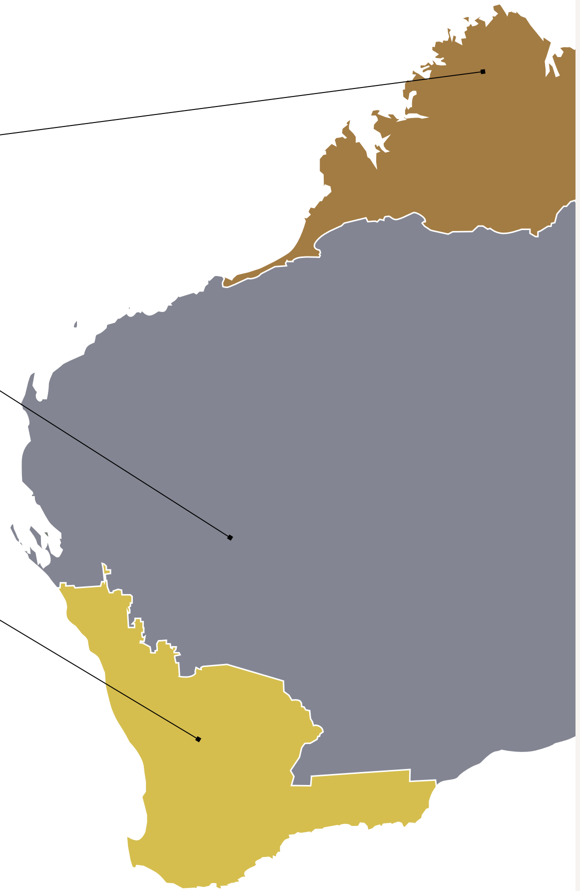
Information is presented across three Natural Resource Management (NRM) regions of Western Australia as shown on the next page.

City Beach (© Tourism WA)

Monsoonal North
Covers the Kimberley

Rangelands
Stretches from Shark Bay to the Pilbara, across to the Northern Territory border in the east, and down to the Norseman and Nullarbor coast in the south

South Western Flatlands
Covers the Northern Agricultural, Wheatbelt South Coast, South West and Perth-Peel regions



The information is based on the Climate Change in Australia projections produced by the Commonwealth Scientific and Industrial Research Organisation (CSIRO) and the Bureau of Meteorology (BoM) in 2015. It is designed to support high-level climate risk assessments and adaptation planning.

Climate Science Initiative

To make informed decisions about managing current and future climate risks, decision-makers across government, industry and business require access to credible, up-to-date, useable and relevant information on future changes to our climate.

The Climate Science Initiative will use the latest generation of global climate models to understand Western Australia's future climate. When available, this information will be used to update this guide and provide other guidance and communication materials to help governments, businesses and communities manage climate risk and increase resilience.

The Climate Science Initiative is critical to understanding how future global emissions scenarios will affect Western Australia's climate. Projections will provide a consistent basis for government, businesses and communities to identify climate change risks, and undertake more detailed modelling and adaptation plans.

About climate projections

Projections are used to understand how increasing greenhouse gas concentrations can affect the global climate.

Projections are developed using computer software models that couple various components of the Earth system, including atmospheric processes, land processes, oceans, sea ice, aerosol feedbacks and carbon cycle feedbacks. By using prescribed scenarios of greenhouse gas emissions, it is possible to estimate how quickly the Earth system can warm and some of the responses to this warming by the different Earth system components (e.g. melting sea ice).

Emissions scenarios

Most climate change projections are based on a range of greenhouse gas scenarios, called Representative Concentration Pathways (RCPs), developed by the IPCC.

Each RCP provides a possible emissions trajectory over time (generally up to 2100). Figure 1 depicts the four RCPs and projected climate impacts at 2100.

In this guide, three RCPs are referred to:

High	RCP8.5	Little global action to reduce greenhouse gas emissions, similar to business as usual.
Intermediate	RCP4.5	Strong global action to reduce emissions towards the end of this century
Low	RCP2.6	Ambitious global action to reduce emissions in line with the Paris Agreement to keep global warming below 2 °C above pre-industrial temperatures.

It is important to note that projections are not forecasts.
They do not provide a prediction of exactly what will happen by a particular date.
Instead, they draw on the best available information to indicate how the climate is likely to change based on different scenarios of human activity.

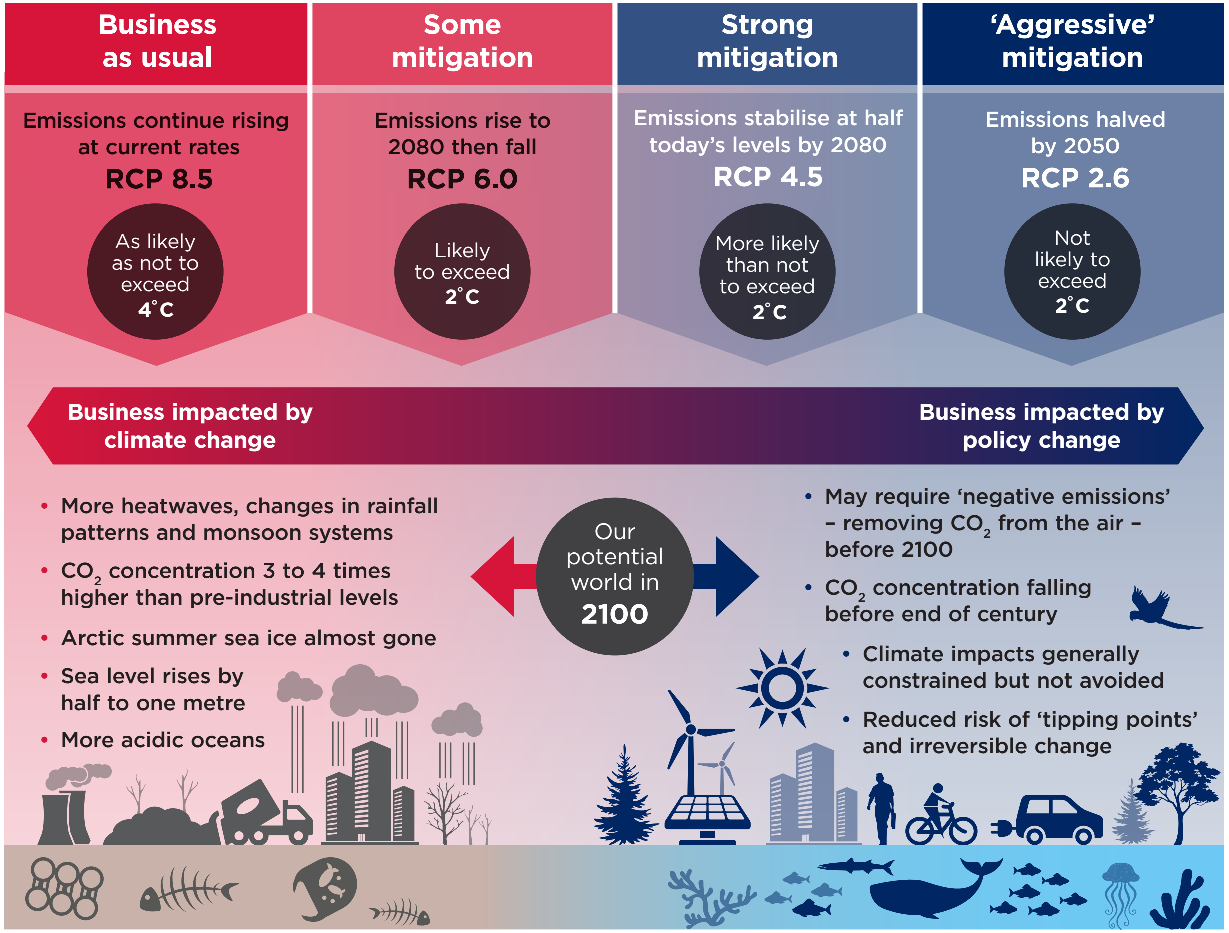


Figure 1: The four Representative Concentration Pathways project different scenarios for future climate change (University of Cambridge 2013)

