CLIMATE COUNCIL

WEATHER GONE WILD: CLIMATE CHANGE-FUELLED EXTREME WEATHER IN 2018

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Key Findings

1

The past four years have been the four hottest years on record for global surface temperature, continuing a long-term warming trend.

- Globally, 2018 was the fourth hottest year on record for surface temperature, following 2017 (the third hottest), 2015 (the second hottest) and 2016 (the hottest).
- The global average surface temperature in 2018 was between 0.9 and 1.1°C above temperatures in the late 19th Century (1880 – 1900).
- In Australia, the surface air temperature for 2018 was 1.14 °C above the 1961-1990 average, making 2018 the third hottest year on record.
- 2018 was the warmest on record in the oceans, surpassing the previous record set in 2017.
- Globally, the 20 hottest years on record have been in the past 22 years and in Australia, nine of the 10 hottest years on record have occurred since 2005.

2

Climate change is increasing the frequency and/or severity of extreme weather, with 2018 being a year of wild weather both globally and in Australia.

- All extreme weather events are being influenced by climate change, as they are occurring in an atmosphere that contains more energy than fifty years ago.
- Extreme weather events during 2018 are part of a trend of increasing extreme weather since the 1980s, both globally and in Australia.
- In 2018, Australia experienced extreme heat across many parts of the country, severe bushfires affected parts of South Australia, New South Wales, Queensland, Victoria and Western Australia, intense rainfall triggered flooding in northern Queensland, Hobart and southwest Western Australia, and drought conditions persisted across southern Australia.
- Globally, in 2018 the United States was plagued by a series of intense hurricanes in the southeast and record-breaking wildfires in California, severe drought created a crisis for Cape Town's water security, the Nordic region was hit with extreme heat in Norway and Finland and fires in Sweden, and a series of extreme weather events brought both extreme heat and extensive flooding to many parts of Japan.

3

The impacts of extreme weather during 2018 have been damaging and costly.

- Globally, economic losses associated with weather-related disasters in 2018 are estimated to be US $215 billion.
- Insurance companies in Australia paid out more than $1.2 billion in claims following major extreme weather events during 2018. This represents just a small proportion of the total cost of extreme weather to the Australian economy.
- The current drought in eastern Australia is forecast to cut the country's GDP growth in 2018-19 by up to 0.75 percent or $12.5 billion.

4

To slow and eventually stop the increase in the frequency and severity of extreme weather, Australia needs an effective national climate policy that drives down greenhouse gas pollution deeply and rapidly as part of a global effort.

- The Federal Government's current climate policy is an abject failure, with greenhouse gas pollution increasing over the past four years.
- Tackling climate change effectively requires a credible national policy to drive down greenhouse gas pollution across all sectors: electricity, transport, industry, agriculture and land use.
- To do our fair share of meeting the Paris climate target, Australia's greenhouse gas pollution levels must be reduced by 45-65 percent below 2005 levels by 2030, as recommended by the Climate Change Authority in 2015.
- Australia is currently not on track to meet its much weaker 2030 target of 26-28 percent reduction in greenhouse gas pollution below 2005 levels.

1. Introduction

The global average surface temperature in 2018 was between 0.9 and 1.1°C above the late 19th century average (between 1880 and 1900) (Carbon Brief 2019). The actual temperature rise for 2018 would be slightly higher if a pre-industrial baseline were used. Globally, 2016 remains the hottest year on record (1.2°C above the pre-industrial era). 2017 and 2015 were both 1.1°C above pre-industrial levels (with 2015 being less than one hundredth of a degree hotter than 2017) (WMO 2018a). This made 2018 the fourth hottest year on record for surface air temperature.

The hot global average temperatures in 2018, 2017, 2016 and 2015 are part of a long-term upswing in global average temperature that began most clearly in the mid-20th century and has persisted since then. A rapidly warming world is the result of increasing greenhouse gas pollution from the burning of fossil fuels and other human activities such as land clearing. Globally, the 20 hottest years on record have occurred in the past 22 years. 2018 is the 42nd consecutive year with an above-average global temperature. No one aged under 40 has lived in a year with global average temperatures at or below the global 20th century average.

Similar trends are evident in Australia, where the average air temperature for 2018 was 1.14°C above the 1961-1990 average, making 2018 the third hottest year on record. The mean maximum temperature was the second hottest on record (1.55°C above average). It is important to note that the Australian average surface temperature refers to land only, while the global surface temperature refers to a combination of land surface and sea surface temperatures. Nine of the 10 hottest years on record in Australia have occurred since 2005 (CSIRO and BoM 2018).

Greenhouse gas pollution in the atmosphere has risen steadily since around 1750. The mean carbon dioxide (CO_2) level during 2017 was 405 parts per million in the atmosphere - a 46 percent increase from the levels in 1750 (278 ppm) (CSIRO and BoM 2018). The increase in greenhouse gas pollution has led to more heat (or energy) being trapped in the lower atmosphere, raising the global average temperature by around 1°C compared to pre-industrial levels (CSIRO and BoM 2018).

[1] The on-going US government shutdown has delayed the final reporting of December 2018 temperatures. The 2018 estimate was made using January – November data from the National Oceanic and Atmospheric Administration, with estimates for December derived from the Copernicus/ECMWF dataset, which was not delayed by the shutdown.

Whilst some of the heat trapped in the lower atmosphere has gone towards warming the Earth's surface, the majority of the heat – around 93 percent – has gone into the oceans. Roughly two thirds of this has accumulated in the top 700 metres, but some heat has also reached depths of 700 – 2000 metres. Ocean heating has been rising steadily since the 1950s, and has accelerated since the 1990s (Cheng et al. 2019). Ocean heat content is a better metric for climate change than global surface temperatures, as it is where the vast majority of the excess heat from greenhouse gas pollution is stored and is less variable from year-to-year than surface air temperatures. In 2018, ocean heat content in the upper 2000 metres was the hottest on record (see Figure 1) (Cheng et al. 2019).

Nine of the 10 hottest years on record in Australia have occurred since 2005.

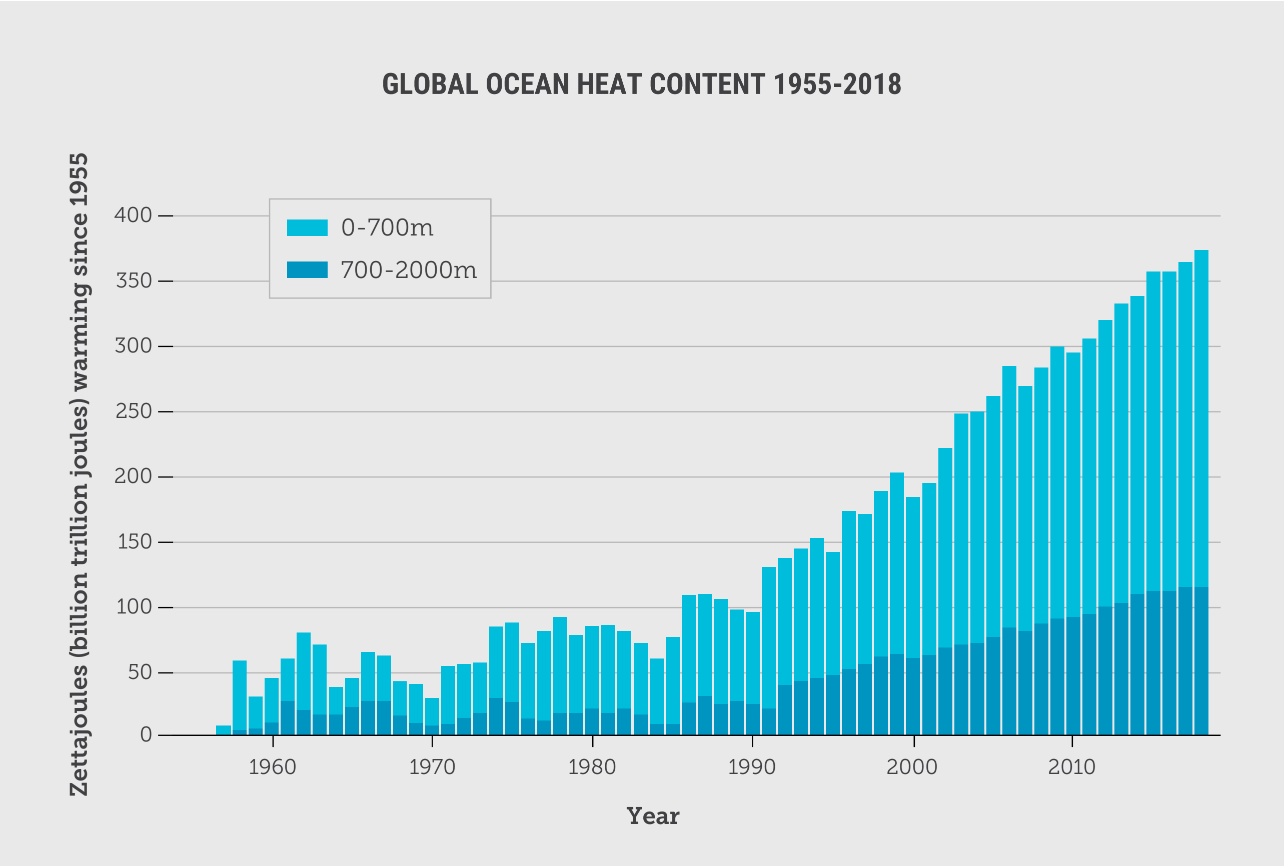


Figure 1: Annual global heat content from 1955 to 2018 in zettajoules (billion trillion joules) for 0-700 metres and 700 – 2000 metres. **Source:** Carbon Brief (2019).

