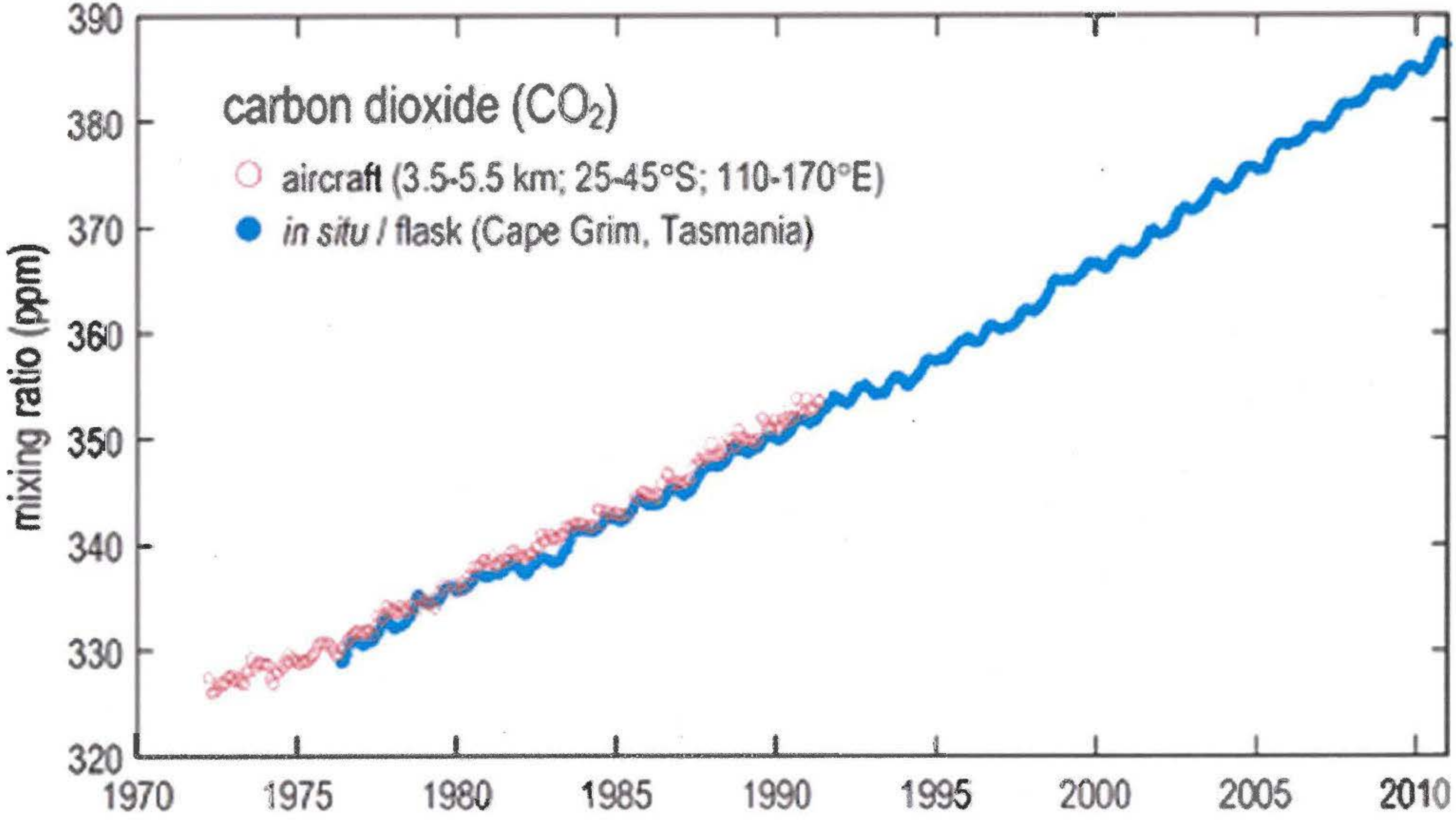
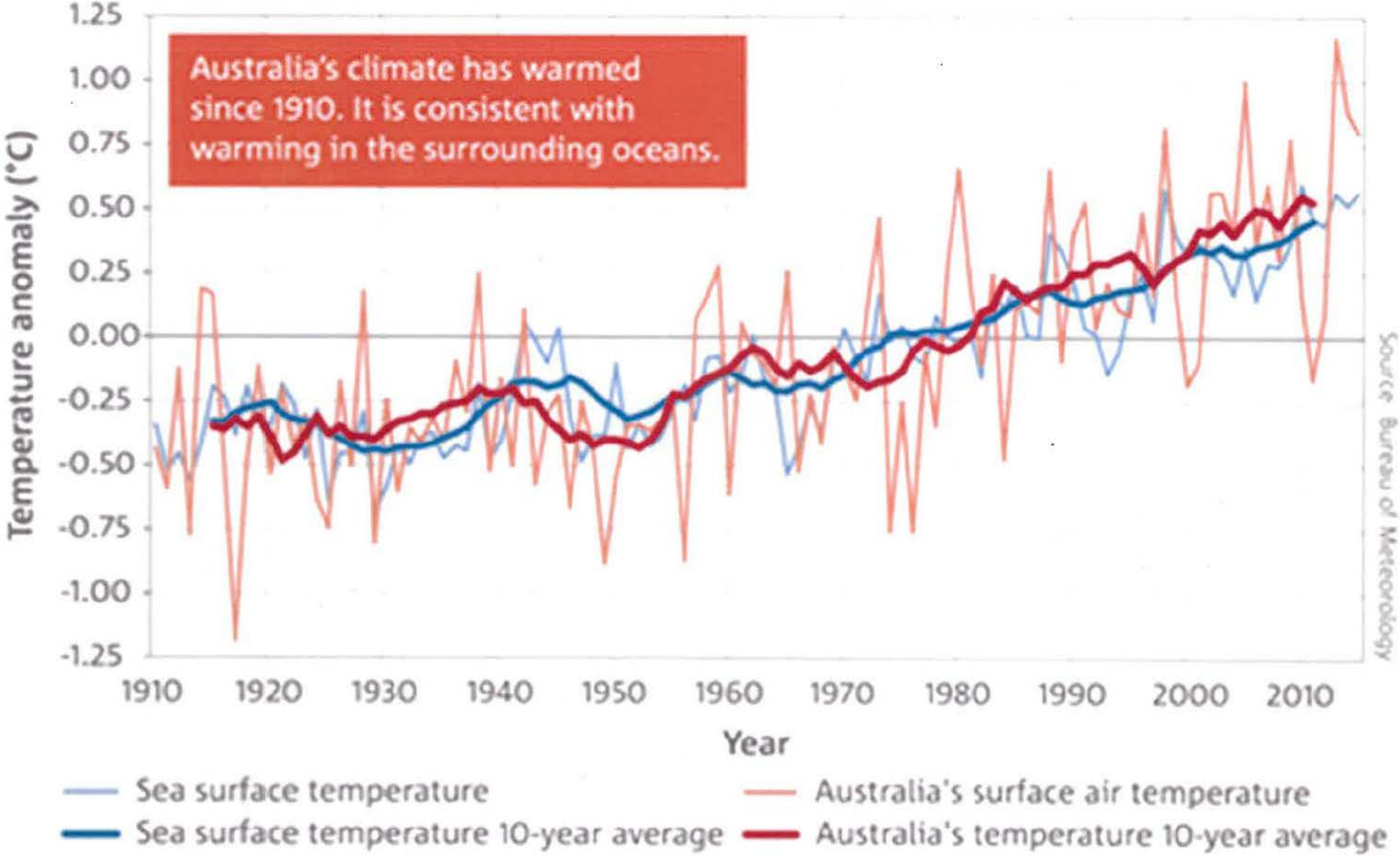
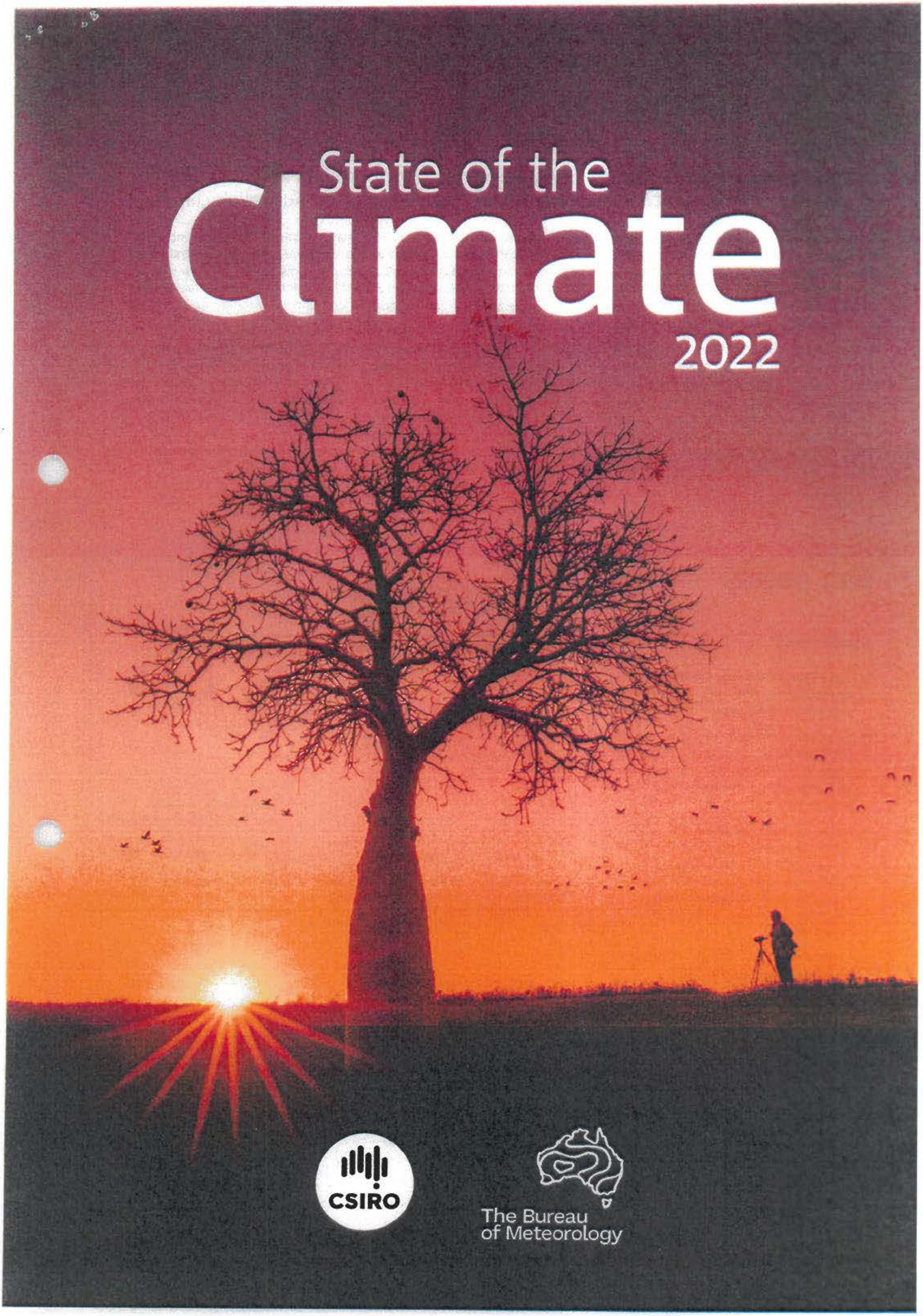


carbon dioxide (CO_2)
aircraft (3.5-5.5 km; 25-45°S; 110-170°E)
in situ / flask (Cape Grim, Tasmania)
mixing ratio (ppm)
390
380
370
360
350
340
330
320
1970
1975
1980
1985
1990
1995
2000
2005
2010



Australia's climate has warmed since 1910. It is consistent with warming in the surrounding oceans.
Temperature anomaly (°C)
1.25
1.00
0.75
0.50
0.25
0.00
-0.25
-0.50
-0.75
-1.00
-1.25
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
Year
Source Bureau of Meteorology
Sea surface temperature
Sea surface temperature 10-year average
Australia's surface air temperature
Australia's temperature 10-year average

State of the Climate 2022



CSIRO

The Bureau of Meteorology

Report at a glance

The Bureau of Meteorology and CSIRO play an important role in monitoring, analysing and communicating observed and future changes in Australia's climate.

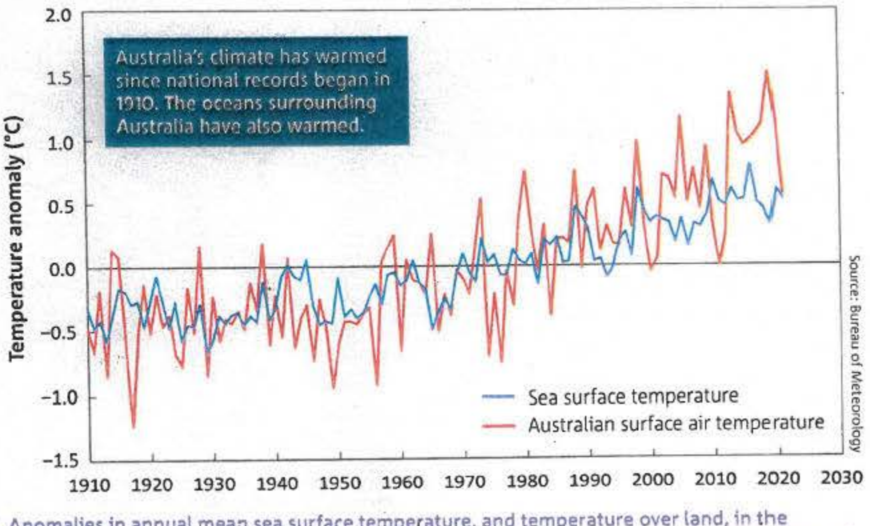
This seventh biennial State of the Climate report draws on the latest national and international climate research, encompassing observations, analyses and future projections to describe year-to-year variability and longer-term changes in Australia's climate. The report is a synthesis of the science informing our understanding of Australia's climate. It includes new information since the last report in 2020, such as that published in the 2021 Sixth Assessment Report by the Intergovernmental Panel on Climate Change (IPCC). The State of the Climate report is intended to inform a range of economic, environmental and social decision-making by governments, industries and communities.

Observations, reconstructions of past climate and climate modelling continue to provide a consistent picture of ongoing, long-term climate change interacting with underlying natural variability. Associated changes in weather and climate extremes—such as extreme heat, heavy rainfall and coastal inundation, fire weather and drought—have a large impact on the health and wellbeing of our communities and ecosystems. These changes are happening at an increased pace—the past decade has seen record-breaking extremes leading to natural disasters that are exacerbated by anthropogenic (human-caused) climate change. These changes have a growing impact on the lives and livelihoods of all Australians. Australia needs to plan for, and adapt to, the changing nature of climate risk now and in the decades ahead. The severity of impacts on Australians and our environment will depend on the speed at which global greenhouse gas emissions can be reduced.