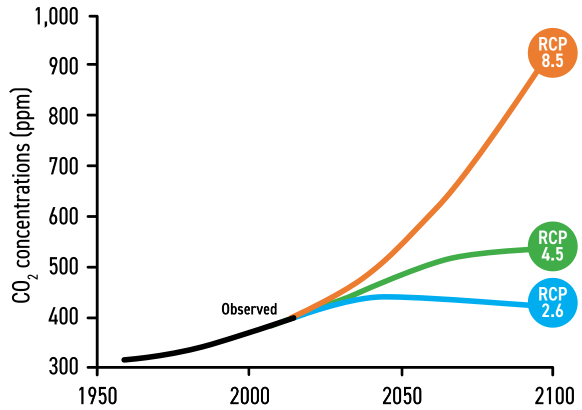


Figure 2. Carbon dioxide concentrations associated with the RCPs

All the RCPs are quite similar up to 2030 (Figure 2) but grow increasingly divergent after that.

About the projections used in this guide

In 2015, CSIRO and BoM released national climate projections for Australia drawing on the most up-to-date global climate models available at that time.

The Climate Change in Australia projections were produced using up to 40 global climate models (GCMs) from the Coupled Model Intercomparison Project Phase 5 (CMIP5).

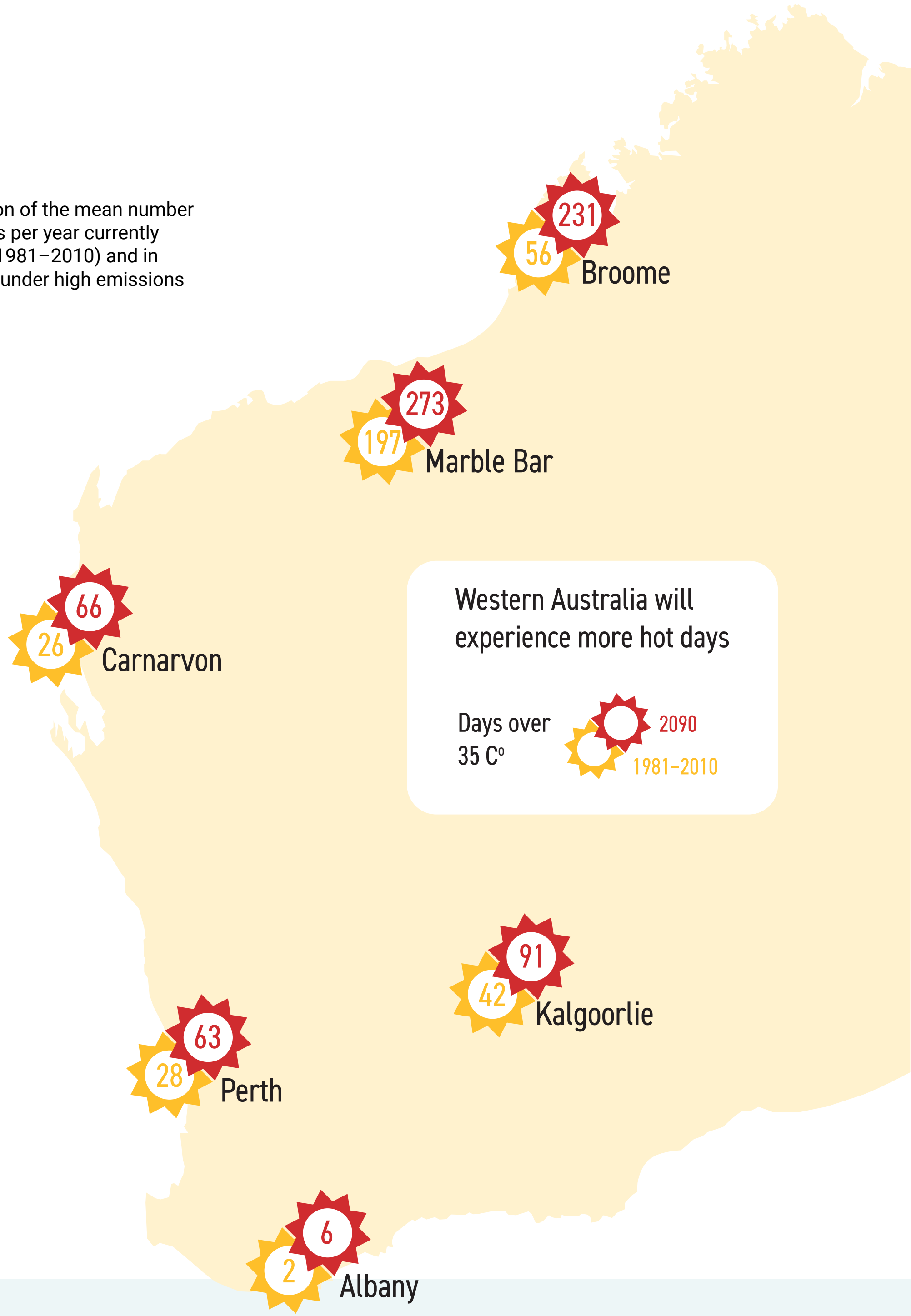
Using multiple models provides robust regional climate projections that span the range of likely future changes. In this guide, the median projection across the models is shown with the 10th and 90th percentile range of model results in brackets where available.

For more information on the methods used to generate the projections see the Climate Change in Australia Technical Report.

Confidence in the projections

While confidence in the direction and range of projected change is important, uncertainty should not stand in the way of action. The Climate Change in Australia projections include confidence ratings for different climate variables, regions, emissions scenarios and time periods, which are reflected in this guide. Ratings range from 'very high' to 'low', depending on the amount of evidence and the level of agreement between the different lines of evidence. For further information on confidence ratings see Section 6.4 of the Climate Change in Australia Technical Report.

Figure 3:
Comparison of the mean number of hot days per year currently (between 1981–2010) and in the 2090s under high emissions (RCP 8.5)



Summary of climate trends

1900

Western Australia is already experiencing the impacts of climate change

- Western Australia has warmed by about 1.3 °C since 1910.
- Since 1900, rainfall has increased over most of Western Australia, apart from the far west and south-west where it has declined. The decline in south-west Western Australia has been larger than anywhere else in Australia and is highly attributable to human influence.
- The number of days with dangerous weather conditions for bushfires has increased in nearly all locations.

2021 — **2050**

Western Australia's climate will continue to change over the coming decades. By 2050, the following changes are projected:

- Under a high emissions scenario (RCP8.5), Western Australia's temperature is expected to increase by about 2°C (range of 1.5 to 2.4 °C).
- Large and sustained reductions in global greenhouse gas emissions (RCP2.6) reduces this projected warming to about 1.2 °C (range of 0.8 to 1.6 °C).
- Extreme temperatures in all regions are very likely to increase into the future. The number of very hot days (>40 °C) is projected to increase from about 1.5 to five days per year in Perth, and from six to 16 days in Broome.
- By mid-century under a high emissions scenario 2:
  - the climate of Perth is projected to be more like the current climate of Jurien
  - the climate of Albany is projected to be more like the current climate of Busselton
  - the climate of Broome is projected to be more like the current climate of Derby.
- Western Australia can expect longer fire seasons, with about 40 per cent increase in very high fire danger days.
- Sea levels are projected to rise by about 24 cm along the West Australian coast.
- Mean rainfall is projected to continue to decrease in south-western Australia, while changes over northern Australia remain uncertain.
- Rainfall variability and extreme rain events are projected to become more intense, leading to more very wet and very dry years.
- Tropical cyclones are projected to decrease in frequency, but it is expected that a greater proportion will have higher intensity.