The increase in ocean heat affects weather systems by supplying more energy and moisture to extreme weather events, leading to an increase in the frequency and/or severity of heavy rainfall and tropical storms (Patricola and Wehner 2018; Trenberth et al. 2018). In 2018, the world experienced a number of major tropical storms including hurricanes Florence and Michael in the Atlantic and typhoons Jebi, Trami, Mangkhut and Maria in the Pacific. The number of tropical cyclones was above average in all four northern hemisphere basins, and the accumulated cyclone energy was the highest on record for the northeast Pacific basin (WMO 2018b).

Climate change, driven by the burning of fossil fuels, is worsening extreme weather.

This report provides a snapshot of major extreme weather events in 2018 in Australia and globally. The report discusses how climate change is influencing extreme weather events including extreme heat events, intense rainfall events, droughts and drying, tropical cyclones and bushfires. It then goes on to outline major temperature records that were broken and significant extreme weather events that occurred, both in Australia and globally.

Overall, global economic losses associated with weather-related natural disasters in 2018 are estimated to be at least US $215 billion, with insured losses of US $89 billion (Aon 2019). The costliest back-to-back years for weather-related disasters globally were 2017 and 2018, with total estimated economic damages amounting to US $653 billion (Aon 2019). In Australia, extreme weather events caused insured losses of at least $1.2 billion (ICA 2018). The drought across eastern Australia during 2018 is expected to cut the growth rate of GDP in 2018-19 by up to 0.75 percent.

The extreme weather events of 2018 are the latest in a long-term trend of worsening extreme weather, both in Australia and globally, as a result of climate change. Over the past several decades, heatwaves in Australia have increased in duration, frequency and intensity in many parts of the country; southern Australia has experienced a rainfall decline in the cooler months, heavy rainfall events have accounted for an increased proportion of total annual rainfall, and extreme fire weather days have increased at 24 out of 38 sites (CSIRO and BoM 2015).

Globally over the past half-century, the frequency and/or duration of warm spells and heatwaves has increased over most land areas, heavy precipitation events have increased over more land areas than have decreased, the North Atlantic has experienced an increase in intense tropical cyclone activity since 1970, and there has been an increase in flooding from high sea-level events (IPCC 2013).

2. Climate change and extreme weather

Climate change is influencing all extreme weather events as they are occurring in a more energetic climate system (Trenberth 2012). Australia is one of the most vulnerable developed countries in the world to the impacts of climate change. Heatwaves are becoming longer, hotter and starting earlier in the year. In the south of the country, where many Australians live and work, dangerous bushfire weather is increasing and cool season rainfall is dropping off, stretching firefighting resources, putting lives at risk and presenting challenges for the agriculture industry and other sectors, such as tourism.

EXTREME TEMPERATURES

The increase in global average temperatures has increased the probability of hot extremes (including record-breaking hot temperatures) and decreased the probability of cold extremes (see Figure 2). In Australia, the ratio of observed hot to cold temperature records was 12 to 1 between 2000 and 2014 (Lewis and King 2015). The annual number of hot days (above 35°C) and very hot days (above 40°C) has also increased strongly over most areas since 1950. Heatwaves are also lasting longer, reaching higher maximum temperatures and occurring more frequently over many regions of Australia (Perkins-Kirkpatrick et al. 2016).

There were twelve times more hot temperature records than cold temperature records in Australia from 2000 to 2014.

Attribution studies - where models are used to examine how much more likely extreme weather events were as a result of climate change - have clearly linked the increase in extreme heat events to climate change. For example, Australia's record hot year of 2013, when mean temperatures were 1.2°C above the 1961-1990 average, would have been virtually impossible without climate change (Knutson et al. 2014; Lewis and Karoly 2014). Likewise, the marine heatwave that caused widespread coral bleaching of the Great Barrier Reef during 2016 was made 175 times more likely due to climate change (King et al. 2016). Extreme heat events are projected to continue to increase if greenhouse gas pollution continues along a business-as-usual trajectory. By 2100, three out of four people globally could experience at least 20 days of heat and humidity per year associated with severe heatwaves if greenhouse gas pollution continues to rise at current rates (Mora et al. 2017).

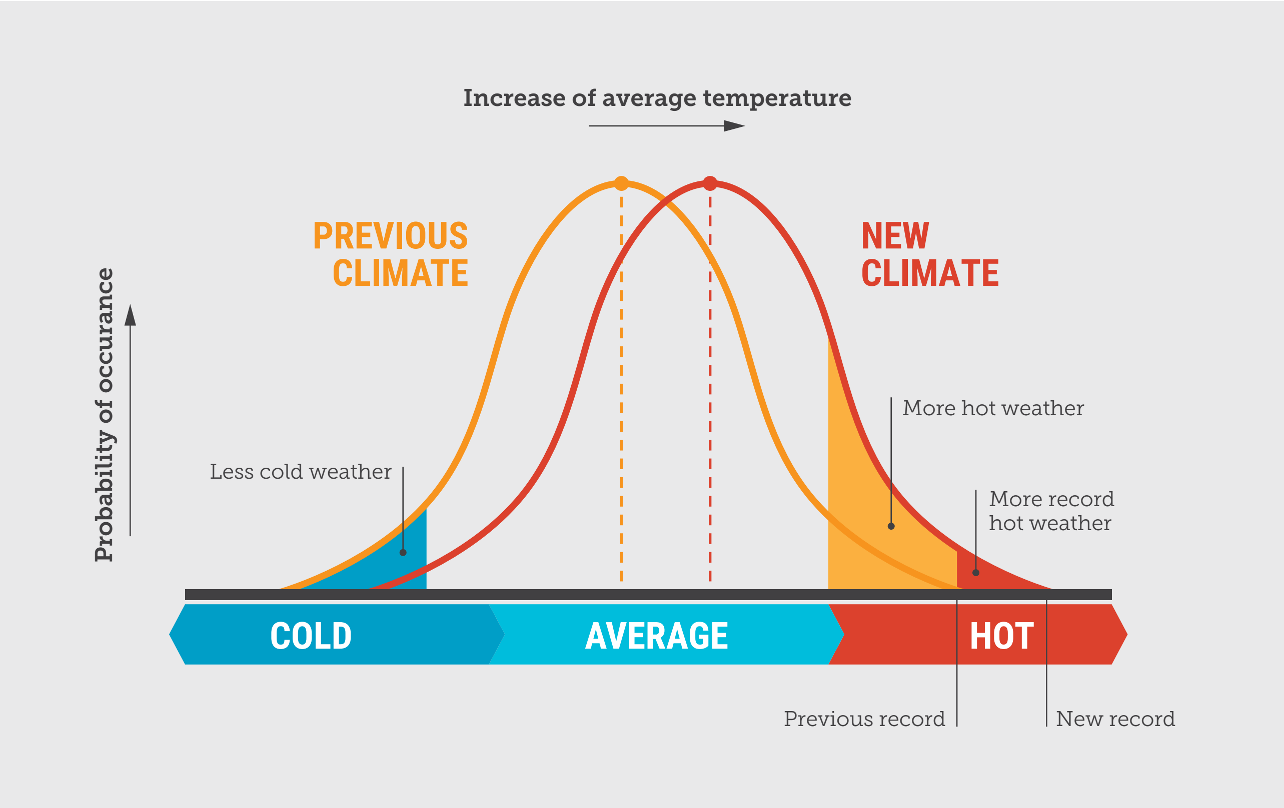


Figure 2: Schematic showing the increased probability of hot extremes and decreased probability of cold extremes with an increase in average temperatures.

INTENSE RAINFALL

Extremes of intense precipitation (rain, snow or hail) over various time periods are increasing across most of the world, despite regional variability. Long-term observations suggest there has been a net increase in the number of heavy precipitation events globally since 1951, with the most consistent trends found in central North America and Europe (Hartmann et al. 2013). In Australia, there has also been an increasing trend over recent decades in the proportion of total annual rainfall stemming from heavy rainfall days (CSIRO and BoM 2018). The physical relationship between temperature and the moisture holding capacity of the atmosphere suggests that for each 1°C rise in global average temperature, the atmosphere can hold approximately 7 percent more moisture (Trenberth 2011). In Australia, the magnitude of extreme daily rainfall (mm/day) is increasing in line with this rate, whilst the magnitude of extreme hourly rainfall (mm/hour) is increasing at double this rate, and more than triple this rate in the tropical north (Guerreiro et al. 2018).

CYCLONES, STORMS AND HURRICANES

There is substantial evidence that climate change is influencing the large-scale environment in which tropical cyclones form and develop. The increasing ocean temperature affects the intensity of cyclones (along with changes in upper atmosphere conditions), both in terms of maximum wind speeds and in the intensity of rainfall that occurs in association with the cyclone. Storms draw energy from the surface waters of the ocean, and as more heat is stored in these upper waters, cyclones have a larger source of energy on which to draw (Emanuel 2000; Wing et al. 2007).

Global studies project that climate change will increase the frequency of severe tropical cyclones (Category 4 and 5) and decrease the frequency of weaker tropical cyclones, resulting in a probable overall decline in tropical cyclone numbers (Bender et al. 2010; Knutson et al. 2010; Done et al. 2015; Holland and Bruyère 2014).