Key points

Australia

- Australia's climate has warmed by an average of 1.47 ± 0.24 °C since national records began in 1910.
- Sea surface temperatures have increased by an average of 1.05 °C since 1900. This has led to an increase in the frequency of extreme heat events over land and sea.
- There has been a decline of around 15 per cent in April to October rainfall in the southwest of Australia since 1970. Across the same region, May to July rainfall has seen the largest decrease, by around 19 per cent since 1970.
- In the south-east of Australia, there has been a decrease of around 10 per cent in April to October rainfall since the late 1990s.
- There has been a decrease in streamflow at most gauges across Australia since 1975.
- Rainfall and streamflow have increased across parts of northern Australia since the 1970s.

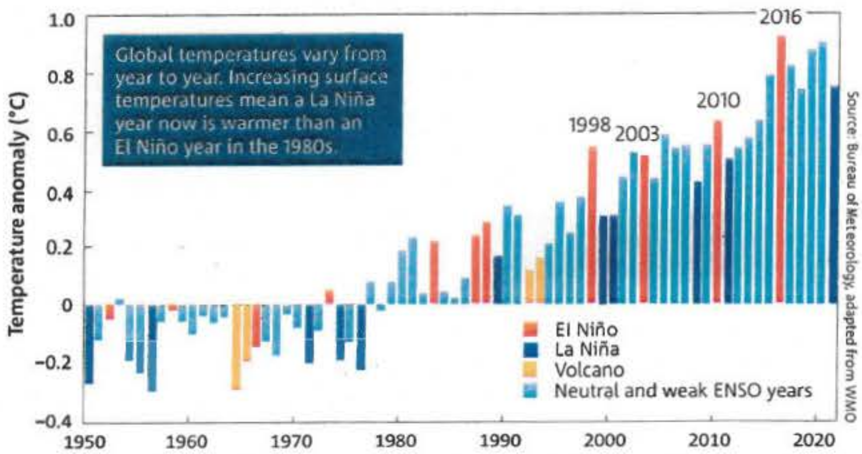


Anomalies in annual mean sea surface temperature, and temperature over land, in the Australian region. Anomalies are the departures from the 1961–90 standard averaging period. Sea surface temperature values (data source: ERSST v5, www.esrl.noaa.gov/psd/) are provided for a region around Australia (4–46 °S and 94–174 °E).

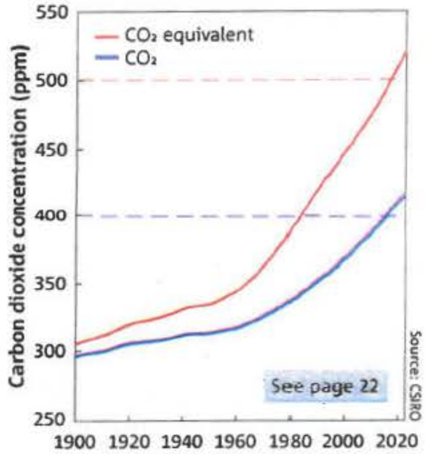
- There has been an increase in extreme fire weather, and a longer fire season, across large parts of the country since the 1950s.
- There has been a decrease in the number of tropical cyclones observed in the Australian region.
- Snow depth, snow cover and number of snow days have decreased in alpine regions since the late 1950s.
- Oceans around Australia have continued to become more acidic, with changes happening faster in recent decades.
- Sea levels are rising around Australia, including more frequent extremes that are increasing the risk of inundation and damage to coastal infrastructure and communities.

Global

- Concentrations of all the major long-lived greenhouse gases in the atmosphere continue to increase, with global annual mean carbon dioxide (CO_2) concentrations reaching 414.4 parts per million (ppm) in 2021 and the CO_2 equivalent (CO_2-e) of all greenhouse gases reaching 516 ppm. These are the highest levels on Earth in at least two million years.
- The decline in global fossil fuel emissions of CO_2 in 2020 associated with the COVID-19 pandemic will have a negligible impact on climate change. Atmospheric CO_2 concentrations continue to rise, and fossil fuel CO_2 emissions, the principal driver of this growth, were back to near pre-pandemic levels in 2021.
- The rate of accumulation of methane (CH_4) and nitrous oxide (N_2O) (both greenhouse gases) in the atmosphere increased considerably during 2020 and 2021.
- Globally averaged air temperature at the Earth's surface has warmed by over 1 °C since reliable records began in 1850. Each decade since 1980 has been warmer than the last, with 2011–20 being around 0.2 °C warmer than 2001–10.
- The world's oceans, especially in the Southern Hemisphere, have taken up 91 per cent of the extra energy stored by the planet (as heat) as a result of enhanced greenhouse gas concentrations.
- More than half of all CO_2 emissions from human activities are absorbed by land and ocean sinks, which act to slow the rate of increase in atmospheric CO_2.
- Global mean sea levels have risen by around 25 cm since 1880 and continue to rise at an accelerating rate.



Annual global surface temperature anomalies of the Earth (land and ocean), 1950–2021. Anomalies are with respect to the 1961–90 standard averaging period. Major tropical volcanic eruptions are associated with cooler global temperatures. Strong El Niño–Southern Oscillation (ENSO) years see a response in annual global temperatures, such that the year following the start year of an ENSO event is typically warmer than usual with an El Niño, and cooler with a La Niña. This is seen in 2016—the warmest year in this dataset—following the start year of the 2015–16 El Niño. Neutral years are those with no moderate or strong El Niño or La Niña events. Based on data from the World Meteorological Organization.



Global mean CO_2 concentration and global mean of all greenhouse gas concentrations expressed as CO_2-e.

Future

In the coming decades, Australia will experience ongoing changes to its weather and climate. Australia is projected to experience:

- Continued increase in air temperatures, more heat extremes and fewer cold extremes.
- Continued decrease, on average, in cool season rainfall across many regions of southern and eastern Australia, which will likely lead to more time in drought, but with ongoing climate variability that will give rise to short-duration heavy-rainfall events at a range of timescales.
- Continued increase in the number of dangerous fire weather days and a longer fire season for southern and eastern Australia.
- Further sea level rise and continued warming and acidification of the oceans around Australia.
- Increased and longer-lasting marine heatwaves that will affect marine environments, such as kelp forests, and increase the likelihood of more frequent and severe bleaching events in coral reefs around Australia, including the Great Barrier Reef and Ningaloo Reef.
- Fewer tropical cyclones, but a greater proportion is projected to be of high intensity, with large variations from year to year.
- Reduced average snow depth in alpine regions, but with variations from year to year.

Australia's changing climate

Temperature

- **Australia has warmed, on average, by 1.47 ± 0.24 °C since national records began in 1910.**
- **There has been an increase in extreme heat events associated with the warming.**

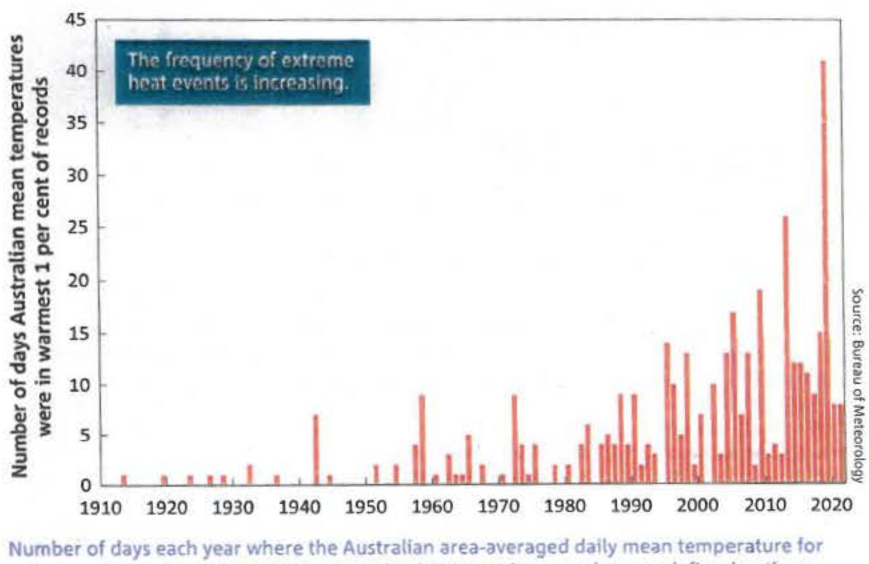
Australia has warmed, on average, by 1.47 ± 0.24 °C since national records began in 1910, with most warming occurring since 1950. Every decade since 1950 has been warmer than preceding decades. The warming in Australia is consistent with global trends, with the degree of warming similar to the overall average across the world's land areas.

Australia's warmest year on record was 2019. The eight years from 2013–20 all rank among the 10 warmest years on record. The long-term warming trend means that most years are now warmer than almost any observed during the 20th century.

Warming is observed across Australia in all months with both day and night-time temperatures increasing. This shift is accompanied by an increased number of extreme nationally averaged daily heat events across all months, including a greater frequency of very hot days in summer. For example, 2019 experienced 41 extremely warm days, about triple the highest number in any year prior to 2000. Also in 2019, there were 33 days when national daily average maximum temperatures exceeded 39 °C, a larger number than seen in the 59 years from 1960–2018 combined. Increasing trends in extreme heat are observed at locations across all of Australia. Extreme heat has caused more deaths in Australia than any other natural hazard and has major impacts on ecosystems and infrastructure.

There has also been an increase in the frequency of months that are much warmer than usual. Very high monthly maximum temperatures that occurred nearly 2 per cent of the time in 1960–89 now (2007–21) occur over 11 per cent of the time. This is about a sixfold increase over the period. Very high monthly night-time temperatures, which are also a major contributor to heat stress, occurred nearly 2 per cent of the time in 1960–89 but now occur around 10 per cent of the time.

The frequencies of extremely cold days and nights have declined across Australia. An exception is for extremely cold nights in parts of south-east and south-west Australia, which have seen significant cool season drying, and hence more clear winter nights. This results in colder nights due to increased heat loss from the ground. The frequency of frost in these parts has been relatively unchanged since the 1980s.



Number of days each year where the Australian area-averaged daily mean temperature for each month is extreme (extremely warm days). Extremely warm days are defined as those where daily mean temperatures are the warmest 1 per cent of days for each month, calculated for the period from 1910–2021.

Fire weather

- **There has been an increase in extreme fire weather, and in the length of the fire season, across large parts of Australia since the 1950s. This has led to larger and more frequent fires, especially in southern Australia.**

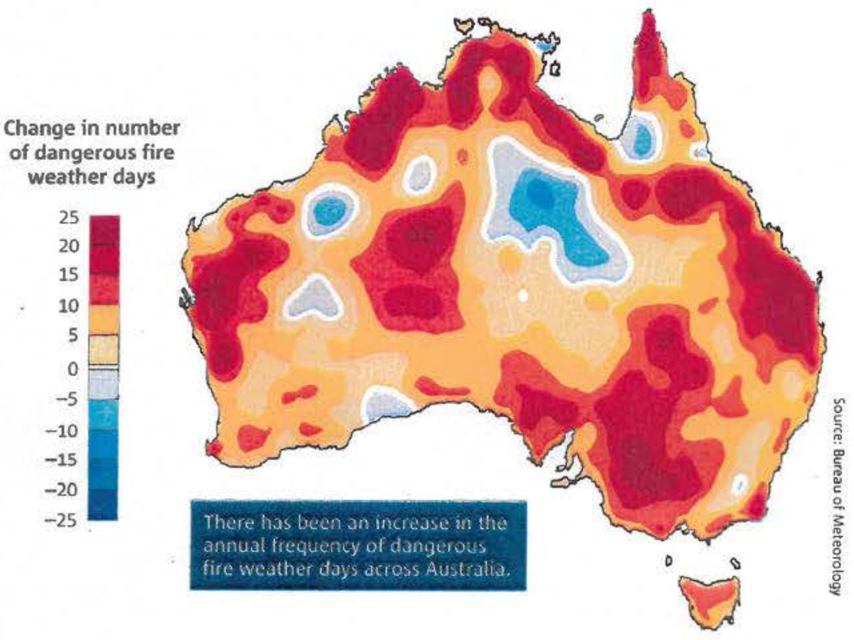
In Australia, fire weather is largely monitored using the Forest Fire Danger Index (FFDI). The FFDI indicates the fire danger on a given day based on observations of temperature, rainfall, humidity and wind speed. The frequency of dangerous fire weather days has increased significantly in recent decades across many regions of Australia, especially in the south and east. These increases are particularly evident during spring and summer and are associated with an earlier start to the southern fire weather season.

Climate change is contributing to changes in fire weather through its impacts on temperature and relative humidity, and the associated changes to fuel moisture content. Considerable year-to-year variability in fire weather also occurs. La Niña years—which occurred, for example, in 2010–11 and 2020–21—are associated with wet and cool climate anomalies and a lower number of days with high FFDI values through southern and eastern Australia. In northern and central Australia, increased rainfall can contribute to vegetation growth, which increases fuel loads when the vegetation dries out. High fuel loads are one of the key contributing factors to fire risk in northern and central regions.

Lightning that occurs without significant rainfall (known as 'dry lightning') is a major source of natural ignition for bushfires. Understanding changes to bushfire ignition in Australia, including the frequency of dry lightning, is a current area of active research.

There is a significant trend in some regions of southern Australia towards more days with weather that is conducive to extreme bushfires, which can in turn generate thunderstorms within smoke plumes. These fire-generated thunderstorms can lead to extremely dangerous fire conditions, such as during the Australian Black Summer fires (2019–20), the Canberra fires (2003) and the Victorian Black Saturday fires (2009). In some cases, new fires are generated from lightning strikes produced within smoke plumes.

Climate change affects the dryness and amount of available fuel through changes in rainfall, air temperature and atmospheric moisture content that exacerbate landscape drying. Increased CO_2 in the atmosphere has the potential to increase the rate and amount of plant growth, which may also affect fuel load.

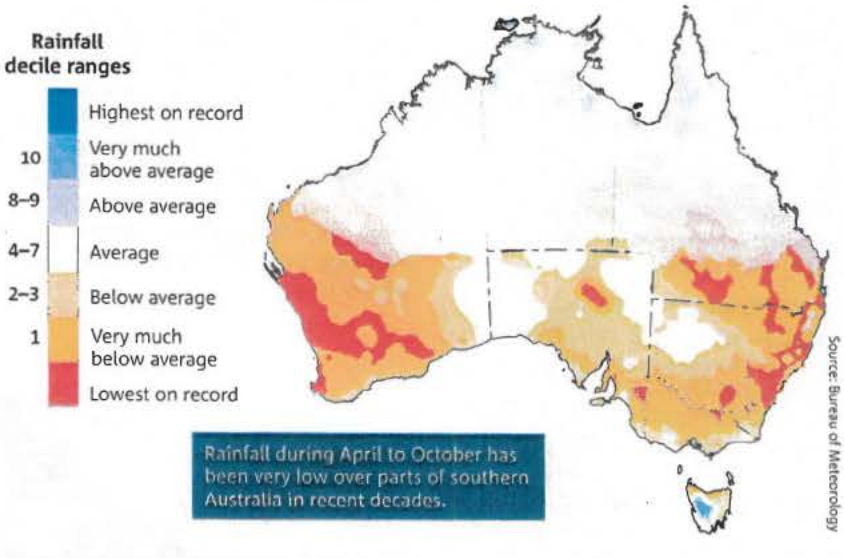


There has been an increase in the number of days with dangerous weather conditions for bushfires. The map shows the change in the annual (July to June) number of days that the FFDI exceeds its 90th percentile between the two periods: July 1950 to June 1986 and July 1986 to June 2022. The FFDI is an indicator of dangerous fire weather conditions for a given location.