Climate change in the South Western Flatlands region of WA

Overview

The South Western Flatlands region of WA covers the Northern Agricultural, Wheatbelt, South Coast, South West and Perth-Peel Natural Resource Management regions. It has a predominantly Mediterranean climate, with high winter rainfall and little summer rainfall (Hope et al. 2015).

Temperature

Higher temperatures

- Mean temperatures have increased by about 1.1 °C since 1910, with the rate of warming higher since 1960.
- Mean, maximum and minimum temperatures are projected to continue to rise.
- By 2030, the mean annual warming across all emissions scenarios is projected to be about 0.5 to 1.1 °C above the climate of 1986–2005.
- By 2090, the projected range of annual warming is:
  - 1.2 to 2 °C under an intermediate emission scenario (RCP4.5)
  - 2.6 to 4 °C under a high emissions scenario (RCP8.5)
- Each individual season is projected to warm by about the same amount as the annual mean.

Table 1: Projected temperature change (°C) for the South Western Flatlands region of WA compared with 1986–2005 for 20-year periods (centred on 2030 and 2090) and three RCPs. The median projection across the models is shown with the 10th and 90th percentile range of model results in brackets.

Mean annual warming above the climate of 1986–2005			
	RCP2.6 Low	**RCP 4.5** Intermediate	**RCP8.5** High
2030	0.7 °C (0.5 to 0.9)	0.8 °C (0.5 to 0.9)	0.8 °C (0.5 to 1.1)
2090	0.8 °C (0.5 to 1.3)	1.7 °C (1.2 to 2.0)	3.4 °C (2.6 to 4.0)

Hotter and more frequent hot days – less frost

- The temperature and frequency of very hot days is expected to increase, and heatwaves will get longer and more intense.
- The region will experience a reduced number of days with frost risk.

For example, Perth currently experiences 28 days per year over 35 °C. Under an intermediate emissions scenario (RCP4.5) this will increase to 36 days by 2030 and 63 days by 2090 (a 125 per cent increase).

For more details on Perth's future climate see the snapshot on page 13.

Rainfall

Less rainfall in winter and spring. Changes in other seasons unclear.

- The South West has experienced a marked drying trend since 1970, particularly in autumn and early winter.
- The decline in this region has been larger than anywhere else in Australia.
- Decreases in annual, winter and spring rainfall are projected with high confidence.
- By 2030 under all emission scenarios, winter rainfall is projected to decrease by up to 15 per cent.
- By 2090 rainfall is projected to decrease by:
  - up to 25 per cent under intermediate emissions (RCP4.5)
  - up to 45 per cent under high emissions (RCP8.5).
- By 2090 under RCP8.5, every year's winter rainfall is projected to be lower than the current average.

Changes in autumn and summer are less clear, although projections suggest a continuation of the observed autumn declines.

Increased intensity of heavy rainfall events. Drought duration to increase.

- Under all emission scenarios, the time spent in drought is projected to increase.
- Even though the total annual rainfall is expected to reduce, the intensity of heavy rainfall events will likely increase.

Increased evaporation rates, reduced soil moisture and runoff.

- Drier and hotter conditions will lead to decreases in soil moisture and runoff because of increased water loss from plants and soils (evapotranspiration). This could further exacerbate drought conditions.

Explore what the future climate will be like across Western Australia using the climate analogues tool on the Climate Change in Australia website at www.climatechangeinaustralia.gov.au.

In 2050, under a high emissions scenario, the climate of Perth will be more like the current climate of Jurien, and the climate of Albany could be more like the current climate of Busselton.

Table 2. Projected rainfall differences (per cent) for the South Western Flatlands region compared with 1986–2005 for 20-year periods (centred on 2030 and 2090) and two RCPs. The 10th and 90th percentile range of model results is shown. For 2030, results for all RCPs are similar so only RCP4.5 values are shown. Median results are not shown because models do not always agree on the direction of change.

	2030	2090	
	RCP4.5	RCP4.5	RCP8.5
Annual	**-13 to 0**	**-22 to -1**	**-36 to -2**
Summer	-22 to +14	-22 to +25	-26 to +28
Autumn	-18 to +9	-22 to +10	-33 to +14
Winter	-16 to +2	-26 to -3	-44 to -13
Spring	-20 to +3	-33 to +3	-52 to -5

Fire

Harsher fire weather climate

- There is high confidence that climate change will result in a harsher fire weather climate in the future.
- There is low confidence in the magnitude of the change as fire weather is strongly dependent on the summer rainfall projection.
- There is considerable variability in fire danger rating across individual sites. At locations with cooler temperatures (e.g. Esperance and Albany) the relative change is larger for both the number of severe fire weather days and the total Forest Fire Danger Index than warmer stations (e.g. Geraldton).

The number of days with 'severe' fire danger rating is projected to increase by…

	RCP4.5 Intermediate	RCP8.5 High
Current	4.2 days	
by 2030	5 days (19% ↑)	4.7 days (12% ↑)
by 2090	5.3 days (26% ↑)	6.9 days (64% ↑)

Current refers to 1986–2005 baseline

Marine and coastal projections

Higher sea levels and more frequent sea level extremes

- There is very high confidence that sea levels will continue to rise during the 21st century, with projections sensitive to RCP pathways as the century progresses.
- These ranges of sea level rise are considered likely (at least 66% probability); however, if a collapse in the marine-based sectors of the Antarctic ice sheet were initiated, these projections could be several tenths of a metre higher by late in the century.

Sea levels at Fremantle are projected to increase by…

	RCP4.5 Intermediate	RCP8.5 High
by 2030	0.12 (0.07 to 0.16)	0.12 (0.08 to 0.17)
by 2090	0.46 (0.28 to 0.65)	0.61 (0.39 to 0.84)

Change relative to 1986–2005 (m)

Warmer and more acidic oceans in the future

- By 2090, coastal waters are projected to warm by 1.5 to 3.9 °C under a high emissions scenario (RCP8.5).
- There is very high confidence that oceans will become more acidic and the rate of ocean acidification will be proportional to carbon dioxide emissions.

Sea surface temperatures at Fremantle are projected to increase by…

	RCP4.5 Intermediate	RCP8.5 High
by 2030	0.6 (0.4 to 0.7)	0.6 (0.4 to 0.9)
by 2090	1.2 (0.7 to 1.7)	2.6 (1.8 to 3.3)

Change relative to 1986–2005 (°C)

Explore expected changes in the marine climate using the Climate Change in Australia Marine Explorer.

With a significant part of the population living in coastal cities and towns, rising sea levels pose significant risks to Western Australia's coastal infrastructure and iconic sandy beaches. In Fremantle, coastal flooding has increased three-fold (Church et al. 2006), while parts of Perth along the Swan River including Elizabeth Quay, Heirisson Island and sections of East Perth are at risk of being submerged by early next century (Department of Biodiversity, Conservation and Attractions 2019). Mandurah, Busselton, Rockingham and Bunbury are also at great risk of inundation and sea levels rise (Department of Climate Change 2009).