In the North Atlantic region, there has been a statistically significant increase in intense cyclone activity over recent decades (Kossin et al. 2007; IPCC 2013). Since 1980, the number of storms with winds stronger than 200 kilometres per hour (124 mph, or a strong Category 3) has doubled, and those with winds stronger than 250 kilometres per hour (155 mph) have tripled (Rahmstorf et al. 2018). Category 4 and 5 cyclones have increased by 25-30 percent per degree of global warming since 1975, balanced by a decline in Category 1 and 2 cyclones (Holland and Bruyère 2014).

Climate change has also increased the rainfall from tropical storms. A recent attribution study found that rainfall from Hurricane Katrina was increased by between four and nine percent by climate change (see Figure 4). Likewise, rainfall from Hurricane Irma was increased by six percent because of climate change, and rainfall from Hurricane Maria was increased by nine percent because of climate change (Patricola and Wehner 2018). This is significant as flooding associated with heavy rainfall often causes more damage than strong winds. Under a high greenhouse gas pollution scenario, rainfall associated with these hurricanes would increase by up to 30 percent in some areas and peak wind speeds would be 54 km/hour faster (Patricola and Wehner 2018).

Figure 3: Tropical Cyclone Maria approaches landfall, July 10, 2018.

Recent studies have also suggested that the translation speed of tropical cyclones globally has declined by 10 percent over the period 1949 – 2016. The translation speed is the linear pace at which tropical cyclones move forward (distinct from maximum wind speeds, which occur near the centre of a tropical cyclone). The slower translation speed means tropical cyclones can dump more rain when they make landfall, thereby increasing the risk of flash flooding (Kossin 2018).

In the southern hemisphere and Australian region, there is a general tendency for climate models to project an overall decline in the frequency of tropical cyclones (Walsh et al. 2012; Walsh 2015); however, it is likely that the intensity of tropical cyclones will increase, leading to an increase in the percentage of severe tropical cyclones (Category 4 and 5) (Emanuel et al. 2008; Leslie et al. 2007; Lavender and Walsh 2011; Abbs 2012).

The availability, quality and temporal (time related) range of historical data is limited. This, along with strong variability associated with the El Niño Southern Oscillation (ENSO) regime, make it difficult to discern strong trends for tropical cyclone activity in the Australian region. Observational data shows that there has been a decreasing trend in the number of tropical cyclones since 1970. However, the definition of a tropical cyclone was changed in 1978, which means some systems that were previously classed as tropical cyclones would now be classed as sub-tropical systems, potentially influencing the decreasing trend (BoM 2019a). Lack of continuous satellite coverage prior to 1979 also complicates analysis of long-term changes in the frequency or intensity of tropical cyclones (BoM 2019a).

The number of storms with winds stronger than 250 kilometres per hour have tripled since 1980.

Figure 4: Climate change increased the rainfall from Hurricane Katrina by between four and nine percent.

Rainfall intensity is projected to increase for all weather systems including tropical cyclones. This is of significance to Australia as most tropical cyclones have historically been associated with major flooding. Mean sea levels in the Australian region have been increasing at close to the global rate around most of Australia, despite regional variability (about 20 cm since the late 19th century) (CSIRO and BoM 2018). Storm surges associated with tropical cyclones, when combined with higher sea levels, create more potential for damages through coastal erosion and inundation.

Climate change is causing sea levels to rise, driving more devastating coastal flooding during storm surges.

DROUGHTS

In the Mediterranean, the western United States and parts of Africa (particularly West Africa) there has been an observed reduction in rainfall over land since 1950 (IPCC 2013). It is likely that reduced precipitation in these regions has increased the frequency and/or severity of droughts. A strong drying trend is also emerging in northeast China, the country's most important agricultural region (IPCC 2013).

In Australia, it is clear that climate change has influenced rainfall in the southeast and southwest corners of the continent (CSIRO and BoM 2018). Precipitation patterns have changed markedly in these regions, with a pronounced drying trend during the cool season (April – October), which is also the growing season. In the southeast of Australia, rainfall has declined by around 11 percent since the late 1990s (CSIRO and BoM 2018). In the southwest of Australia, May to July rainfall has decreased by around 20 percent since 1970.

Rainfall has declined by around 11 percent in southeast Australia since the late 1990s.

BUSHFIRES

The major factors influencing bushfires are sufficient fuel, a source of ignition and conducive weather conditions. Climate change is influencing all of these variables. In Australia, bushfire weather is measured using the Forest Fire Danger Index (FFDI), which estimates fire danger on a given day based on observations of temperature, rainfall, humidity and wind speed. The FFDI shows that extreme fire weather (the most extreme 10 percent of fire weather days) has increased over recent decades over large areas of Australia, particularly across southern Australia and eastern Australia. The duration of the bushfire season has also lengthened over many areas of Australia. Climate change is contributing to these changes, including through the increase in average temperature (CSIRO and BoM 2018). Hot weather dries out fuel and increases its flammability, increasing the rate of spread and intensity of bushfires.

Globally, the length of the bushfire season increased by 19 percent between 1979 and 2013 (Jolly et al. 2015). In the Western United States, climate change has led to increased pest infestations, contributing to the death of forests, leading to more fuel for fires. Pine bark beetle infestations killed 7 percent of forests in the western United States between 1979 and 2012, due primarily to warmer winters. Analysis suggests the cumulative forest area burned between 1984 and 2015 in the western United States was twice what it would have been without climate change (Gonzalez et al. 2018). Models project more fires across the southwest region of the United States with continued greenhouse gas emissions. Climate change is also projected to increase the area burned by fires in Mediterranean Europe. One study found that if warming were to reach 3°C, the area burned would increase by 100 percent, but limiting temperature rise to 1.5°C would see just a 40 percent increase in burned area (Turco et al. 2018).

Overall, climate change is driving a long-term increase in the number of extreme weather events worldwide. As a result, the number of climate-related natural catastrophes has been rising steeply since the 1980s (see Figure 5).

The most damaging extreme weather events are often the result of combinations of variables, such as simultaneous low rainfall and heat (leading to drought), or co-occurring heavy precipitation, strong winds and sea level rise leading to storm surges and coastal flooding. These are called compound extremes. Climate change is increasing the frequency of some types of compound extremes (see Box 1).

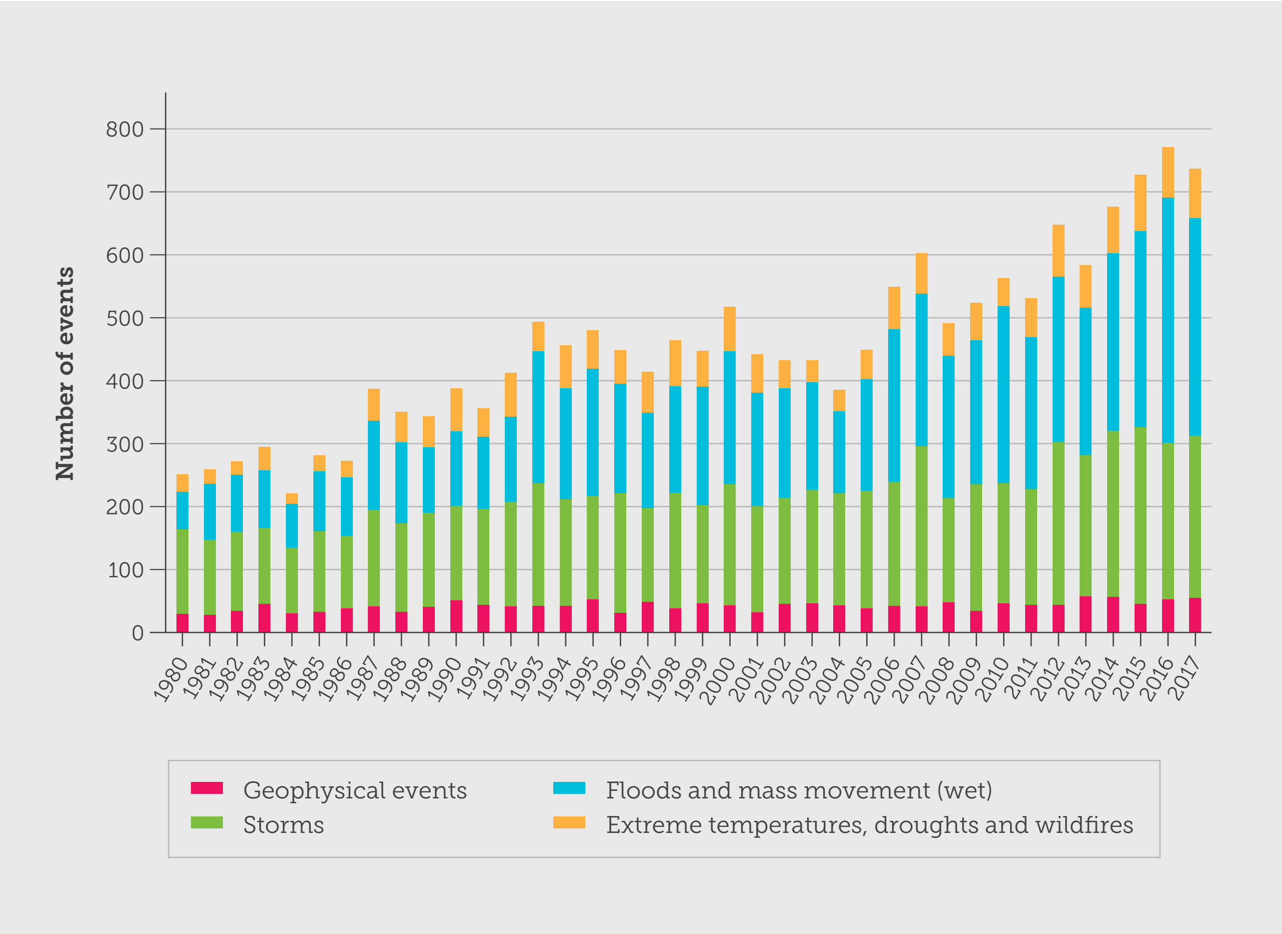


Figure 5: The number of natural catastrophes worldwide has been rising steeply since the 1980s. Red shows geophysical events (earthquakes, volcanoes, and dry mass movement such as subsidence, rock fall or landslides), while the other colours show weather/climate-related events. Green shows changes in the number of storms (tropical storms, extratropical storms, convective storms and local windstorms); blue shows changes in floods and wet mass movement such as subsidence, landslides or avalanches caused by intensive rain; yellow shows changes in extreme temperatures, droughts and wildfires. **Source:** Munich RE 2018.