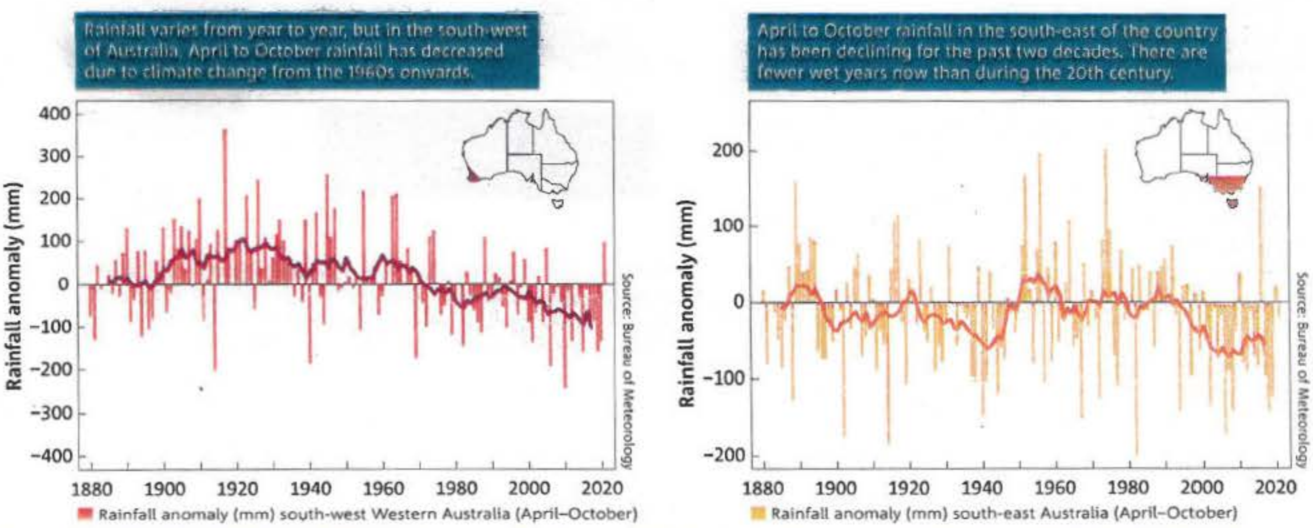
Rainfall

- **There has been a decline of around 15 per cent in April to October rainfall in the south-west of Australia since 1970. Across the same region, May to July rainfall has seen the largest decrease, of around 19 per cent since 1970.**
- **In the south-east of Australia, there has been a decrease of around 10 per cent in April to October rainfall since the late 1990s.**
- **Rainfall has increased across most of northern Australia since the 1970s.**

Australian rainfall is highly variable and is strongly influenced by drivers such as El Niño, La Niña, the Indian Ocean Dipole and the Southern Annular Mode. Despite this natural variability, long-term trends are evident in Australia's rainfall records. There has been a shift towards drier conditions across the south-west and south-east, with more frequent years of below-average rainfall, especially for the cool season months of April to October. In 19 of the 22 years from 2000–21, April to October rainfall in southern Australia has been below the 1961–90 average. This is due to a combination of natural variability on decadal timescales and changes in large-scale circulation caused by an increase in greenhouse gas emissions.



April to October rainfall deciles for the past 22 years (2000–21). A decile map shows where rainfall is above average, average, or below average for this period compared to all years from 1900 (when reliable rainfall records began). Areas across northern and central Australia that receive less than 40 per cent of their annual rainfall from April to October are faded.



Anomalies of April to October rainfall for south-western (south-west of the line joining the points 30° S, 115° E and 35° S, 120° E) and south-eastern (south of 33° S, east of 135° E inclusive) Australia, with respect to 1961–90 averages. 11-year running means are also shown as the bolded lines.

The drying trend in southern Australia is most evident in the south-west and south-east of the country. The recent drying across these regions is the most sustained large-scale change in observed rainfall since widespread observations became available in the late 1880s. The trend is particularly strong for the period from May to July over south-west Western Australia, with rainfall since 1970 around 19 per cent less than the average from 1900–69. Over the full April to October season the decline over the same period is around 15 per cent. Since 2000, this decline has increased to around 27 per cent, despite relatively high cool season rainfall during 2021.

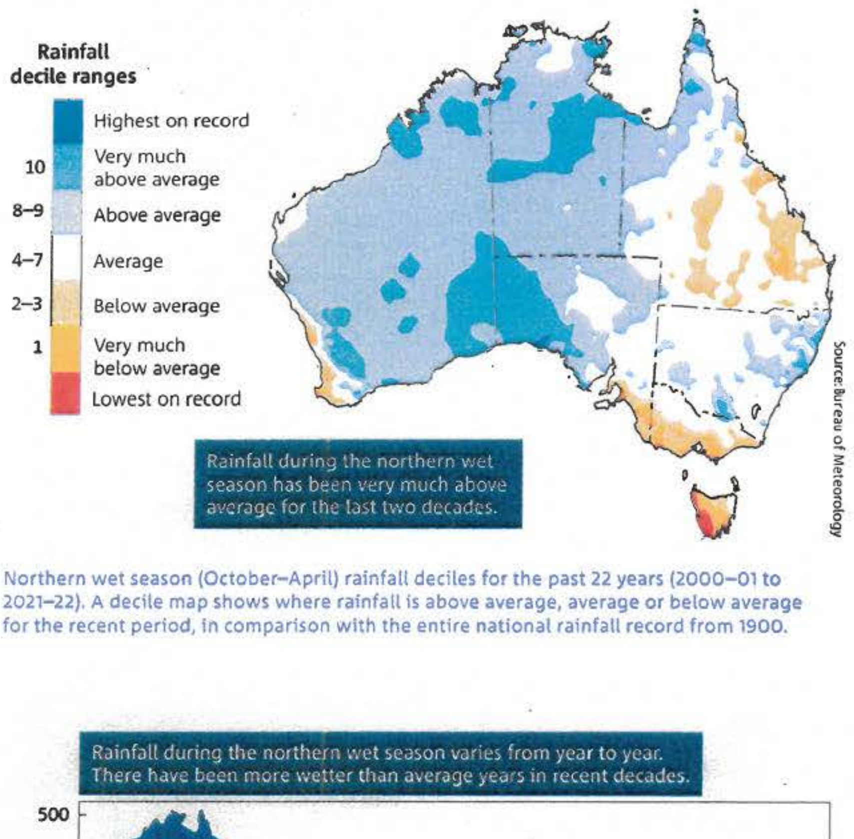
For the south-east of the continent, average April to October rainfall for the period 2000–21 was around 10 per cent lower than the 1900–99 period. The Millennium Drought was a major influence on this, affecting rainfall totals across the region from 1997–2009.

However, cool season rainfall totals are still 7 per cent below the 1900–99 average in the years since 2010. The only years with above-average cool season rainfall in south-east Australia in the past two decades (2010, 2016 and 2020) occurred during the La Niña events of 2010–12 and 2020–22, and the strong negative Indian Ocean Dipole event of 2016.

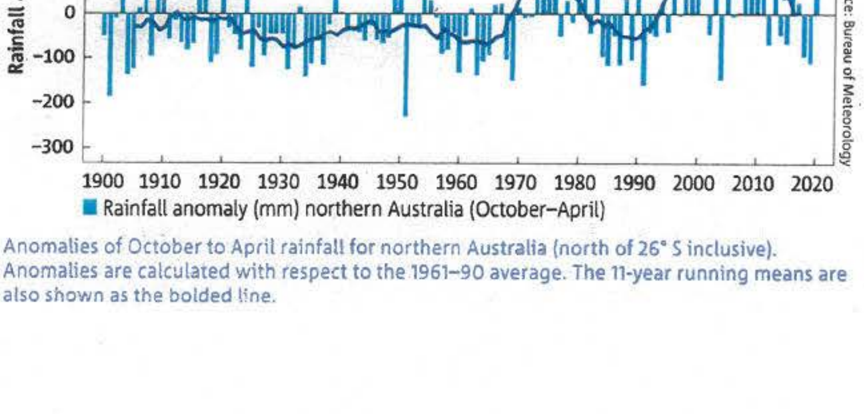
Rainfall in the cooler months (April to October) is particularly important for southern Australia, as it is the main growing season for many crops. It is also when peak streamflow occurs in most catchments in the region, as cool season rainfall is generally more effective than warm-season rainfall in generating runoff. The declining trend in rainfall during this period is associated with a trend towards higher surface atmospheric pressure in the region and a shift in large-scale weather patterns, more highs, fewer lows and a reduction in the number of cold fronts that produce rainfall.

Conversely, northern Australia has been wetter in the 21st century than in the 20th century, across all seasons, especially in the north-west during the northern wet season (October to April). However, rainfall variability remains high, with the 2010s being not as far above average as the 2000s. In southern Queensland, there has been a trend towards lower rainfall throughout the year, particularly during the past decade.

Warm season rainfall has also been below average in parts of Tasmania and the south-east and south-west coasts of mainland Australia in recent decades.



Northern wet season (October–April) rainfall deciles for the past 22 years (2000–01 to 2021–22). A decile map shows where rainfall is above average, average or below average for the recent period, in comparison with the entire national rainfall record from 1900.



Anomalies of October to April rainfall for northern Australia (north of 26° S inclusive). Anomalies are calculated with respect to the 1961–90 average. The 11-year running means are also shown as the bolded line.

Heavy rainfall

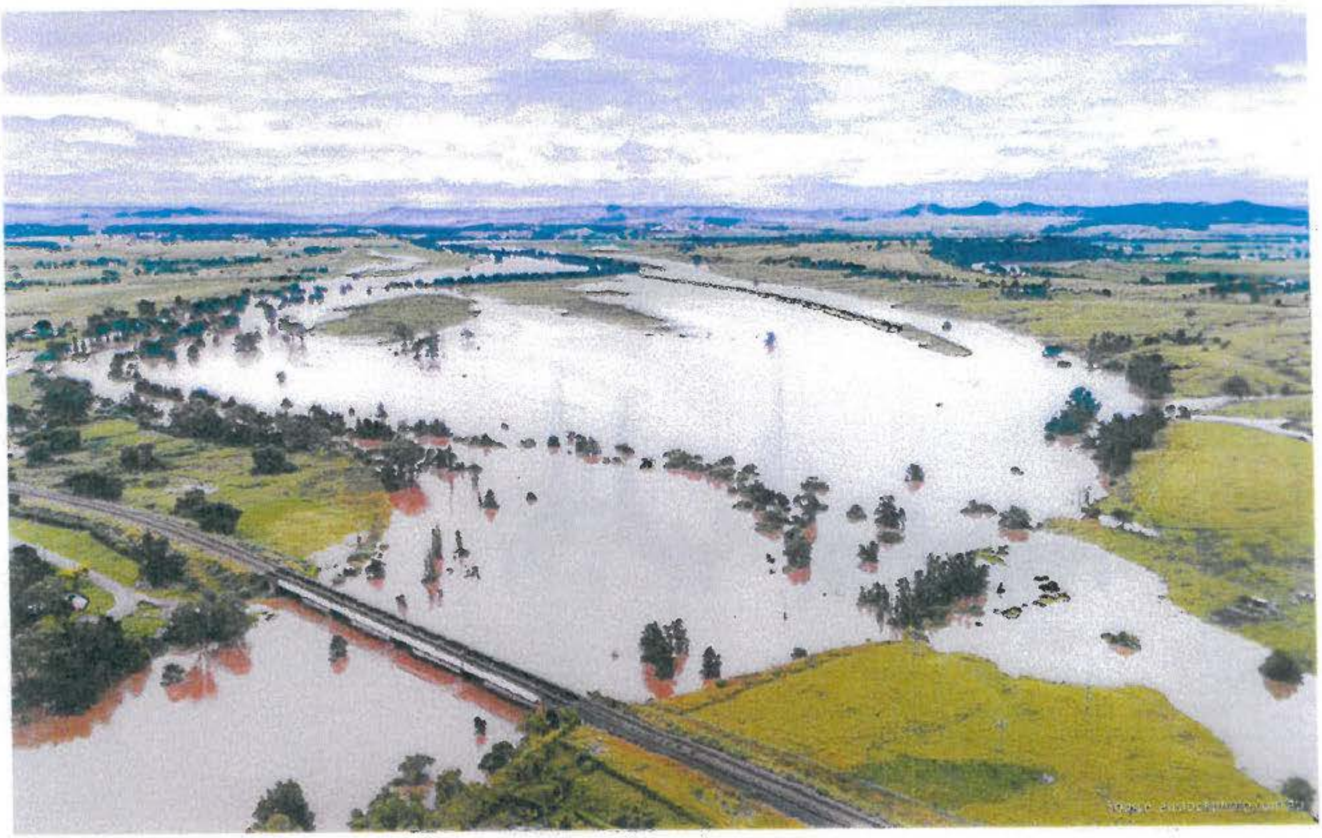
- Heavy rainfall events are becoming more intense.

Observations show an increase in the intensity of heavy rainfall events in Australia that occur on timescales of less than a day. The intensity of short-duration (hourly) extreme rainfall events has increased by around 10 per cent or more in some regions and in recent decades, with larger increases typically observed in the north of the country. Short-duration extreme rainfall events (such as for hourly rainfall totals) are often associated with flash flooding, which brings increased risk to communities. This is particularly the case in urban environments, where the large amount of impervious ground cover (e.g. concrete) leads to increased flooding during heavy downpours.

Heavy rainfall events are typically caused by weather systems such as thunderstorms, cyclones and east coast lows. Daily rainfall totals associated with thunderstorms have increased since 1979, particularly in northern Australia. This is primarily due to an increase in the intensity of rainfall per storm.

Conversely, the number of low-pressure systems that can bring sustained heavy rainfall to highly populated parts of southern Australia has declined in recent decades. This has implications for recharging water storages and water resource management.

As the climate warms, the atmosphere can hold more water vapour than cooler air can. This relationship alone can increase moisture in the atmosphere by 7 per cent per degree of warming, all other things being equal. This can cause an increased likelihood of heavy rainfall events, even in parts of Australia where average rainfall is expected to decrease. Increased atmospheric moisture can also provide more energy for some processes that generate extreme rainfall events, which can further increase the intensity of heavy rainfall due to global warming.