Perth City Skyline (© Tourism WA)

Perth Snapshot

As of 31 December 2020, WA had an estimated resident population of about 2.67 million. Most of the population (78%) reside in the metropolitan region of the capital city Perth (ABS 2021).

Perth's climate is expected to become harsher under all future emission scenarios. As Perth's population density continues to rise, state and local governments, industry and the wider community face greater climate risks. People living in larger cities can be more susceptible to the effects of climate change, particularly from heatwaves which can be amplified by the prevalence of concrete, dark-coloured roofs and a lack of shade and green space.

Perth's future climate

Confidence	Events
Very high	Average temperatures will continue to increase in all seasons
	Higher sea levels and more frequent sea level extremes
High	Hotter and more frequent hot days
	Less frost
	Less rainfall in winter and spring; changes in other seasons are unclear
	Increased evapotranspiration, reduced soil moisture and runoff
	Harsher fire weather climate
Medium	More intense extreme rainfall events

Table 3: Projected changes for 2030 and 2090 for average temperature, rainfall, evapotranspiration, wind speed, solar radiation, relative humidity and sea level rise for the sub-cluster in which Perth is located, relative to the 1986–2005 average. The projections have been derived from the available global climate model simulations in the CMIP5 archive (up to 40 models) driven by RCP4.5 and RCP8.5 (intermediate and high emission scenarios for greenhouse gases and aerosols). For 2030, results for all RCP's are similar so only RCP4.5 values are shown. The median projection is shown with the 10th to 90th percentile range in brackets (*5th to 95th for sea level rise projections).

Variable	Season	2030	2090	
		RCP4.5	RCP4.5	RCP8.5
Temperature (°C)	**Annual**	**0.8** (0.6 to 1)	**1.7** (1.1 to 2.1)	**3.5** (2.6 to 4.2)
Rainfall (%)	**Annual**	**-6** (-15 to -1)	**-12** (-22 to -1)	**-18** (-37 to -5)
	Summer	-8 (-31 to +17)	-4 (-29 to +28)	-5 (-31 to +36)
	Autumn	-4 (-20 to +10)	-4 (-26 to +12)	-6 (-32 to +13)
	Winter	-7 (-18 to +4)	-14 (-28 to -4)	-29 (-44 to -15)
	Spring	-11 (-23 to +4)	-19 (-36 to +1)	-36 (-59 to -14)
Evapotranspiration (%)	**Annual**	**2.5** (1.2 to 3.5)	**5.4** (3.4 to 7.2)	**10.3** (7.1 to 15.2)
Wind speed (%)	**Annual**	**-0.1** (-1.7 to +1.1)	**-0.3** (-2.6 to +1.4)	**+0.3** (-2.7 to +3.3)
Solar radiation (%)	**Annual**	**+0.6** (-0.4 to +1.6)	**1** (0 to 2.1)	**+1** (-0.6 to +3)
Relative humidity (%) (absolute)	**Annual**	**-0.6** (-1.5 to +0.1)	**-1.2** (-2.3 to 0)	**-2.2** (-3.8 to -1)
Sea level rise (m)* (Fremantle)	**Annual**	**0.12** (0.07 to 0.16)	**0.46** (0.28 to 0.65)	**0.61** (0.39 to 0.84)

Table 4: Average annual number of days above 35 and 40 °C for Perth for the 30-year period centred on 1995 (1981–2010) and for the future 30-year periods (centred on 2030 and 2090) for two RCPs. The median projection across the models is shown with the 10th and 90th percentile range of model results in brackets.

Threshold	Current (1981–2010 average)	2030	2090	
		RCP4.5	RCP4.5	RCP8.5
Over 35 °C	**28**	**36** (33 to 39)	**43** (37 to 52)	**63** (50 to 72)
Over 40 °C	**4**	**6.7** (5.4 to 7.5)	**9.7** (6.9 to 13)	**20** (12 to 25)
Below 2 °C	**3.4**	**2.1** (2.5 to 1.4)	**0.9** (1.3 to 0.7)	**0.1** (0.4 to 0.0)

From Webb, L.B. and Hennessy, K. 2015. Projections for selected Australian cities, CSIRO and Bureau of Meteorology, Australia.

Climate change in the Monsoonal North of WA

Overview

The Monsoonal North West covers the Kimberley region of WA. This region experiences a pronounced wet and dry season, with differences in the timing between eastern and western parts (Moise et al. 2015).

Temperature

Higher temperatures

- Mean temperatures have increased by about 1 °C since 1910.
- Mean, maximum and minimum temperatures will continue to increase in all seasons.
- By 2030, the mean annual warming is projected to be 0.5 to 1.3 °C above the climate of 1986–2005, with only minor differences between RCPs.

Table 5: Projected temperature change (°C) for the Monsoonal North region compared with 1986–2005 for 20-year periods (centred on 2030 and 2090) and three RCPs. The median projection across the models is shown with the 10th and 90th percentile range of model results in brackets.

Mean annual warming above the climate of 1986–2005			
	RCP2.6 Low	**RCP4.5** Intermediate	**RCP8.5** High
2030	0.8 °C (0.5 to 1.2)	0.9 °C (0.6 to 1.3)	1.0 °C (0.7 to 1.3)
2090	0.9 °C (0.5 to 1.6)	1.8 °C (1.3 to 2.7)	3.8 °C (2.8 to 5.1)

Use the Climate Change in Australia threshold calculator to find out the frequency of days exceeding selected temperature thresholds in your region.

Hotter and more frequent hot days

- The temperature and frequency of very hot days are expected to increase, and heatwaves will get longer and hotter.
- In Broome, the number of days above 35 °C is expected to increase from 56 to 87 by 2030 and up to 133 days by 2090 under RCP4.5. This means days with temperatures over 35 °C could be experienced for about a third of the year by late century. Under a high emissions future (RCP8.5), the number of days over 35 °C could increase to 231 days (see table 6).

Lake Argyle

Explore what the future climate will be like in towns across Western Australia using the climate analogues tool on the Climate Change in Australia website at www.climatechangeinaustralia.gov.au.

The tool matches projected rainfall and maximum temperature in one location with the current climate experienced in another location for 2030, 2050 and 2090.

In 2050, under a high emissions scenario, the climate of Broome will be more like the current climate of Derby, and the climate of Halls Creek could be more like the current climate of Looma.

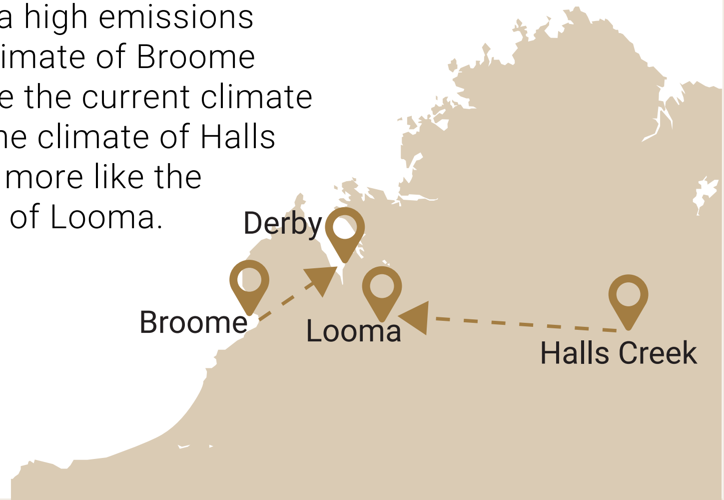


Table 6: Average annual number of days of 35 and 40 °C for Broome for the 30-year period centred on 1995 (1981–2010) and for future 30-year periods and two RCPs. The median projection across the models is shown with the 10th and 90th percentile range of model results in brackets.