BOX 1: WHAT IS A COMPOUND EXTREME?

A compound extreme is defined as the simultaneous or sequential occurrence of multiple extremes at singular or multiple locations (Hao et al. 2017). Compound extremes have the capacity to make the impact of related extreme events worse when compared to the impact of each individual event in isolation (Hao et al. 2017; Kopp et al. 2017).

Combinations of events that form a compound event can be of a similar or different nature. For example, tropical cyclones that are generated a few days apart, follow similar tracks and reach a similar intensity are an example of similar events that occur due to persistent underlying atmospheric conditions.

Different events can also combine concurrently or sequentially to form a compound extreme. For example, heavy rain falling on a landscape previously charred by bushfires increases the likelihood of landslides occurring (Hao et al. 2017, AghaKouchak et al. 2018). This occurred in early 2018 in Montecito, California, when heavy rain fell on a landscape that had been burned by wildfires in late 2017, causing a landslide that killed at least 21 people (NBC 2018).

Compound extremes can also be caused by combinations of similar or different events that are not in themselves extreme, but when combined lead to extreme events. For example, high sea levels and strong winds may not individually lead to significant impacts, but may result in damaging storm surges when combined. Warm temperatures and below average rainfall may not individually be extreme, but may result in agricultural or hydrological drought and bushfire risk when combined.

As the climate warms, compound extremes are likely to occur more frequently (AghaKouchak, et al. 2018). Climate change can affect the probability of a compound extreme through changing baseline conditions (e.g. increasing the average temperature or increasing the sea level), or by influencing the frequency or intensity of individual events (increasing the probability of events coinciding) (Kopp et al. 2017, Chen et al. 2011).

In the United States, week-long heatwaves that coincide with drought now occur twice as often as they did during the 1960s and 70s (Mazdiyasni and AghaKouchak 2015). Projections indicate that climate change is likely to cause an increase in the number of summers that are both hot and dry in many regions, due to a stronger negative correlation between temperature and precipitation (Zscheischler and Seneviratne 2017). In Australia, there has been an increase in the number of days when high fire danger weather coincides with conditions that generate thunderstorms. This increases the risk of additional fires being lit due to lightning strikes (CSIRO and BoM 2018).

Being able to understand and project the likelihood of compound extremes is important, as compound extremes have the potential to inflict significant damage on human health, the economy and ecosystems.

3. Global heat records in 2018

Hot temperature records that were broken around the globe in 2018 include:

- January 2018 in New Zealand was the warmest month for any month the country has experienced since records began in 1909. The national temperature was 3.1°C above the national average from 1981 – 2010.
- France experienced its highest January temperature since national records began in 1900 (3.4°C above the national average from 1981 – 2010).
- New Zealand experienced its hottest February on record (2.1°C above the 1981–2010 average).
- Bahrain experienced its hottest March by mean temperature since record-keeping began in 1902 at 24.6°C (which is 3.6°C above average).
- Asia set a new continental maximum temperature record in March when temperatures in Pakistan soared to 45.5°C, breaking the previous record set in India by 0.1°C.
- According to Meteo France, at least seven countries set national March temperature records: Iraq, United Arab Emirates, Qatar, Turkmenistan, Pakistan, Uzbekistan, and Tajikistan.
- Europe had its hottest April since continental records began in 1910. Germany had its hottest April since national records began in 1881 (4.0°C above average). Poland also had its hottest April on record.
- Pakistan experienced its hottest April day on April 30 when the temperature soared to 50.2°C.
- Argentina experienced its hottest April since national records began in 1961, with temperatures 2.6°C above average.
- The contiguous United States experienced its hottest May since record-keeping began in 1895, with temperatures 2.89°C above the 20th century average.
- Europe experienced its hottest May since record-keeping began in 1910.
- Oman recorded its highest minimum temperature on June 26 when overnight temperatures only dropped to 42.6°C in Quriyat.
- California had its hottest July on record. The average July temperature at Death Valley in California was 42.3°C (108.1°F) – the highest average monthly temperature observed anywhere on the planet.
- Parts of Asia recorded their hottest July on record.
- South Korea had its hottest August on record for mean temperatures.
- Europe experienced its hottest August on record for mean temperature, followed by its hottest September on record for mean temperature.
- Argentina had its highest September temperature on record at 1.8°C above average, surpassing the previous record set in 1971.

Source: Unless otherwise stated, all records come from NOAA (2018a).

4. Australian heat and rainfall records in 2018

A national and regional 2018 climate summary is shown in Figure 6. In addition, numerous temperature and rainfall records were broken (both for high and low rainfall). Records below are sourced from BoM's climate archives: http://www.bom.gov.au/climate/current/statement_archives.shtml. The dataset for temperatures extends back to 1910 and for rainfall to 1900. Long-term averages are for the period 1961 to 1990.

Figure 6: National and regional climate snapshot, 2018. **Source:** BoM (2019b).

AUSTRALIA

- Third-warmest year on record; mean temperature +1.14 °C.
- Maximum temperatures; second-warmest on record (+1.55 °C).
- Annual rainfall 11% below average at 412.8 mm.
- Much of Queensland, New South Wales, Victoria, and eastern South Australia affected by drought.
- Pacific Ocean ENSO neutral most of the year; positive Indian Ocean Dipole in Spring.
- Sea surface temperature above average for the Australian region; very much warmer than average for the eastern half.

WESTERN AUSTRALIA

Annual maximum temperature fourth warmest on record. Autumn rainfall seventh lowest on record in south west Western Australia. Summer rainfall (2017-18) tenth wettest on record.

VICTORIA

Third warmest on record. Annual ranfall twelfth lowest on record.

NORTHERN TERRITORY

Annual maximum temperature second warmest on record. Cyclone Marcus (March 17) strongest to cross Darwin since Cyclone Tracy in 1974.

TASMANIA

Fifth warmest on record. Thunderstorms in southeast in mid-May led to severe flash flooding, including in Hobart.

QUEENSLAND

Fifth warmest year on record. Extreme heatwaves in late November and early December spark fires along the east coast.

SOUTH AUSTRALIA

Annual maximum temperature fourth warmest year on record. Autumn rainfall second lowest on record across southern Australia. September driest on record.

NEW SOUTH WALES

Warmest year on record. Rainfall sixth lowest on record. Significant fires on south coast in August and September. Thunderstorms with giant hail in Sydney and Central Coast in December.

SUMMER 2017-18

- For Australia as a whole, the summer was the warmest on record for mean minimum temperatures (0.96°C above average), and the second warmest on record for mean temperature (1°C above average).
- On January 7, Penrith in Western Sydney reached 47.3°C, making it the hottest place anywhere on Earth that day.
- On February 12, Queensland had its hottest February day, with a state-wide mean maximum temperature of 40.46°C.
- In March, one site in Victoria (Walpeup) saw a sequence of 14 days reaching over 35°C, breaking the previous record set in March 2008.
- A number of other sites in Victoria (Bendigo Airport, Echuca, Kyabram and Shepparton) experienced a record-breaking 12 consecutive days over 35°C.
- Overall, at least 72 summer, site-specific hot temperature records were broken or equalled (with the previous record) across Australia during the summer.[2]
- Many areas of central inland and western Queensland received below average rainfall during each month of summer, with total summer rainfall the lowest on record at 10 stations in western Queensland and multiple other sites receiving their lowest rainfall in decades.
- Western Australia received above average rainfall during summer, with a number of highest summer total or highest summer daily rainfall records broken at specific sites. Records for highest summer daily rainfall were set at 26 sites and at 19 sites for highest summer total rainfall.
- Broome airport received more than 1,550 mm of total rainfall during January and February, exceeding the previous annual record for Broome (1,496.6 mm in 2000).
- In the first week of December, daily rainfall records for the month were broken at specific sites in southern New South Wales, northern Victoria and northern Tasmania, with 15 sites in northern Victoria having their wettest day on record for any month of the year.

2 These included records for summer highest temperature, record highest summer daily maximum, record highest summer daily minimum, record highest summer mean daily maximum and record highest summer mean daily minimum.