Streamflow

- 60 per cent of hydrologic reference stations around Australia show a declining trend in streamflow.

The observed long-term reduction in rainfall across many parts of southern Australia has led to reduced streamflow, although with considerable interannual variability. Declines in annual median streamflow have been observed in the South Australian Gulf, Tasmania, Pilbara Gascoyne, and Lake Eyre Basin drainage divisions. In each of these, around half of the gauges show a declining streamflow trend since 1975.

In the Murray–Darling Basin, nearly half of the long-term streamflow gauges show a declining trend since records began in 1970. This is more severe in the northern Basin where most gauges show a declining trend in streamflow. In the northern Basin catchments, where these trends are strongly evident, there are statistically significant declining trends in the headwaters, including the Namoi, Border Rivers, Condamine–Culgoa and Gwydir River catchments. In the Murrumbidgee, Lachlan, Goulburn and Loddon River catchments of the southern Basin, the majority of streamflow gauges also show declining trends. In the Darling River region, declining trends were observed at almost all gauges.

In the Tanami–Timor Sea Coast drainage division in northern Australia, which includes Darwin and much of the Northern Territory, there has been an increasing trend in annual median flows at about 51 per cent of the gauges since 1975. This is consistent with the observed increase in rainfall since the 1970s in the region.

More than 60 per cent of Australia's hydrologic reference stations show a declining trend in streamflow, and more than 20 per cent show a statistically significant declining trend. Hydrologic reference stations are an indicator of long-term impacts from climate change on streamflow, as they are gauges in catchments with little disturbance from human activities and with at least a 30-year record.

Changes in weather systems and climate drivers

Australia's weather systems are changing. Southern Australia receives much of its rainfall during the cooler months of the year from low-pressure systems and cold fronts to the south of the subtropical high-pressure ridge. During recent decades, these systems have become less common over southern Australia, and are less likely to produce rainfall when they do occur, contributing to declines in cool season rainfall. Mean sea level pressure is increasing over Australia, and there has been an increase in the number of high-pressure systems over southern Australia, which bring dry, clear weather and little rainfall. This increase in surface pressure across southern latitudes is a known climate system response to climate change.

There is large variability in the frequency of individual weather systems between months and years. However, many of these trends are consistent with simulations from climate models, which demonstrate that increased greenhouse levels lead to fewer low-pressure systems in southern Australia and a stronger subtropical ridge, but an increase in the intensity of heavy rainfall, including from thunderstorms.

Australia's climate is also strongly influenced from year to year by various broadscale climate drivers, such as the El Niño-Southern Oscillation (ENSO), the Indian Ocean Dipole (IOD) and the Southern Annular Mode (SAM). SAM shows a sustained trend towards more positive conditions from 1950 to the present day, particularly in summer. The level of ENSO activity over the past 50 years is higher, with more significant El Niño and La Niña events than in the years between 1920 and 1970. However, there is no clear indication that recent activity levels are outside the long-term range of variability, with evidence of high levels of ENSO activity in the late 19th and early 20th centuries. There is low confidence in long-term trends in the IOD, particularly prior to the 1960s, although paleoclimate data indicate that the recent frequency of strong positive IOD events is high in the context of multi-century variability.

Tropical cyclones

- **There has been a decrease in the number of tropical cyclones observed in the Australian region since at least 1982.**

Tropical cyclone activity in Australia's cyclone region varies substantially from year to year. This is partially due to the influence of large-scale climate drivers: the number of cyclones in our region generally declines with El Niño and increases with La Niña. Intense tropical cyclones can cause serious impacts associated with catastrophic winds, storm surges and extreme rainfall and flooding.

There has been a downward trend in the number of tropical cyclones observed in the Australian region since reliable satellite observations began in 1982. Additional non-satellite observations suggest there has also been a longer-term reduction in the number of tropical cyclones since 1900.

The trend in cyclone intensity in the Australian region is harder to quantify than cyclone frequency, due to uncertainties in estimating the intensity of individual cyclones and the relatively small number of intense cyclones.

Climate change, extreme rainfall and flood risk

Flooding is one of the major natural hazards facing Australia. Multiple factors contribute to the risk of flooding. The most important weather-related factors include how extreme a rainfall event is and how wet catchments are prior to the rain event. In estuarine and coastal environments, tides and sea levels can also be important. Flood risk can also change over time as a result of changes in land use and land cover, and through changes in the extent to which streams in the catchment area are regulated.

Sustained heavy rainfall and associated flooding in much of Australia, particularly the east, is most common during La Niña, as illustrated by the multiple floods that occurred in eastern Australia in 2022. The 11 wettest years on record in eastern Australia were all influenced by La Niña. Many of eastern Australia's most significant flood years, such as 1974, 2010–11 and 2021–22, have occurred during strong La Niña events, although significant flooding can sometimes occur in non-La Niña years. The impact of multiple flood events is particularly pronounced when La Niña events occur in multiple successive years, as occurred in 2020–22, and previously in periods such as 1954–56 and 1973–76.

Flood risk is influenced by rainfall at a range of timescales, depending on the catchment. Flash flooding is driven by intense rainfall in localised regions on timescales of minutes to hours, while river flooding in larger catchments responds to rainfall on timescales of days to weeks. While the observed trend in daily rainfall extremes is mixed across Australia, with some areas showing increases and others decreases, an increase in sub-daily extremes is now very clear over recent decades.

It is expected that extreme rainfall will increase in Australia with climate change. At particular locations, extreme rainfall changes in particular locations are also influenced by changes in weather systems, such as east coast lows and tropical cyclones (both of which are expected to become less frequent). This may lead to some regions experiencing trends in extreme rainfall that differ from typical values at national or global scale. Climate change may also affect the drivers of multi-day rainfall extremes, such as atmospheric rivers for moisture transport, the behaviour of El Niño and La Niña, and persistent blocking highs (strong high-pressure systems that remain almost stationary for an extended period of time, blocking the eastward progression of weather systems across southern Australia) in the Tasman Sea, but the details of these effects are subject to ongoing research. Changes in extreme rainfall will not necessarily follow those in mean rainfall: regions in southern Australia, which are expected to see continued long-term drying, may still experience increases in extreme rainfall.

Snowfall

- Maximum snow depth, snow cover and number of snow days have decreased in Australian alpine regions since the late 1950s.

Downward trends in maximum snow depth have been observed for Australian alpine regions since the late 1950s, with the largest declines during spring and at lower altitudes. Downward trends in the temporal and spatial extent of snow cover have also been observed. The number of snowfall days has also decreased. Years with persistent heavy snow cover have become rare.

Snow depth is closely related to temperature, and the observed declines are associated with global warming trends. Decreasing trends in snow depth are greater over the corresponding period in the late-season month of September than during winter. Maximum snow depth remains highly variable and is strongly influenced by rare heavy snowfall days, which have no observed trends in frequency. Several heavy snowfall events contributed to average to high maximum snow depths in the years from 2017–19.

Source: unsplash.com

Oceans

Sea surface temperature

- **Sea surface temperatures around Australia have warmed by over 1 °C since 1900.**

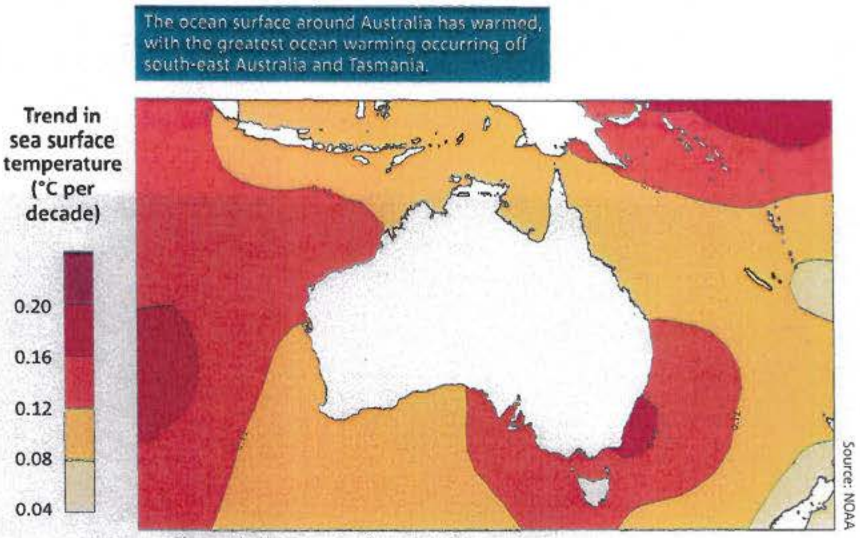
Average sea surface temperature in the Australian region has warmed by 1.05 °C since 1900, with eight of the 10 warmest years on record occurring since 2010. The year with the highest sea surface temperature on record was 2016, which was associated with one of the strongest negative Indian Ocean Dipole events on record and the 2015–16 extreme El Niño event.

The greatest ocean warming in the Australian region since 1970 has occurred off south-east Australia and Tasmania. The East Australian Current now extends further south, creating an area of more rapid warming in the Tasman Sea, where the warming rate is now twice the global average. There has also been warming across large areas of the Indian Ocean region to the west coast of Australia.

Warming of the ocean has contributed to longer and more frequent marine heatwaves. Marine heatwaves are periods when temperatures are in the upper range of historical baseline conditions for at least five days. Heatwaves in the ocean often persist much longer than heatwaves on land, sometimes spanning multiple months or even years.

As discussed in the 2021 Australian *State of the Environment* report, the increasing frequency of marine heatwaves around Australia in recent years has permanently impacted marine ecosystem health, marine habitats and species.

These impacts include depleting kelp forests and seagrasses, a poleward shift in some marine species, and increased occurrence of disease.



Trends in sea surface temperature in the Australian region (4–46° S and 94–174° E) from 1950–2021.

Ocean heat content

- **The world's oceans have taken up 91 per cent of the extra energy stored by the planet as a result of enhanced greenhouse gas concentrations. Measuring changes in ocean heat content is therefore an accurate way to monitor global warming.**
- **The ocean does not warm evenly. Some regions, including around Australia, are warming several times faster than the global mean.**
- **The rate at which the oceans are taking up heat has increased over recent decades.**

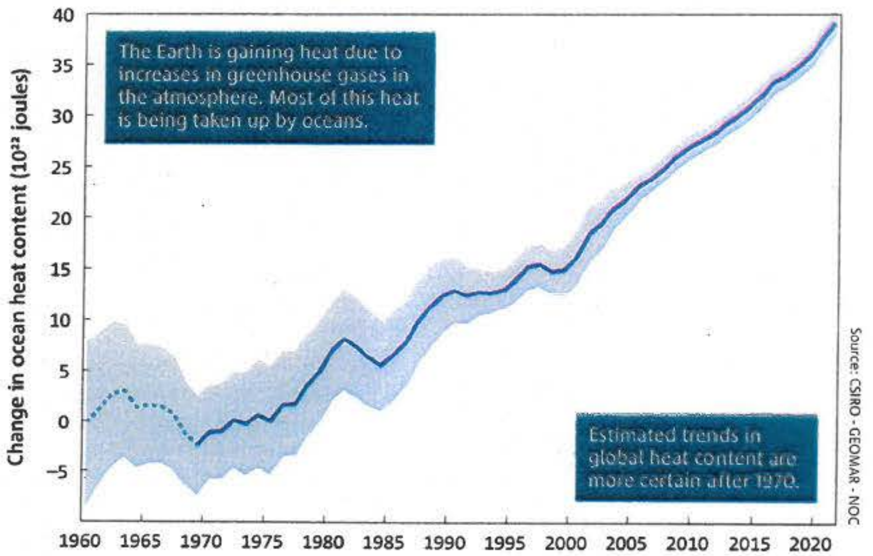
The world's oceans are a major component of the Earth's climate system and have a profound effect on the climate by redistributing heat and influencing wind patterns.

Seawater stores about four times more heat for every degree of temperature rise than dry air of the same weight. The total weight of water in the ocean is about 280 times greater than the weight of the Earth's atmosphere, so the capacity for the ocean to store heat is vast.

While the temperature changes over the whole ocean depth are small compared to those at the land and ocean surface, the ocean has taken up 91 per cent of the excess energy in the Earth system from enhanced greenhouse gas concentrations. Oceans have therefore slowed the rate of warming near the Earth's land and ocean surface. Heat absorbed at the surface is redistributed both horizontally and vertically by ocean circulation. As a result, the ocean is warming both near the surface and at depth, with the rate of warming varying between regions and depths.

Warming has accelerated since the early 2000s. In 2021, the global ocean was the warmest on record, with an estimated additional 39 x 10^{22} joules of energy relative to 1960. The Southern Ocean takes up more than half of that warming. This is because the Southern Ocean circulation takes heat from near the surface and transfers it into the deep ocean. A warming ocean affects the global ocean and atmospheric circulation, the cryosphere, global and regional sea levels, uptake of anthropogenic CO_2, and causes losses in dissolved oxygen and impacts on marine ecosystems.

Regionally, ocean warming can vary substantially from year to year due to climate phenomena such as ENSO. In areas of strong warming, changes in heat content can be several times larger than the global mean change. This is the case in the oceans around Australia, where strong warming results from a redistribution of heat due to a southward extension of the East Australian Current, and enhanced heat uptake in the subantarctic region south of Australia.

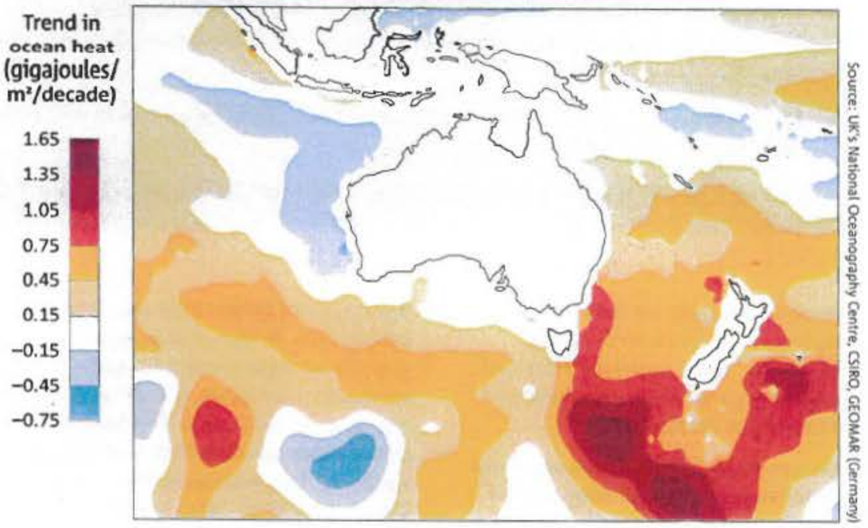


Estimated change in ocean heat content globally averaged over the full ocean depth, from 1960–2021. Shading provides an indication of the confidence range of the estimates. The measurements contributing to the early part of the record, before 1970, are sparse and trends estimated over this period are small compared to the confidence range and hence are considered less reliable. Source: CSIRO, GEOMAR (Germany) and National Oceanographic Centre (UK)

Changes in ocean heat content associated with climate variability are large in the top 300 m of the ocean but have little impact on the waters below. The deep waters below 2000 m have also warmed throughout most of the global ocean. However, there are far fewer observations of the deep ocean, and the magnitude of this warming is less certain.