Threshold	Current	2030	2090	
		RCP4.5	RCP4.5	RCP8.5
Over 35 °C	**56**	**87** (72 to 111)	**133** (94 to 204)	**231** (173 to 282)
Over 40 °C	**4**	**7.2** (6.0 to 9.3)	**11** (7.7 to 22)	**30** (17 to 61)

Current = 1981–2010 average.

Rainfall

Large increases or decreases in rainfall

- The region experienced an overall slight increase in rainfall during the 20th century. This includes prolonged periods of drying as well as above-average rainfall.
- There is generally low confidence in projected rainfall changes for later in the century (2090) in this region.
- By 2030, the magnitude of possible summer rainfall changes is about -10 to +5 per cent.
- Late in the century (2090) it is about -15 to +7 per cent under RCP4.5 and about -24 to +24 per cent under RCP8.5.

Increased intensity of heavy rainfall events, changes to drought are less clear

- There is high confidence that the intensity of heavy rainfall events will increase. The magnitude of change, and the time when any change may be evident against natural variability, cannot be reliably projected.
- There is low confidence in projected changes in the frequency and duration of extreme meteorological drought.

Table 7: Projected rainfall differences (per cent) for the Monsoonal region compared with 1986–2005 for 20-year periods (centred on 2030 and 2090) and two RCPs. The 10th and 90th percentile range of model results is shown. For 2030, results for all RCPs are similar so only RCP4.5 values are shown. Median results are not shown here because models do not always agree on the direction of change.

	2030	2090	
	RCP4.5	RCP4.5	RCP8.5
Annual	**-10 to +5**	**-15 to +7**	**-24 to +24**
Summer	-7 to +9	-17 to +9	-24 to +20
Autumn	-19 to +9	-19 to +15	-31 to +3
Winter	-31 to +19	-39 to +19	-53 to +44
Spring	-26 to +18	-30 to +29	-46 to +30

Winds, storms and weather systems

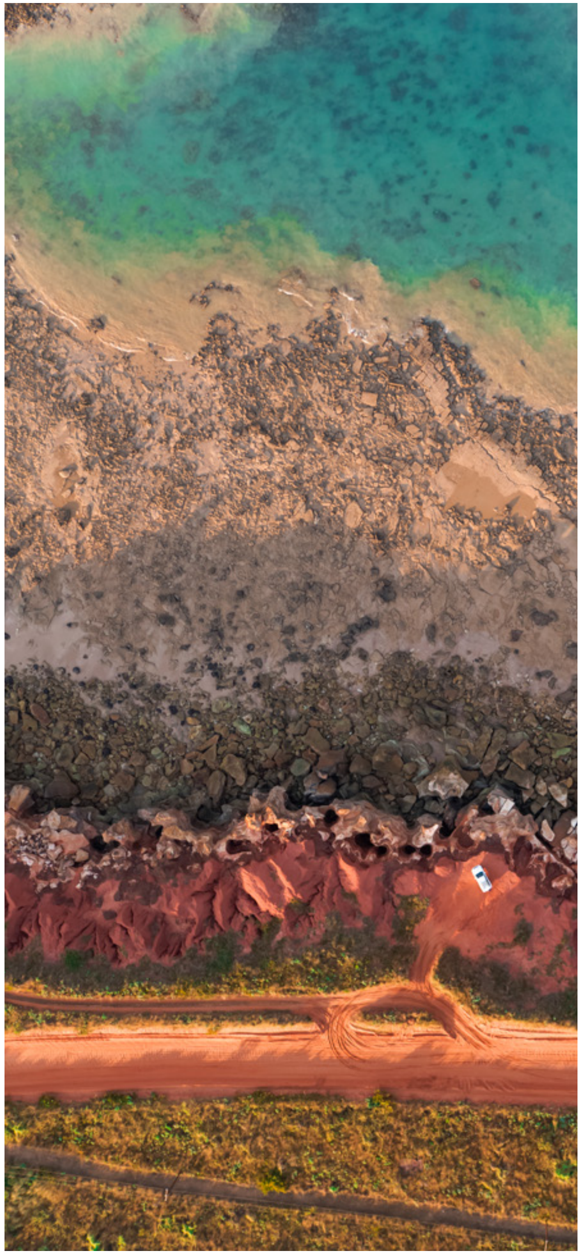
Fewer but possibly more intense tropical cyclones

- The north-west coastline between Broome and Exmouth is the most cyclone-prone region of the Australian coast (Bureau of Meteorology n.d.).
- Tropical cyclones are projected to decrease in frequency but it is expected that a greater proportion will be higher intensity.

Fire weather

Changes to fire conditions not clear

- The primary determinant of bushfire in the Monsoonal North is fuel availability which varies mainly with rainfall.
- In the Kimberley, where abundant rainfall and bushfire are common, climate change is not expected to change the frequency of fire (high confidence). However, when fire does occur, there is high confidence that fire behaviour will be more extreme.



Gantheaume Point, Broome (© Tourism WA)

Marine and coastal projections

Higher sea levels and more frequent sea level extremes

- There is very high confidence that sea levels will continue to rise across the region.
- By 2030, the projected range of sea-level rise is 0.06 to 0.17 m above the 1986–2005 level, with only minor differences between emission scenarios.
- Sea levels will rise across the region.
  - 0.28 to 0.64 m for RCP4.5
  - 0.38 to 0.85 m for RCP8.5.

Warmer and more acidic oceans in the future

- Coastal waters across the region are projected to warm by 2.2 to 4.1 °C by 2090 under high emissions.
- There is very high confidence that the ocean around Australia will become more acidic and also high confidence that the rate of ocean acidification will be proportional to carbon dioxide emissions.
- By 2030 pH is projected to fall by an additional 0.07 units in the coastal waters of the cluster.
- By 2090, a decrease of up to 0.14 is projected under RCP4.5 and up to 0.3 under RCP8.5. These values would represent a 40 and 100 per cent increase in acidity respectively.

Table 8: Projected sea-level change (metres) for Broome compared with 1986–2005 for 20-year periods (centred on 2030 and 2090) and three RCPs. The median projection across the model is shown with the range of the model results in brackets. These ranges of sea-level rise are considered 'likely'. However, if a collapse in the marine-based sectors of the Antarctic ice sheet were initiated these projections could be several tenths of a meter higher by late century.

Region	2030			2090		
	RCP2.6	RCP4.5	RCP8.5	RCP2.6	RCP4.5	RCP8.5
Broome	0.12 (0.07 to 0.16)	0.12 (0.07 to 0.16)	0.13 (0.08 to 0.17)	0.38 (0.22 to 0.55)	0.46 (0.30 to 0.64)	0.61 (0.40 to 0.84)

Climate change in the Rangelands of WA

Overview

The Rangelands of WA contains many varied landscapes and includes the town of Kalgoorlie, the ranges of the Pilbara and the coasts of Carnarvon. Cattle and sheep grazing are important agricultural activities. Rainfall systems vary from seasonally reliable monsoonal influences in the far north through to very low and variable rainfall patterns in much of the centre and south (Watterson et al. 2015).

Temperature

Higher temperatures

- Mean temperatures have increased by about 0.9 °C in the south and 1.0 °C in the north since 1910.
- Mean, maximum and minimum temperatures are projected to continue to rise.
- By 2030, the mean annual warming across all emissions scenarios is projected to be about 0.6 to 1.4 °C above the climate of 1986–2005.
- By 2090, temperatures are projected to be 1.5 to 2.9 °C warmer under an intermediate emissions scenario (RCP 4.5).