AUTUMN

- Throughout autumn, mean monthly maximum temperatures were the warmest on record for much of New South Wales, including Sydney, and parts of eastern Victoria and northwest Western Australia.
- In New South Wales the mean maximum temperature for autumn was the hottest on record (2.66°C hotter than average) and the mean temperature was the second hottest on record (1.88°C warmer than average).
- April 9 was Australia's hottest April day ever recorded with a national average of 34.97 °C - 0.65 °C above the previous record set on 8 April 2005.
- New South Wales had its warmest April on record, and its warmest April night on record (April 12).
- New South Wales had a total of 32 days where the state-wide area average maximum temperature was 30°C or more, exceeding the previous record of 28 days, which occurred during the autumns of 1986 and 1940.
- Sixty-nine site-specific autumn hot temperature records were broken in New South Wales, with 22 in Victoria and 16 in Western Australia, including a record highest autumn mean temperature set at Carnarvon (25.2°C) and Onslow (29.3°C). In late March, exceptionally hot temperatures were recorded in northern Western Australia, with a maximum temperature of 45.9°C at Mardie on March 29, the highest temperature recorded so late in March anywhere in Australia.
- Southern mainland Australia had its second driest autumn on record.
- In March, rainfall records were set in Queensland associated with a low-pressure system and then tropical Cyclone Nora.
- In May, a complex low-pressure system brought record-breaking rainfall to many sites in southeastern Tasmania on May 11. Record highest autumn daily rainfall occurred at 20 sites and record highest daily rainfall for any time of year occurred at 12 sites. Huonville set a record for highest autumn total rainfall and Hobart set a record for highest daily May rainfall (129.2 mm on May 11), resulting in significant flooding in Hobart.

WINTER

- In New South Wales, 11 site-specific winter mean daily maximum temperature records were equalled or exceeded.
- In Queensland, two sites (Mackay M.O. and Alva Beach) had record-breaking hottest winter temperatures.
- New South Wales pan evaporation was at its highest level in winter since the Millennium Drought. This is measured by calculating the amount of water that evaporates from a pan of water (with monthly measurements available from 1970).
- Overall, at least 20 site-specific winter hot temperature records were broken or equalled (with the previous record) across Australia throughout the winter.
- Winter rainfall was below average nationally, particularly in New South Wales. In New South Wales four sites saw their record lowest winter total rainfall and a further 45 sites saw their lowest total winter rainfall for at least 20 years.

SPRING

- Spring maximum, mean and minimum temperatures were above average for Australia. November saw very hot temperatures in some parts of the country. At the beginning of November, several sites in southern New South Wales and northern Victoria set spring temperature records. At the end of November an extended heatwave in northern Queensland brought record-breaking monthly or annual daily hot temperatures, and numerous records for consecutive hot days.
- Early spring was very dry, with Australia experiencing its driest September on record.
- A low pressure system late in November brought heavy rainfall to Sydney, the Illawarra, the Hunter and the Central Tablelands, with some locations around Sydney reporting more than 100 mm of rain in less than three hours; a few sites with relatively short records (Mount Boyce, Penrith Lakes, Poonkarie and Box Hill) had their highest spring daily rainfall on record.

5. Extreme weather in Australia during 2018

JANUARY: HEATWAVES, BUSHFIRES AND TROPICAL CYCLONES

In early January, residents of New South Wales, South Australia and Victoria experienced scorching heatwaves. Penrith in Sydney reached a maximum of 47.3°C on January 7, making it the hottest place on Earth in that 24-hour period.

Hot conditions led to high bushfire danger across southern Australia. On Saturday January 6, a fire, believed to be deliberately lit, started in the Sherwood district in South Australia. The hot, dry conditions caused the fire to spread quickly, leading to emergency warnings being issued for Sherwood, Brimbago, Lowan Vale, McCallum and other areas. The fires affected 41 properties and destroyed five homes. In addition, 101 hectares of crops, 4,000 olive trees and an estimated 2,600 livestock (mostly sheep) were lost. The conservative estimated value of lost stock alone was more than $500,000 (ICA 2018).

On January 12, Tropical Cyclone Joyce made landfall over Eighty Mile Beach in Western Australia as a Category 1 system. The cyclone then weakened to a tropical low as it travelled south over the Pilbara, bringing heavy rainfall and some flooding. The storm system continued south, affecting farming areas around Cunderdin and causing some property damage, before dumping heavy rainfall on Perth, leading to flooding there.

FEBRUARY: TROPICAL CYCLONE KELVIN HITS WESTERN AUSTRALIA

On Sunday, February 18, Tropical Cyclone Kelvin made landfall at Anna Plains in the West Kimberley region of Western Australia as a Category 2 system, with wind gusts of up to 150km/hour (which intensified as the cyclone moved inland, reaching 155 km/hour). While there were reports of damaged roofs and destroyed sheds, insurance losses were minimal given the region is sparsely populated. Heavy rainfall as a result of the cyclone caused flooding in the region damaging roads and rail infrastructure (ICA 2018).

MARCH: TROPICAL CYCLONES AND FLOODING IN QUEENSLAND, BUSHFIRES IN VICTORIA AND NEW SOUTH WALES

From March 5 to 12 heavy rainfall across much of northern and central Queensland led to significant flooding in Ingham, Cordelia and Innisfail. Approximately 525 insurance claims were submitted, with insured losses amounting to more than $16.8 million (ICA 2018).

On Saturday, March 17, Tropical Cyclone Marcus made landfall over the Northern Territory coast. It had maximum winds of 260km/hour, making it the strongest cyclone in the Australian region in more than a decade, and the strongest cyclone to hit Darwin since Cyclone Tracy in 1974 (NOAA 2018). The system struck Darwin as a Category 2 cyclone, with numerous reports of fallen trees causing damage to buildings and vehicles. The insured losses alone were more than $61 million (ICA 2018).

Heavy rainfall continued to affect Queensland through March, with the town of Winton receiving 252.6 mm from March 4 to 7, compared to a historical average March rainfall of 96.7 mm (BoM 2018a). The flooding in Winton peaked at 3.7 metres, cutting off all but one access road to the town (ABC 2018a). The floods also stranded truck drivers in Longreach and cut off supplies of groceries and diesel to Mount Isa (ABC 2018a).

On March 25 Cyclone Nora made landfall in Cape York as a Category 3 system, with winds of around 141 km/hour and heavy rain resulting in flooding. On March 26, torrential rain from Nora caused flash flooding in north Queensland, including in Cairns and Port Douglas. Cairns recorded 217.6 mm of rain on March 26, more than half of the monthly March average (BoM 2018b). Landslides to the north of Cairns resulted in road closures (The Guardian 2018a).

On March 18 several fires broke out near Bega on the far south coast of New South Wales. They were fuelled by high temperatures, very low humidity, and strong winds. One of the fires bore down on the coastal community of Tathra. At least 65 homes were destroyed or damaged by the fires (see Figure 7). Major fires near Bega are very unusual in March; these were among the worst ever recorded in that area. Bushfires in New South Wales and Victoria during March resulted in the loss of roughly 100 structures in New South Wales and 27 in Victoria, and insured losses of over $80 million (ICA 2018).

In late March an unusual heat event saw persistent summer-like temperatures spreading from northwestern Australia in late March to southern Australia in April. Prior to 2018, there was no record of any location in Australia reaching a temperature of 45°C after March 21. However, on March 28 this value was surpassed in Western Australia at Mardie (45.4°C), Roebourne (45.9°C) and Port Hedland (45.3°C) and again on March 29 at Mardie (45.9°C) (BoM 2018c).

Tropical Cyclone Marcus was the strongest to hit Darwin since Cyclone Tracy in 1974, and the strongest in the Australian region in more than a decade.

Figure 7: Aftermath of the Tathra Bushfire on the south coast of New South Wales, March 2018. Properties destroyed by fire can be seen along the ridge at the top of this photo.

APRIL: SUMMER-LIKE HEAT AND BUSHFIRES

New state temperature records were set for South Australia (42.2°C at the Nullarbor on April 9), Victoria (39.3°C at Mildura on April 10) and New South Wales (45.5°C at Pooncarie on the 10^{th}). A nationwide record was also set, with April 9 Australia's hottest ever April day (April 8 also broke the previous record).

On April 10 numerous sites in Victoria, New South Wales and South Australia set location specific records. Record-high April maximum temperatures were set over 23.4 percent of New South Wales, 17.1 percent of Victoria and 10.2 percent of South Australia (BoM 2018c). Overall, April was the second warmest on record for mean temperature, and the hottest on record for mean maximum temperature (BoM 2018d).

On April 14, Sydney experienced very strong winds, low humidity and high temperatures. A bushfire believed to have been deliberately lit broke out at Holsworthy in the city's southwest. The fire spread quickly, threatening thousands of homes in Holsworthy, Wattle Grove, Sandy Point, Lucas Heights, Menai and other suburbs (see Figure 8). Thousands of hectares were burnt and a number of homes were damaged. These April fires in New South Wales occurred outside of the statutory bushfire danger period, which runs from October 1 to March 31. In Sydney, most major bushfires have historically occurred from November to January.

Figure 8: Firefighter looks out over bushfires at Holsworthy, April 2018.

MAY: INTENSE RAINFALL AND FLOODING IN HOBART

On the morning of May 11, heavy rainfall brought significant inundation and flooding to the Hobart region, with the suburbs of Kingston, Sandy Bay, and Blackmans Bay being the worst affected. Hobart recorded 129.2 mm of rainfall in 24 hours (BoM 2018e). Inundation resulted from both stormwater run-off and the breaching of the Hobart Rivulet in two locations, causing flooding to low-lying properties. The flooding resulted in insured losses of more than $99 million (ICA 2018).

On May 25, strong winds and heavy rain affected southwest Western Australia, including Perth. The storm drove winds as strong as 67km/hour around Perth, while 53.8 mm of rain fell within 48 hours, taking down power lines and causing widespread blackouts (BoM 2018f). Busselton near Perth also received 67.2 mm of rain, flooding the streets (BoM 2018g).