Monitoring heat content globally over time is the most effective way to track climate change and the impacts of a warming ocean. Maintaining the ocean observing system and expanding coverage in the deep ocean, the polar oceans, and continental shelves will be critical to prepare for, and adapt to, a changing climate.

Southern Hemisphere oceans have taken up the majority of the extra heat from global warming. Since 2005, Argo floats have provided unprecedented resolution of the ocean. Trends derived over this period are consistent with the long-term record.



Linear trend in ocean heat content in the upper 2000 m, estimated between 2005 and 2021 when profiling floats from the Argo program provided observations of the ocean globally in waters deeper than 2000 m. The highest uptake of heat occurred in regions where the circulation draws heat into the deep ocean, such as the Southern Ocean.

Marine heatwaves and coral reefs

Warming oceans, together with an increase in the frequency, intensity and duration of marine heatwaves, pose a significant threat to the long-term health and resilience of coral reef ecosystems. Mass coral bleaching events have occurred with increasing frequency and extent around the world since the 1970s, including on the Great Barrier Reef. Mass bleaching is a stress response of corals that occurs primarily due to elevated ocean temperature. Recovery is possible, but mortality can occur if the thermal stress is too severe or prolonged. Ocean acidification places further stress on corals.

Four mass coral bleaching events have occurred on the Great Barrier Reef over the past 10 years: in 2016, 2017, 2020 and 2022. In 2016, bleaching was associated with record high sea surface temperatures, which in turn led to the largest recorded mass bleaching on the Great Barrier Reef. The impact of the 2020 mass bleaching event appears to be second only to 2016 and was associated with severely bleached coastal reefs along the entire 2300 km length of the Great Barrier Reef. The 2022 event was the first time that mass bleaching has occurred on the Reef during a La Niña year.

These four recent bleaching events are associated with marine heatwaves driven by anthropogenic climate change. Rapidly recurring bleaching events do not give the reef ecosystem time to fully recover.

In 2022, bleaching was also observed on some reefs on Australia's west coast, including Ningaloo Reef. This was due to warm ocean temperatures, driven by the 2021–22 La Niña. The region's last severe marine heatwave was driven by the 2010–11 La Niña, which resulted in bleaching being recorded for the first time on Ningaloo and the closure of several Western Australian fisheries.

Climate models project more frequent, extensive, intense and longer-lasting marine heatwaves in the future. Worsening impacts on coral reefs from marine heatwaves are expected in the future with continued warming. The intensification of marine heatwaves is much greater under high greenhouse gas emission scenarios. This implies more frequent and severe coral bleaching events are likely, leading to the potential loss of many types of coral and impacts on reef fisheries. Along with ocean acidification and nutrient runoff, the increased severity and frequency of marine heatwaves are likely to reduce reef resilience and hinder coral recovery from future bleaching events.

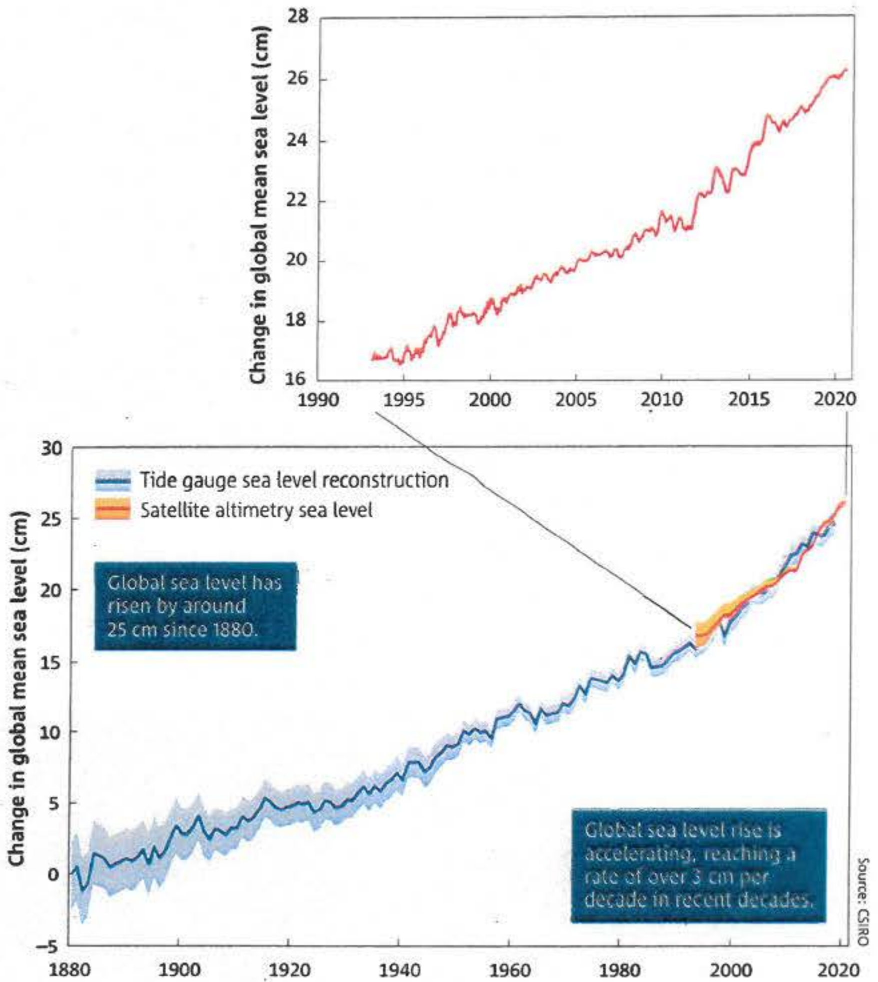
Sea level

- Global mean sea level has risen by around 25 cm since 1880; half of this rise has occurred since 1970.
- Rates of sea level rise since 1993 vary across the Australian region, with the largest increases to the north and south-east of the Australian continent.

As the ocean warms, it expands and sea level rises. This thermal expansion has contributed about one-third of the sea level rise observed globally—around 25 cm since the late 19th century. Ice loss from glaciers and polar ice sheets, together with changes in the amount of water stored on the land, contribute the remaining two-thirds of the observed global sea level rise. Ice loss from Greenland, Antarctica and glaciers has been the dominant contributor to global sea level rise from 1993 to the present.

Global mean sea level rise is accelerating. Tide gauge and satellite altimetry observations show that the rate of global mean sea level rise increased from 1.5 ± 0.2 cm per decade (1901–2000) to 3.5 ± 0.4 cm per decade (1993–2021). The dominant cause of global mean sea level rise since 1970 is anthropogenic climate change.

Confidence in assessing changes in mean global sea level has continuously improved because there has been more analysis of satellite altimetry and longer records. Efforts to reliably quantify the various contributions to sea level rise have also led to greater confidence and process understanding.



Global mean sea level with reconstruction based on tide gauges and satellite altimetry. Annual global sea level change from 1880 is from tide gauge data (1880–2019, blue line, shading indicates confidence range), and annual sea level change from 1993 is from satellite altimetry (1993–2020, orange line). The pull-out figure shows monthly sea level change from 1880, measured using satellite altimetry from 1993–2020.

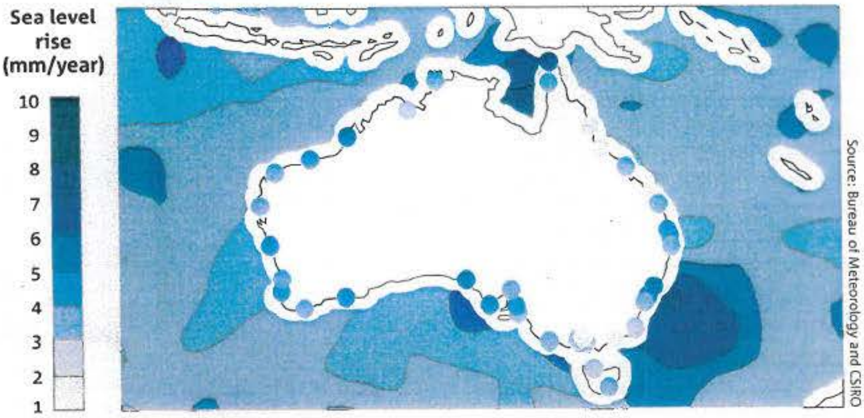
Australia, like other nations, is already experiencing sea level rise. Sea level varies from year to year and from place to place, partly due to the natural variability of the climate system from the effect of climate drivers such as El Niño and La Niña. Based on satellite altimetry observations since 1993, the rates of sea level rise to the north and south-east of Australia have been significantly higher than the global average, whereas rates of sea level rise along the other coasts of the continent have been closer to the global average.

The long-term altimetry sea level record is typically restricted to the offshore region, beyond 25–50 km, while changes closer to Australia's shoreline are estimated from tide gauge measurements at a limited number of locations. Local coastal processes, the effects of vertical land motion, and changes in site and/or reference levels affect local estimates of sea level change. For example, estimates from nearshore tide gauge measurements may differ from estimates derived from satellite altimetry tens of kilometres offshore.

Nevertheless, tide gauges with good long-term records around Australia show overall changes in sea level rise consistent with offshore observations from satellite altimetry.

Rising sea levels pose a significant threat to coastal communities and coastal ecosystems by amplifying the risks of coastal inundation, storm surge, erosion, and saltwater intrusion into groundwater systems. As emphasised in the 2021 *State of the Environment* report, coastal communities in Australia are already experiencing some of these changes.

Sea levels have risen around Australia.



The rate of offshore sea level rise around Australia measured using satellite altimetry from 1993–2020 and onshore rate of sea level rise (coastal points) from the ANCHORS multi-decadal tide gauge dataset. The colour scale applies to both the contour (satellite altimetry) and dots (tide gauges) observations.

Ocean acidification

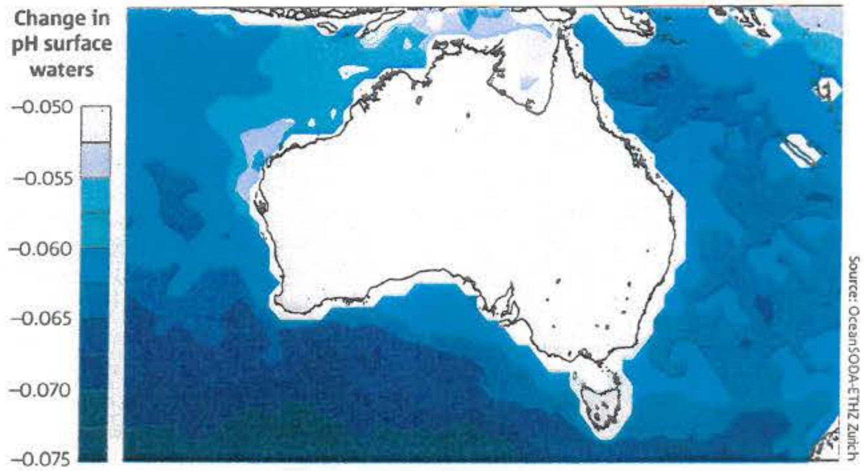
- The acidification of the oceans around Australia continues (pH is decreasing), with changes happening faster in recent decades.
- Increasing CO_2 in the atmosphere will continue to drive ocean acidification, with the greatest changes in temperate and cooler waters in the south.

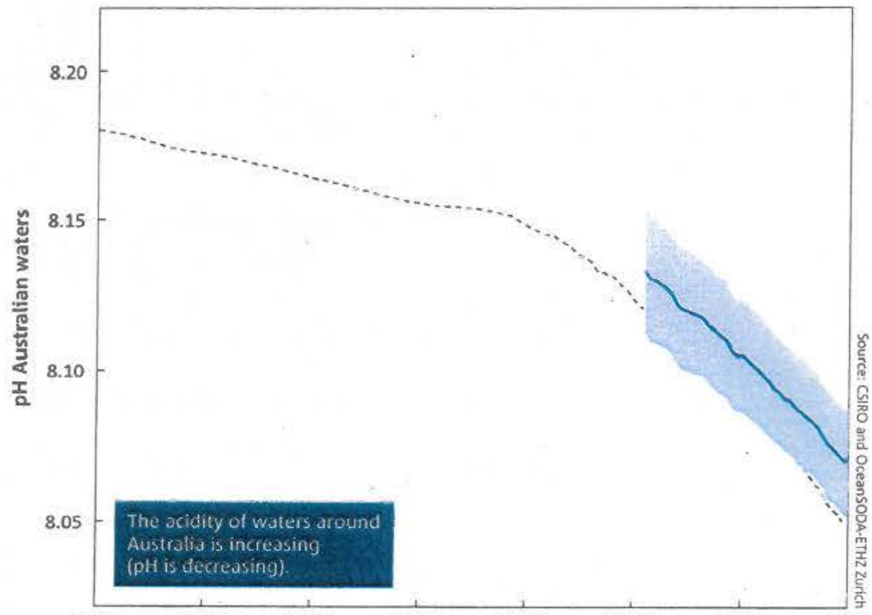
Rising atmospheric CO_2 levels increase the uptake of CO_2 by the oceans, which take up 26 per cent of annual global emissions. This affects the oceans' carbonate chemistry and decreases their pH, a process known as ocean acidification. In conjunction with other environmental changes, such as ocean warming and deoxygenation, ocean acidification brings additional pressures to the marine environment.

Impacts of ocean acidification on marine ecosystems include changes in reproduction, organism growth and physiology, species composition and distributions, food web structure, nutrient availability, and reduced calcification rate; the latter is particularly important for species that produce shells or skeletons of calcium carbonate, such as corals and shellfish.

Since the decade of 1880-1889 the average pH of surface waters around Australia and globally is estimated to have decreased by about 0.12, corresponding to about a 30% increase in acidity. The rate of increase has grown in recent decades and updates indicate an increase in acidity of between 12 per cent and 18 per cent between 1982 and 2020. The changes are linked to increased concentrations of CO_2 in the atmosphere. Due to latitudinal differences in ocean chemistry, the oceans to the south of Australia are acidifying faster than those to the north.

The current rate of change for pH in open ocean surface waters is about 10 times faster than at any time in the past 300 million years. Some ecosystems are now exposed to conditions outside the pH ranges experienced in the pre-industrial era before 1850. The impacts will be compounded by other stressors, including ocean warming and pollution. This reduces the capacity of coral reefs, including those of the Great Barrier Reef, to survive and grow.