Table 9: Projected temperature change (°C) for the Rangelands region compared with 1986–2005 for 2030–2039 (2030) and 2080–2099 (2090) and three RCPs. The median projection across the models is shown with the 10th and 90th percentile range of model results in brackets.

Mean annual warming above the climate of 1986–2005			
	RCP2.6 Low	**RCP4.5** Intermediate	**RCP8.5** High
2030	0.9 °C (0.6 to 1.3)	1.0 °C (0.6 to 1.4)	1.0 °C (0.8 to 1.4)
2090	1.1 °C (0.6 to 1.8)	2.1 °C (1.5 to 2.9)	4.3 °C (2.9 to 5.3)

Hotter and more frequent hot days. Less frost

- A substantial increase in the temperature reached on the hottest days and the frequency of hot days is projected with very high confidence.
- In Kalgoorlie, the number of days above 35 °C is expected to increase from 42 to 54 by 2030 and up to 66 days by 2090 under RCP4.5. Under a high emissions future (RCP8.5), the number of days over 35 °C could increase by 117 percent to 91 days per year.

Table 10: Average annual number of days of 35 and 40 °C for three locations for the 30-year period centred on 1995 (1981–2010) and for future 30-year periods and two RCPs. The mean projection across the models is shown rounded to the nearest day.

Location	Threshold	Current (1981–2010 average)	2030	2090	
			RCP4.5	RCP4.5	RCP8.5
Mount Magnet	**Over 35 °C**	**88**	107	122	154
	Over 40 °C	**25**	40	51	84
Kalgoorlie	**Over 35 °C**	**42**	54	66	91
	Over 40 °C	**9**	15	20	34
Marble Bar	**Over 35 °C**	**197**	220	238	273
	Over 40 °C	**94**	122	144	188

Rainfall

Less rainfall in winter. Changes in other seasons unclear

South Rangelands

- There has been a small decline in winter rainfall since 1960.
- Winter rainfall is projected to decrease in the South Rangelands with high confidence under both intermediate (RCP4.5) and high (RCP8.5) emissions scenarios.
- Decreases are also projected for spring but with medium confidence only.
- Changes to summer and annual rainfall for late in the century (2090) are possible but the direction of change cannot be confidently projected given the spread of results.

North-west Rangelands

- Observations show an increasing trend in summer rainfall over the north-west of the Rangelands, although with intermittent periods of wetter and drier conditions throughout the 20th century.
- Year-to-year variability is strongly influenced by the El Niño Southern Oscillation.
- Changes to rainfall are possible but the direction of change cannot be confidently projected given the spread of model results.
- Impact and risk assessments in this region should consider the risk of both a drier and wetter climate.

Explore what the future climate will be like in towns across Western Australia using the climate analogues tool on the Climate Change in Australia website at www.climatechangeinaustralia.gov.au.

In 2050, under a high emissions scenario, the climate of Dalwallinu will be more like the current climate of Morawa, and the climate of Kalgoorlie could be more like the current climate of Leonora

Table 11: Projected rainfall differences (per cent) for the Rangelands region on average compared with 1986–2005 for 20-year periods (centred on 2030 and 2090) and two RCPs. The 10th and 90th percentile range of model results is shown. For 2030, results for all RCPs are similar so only RCP4.5 values are shown. Median results are not shown here because models do not always agree on the direction of change.

	2030	2090	
	RCP4.5	RCP4.5	RCP8.5
Annual	**-11 to +6**	**-15 to +7**	**-32 to +18**
Summer	-16 to +7	-16 to +10	-22 to +25
Autumn	-23 to +20	-23 to +27	-42 to +32
Winter	-20 to +14	-35 to +7	-50 to +18
Spring	-21 to +19	-26 to +11	-50 to +23

Fire

Increased intensity of heavy rainfall events. Changes to drought less clear

- Under all emissions scenarios, there is high confidence that the intensity of heavy rainfall events will increase.
- There is low confidence in projecting how the frequency and duration of extreme meteorological drought may change, although there is medium confidence that under RCP8.5 the time spent in drought will increase by 2090.

Fewer but possibly more intense tropical cyclones

- The north-west coastline between Exmouth and Broome is the most cyclone-prone region of the Australian coast (Bureau of Meteorology n.d.). The frequency of cyclones has remained relatively stable in WA but it is thought that the intensity has increased. This trend is expected to continue with medium confidence.

Increased evaporation rates, and reduced soil moisture. Changes to runoff unclear

- Potential evapotranspiration is expected to increase in all seasons, with the largest absolute rates occurring in 2090.
- Soil moisture projections suggest overall seasonal decreases by 2090 but predominately in winter.

A harsher fire weather climate

- Bushfire in the Rangelands depends highly on fuel availability, which mainly depends on rainfall. As a result, bushfire activity is very episodic in most of the Rangelands.
- There is high confidence that climate change will result in a harsher fire weather climate in the future.
- There is low confidence in the magnitude of the change as this is strongly dependent on rainfall projections.

Port Hedland

Marine and coastal projections

Higher sea levels and more frequent sea level extremes

- There is very high confidence that sea levels will continue to rise during the 21st century.
- By 2030, the projected range of sea-level rise at Port Hedland is 0.07 to 0.17 m above the 1986–2005 level, with only minor differences between emission scenarios.
- By 2090, projected sea level rise is:
  - 0.28 to 0.64 m for RCP4.5
  - 0.40 to 0.84 m RCP8.5.
- These ranges of sea level rise for 2090 are considered likely (at least 66 per cent probability).

Warmer and more acidic oceans

- By 2090 in the region, coastal waters are projected to warm by 2.4 to 3.7 °C under a high emissions scenario (RCP8.5.)
- There is very high confidence that oceans will become more acidic and that the rate of ocean acidification will be proportional to carbon dioxide emissions.
- By 2030, pH is projected to fall by an additional 0.07 units in the coastal waters of the Rangelands region.
- By 2090, a decrease of up to 0.14 pH units is projected under RCP4.5 and a decrease of up to 0.3 units under RCP8.5. These values would represent a 40 per cent and 100 per cent increase in acidity respectively.

Heatwaves occur in the ocean, as well as on land, and can contribute to coral bleaching and the death of marine life. The number of marine heatwave days a year increased by over 50 per cent between 1987 and 2016, compared with the period from 1925–54 (Smale et al. 2019). In December 2019, the WA coastline experienced its most widespread marine heatwave since reliable recording began in 1993, with ocean temperatures 1.5 to 2 °C warmer than normal for that month (Ceranic 2019).

Table 12: Projected sea-level change (metres) for four Rangelands sites compared with 1986–2005 for 20-year periods (centred on 2030 and 2090) and three RCPs. The median projection across the models is shown with the range of model results in brackets. These ranges of sea-level rise are considered 'likely'. However, if a collapse in the marine based sectors of the Antarctic ice sheet were initiated these projections could be several tenths of a meter higher by late century.