JUNE, JULY, AUGUST, SEPTEMBER: RAINFALL DEFICIENCIES WORSEN DROUGHT

June marked the start of the southern wet season for Australia, but the month was drier than average for every state and territory. Low rainfall increased long-term rainfall deficiencies, with autumn going down as the second driest on record (since 1900) across southern Australia (BoM 2018h). July was the second-hottest on record for Australia as a whole, and the driest since 2002 during the Millennium Drought. Total rainfall across Australia as a whole was 51 percent below average. New South Wales was particularly dry, with more than 80 percent of the state receiving very much below average rainfall (the driest on record since 2002 during the Millennium Drought). Twenty-six locations in New South Wales reported their record-lowest July rainfall totals (BoM 2018i). In August, the whole of the state was declared in drought. Australia experienced its driest September on record (BoM 2018j).

The drought over eastern Australia affected crop production, farmers' incomes, and the Australian economy more broadly (see Figure 8). Crop production in the eastern Australian wheat-sheep zone in the 2018-19 financial year is forecast to be 53 percent lower than the 20-year average (1998-2018), with the most significant decline forecast for New South Wales, where winter crop production may be 65 percent below the 20-year average (ABARES 2018). Larger than average crop production is forecast for Western Australia, which will offset the declines at the national level, resulting in a national crop production that's predicted to be 23 percent below the 20-year average (ABARES 2018).

The effect of the drought on farmers' incomes (holding other variables constant) has been the second-worst since 1978, comparable only to 2002-03 during the Millennium Drought. The effects of the drought on farmers' incomes is likely to be partially offset by other factors (ABARES 2018). Nevertheless, in August, the Commonwealth Bank warned that if the drought worsened it could potentially cut GDP growth by between 0.5 and 0.75 percent in 2018-19 – equivalent to between $8 billion and $12.5 billion (SBS News 2018). Citigroup also forecast that the drought could cut GDP growth by 0.5 percent, assuming a 20 percent fall in farm production (AFR 2018a). The Federal Government's 2018-19 economic outlook forecast that a decline in rural exports due to the drought would cut GDP growth by 0.25 percent, assuming that seasonal conditions are average in 2019-20, allowing farm production to return to normal (Commonwealth of Australia 2018).

In 2018 southern Australia experienced its second driest Autumn on record since 1900, worsening prior rainfall deficiencies.

The warm, dry conditions over winter also led to elevated bushfire risk. In July, a fire broke out in the Holsworthy army range in southwest Sydney, burning around 3,000 hectares and in August more than 1,000 bushfires burned in southern Queensland. Many local government areas in New South Wales were declared to be in the Bushfire Danger Period in August, at least two months before the beginning of the traditional bushfire season.

The current drought in eastern Australia is forecast to cut Australia's GDP growth by up to $12.5 billion in 2018-19.

OCTOBER: SUPERCELL STORMS HIT QUEENSLAND

On October 11, a series of powerful storm supercells affected the South Burnett Region in Queensland. The storms brought significant rain, large hailstones and tornado-strength winds, causing damage to properties and home contents as well as agricultural losses, including the loss of livestock.

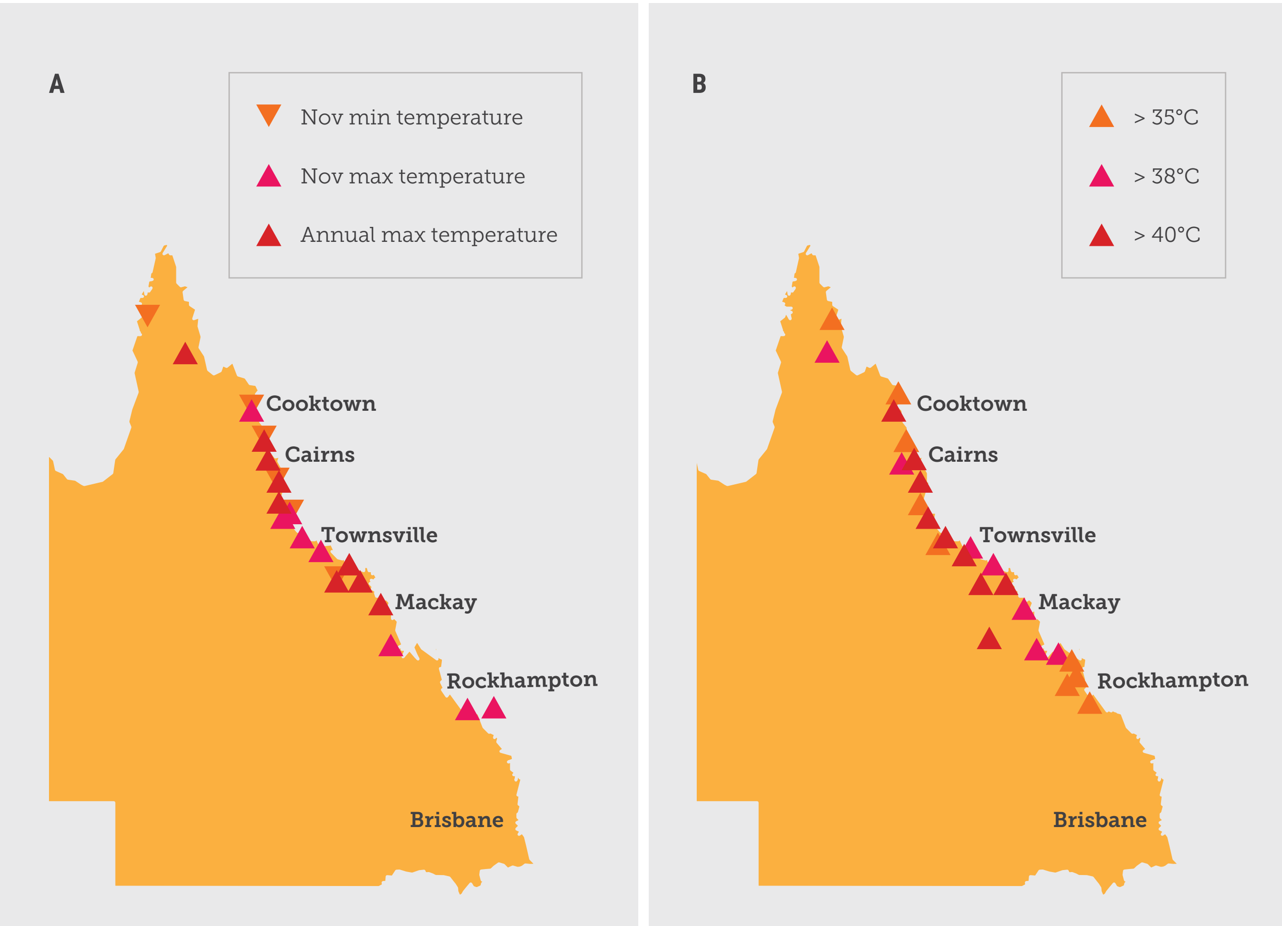
Figure 9: Dead Sorghum Crop, Quirindi, November 2018.

NOVEMBER: HEATWAVES AND FIRES SPREAD ACROSS QUEENSLAND

From November 23, heatwaves struck the north tropical and central coasts of Queensland. During this period, areas around Lockhart River in the far north of the Cape York Peninsula to the Capricornia coast near Yeppoon experienced extreme heatwave conditions. Adjacent inland areas also experienced severe heatwaves, and much of the rest of northern and eastern Queensland experienced low intensity heatwaves (BoM 2018k). Numerous highest maximum and minimum temperature records for November (or at some locations for any month) were broken, some by a large margin. On November 26, Cooktown, Cairns, Innisfail, Townsville (Mt Stuart), Proserpine and Mackay (racecourse) sweltered in daily maximum temperatures above 40°C, with Townsville recording the highest daily maximum of 45.2°C. The following day, records were broken at Cairns and Cooktown for two consecutive days above 42°C.

Around 4,000 locally endemic spectacled flying foxes in Cairns died due to heat stress (BoM 2018k). Paramedics in Queensland reportedly attended 3,567 incidents on November 26 - nine percent more incidents than on the same day in 2017 - including treating 25 heat related cases (Queensland Government 2018). Temperature records broken over this period are shown in Figure 10.

Figure 10: Maps show locations where temperature records were broken during the November Queensland heatwave event: a) sites where November minimum (orange), maximum (pink) and annual maximum (red) records were set; b) sites where records were set for consecutive days over 35°C (orange), consecutive days over 38°C (pink) and consecutive days over 40°C (red). **Source:** BoM 2018k.



Strong winds, low humidity and high temperatures brought elevated fire risk to the region, with extreme fire danger weather (over 75 on the Macarthur Forest Fire Danger Index or FFDI) recorded over large areas of the state. Rockhampton Aero reached catastrophic fire danger conditions (over 100 on the FFDI) on November 27, reaching a peak FFDI reading of over 130. The dangerous fire conditions resulted in numerous bushfires over a region of one million hectares, forcing the evacuation of thousands of residents of towns such as Deepwater and Gracemere. Nine dwellings were destroyed and eight were damaged, along with dozens of other structures (BoM 2018k). The unprecedented bushfire conditions led to fires that were so ferocious they penetrated rainforests. As rainforest species are not adapted to fire, it may take hundreds of years for the rainforests that were decimated by fires in Queensland to recover (ABC 2018b).

There has been an upward trend in the annual accumulated FFDI over recent decades, particularly across eastern Australia, including Queensland, and across southern Australia. The annual accumulated FFDI reflects an increase in both the frequency and severity of dangerous bushfire weather (BoM 2018k).

DECEMBER: STORMS ACROSS THE EASTERN STATES

In December, Tropical Cyclone Owen, the first for the 2018-19 summer, made landfall at two separate locations on the Gulf of Carpentaria coast, both times as a Category 3 system. Owen brought heavy rainfall to much of Queensland, with totals above 200 mm recorded along much of the Queensland coast. At Halifax, 681 mm was recorded in 24 hours, the highest daily rainfall for December recorded for any location in Australia (BoM 2018l).