The estimated pH in surface waters around Australia. Top: change of annual mean pH between 1982 and 2020. Bottom: the estimated change in the average annual pH of surface waters. Calculations are based on data from the Integrated Marine Observing System and other programs. Earlier estimates (grey) extend back to 1880 using CO_2 concentration changes in air, and an updated estimate (blue) is based on more data collected from1982–2020, which shows a slight offset but similar rate of change to the earlier estimate. Shading for each line is the standard deviation of the annual mean.

Cryosphere

- **The ice sheets and ice shelves of Antarctica and Greenland are losing ice and contributing to global sea level rise due to a warmer climate.**
- **There has been an abrupt decrease in Antarctic sea-ice extent since 2015, after a small increase over the period from 1979–2014.**

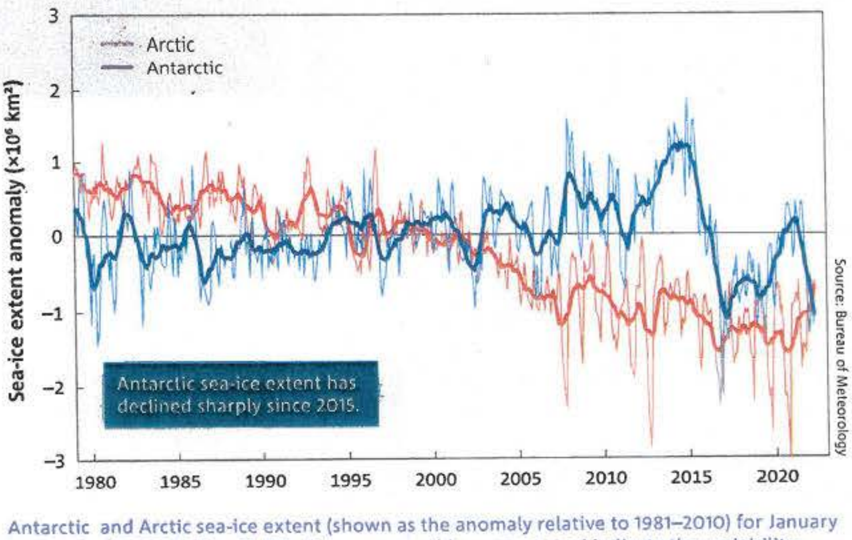
The Earth's ice sheets—glacial ice that has accumulated from precipitation over land—and ice shelves, which are floating sheets of ice formed from glacial ice sheets, play crucial roles in our global climate system. Ice shelves help stabilise the Antarctic ice sheet by restricting the flow of glacial ice from the continent to the ocean. Warm ocean water penetrating below the ice shelves of the West Antarctic ice sheet is destabilising several glaciers, increasing the Antarctic contribution to sea level rise. Atmospheric warming is also causing surface melting of ice sheets and ice shelves, particularly in Greenland and on the Antarctic Peninsula. From 1993–2018, melt from Greenland and Antarctica combined contributed around 1.7 cm of global sea level rise.

Changes in sea ice have little direct impact on sea level because sea ice is frozen seawater that floats. When it melts, it returns the original volume of water to the sea. However, the presence or absence of sea ice influences the climate, including the rate of regional climate warming.

Antarctic sea ice also acts as a protective buffer for ice shelves against destructive ocean swells. Changes in Antarctic sea-ice cover can also be an indicator of wider changes in climate because it is an integrator of ocean, atmosphere and cryosphere components, from local change to the tropics.

Satellite monitoring of sea ice began in the late 1970s. Since then, Arctic sea-ice cover has consistently decreased, whereas net sea-ice cover changes within the Antarctic have been mixed.

Overall, Antarctic sea-ice extent showed a small increase from 1979–2014, but with substantial regional variations. The largest daily recorded wintertime extent of approximately 20.2 million km² was in September 2014. Since 2014, there has been a marked, abrupt and relatively persistent decrease in sea-ice extent, which in early 2022 dropped below 2.0 million km² for the first time since observations began.

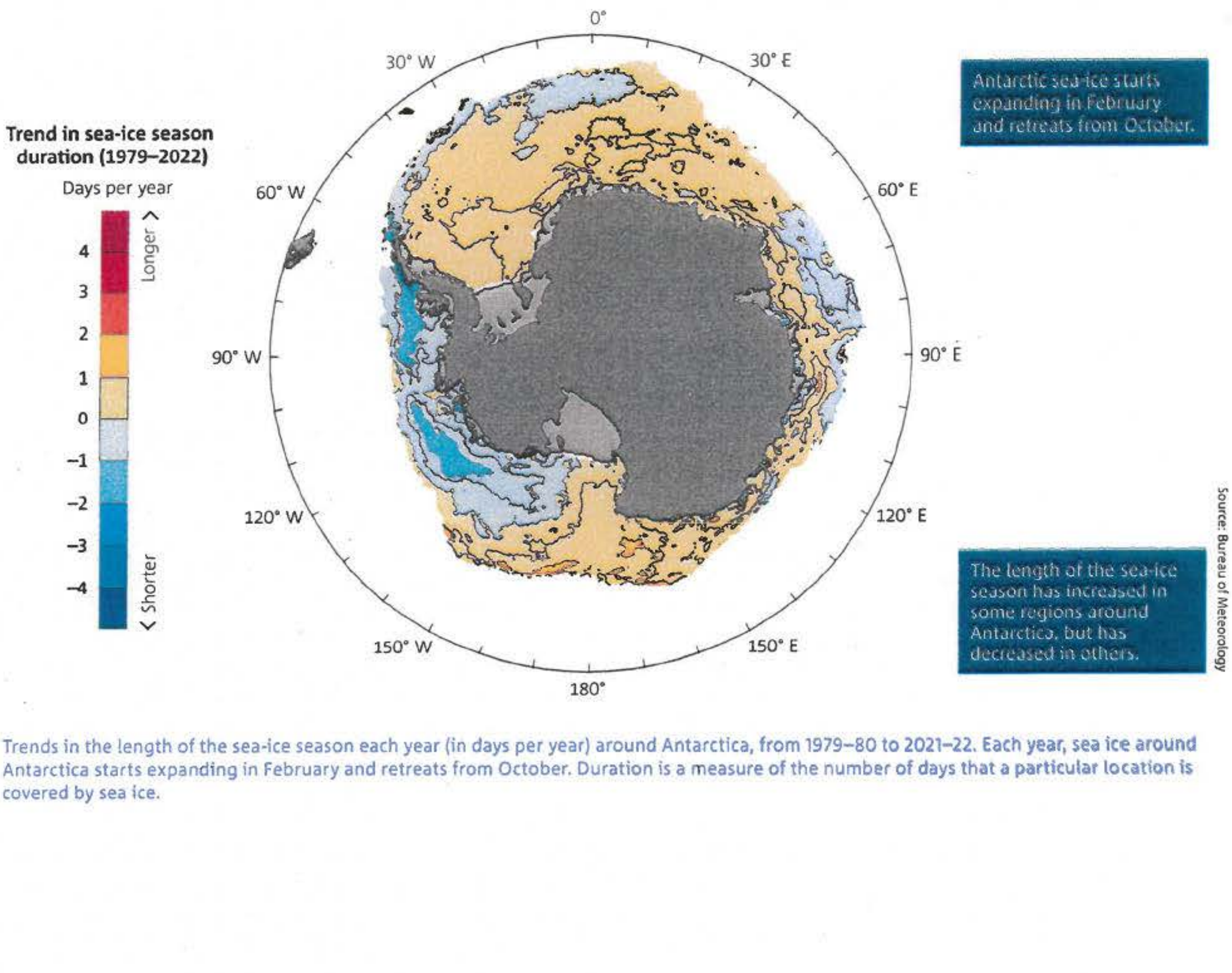


Antarctic and Arctic sea-ice extent (shown as the anomaly relative to 1981–2010) for January 1979 to April 2022 (10^6 km²). Thin lines are monthly averages and indicate the variability at shorter timescales, while thick lines are 11-month moving averages (centred)—tapered towards end-points.

The overall increase in Antarctic sea-ice extent during 1979–2014 has mostly been attributed to changes in westerly wind strength, whereas the marked decrease since 2015 has been attributed to a combination of atmospheric and oceanic anomalies.

Observed changes in Antarctic sea-ice cover are also regionally variable, as depicted in the trends of yearly sea-ice duration. Statistically significant increases of up to two days per year in sea-ice duration have occurred in the Ross Sea, between 160° E and 150° W. Decreases in sea-ice duration of as much as four days per year are seen west of the Antarctic Peninsula and the Bellingshausen Sea offshore of West Antarctica. Recent sea-ice seasons (since 2015) have shown opposite regional responses to the long-term trend.

The rate of mass loss from the Antarctic ice sheet has increased over recent decades, with a total loss of 2670 ± 870 Gt of ice over the period 1992–2020.



Trends in the length of the sea-ice season each year (in days per year) around Antarctica, from 1979–80 to 2021–22. Each year, sea ice around Antarctica starts expanding in February and retreats from October. Duration is a measure of the number of days that a particular location is covered by sea ice.

Greenhouse gases

- **Global average concentrations of all major long-lived greenhouse gases continue to rise in the atmosphere, driving further climate change.**
- **The rate of CO_2 accumulation in the atmosphere has increased every decade since atmospheric measurements began. Global average annual mean CO_2 concentration reached 414.4 ppm in 2021. Adding all greenhouse gases together, concentrations reached 516 ppm of CO_2-e.**
- **Over the past two years, the amounts of atmospheric methane and nitrous oxide have grown very rapidly.**

The global annual mean CO_2 concentration in 2021 was 414.4 ppm—a 50 per cent increase from the concentration of 277 ppm in 1750.

Other long-lived greenhouse gases also contribute to global warming. The most significant of the non-CO_2 greenhouse gases are methane and nitrous oxide. In 2021, the global annual mean concentration of methane was 1890 parts per billion (ppb), while for nitrous oxide it was 334 ppb. Respectively, these are rises of 158 per cent and 22 per cent above their 1750 levels of 731 ppb and 273 ppb.

Global mean surface warming in the future will be largely determined by cumulative emissions of CO_2 and the other long-lived greenhouse gases. Because of the thermal inertia of the oceans and the fact that these gases persist in the atmosphere for decades to centuries, the Earth system is committed to further warming.

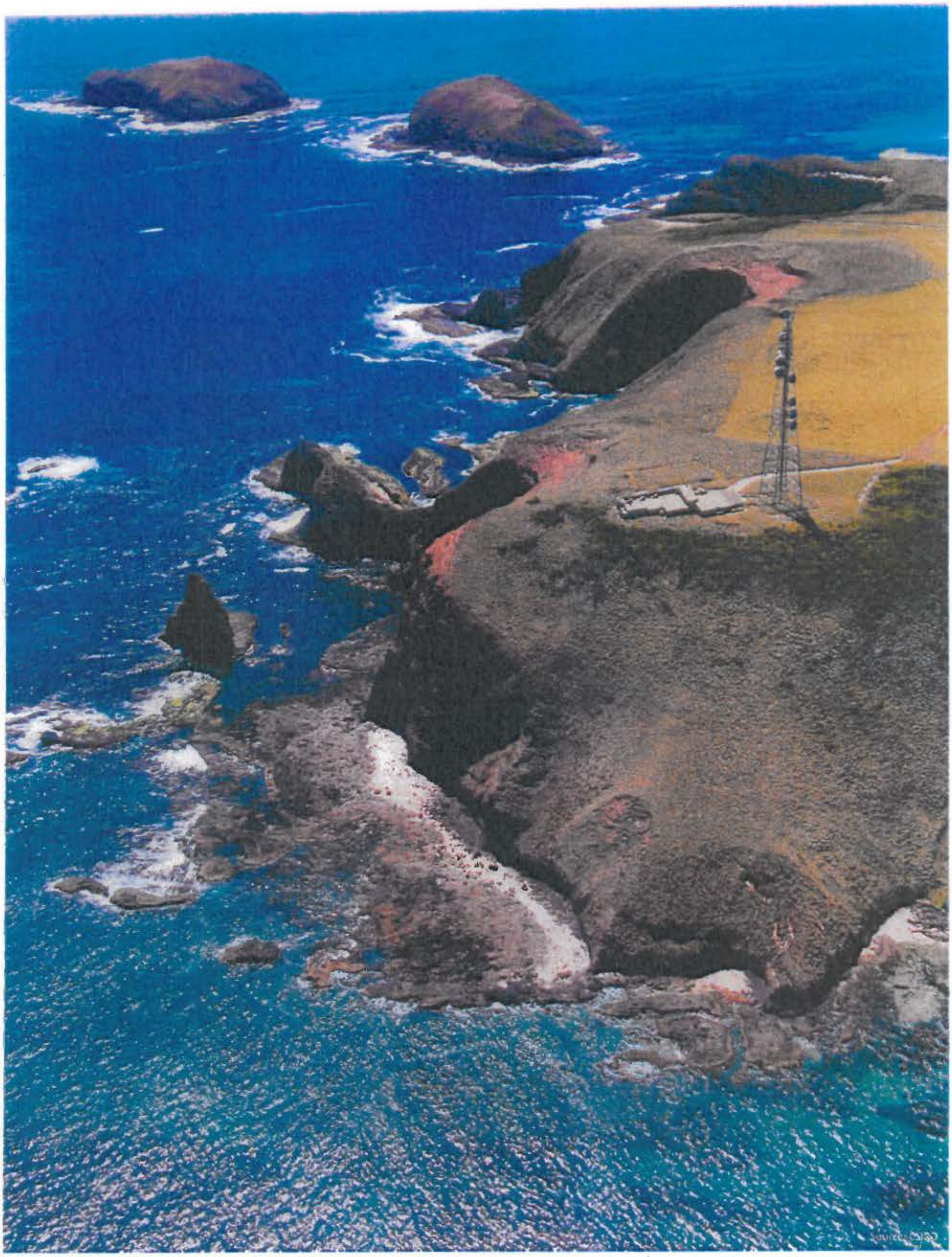
Methane is the second most important greenhouse gas and is emitted from a wide range of sources. Natural microbial decomposition of organic matter in wetlands is the largest single source of methane emissions. However, human activities are responsible for emissions from fossil fuel extraction and use (including natural gas), farming of livestock, rice cultivation and waste from landfills and agriculture. Together, these sources account for about 60 per cent of global methane emissions. Because methane is 83 times more potent at trapping heat than CO_2 over a 20-year time period, but persists in the atmosphere for only around a decade, efforts to reduce methane emissions will have a large impact on reducing warming on a short timescale. Therefore, reducing atmospheric methane is an important component of pathways to manage climate change. However, in 2020 and 2021, atmospheric methane concentration increased by 13 and 20 ppb, respectively. Increases of these sizes are unparalleled in three decades of direct atmospheric measurements.