Region	2030			2090		
	RCP2.6	RCP4.5	RCP8.5	RCP2.6	RCP4.5	RCP8.5
Port Hedland	0.11 (0.07 to 0.16)	0.12 (0.07 to 0.16)	0.12 (0.08 to 0.17)	0.38 (0.22 to 0.55)	0.46 (0.28 to 0.64)	0.61 (0.40 to 0.84)
Onslow	0.12 (0.07 to 0.17)	0.12 (0.07 to 0.17)	0.13 (0.08 to 0.17)	0.39 (0.22 to 0.56)	0.46 (0.28 to 0.65)	0.62 (0.40 to 0.85)
Carnarvon	0.12 (0.07 to 0.16)	0.12 (0.07 to 0.16)	0.13 (0.08 to 0.18)	0.39 (0.22 to 0.57)	0.46 (0.28 to 0.65)	0.62 (0.40 to 0.85)

Other Resources

Understanding global climate change

- The Intergovernmental Panel on Climate Change (IPCC) provides regular assessments of the scientific basis of climate change, its impacts and future risks, and options for adaptation and mitigation. The IPCC is now in its sixth assessment cycle. The Sixth Assessment Report (AR6) will include contributions by three Working Groups and a Synthesis Report, three Special Reports, and a refinement to its latest Methodology Report. The Synthesis Report will be the last of the AR6 products, currently due for release in 2022. More information on the Sixth Assessment cycle is available at www.ipcc.ch/assessment-report/ar6/

Accessing historical climate data

- Historical weather data is available via the Bureau of Meteorology's Climate Data Online portal. The results provide insight into historical averages, including extremes such as number of days over 35 °C per year, daily rainfall records, and wind speeds.

Karijini National Park (© Tourism WA)

Glossary

Adaptation	The process of adjustment to actual or expected climate and its effects. Adaptation can be autonomous or planned.
Aerosol	A suspension of very small solid or liquid particles in the air, residing in the atmosphere for at least several hours.
Atmosphere	The gaseous envelope surrounding the Earth. The dry atmosphere consists almost entirely of nitrogen and oxygen, together with a number of trace gases (e.g. argon, helium) and greenhouse gases (e.g. carbon dioxide, methane, nitrous oxide). The atmosphere also contains aerosols and clouds.
Carbon dioxide	A naturally occurring gas, also a by-product of burning fossil fuels from fossil carbon deposits (such as oil, gas and coal), of burning biomass, of land use changes and of industrial processes (e.g. cement production). It is the principle anthropogenic greenhouse gas that affects the Earth's radiative balance.
Climate	The average weather experienced at a site or region over a period of many years, ranging from months to many thousands of years. The relevant measured quantities are most often surface variables such as temperature, rainfall and wind.
Climate change	A change in the state of the climate that can be identified (e.g. by statistical tests) by changes in the mean and/or variability of its properties, and that persists for an extended period of time, typically decades or longer.
Climate projection	The simulated response of the climate system to a scenario of future emission or concentration of greenhouse gases and aerosols, generally derived using climate models. Climate projections are distinguished from climate predictions by their dependence on the emission/concentration/radiative forcing scenario used, which in turn is based on assumptions concerning, for example, future socio-economic and technological developments that may or may not be realised.
Climate scenario	A plausible and often simplified representation of the future climate. This is based on an internally consistent set of climatological relationships that has been constructed for explicit use in investigating the potential consequences of anthropogenic climate change, often serving as input to impact models
Climate variability	Variations in the mean state and other statistics (such as standard deviations, the occurrence of extremes, etc.) of the climate on all spatial and temporal scales beyond that of individual weather events. Variability may be because of natural internal processes within the climate system (internal variability), or to variations in natural or anthropogenic external forcing (external variability).
CMIP5 and CMIP6	Phases five and six of the Coupled Model Intercomparison Project, which coordinated and archived climate model simulations based on shared model inputs by modelling groups from around the world. The CMIP5 dataset includes projections using the Representative Concentration Pathways (RCPs) and is used in this document. The CMIP6 dataset informed the recently released Intergovernmental Panel on Climate Change (IPCC) Sixth Assessment Report (AR6). CMIP6 downscaled projections are not currently available for Western Australia.

Confidence	The validity of a finding based on the type, amount, quality and consistency of evidence (e.g. mechanistic understanding, theory, data, models, expert judgment) and on the degree of agreement.
Downscaling	A method that derives local to regional-scale information from larger-scale models or data analyses. Different methods exist (e.g. dynamical, statistical and empirical downscaling).
Drought	A period of time when an area or region experiences below-normal precipitation. The lack of adequate precipitation, either rain or snow, can cause reduced soil moisture or groundwater, diminished stream flow, crop damage, and a general water shortage.
Emissions scenario	A plausible representation of the future development of emissions of substances that are potentially radiatively active (e.g. greenhouse gases, aerosols) based on a coherent and internally consistent set of assumptions about driving forces (such as demographic and socio-economic development, technological change) and their key relationships.
Evapotranspiration	Part of the water cycle which moves liquid water from an area with vegetation and into the atmosphere by the processes of both transpiration and evaporation.
Extreme weather	An event that is rare at a particular place and time of year. Definitions of rare vary but an extreme weather event would normally be as rare as or rarer than the 10th or 90th percentile of a probability density function estimated from observations.
Fire weather	Weather conditions conducive to triggering and sustaining wildfires, usually based on a set of indicators and combinations of indicators including temperature, soil moisture, humidity, and wind. Fire weather does not include the presence or absence of fuel load.
Greenhouse gas	Gaseous constituents of the atmosphere, both natural and anthropogenic, that absorb and emit radiation at specific wavelengths within the spectrum of terrestrial radiation emitted by the Earth's surface, the atmosphere itself, and by clouds. Water vapour (H_2O), carbon dioxide (CO_2), nitrous oxide (N_2O), methane (CH_4) and ozone (O_3) are the primary greenhouse gases in the Earth's atmosphere.
Monsoon	A tropical and subtropical seasonal reversal in both the surface winds and associated rainfall, caused by differential heating between a continental-scale land mass and the adjacent ocean. Monsoon rains occur mainly over land in summer.
Percentile	A value on a scale of 100 that indicates the percentage of the data set values that is equal to, or below it. The percentile is often used to estimate the extremes of a distribution. For example, the 90th (or 10th) percentile may be used to refer to the threshold for the upper (or lower) extremes.
Representative Concentration Pathways (RCPs)	Follow a set of greenhouse gas, air pollution (e.g. aerosols) and land-use scenarios that are consistent with certain socio-economic assumptions of how the future may evolve over time. The well-mixed concentrations of greenhouse gases and aerosols in the atmosphere are affected by emissions as well as absorption through land and ocean sinks. There are four RCPs that represent the range of plausible futures from the published literature.
Risk	The potential for consequences where something of value is at stake and where the outcome is uncertain. Risk is often represented as a probability of occurrence of hazardous events or trends multiplied by the consequences if these events occur.

References

Australian Bureau of Statistics (2021), National, state and territory population [Internet]. Canberra (ACT): Commonwealth of Australia; 2021 [cited 7 Sep 21]. Available from: www.abs.gov.au/statistics/people/population/national-state-and-territory-population/dec-2020

Bureau of Meteorology (n.d.), *Climatology of tropical cyclones in Western Australia*, Bureau of Meteorology, website accessed 4 August 2021.

Bureau of Meteorology (n.d.), *Regional Weather and Climate Guides*, Bureau of Meteorology, website accessed 11 August 2021.

Ceranic I (2019), *As heatwave bakes Australia on land, an unprecedented marine heatwave causes fish kills in the ocean*, ABC News, accessed 4 August 2021.

Church JA, Hunter JR, McInnes KL, White NJ (2006), *Sea-level rise around the Australian coastline and the changing frequency of extreme sea-level events*, Australian Meteorological Magazine, 55(4): pp. 253-60.

CSIRO and Bureau of Meteorology (2015), *Climate Change in Australia Information for Australia's Natural Resource Management Regions: Technical Report*, CSIRO and Bureau of Meteorology, Australia.