Moisture associated with Owen interacted with a low-pressure system that developed over Victoria. Between December 13 and 16, severe storms brought heavy rainfall, hail and wind to the eastern states of Australia (all states and territories except the Northern Territory and Western Australia). The worst affected areas were Campbelltown and the Hills District in Sydney. Insured losses were estimated at around $60 million (ICA 2018).

On December 20 a series of severe storms once again brought torrential rainfall to the Hunter Valley, the Central Coast, Sydney and Wollongong, as well as Grafton, Tamworth, Moree, Nowra and Batemans Bay. Hail reportedly the size of tennis balls damaged vehicles and property in Sydney's west, whilst hail the size of golf balls damaged property in Sydney's inner suburbs (The Guardian 2018b). The Insurance Council of Australia declared the event a catastrophe. The estimated insured loss value from the series of storms is $871.3 million (as at January 17) making it the costliest extreme weather event of the year for the insurance industry and amongst the top 20 most expensive events in terms of insured losses of all extreme weather events in Australia extending back to 1967 (ICA 2018; AFR 2018b). Overall, insured losses from weather-related extreme weather events cost $1.2 billion in Australia in 2018 (see Table 1).

Table 1: Summary of economic losses from extreme weather in Australia in 2018.

Month	Location	Event	Economic losses (AUD)	Declared catastrophe *
January	South eastern Australia	Summer heatwaves	Unknown	No
January	South Australia	Bushfires	Unknown	No
January	Western Australia	Tropical Cyclone Joyce	Unknown	No
February	Western Australia	Tropical Cyclone Kelvin	Unknown	No
March	Queensland	Flooding in Northern and Central Queensland	$16.8 million in insured losses	Yes
March	Northern Territory	Tropical Cyclone Marcus	$61 million in insured losses	Yes
March	Queensland	Flooding in Winton	Unknown	No
March	Queensland	Flooding in Cairns and Port Douglas	Unknown	No
March	New South Wales and Victoria	Bushfires in New South Wales and Victoria	$80 million in insured losses	Yes
March-April	Northwestern and southern Australia	Heatwaves in late March and April	Unknown	No
May	Tasmania	Flooding in Hobart	$99 million in insured losses	Yes
Throughout the year	New South Wales, Queensland, Victoria, South Australia	Drought in eastern Australia	Expected to cut GDP growth by 0.25 - 0.75 percent in 2018-19.	No
November	Queensland	Heatwaves and fires in Queensland	Unknown	No
December	Queensland, New South Wales, Victoria, Canberra, Tasmania	Storms along the eastern states	$60 million in insured losses	No
December	East coast of New South Wales	Storms	At least $871.3 million in insured losses (as at January 17)	Yes
TOTAL (insured losses)			$$1.2 billion	
TOTAL (drought)			Up to $12.5 billion	

* Disasters that involve a large number of claims, or that are particularly complex, may be declared a catastrophe by the Insurance Council of Australia. If a disaster is declared a catastrophe, insurers must coordinate their response through an industry taskforce, and work will all levels of government, emergency services and community organisations to resolve issues. Insurers must also prioritise catastrophe claims.

The series of storms that hit New South Wales on December 20 was the most expensive event for insurance companies in Australia during the year.

6. Major extreme weather events globally

UNITED STATES: WILDFIRES, DROUGHT, HURRICANES, SEVERE STORMS

Extreme weather events in the United States were dominated by major wildfires, hurricanes (tropical cyclones) and a few severe storms. The most significant wildfires were a series that burned across southern and northern California during November. The Camp Fire raced through Butte County, destroying the town of Paradise. According to the CalFire Incident Report, the Camp Fire tragically claimed 86 civilian lives and injured three firefighters. It burned through 153,336 acres destroying 13,972 residences, 528 commercial buildings and 4,293 other buildings, making it the deadliest and most destructive wildfire in California's history (see Figure 11) (CalFire 2018a).

The Woolsley Fire burned through an additional 96,949 acres, killing three more people, destroying 1,500 structures and damaging an additional 341 structures (CalFire 2018b). The total economic loss from these fires alone is expected to exceed US $10 billion, marking the first time that insurance payouts from wildfires will exceed US $10 billion for two years in a row (Aon 2018a).

Major wildfires also burned in California from mid-July and through August, particularly in the northern part of the state. These wildfires included the Carr Fire and the Mendocino Complex Fire – a complex of two wildfires, the River Fire and the Ranch Fire - which became the largest fire complex in Californian history. The Ranch Fire also became California's single largest recorded fire. The Carr fire near Redding, California, was so powerful that it started a fire tornado with winds of up to 230 km/hour (Toleffson 2018).

The Camp Fire, which burned during November 2018, was the deadliest and most destructive wildfire in California's history.

Figure 11: Smoke plumes rise from wildfires near Ukiah airport in California, July 2018.

In April 2018, dry, windy and hot conditions led to the rapid spread of several wildfires in Oklahoma. The Rhea fire burned through more than 290,000 acres, destroying more than 50 homes. The 34 Complex fire burned through 60,000 acres. In June, the largest fire in southwestern Colorado, dubbed the 416 fire, burned through 33,000 acres of land in the San Juan National Forest and nearby areas, leading to the temporary closure of the San Juan National Forest for the first time in its 113-year history (NOAA 2018b).

The number of large fires has increased in the western United States across seven out of ten states between 1984 and 2011 (Dennison et al. 2014; Wehner et al. 2017). One study has found that warmer and drier conditions contributed to an increase in burned area in mid-elevation conifer forests in the western United States by 650 percent between 1970 and 2003 (Westerling et al. 2006).

If greenhouse gas pollution continues at current high levels, the risk of very large fires could increase six-fold in the western United States by 2050 (Barbero et al. 2015) and the area ravaged by wildfires in California each year could increase by 74 percent by 2085 (Westerling et al. 2011).

The 2018 north Atlantic hurricane season saw above average activity, both in terms of the number of hurricanes and named tropical storms, and their strength and duration (NOAA 2018c). During the season 15 named storms were recorded, eight of which became hurricanes and two of which became major hurricanes. Unusually, seven of the systems were subtropical at some point in their life, breaking the previous record of five in 1969 (NOAA 2018c).

Figure 12: National Guard rescue mission during Hurricane Florence, North Carolina.

Hurricane Florence (August 31 – September 17), with maximum winds of 225km/hour, stalled over the Carolinas, bringing record-breaking rainfall. Florence was the third wettest storm on record in the United States (with the top three having occurred since 2016) (see Figure 12). Florence caused widespread damage and killed 51 people. Total economic losses from the hurricane are estimated to be upwards of US $15 billion (Aon 2018a).

Hurricane Michael (October 7-12), with winds of 250km/hour, was the third most intense hurricane to make landfall in the contiguous United States based on central pressure, and the fourth most intense based on wind speed (NOAA 2018). It was the strongest hurricane on record to strike the Florida Panhandle. The official death toll from the storm stood at 45 at the end of October. More than one million people lost power and roads were blocked across Virginia, Alabama, Florida, Georgia and North Carolina; the town of Mexico Beach was almost completely wiped out by the hurricane (NOAA 2018). Economic losses associated with Hurricane Michael are expected to exceed US $15 billion, with US $8 billion covered by insurance payouts (Aon 2018a; 2018b).

Figure 13: Storm Eleanor lashes the coastline of Aberystwyth, Wales.

SOUTH AMERICA

During December 2017 and January, February and March 2018) the north-eastern and central regions of Argentina experienced rainfall that was significantly below average leading to drought conditions. Production of soybeans and corn, both important export crops, were significantly reduced. Compared to the previous growing season, soybean production in 2017-18 declined by 31 percent and corn production declined by 22 percent (USDA 2018). Economic losses due to the drought in Argentina are expected to exceed US $3.4 billion (CRED 2018).

EUROPE

In January four storms hit western Europe resulting in casualties and significant damages. The worst were Eleanor on January 3 (see Figure 13) and Friederike on January 18. Storm Friederike struck Germany, the Netherlands and Belgium with at least 12 casualties across the three countries. Germany's Federation of Private Insurers estimated that Storm Friederike was the second most expensive storm to strike Germany in the past 20 years (WWA 2018), with estimated economic losses of US $2.75 billion, including insured losses of US $1.8 billion (€1.5 billion) (PERILS 2018; Aon 2018).

Climate change made the 2018 summer heatwave in the United Kingdom 30 times more likely.

In July, much of Europe experienced an extended heatwave. In the Nordic region temperatures exceeded 30°C above the Arctic Circle. Norway saw a record temperature of 33.5°C in Badufoss on July 17, and the temperature reached 33.4°C in Kevo, Finland. A new record minimum overnight temperature of 25.2°C was set on July 18 in the far north of Norway (Makkaur), and Finland experienced its hottest July on record (WMO 2018c). Climate change made the extreme heat event in the Nordic region two to three times more likely (WWA 2018b).

France experienced more than 10 minimum overnight temperatures above 20°C, setting a new July record (WMO 2018c). In the United Kingdom, temperatures soared, reaching a maximum of 35.6°C at Felsham in Suffolk on July 27. Many places across southeast England and East Anglia reached temperatures above 32°C on the 26th and 27th, with some sites recording temperatures of 35°C in Kent, London and East Anglia (UK Met Office). The 2018 summer heatwave in the United Kingdom was made 30 times more likely due to climate change (UK Met Office 2018).