Nitrous oxide has a global warming potential 273 times that of CO_2. It is emitted naturally from the land and oceans. Use of nitrogenous fertilisers is the largest anthropogenic source, and it has been rising steadily in recent decades, leading to accelerating atmospheric growth rates. Throughout 2020 and 2021, nitrous oxide has grown in the atmosphere by more than 1.3 ppb per year. The growth rate of nitrous oxide, measured directly or through Antarctic ice and compressed snow (firn), has been less than 1 ppb per year for at least the past 2000 years except for five of the past eight years.

Actions to reduce the impact of the COVID-19 pandemic led to a reduction in CO2 emissions from human activities in many countries during 2020 (and to a lesser extent 2021), relative to 2019. In April 2020, during the period of most severe and widespread restrictions globally, daily CO_2 emissions are estimated to have dropped by 17 per cent. This sharp decline was short-lived, so global annual CO_2 emissions for all of 2020 were only around 6 per cent lower than in 2019. A drop in CO_2 emissions, such as was seen in 2020, has not been recorded since the two world wars and the Great Depression, during the first half of the past century.

Ongoing fossil fuel use and land-use change mean that CO_2 has continued to grow in the atmosphere throughout 2020 and 2021 at a rate of more than 2 ppm per year, similar to the past decade. Substantial global emissions reductions, of the order of those seen in 2020 but that are sustained for 5–10 years, will be required before there is an attributable decline in the atmospheric growth rate of CO_2. Global net zero emissions will be required to stop greenhouse gas accumulation in the atmosphere, abating climate change.

The Kennaook/Cape Grim Baseline Air Pollution Station (pictured opposite), located at the north-west tip of Tasmania, is the Southern Hemisphere's key greenhouse gas monitoring station in the World Meteorological Organization's Global Atmosphere Watch program. It has been running continuously for 46 years.



Atmospheric concentrations of CO_2 measured at Kennaook/Cape Grim continue to show an upward trend with the decadal growth rates accelerating since measurements began. This is consistent with other stations globally. The annual average CO_2 at Kennaook/Cape Grim reached 412 ppm in 2021, slightly lower than the global average of 414.4 ppm.

Kennaook/Cape Grim greenhouse gas concentrations are typically lower than the global averages because most emissions originate in the Northern Hemisphere. It takes many months for Northern Hemisphere air, with higher greenhouse gas concentrations, to mix into the Southern Hemisphere and appear in the Kennaook/Cape Grim observations.

Globally averaged atmospheric concentrations of all major long-lived greenhouse gases and a group of synthetic greenhouse gases (industrially produced for uses such as refrigeration) continue to rise.

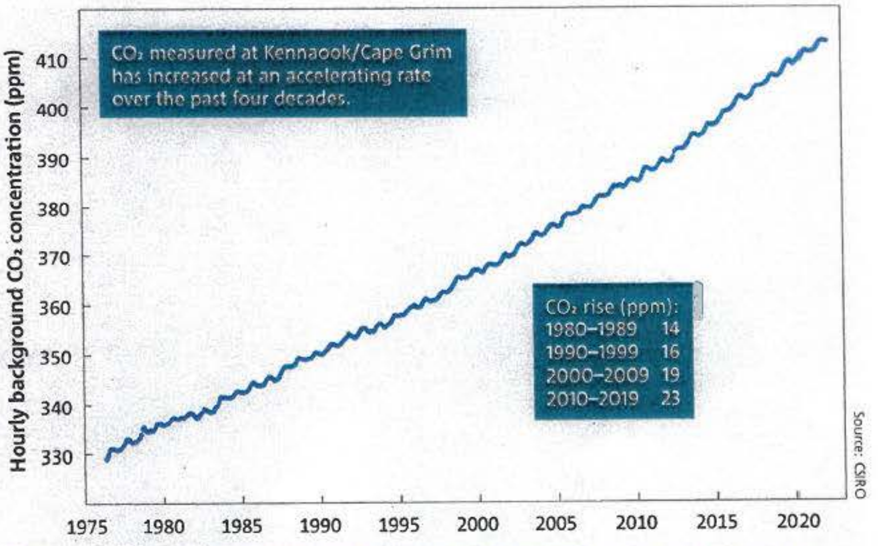
The cumulative climate effect of all the long-lived greenhouse gases in the atmosphere can be expressed as radiative forcing. Radiative forcing is the enhancement of the net radiation. It quantifies the increase in energy in the climate system due to the addition of long-lived greenhouse gases into the atmosphere relative to 1750. Because it is the most abundant greenhouse gas, CO_2 is the largest contributor to radiative forcing. Other gases make substantial and growing contributions.

The combined impact of all greenhouse gases can be converted to a CO_2-e atmospheric concentration, by considering the global warming potential (ability to trap heat in the atmosphere) of each gas and its concentration. The annual average CO_2-e measured at Kennaook/Cape Grim reached 511 ppm in 2021, and 516 ppm globally. This is approaching twice the pre-industrial level of 278 ppm CO_2-e in 1750.

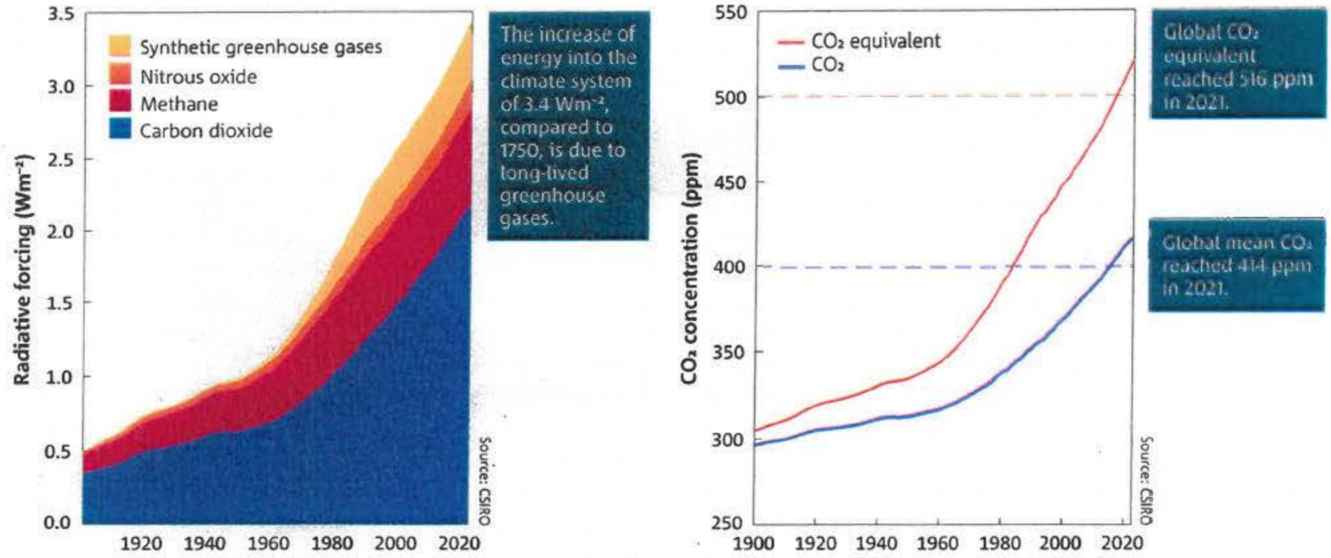
Measurements of air extracted from Antarctic ice cores and firn extend the atmospheric composition record back before direct observations commenced.

These measurements show that all three major greenhouse gases (CO_2, methane and nitrous oxide) were relatively stable for most of the past 2000 years, before beginning to rise in the late 18th century, coincident with industrialisation. All three major greenhouse gases have been increasing at an accelerating pace since around 1850 and are now rising at historically unprecedented rates.

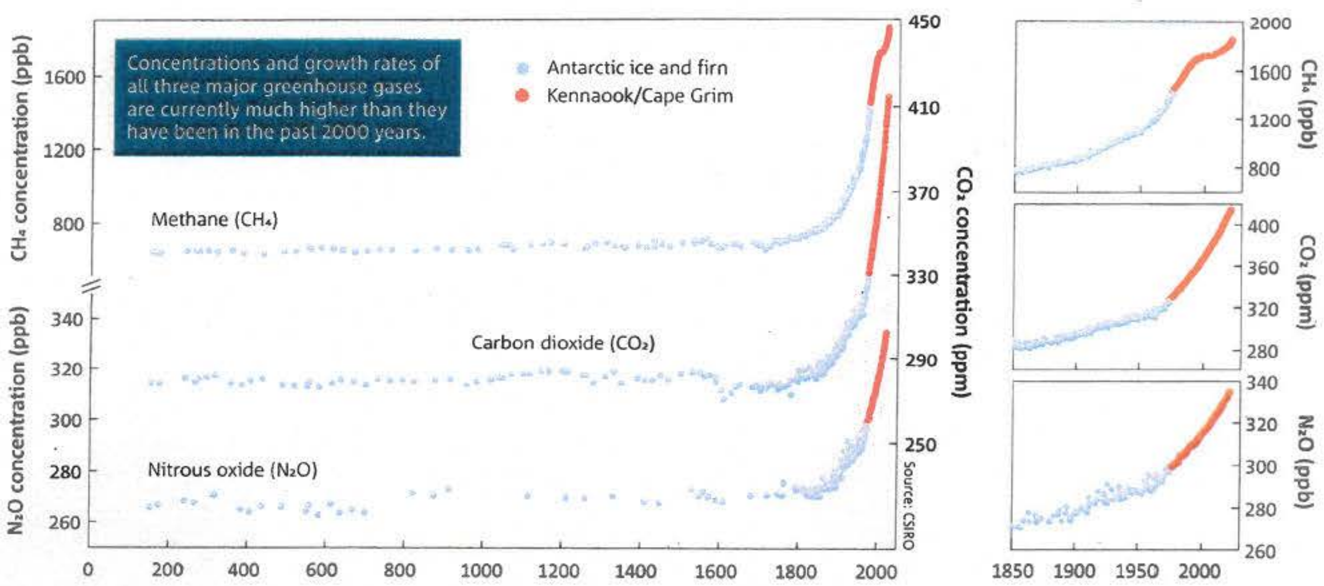
The isotopes of carbon in atmospheric CO_2 are used to identify its different sources. Measurements of carbon-13 and carbon-14, relative to carbon-12, confirm that the increase in CO_2 concentration since 1800 originates principally from fossil fuel and land clearing emissions.



Background hourly CO_2 in clean air as measured at the Kennaook/Cape Grim Baseline Air Pollution Station from 1976 to June 2022. The hourly data represent thousands of individual measurements. To obtain clean air measurements, the data are filtered to include only periods when weather systems have travelled across the Southern Ocean and the sampled air is thus free from local sources of pollution. The increase in CO_2 concentration for each decade (1 January for the start year and 31 December for the end year) is also shown.



Left: Radiative forcing relative to 1750 due to the long-lived greenhouse gases CO_2, methane, nitrous oxide and the synthetic greenhouse gases, expressed as watts per metre squared. Right: Global mean CO_2 concentration and global mean greenhouse gas concentrations expressed as CO_2-e (ppm). CO_2-e is calculated from the atmospheric concentrations of CO_2, methane, nitrous oxide and the suite of synthetic greenhouse gases.



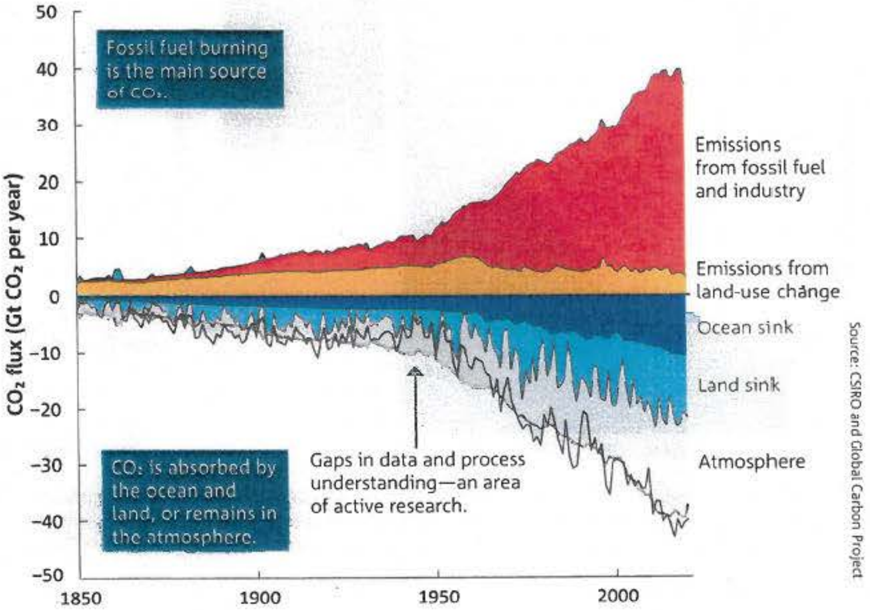
Concentrations of the major greenhouse gases (CO_2, methane and nitrous oxide) in the atmosphere over the past 2000 years. Grey data are measured from air extracted from Antarctic ice cores and the overlying compressed snow (firn) layer. Orange data show the modern *in situ* record measured at Kennaook/Cape Grim Baseline Air Pollution Station. Note the different scales used for the concentration of each gas.

Global carbon budget

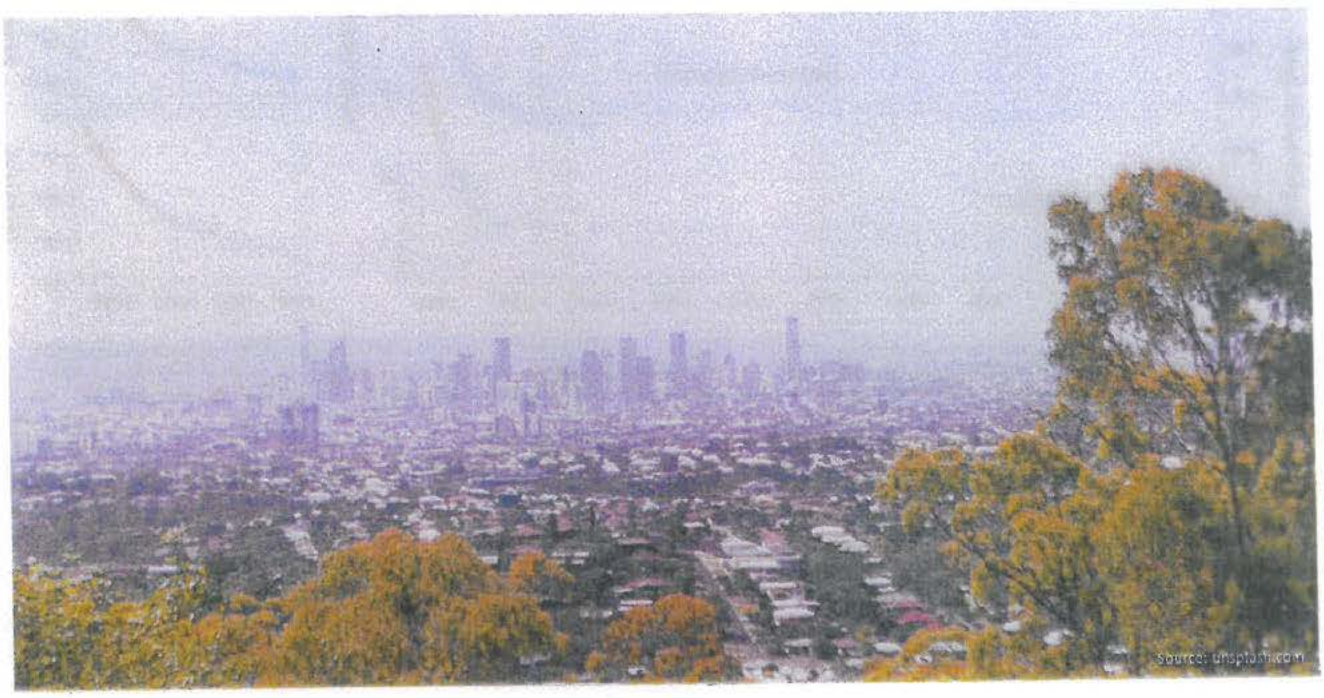
Global emissions of CO_2 from fossil fuel use and land-use change continued to increase in recent decades, reaching 40.6 ± 2.9 gigatonnes per year of CO_2 in 2019 (1 Gt is equal to 1 billion tonnes). In the decade from 2011–20, average global anthropogenic CO_2 emissions were 38.9 ± 1.8 Gt CO_2 per year. Around 90 per cent of global CO_2 emissions were from fossil fuels and 10 per cent from land-use change.