CSIRO and Bureau of Meteorology (n.d.), Climate Change in Australia website, accessed 4 August 2021.

Department of Biodiversity, Conservation and Attractions, (2019), *Draft Perth Water Buneenboro Precinct Plan*, Government of Western Australia.

Hope, P et al. (2015), *Southern and South-Western Flatlands Cluster Report, Climate Change in Australia Projections for Australia's Natural Resource Management Regions: Cluster Reports*, eds. Ekström, M et al., CSIRO and Bureau of Meteorology, Australia.

IPCC, 2021: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., P. Zhai, A. Pirani, S. L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M. I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J. B. R. Matthews, T. K. Maycock, T. Waterfield, O. Yelekçi, R. Yu and B. Zhou (eds.)]. Cambridge University Press. In Press.

IPCC, 2018: Summary for Policymakers. In: *Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty*, World Meteorological Organization, Geneva, Switzerland, 32 pp.

Moise, A et al. (2015), *Monsoonal North Cluster Report, Climate Change in Australia Projections for Australia's Natural Resource Management Regions: Cluster Reports*, eds. Ekström, M et al., CSIRO and Bureau of Meteorology, Australia.

Siebentritt, M (2016), *Understanding sea-level rise and climate change, and associated impacts on the coastal zone*, CoastAdapt Information Manual 2.

Smale DA, Wernberg T, Oliver ECJ, Thomsen M, Harvey BP, Straub SC et al. (2019), *Marine heatwaves threaten global biodiversity and the provision of ecosystem services*, Nature Climate Change 9: 306-312.

University of Cambridge (2013), *Climate change: action, trends and implications for business*, the IPCC's Fifth Assessment Report, Working Group 1, Cambridge Judge Business School with the Cambridge Programme for Sustainability Leadership and European Climate Foundation.

Watterson, I et al. (2015), *Rangelands Cluster Report, Climate Change in Australia Projections for Australia's Natural Resource Management Regions: Cluster Reports*, eds. Ekström, M et al., CSIRO and Bureau of Meteorology, Australia.

Webb, L.B. and Hennessy, K, (2015), *Projections for selected Australian cities*, CSIRO and Bureau of Meteorology, Australia.

Appendix 1: Climate projection summary – South Western Flatlands region

Summary of projections for the South Western Flatlands region of WA, for two time periods (2030 and 2090) and for two emissions scenarios (RCP4.5 and RCP8.5) compared with 1986–2005

Variable		Current (1986–2005)	2030		2090	
			RCP4.5	RCP8.5	RCP4.5	RCP8.5
Annual rainfall			-13 to 0% (minor difference between scenarios)		-22 to -1%	-36 to -2%
Extreme rainfall and drought		Under all emissions scenarios, the time spent in drought is projected to increase. The intensity of heavy rainfall events is also projected to increase with medium confidence.				
Average temperatures			+0.8 °C (0.5 to 0.9)	+0.8 °C (0.5 to 1.1)	+1.7 °C (1.2 to 2.0)	+3.4 °C (2.6 to 4.0)
Frequency of hot days in Perth	**Days over 35 °C**	28 days	36 days	-	43 days	63 days
	Days over 40 °C	4 days	6.7 days	-	9.7 days	20 days
Fire weather (average number of days with a 'severe' fire danger rating)		4.2 days	5 days (19% ↑)	4.7 days (12% ↑)	5.3 days (26% ↑)	6.9 days (64% ↑)
Sea level rise			+0.07 to 0.17 m (minor difference between scenarios)		+0.28 to 0.65 m	+0.39 to 0.85 m

Appendix 2: Climate projection summary – the Monsoonal North

Summary of projections for the Monsoonal North region of WA, for two time periods (2030 and 2090) and for two emissions scenarios (RCP4.5 and RCP8.5) compared with 1986–2005

Variable		Current (1986–2005)	2030		2090	
			RCP4.5	RCP8.5	RCP4.5	RCP8.5
Annual rainfall			Providing confident rainfall projections for the Monsoonal North cluster is difficult because global climate models offer diverse results, and models have shortcomings in resolving some tropical processes. Natural climate variability is projected to remain the major driver of rainfall changes in the next few decades.			
			-10 to +5% (minor difference between scenarios)		-15 to +7%	-24 to +24%
Tropical cyclones			The north-west coastline between Broome and Exmouth is the most cyclone-prone region of the Australian coast (Bureau of Meteorology n.d.). The frequency of cyclones has remained relatively stable in WA but it is thought that the intensity has increased. This trend is expected to continue with medium confidence.			
Extreme rainfall and drought			There is high confidence that the intensity of heavy rainfall events will increase. The magnitude of change, and the time when any change may be evident against natural variability, cannot be reliably projected. There is low confidence in projecting changes in the frequency and duration of extreme meteorological drought.			
Average temperatures			+0.9 °C (0.6 to 1.3)	+1.0 °C (0.7 to 1.3)	+1.8 °C (1.3 to 2.7)	+3.8 °C (2.8 to 5.1)
Frequency of hot days in Broome	**Days over 35 °C**	56 days	87 days	-	133 days	231days
	Days over 40 °C	4 days	7.2 days	-	11 days	30 days
Fire weather (average number of days with a 'severe' fire danger rating)			The primary determinant of bushfire in the Monsoonal North is fuel availability, which varies mainly with rainfall. In the Kimberley, where abundant rainfall and bushfire are common, climate change is not expected to change the frequency of fire (high confidence). However, when fire does occur, there is high confidence that fire behaviour will be more extreme.			
Sea level rise			+0.07 to 0.17 m (minor difference between scenarios)		+0.30 to 0.64 m	+0.40 to 0.84 m

Appendix 3: Climate projection summary – the Rangelands

Summary of projections for the Rangelands region of WA, for two time periods (2030 and 2090) and for two emissions scenarios (RCP4.5 and RCP8.5) compared with 1986–2005

Variable		Current (1986–2005)	2030		2090	
			RCP4.5	RCP8.5	RCP4.5	RCP8.5
Annual rainfall			-11 to +6%		-15 to +7%	-32 to +18%
Tropical cyclones			The north-west coastline between Exmouth and Broome is the most cyclone-prone region of the Australian coast (Bureau of Meteorology n.d.). The frequency of cyclones has remained relatively stable in WA but it is thought that the intensity has increased. This trend is expected to continue with medium confidence.			
Extreme rainfall and drought			There is high confidence in a future increase in the intensity of extreme rainfall events. However, the magnitude of the increases cannot be confidently projected.			
Average temperatures			+1.0 °C (0.6 to 1.4)	+1.0 °C (0.8 to 1.4)	+ 2.1 °C (1.5 to 2.9)	+4.3 °C (2.9 to 5.3)
Frequency of hot days in Kalgoorlie	**Days over 35 °C**	42 days	54 days	-	66 days	91 days
	Days over 40 °C	9 days	15 days	-	20 days	34 days
Fire weather (average number of days with a 'severe' fire danger rating)			There is high confidence that climate change will result in a harsher fire weather climate in the future. There is low confidence in the magnitude of the change as this is strongly dependent on rainfall projections.			
Sea level rise			+0.07 to 0.17 m (minor difference between scenarios)		+0.28 to 0.64 m	+0.40 to 0.84 m

Department of Water and Environmental Regulation

Prime House 8 Davidson Terrace Joondalup WA 6027
Locked Bag 10 Joondalup DC WA 6919

Phone 08 6364 7000

For further information
Email: climate@dwer.wa.gov.au