The heatwaves came on the back of extremely warm and dry conditions during May in northern Europe, leading to elevated forest fire danger in Scandinavia. Sweden suffered its worst outbreak of fires on record, with around 50 fires breaking out in July, burning as far north as the Arctic circle. Hot temperatures and strong winds also contributed to a deadly fire outbreak near Athens, Greece, killing an estimated 126 people (CRED 2018).

Figure 14: Theewaterskloof Dam, Cape Town's main water supply, February 2018.

MIDDLE EAST

In the Middle East, flash flooding occurred in several countries including Bahrain, Jordan and Israel. Bahrain's international airport recorded a monthly rainfall total of 19.9 mm, 40 times the long-term average. This was the wettest October for this site since 1902 (NOAA 2018).

AFRICA

During the first half of 2018, Cape Town's water crisis reached a head. Between 2015 and 2017, the Western Cape region experienced three consecutive years of below-average precipitation, leading to acute water shortages in the storage reservoirs that provide water to Cape Town's population of about 3.7 million people. Water levels were so low by early 2018 that a water ration of 50 litres per person per day was mandated, and washing cars, watering gardens and filling pools was banned. It was anticipated that Cape Town's water reservoirs would fall to just 13.5 percent by March 2018, which is when the taps would be turned off and citizens would have to line up at distribution points around the city to receive a water allocation of 25 litres per person per day (Welz 2018). Fortunately, the severe drought broke just before the city's reservoirs ran dry. The rainfall combined with a concerted demand management campaign significantly boosted the city's water supplies. The drought is expected to result in economic losses of US $1.2 billion (Aon 2018).

Figure 15: Kerala floods in India, August 2018.

Water security will become increasingly challenging in Cape Town in the future. Rainfall is projected to continue to decline due to climate change, placing pressure on the supply-demand balance. Indeed, scientists have calculated that climate change tripled the likelihood of the 2015-2017 Cape Town drought and that the probability of similar droughts occurring in the future will increase with further climate change (WWA 2018c).

Damaging flooding occurred in several countries across Africa in 2018. In Kenya, severe flooding resulted in an estimated 226 deaths and upwards of US $350 million in economic losses (Aon 2018). Nigeria also experienced flash floods in September that resulted in the death of 199 people and upwards of US $275 million in damages (Aon 2018). Flooding in Rwanda led to the deaths of 134 people and upwards of US $28 million in damages (Aon 2018).

ASIA

Japan was hit hard by a series of extreme weather events during 2018. Between June 28 and July 8, many daily rainfall records were broken by extraordinarily heavy rainfall through that period, with western Japan and Hokkaido experiencing particularly heavy falls, according to the Japan Meteorological Agency (JMA) (WMO 2018c; JMA). Total precipitation at many sites was two to four times the mean monthly precipitation for July. For instance, 1,800 mm of rain fell in Shikoku, 1,200 mm in Tokai, 900 mm in North Kyushu, 600 mm in Kinki, and 500 mm in Chugoku. Flash floods and subsequent landslides killed at least 230 people and destroyed or inundated around 10,000 houses (WMO 2018c).

Whilst Japan was recovering from the worst flooding in decades, it was struck by heatwaves. On July 15, 200 out of 977 weather stations nationwide recorded maximum temperatures in excess of 35°C. On July 23, Kumagaya set a new national maximum temperature record of 41.1°C (WMO 2018c). The estimated death toll from the Japanese heatwaves was 80 people (Reuters 2018). Heatwaves also affected the Korean peninsula and China over this period.

In September, Typhoon Jebi slammed into western Japan, reportedly killing at least seven people and injuring more than 100. The storm was the strongest to hit Japan in 25 years (The Guardian 2018c).

In India, extreme monsoon rains in Kerala in the southwest caused flash flooding (see Figure 15), leaving at least 361 people dead with more missing, and affecting 5.4 million people in total (CRED 2018). The Kerala floods were the worst in the region since 1924 and had a higher death toll than any other extreme weather event worldwide during 2018 (CRED 2018). Government officials listed 23,000 homes as destroyed or damaged. The total economic damages from the flood are estimated at around US $4.25 billion (CRED 2018). The General Insurance Companies of India announced that 13,000 insurance claims had been filed worth INR12.4 billion (US $177 million) (AIR 2018).

The Philippines was affected by Super Typhoon Mangkhut, which had maximum winds of 285km/hour. Mangkhut was the strongest tropical cyclone of 2018 and the second strongest tropical cyclone to hit the Philippines after Typhoon Haiyan in 2013 (NOAA 2018a). A set of three intense weather systems in five days also caused flooding in the Philippines, displacing more than half a million people.

OCEANIA

In February, Tropical Cyclone Gita passed by Samoa and Niue, with damages reported in Samoa, including localised flooding. On February 12 Gita struck Tonga with estimated windspeeds of 230 km/hour, causing severe damages to the main island of Tongatapu, including the downing of power lines and damage to the Tongan parliament building. It was the worst storm recorded in Tonga in 60 years, prompting Tongan authorities to declare a state of emergency (NOAA 2018). The Government of Tonga received a record payout of US $3.5 million in insurance from the Catastrophe Risk Insurance Company (PCRIC). Tonga is one of five Pacific Island Countries to have purchased catastrophe insurance from PCRIC.

NORTHERN HEMISPHERE

As mentioned above, unrelenting heat descended on the northern hemisphere during July, with records broken from the Arctic to Algeria. A summary of temperature records broken through the northern hemisphere in June and July is provided in Box 2.

BOX 2: RECORDS BROKEN DURING NORTHERN HEMISPHERE EXTREME HEAT EVENT (JUNE AND JULY

- Amid an extended heatwave in the Nordic region, temperatures topped 30°C above the Arctic Circle. Badufoss, Norway experienced a record temperature of 33.5°C on July 17, and the temperature reached 33.4°C in Kevo, Finland. Influenced by a warm wind, the far north of Norway (Makkaur) set a new record minimum overnight temperature of 25.2°C on July 18.
- Finland experienced its hottest July on record, breaking the previous July monthly temperature record set in 1941 by 0.4°C.
- France set a new July record, with more than 10 minimum overnight temperatures above 20.0°C.
- Armenia experienced a severe heatwave from June 29 to July 12. The average daily temperature was 4 - 7°C above normal and up to 9°C in some regions. A new record temperature of 42.6°C was observed at Areni on July 12.
- Eastern Japan had its hottest July on record and western Japan had its second hottest July on record. Kumagaya near Tokyo set a new national maximum daily temperature record of 41.1°C.
- Ouargla, in Algeria's Sahara Desert, reported a maximum temperature of 51.3°C on July 5. This is likely the highest reliable temperature ever recorded in Algeria.
- On June 25/26, Quriyat in Oman, recorded a 24-hour minimum temperature of 42.6°C. Although the highest "low" temperature is not currently monitored as a category in the WMO Weather and Climate Extremes Archive, it is believed to be the highest such temperature ever recorded.
- Many parts of North Africa experienced a heatwave from July 3 - 10. Morocco set a new record of 43.4°C at Bouarfa on July 3.
- Downtown Los Angeles recorded its highest ever overnight minimum temperature for July of 26.1°C on 7 July. Chino, near Los Angeles, set a record maximum temperature of 48.9°C (120°F). Burbank airport set a new maximum temperature record of 45.6°C (114°F) on 6 July, beating 45°C in 1971, and Van Nuys Airport saw a record temperature of 47.2°C (117°F), according to the US National Weather Service.
- A new record high minimum temperature record was set on July 30 in Death Valley, when temperatures did not fall below 39.4°C (103°F). Waco, Texas reported an all-time maximum temperature record of 45.6°C on July 23.

Source: WMO (2018c).

7. Time for action

The extreme weather events outlined in this report do not provide a comprehensive account of the number of extreme weather events or their impacts during 2018. Rather, this report provides a snapshot of major events. Overall, natural disasters, excluding geological events (e.g., volcanoes and earthquakes), resulted in total economic losses of an estimated US $215 billion, with US $89 billion recorded as insured losses (Aon 2019).

The extreme weather events of 2018 provide the latest evidence of a long-term trend of worsening extreme weather. In Australia, the frequency and intensity of many extreme weather events – heatwaves, bushfires, floods, and storms – have increased over the past several decades, mirroring many of the trends that have been observed globally. The evidence is clear that climate change is influencing the global trend of worsening extreme weather.

Although attribution studies have not been conducted on all of the events outlined in this report, all extreme weather events are now being influenced by climate change as they are occurring in an atmosphere that contains significantly more heat and water vapour than 50 years ago (Trenberth 2012). Of 131 studies investigating whether climate change is influencing extreme weather published in the Bulletin of the American Meteorological Society between 2011 and 2016, 65 percent found that the probability of the event occurring was increased due to climate change caused by humans. In some cases, the probability increased by a large margin (WMO 2018c).

Climate change will increasingly influence extreme weather. In Australia, extreme rainfall events are projected to become more intense, more frequent and hotter days are expected, harsher fire weather is expected in the south and east, and time in drought is projected to increase across southern Australia with a greater frequency of severe drought (CSIRO and BoM 2015). The magnitude of these trends depends on the future rate of greenhouse gas pollution here and around the world.

To slow and eventually stop the increasing trend of more frequent and severe extreme weather events, global greenhouse gas emissions must be rapidly and deeply reduced to achieve net-zero emissions over the next two to three decades. Australia must do its fair share in this global effort by adopting a credible climate policy that tackles greenhouse gas pollution across all sectors of the Australian economy. Fortunately, the benefits of doing so are many and the solutions are at our disposal.

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