The uptake of carbon into ocean and land sinks has grown in response to the higher accumulation of CO_2 in the atmosphere. In the decade from 2011–20, the land and ocean sinks removed on average 29 per cent and 26 per cent of all anthropogenic emissions, respectively. Combined, these sinks are removing more than half of all CO_2 emissions from human activities and thus are slowing the rate of increase in atmospheric CO_2 and the pace of climate change.

Despite this important uptake by the natural CO_2 sinks, CO_2 has continued to accumulate in the atmosphere, growing by 18.6 Gt CO_2 per year over the decade from 2011–20.



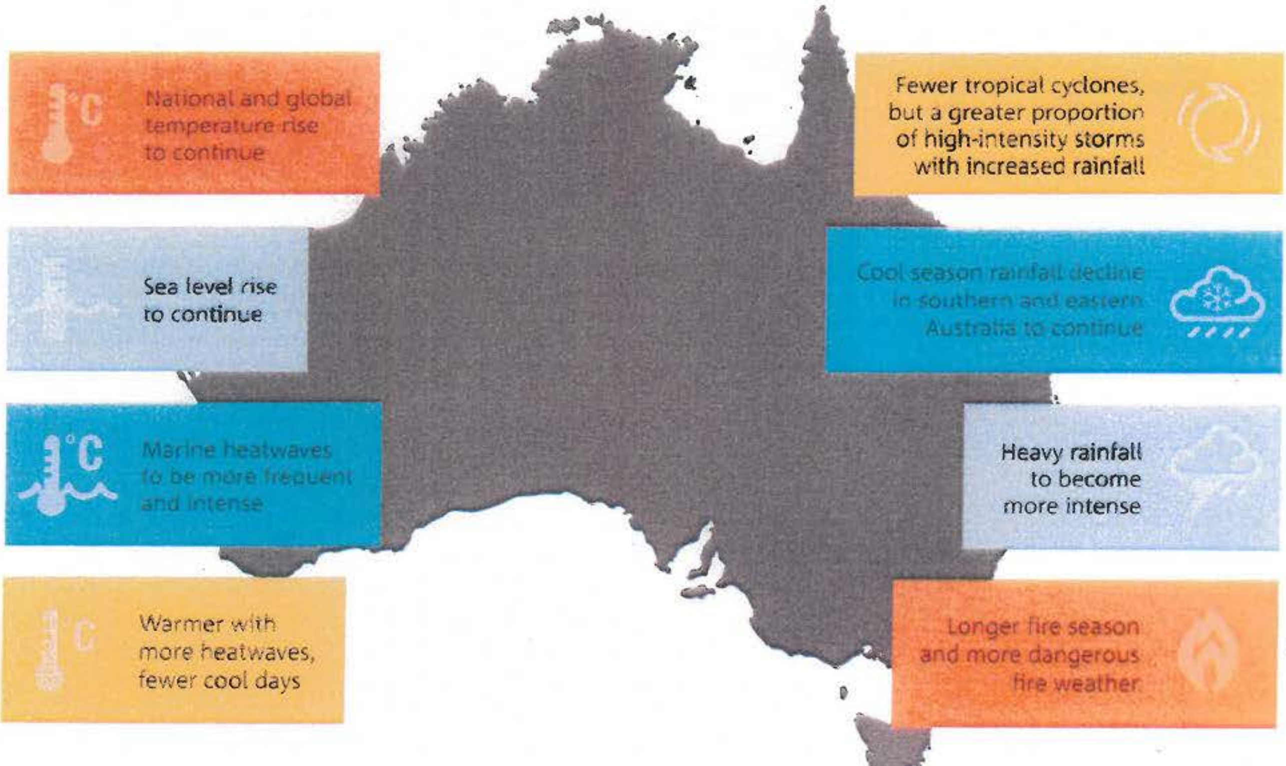
Time series showing the input CO_2 fluxes per year (above zero on graph) from 1850–2021 due to emissions from fossil fuels, industry and land-use change; the amount of CO_2 taken up each year by the oceans and land (below zero on graph); and the net CO_2 being added each year to the atmosphere.



Future climate

New research in Australia and around the world, together with the IPCC's Sixth Assessment Report, enhance understanding of the state of Australia's future climate. In coming decades, Australia is projected to experience:

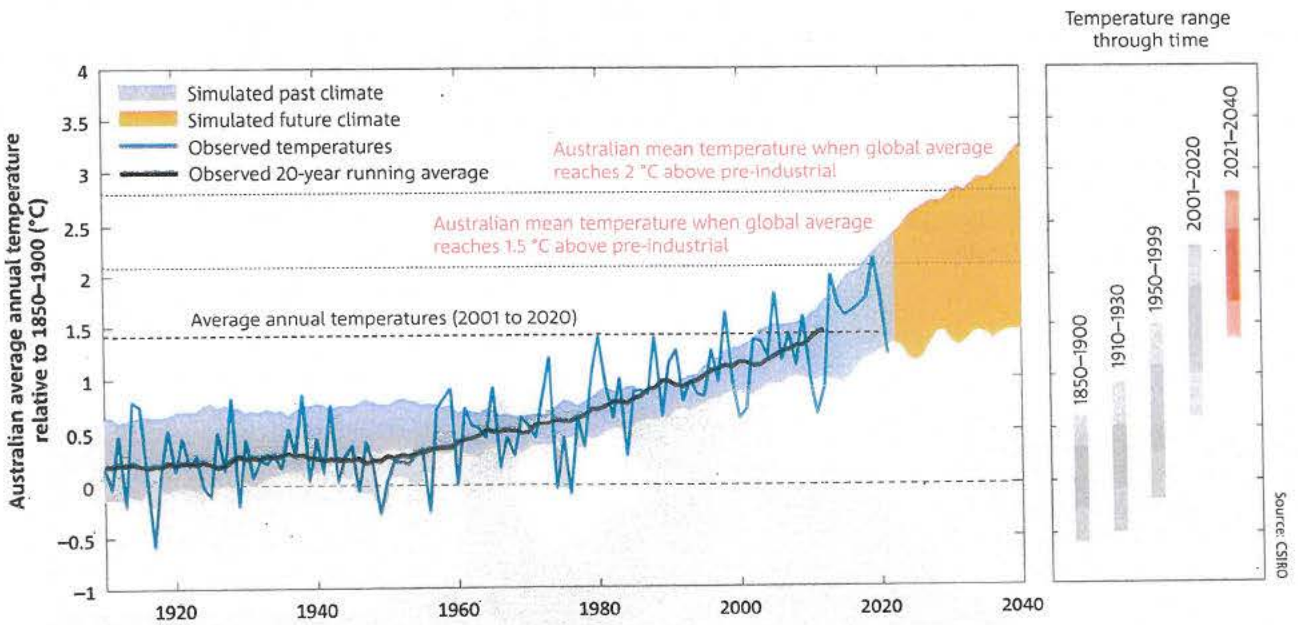
- Continued warming, with more extremely hot days and fewer extremely cool days.
- A further decrease in cool season rainfall across many regions of the south and east.
- Continued drying in the south-west of Western Australia, especially during winter and spring.
- Longer periods of drought on average in the south and east.
- A longer fire season for the south and east, and an increase in the number of dangerous fire weather days.
- More intense short-duration heavy rainfall events, even in regions where the average rainfall decreases or stays the same. This will lead to a complex mix of effects on streamflow, and associated flood and erosion risks, including increased risk of small-scale flash flooding.
- Fewer tropical cyclones, but a greater proportion projected to be of high intensity, with ongoing large variations from year to year. The intensity of rainfall associated with tropical cyclones is also expected to increase and, combined with higher sea levels, is likely to amplify the impacts from those tropical cyclones that do occur.
- Fewer east coast lows on average, particularly during the cooler months of the year.
- Ongoing sea level rise through this century and beyond, at a rate that varies by region. Recent research on potential ice loss from the Antarctic ice sheet suggests that a scenario of larger and more rapid sea level rise can't be ruled out.
- More frequent extreme sea levels linked to coastal inundation and coastal erosion. For most of the Australian coast, extreme sea levels that had a probability of occurring once in a hundred years are projected to become an annual event by the end of this century with lower emissions, and by the mid-21st century for higher emissions.
- Continued warming and acidification of surrounding oceans with consequent impacts on biodiversity and ecosystem processes.
- Increased and longer-lasting marine heatwaves, which will further stress marine environments, such as kelp forests, and increase the likelihood of more frequent and severe bleaching events in coral reefs around Australia, including the Great Barrier Reef and Ningaloo Reef.
- An increase in the risk of natural disasters from extreme weather, including 'compound extremes', where multiple extreme events occur together or in sequence, thus compounding their impacts.



Source: Bureau of Meteorology and CSIRO

Projections of Australia's average temperature over the next two decades show:

- The average temperature of each future year is now expected to be warmer than any year prior to the commencement of human-caused climate change. This is scientifically referred to as climate change 'emergence'.
- Ongoing climate variability means each year will not necessarily be hotter than the last, but the underlying probabilities are changing. This leads to less chance of cool years and a greater chance of repeatedly breaking Australia's record annual average temperature (e.g. record set in 2005 was subsequently broken in 2013 and then again in 2019).
- While the previous decade was warmer than any other decade in the 20th century, it is likely to be the coolest decade for the 21st century.
- The average temperature of the next 20 years is virtually certain to be warmer than the average of the past 20 years.
- The amount of climate change expected in the next decade is similar under all plausible global emissions scenarios. However, by the mid-21st century, higher ongoing emissions of greenhouse gases will lead to greater warming and associated impacts, while lower emissions will lead to less warming and fewer impacts.
- Warming is generally expected to be greater in the interior of Australia than near the coast.



Australian average annual temperature in observations and global climate models shown relative to the 1850–1900 baseline approximating the pre-industrial era. Past and future coloured bands show the 20-year running average from models for historical conditions and all plausible future scenarios to 2040. Black dashed lines show the average warming expected for Australia when the global average temperature reaches 1.5 and 2.0 °C above the pre-industrial era. The panel to the right shows the range of temperatures (one and two standard deviations) in various epochs from observations and the 2021–40 period as simulated by one climate model (the results from which are close to the mean of all models).

Why are Australia and the world warming?

Energy comes from the Sun. In order to maintain stable temperatures at the Earth's surface, in the long run this incoming energy must be balanced by an equal amount of heat radiated back to space. Greenhouse gases in the atmosphere, such as CO_2, act to increase the temperature of the Earth's surface, ocean and atmosphere, by making it harder for the Earth to radiate this heat. This is called the greenhouse effect.

Without any greenhouse gases, the Earth's surface would be much colder, with an average temperature of about −18 °C, due to the radiation balance alone (even colder when feedback mechanisms are considered). For centuries prior to industrialisation, the incoming sunlight and outgoing heat were balanced, and global average temperatures were relatively steady, at a little under 15 °C. Now,mostly because of the burning of fossil fuels and changes in land use, the concentrations of greenhouse gases in the atmosphere are rising and causing surface temperatures to increase. This increase in greenhouse gases, along with an increase in aerosol particles in the air and the flow-on effects to clouds, has created an 'effective radiative forcing' of 2.72 W m^{-2} (averaged globally). The atmosphere and oceans will continue to warm until enough extra heat can escape to space to allow the Earth to return to balance. Because CO_2 persists in the atmosphere for hundreds of years, further warming and sea level rise are locked in. This well-established theory, together with observations of the air, water, land and ice, as well as paleoclimate records and climate models, allows us to understand climate changes and make projections of the future climate.

About State of the Climate

The State of the Climate report draws on the latest monitoring, science and projection information to describe variability and changes in Australia's climate.

Changes to our climate affect all Australians, particularly the changes associated with increases in the frequency or intensity of heat events, fire weather and drought. Australia will need to plan for and adapt to climate change.

This is the seventh State of the Climate report. The report has been published every two years since the first report in 2010.

About Kennaook/Cape Grim

The 46 years of uninterrupted measurement at the Cape Grim Baseline Air Pollution Station, Tasmania, is a source of great pride for the Bureau of Meteorology and CSIRO. In 2021, the dual name of Kennaook/Cape Grim Baseline Air Pollution Station, was formally adopted for Australia's globally important atmospheric observatory, in recognition of the deep history and continuing presence and participation of the Peerapper people in the custodianship of the Kennaook area.

This area has been a site of historical violence and dispossession of its First Peoples, the Peerapper, perpetrated by British colonists. Both the Bureau of Meteorology and CSIRO are committed to taking action towards reconciliation with Australia's First Nations people. We acknowledge the Peerapper people as the traditional custodians of the lands, waters and skies of the area traditionally known as Kennaook, which encompasses the site of the Kennaook/Cape Grim observatory, and pay our respect to Elders past and present.

Further information

The Bureau of Meteorology

The Bureau of Meteorology is Australia's national weather, climate, ocean, water and space weather agency. Through regular forecasts, warnings, monitoring and advice spanning the Australian region and Antarctic territory, the Bureau provides one of the most fundamental and widely used services of government.

bom.gov.au/state-of-the-climate
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CSIRO

CSIRO is Australia's national science agency, solving the greatest challenges through innovative science and technology. CSIRO uses collaborative research to turn science into solutions for food security and quality; clean energy and resources; health and wellbeing; resilient and valuable environments; innovative industries; and a secure Australia and region.

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Further information about the content of this report, and a list of references is available online.

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