The state of weather and climate extremes 2021

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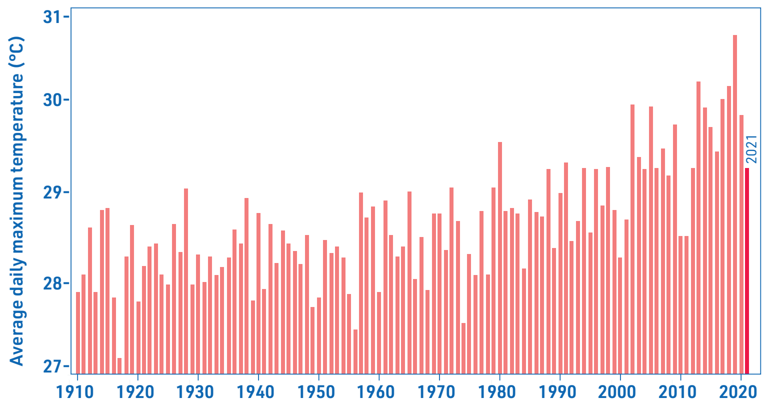
The year 2021 saw a wide range of extreme weather and climate events impacting Australia. These included heatwaves, both on land and in the ocean, in Western Australia, and cold extremes, with Sydney experiencing its coldest day in 37 years in June. However, many of 2021's extremes related to storms and rainfall. Australia experienced its greatest annual number of low-pressure systems since 1964[1]. Perth had its wettest July on record, with 18 consecutive days of rain, and there was extreme rainfall and flooding in eastern and central Australia in March[2].

Extremes such as these are the subject of research by the Australian Research Council's Centre of Excellence for Climate Extremes (CLEX), a $40million consortium of UNSW, Monash University, the University of Melbourne, the University of Tasmania and the Australian National University. CLEX aims to transform the understanding and modelling of climate extremes and works with business and government to reduce Australia's vulnerability to them.

One focus of CLEX's research is how changes in the global climate due to human activity are affecting Australian weather and climate extremes. Australia's climate is warming slightly faster than the global average temperature and the first two decades of the 21st century were both warmer than any decade in the 20th century. However, the occurrence of two consecutive La Niña events[3], when the tropical Pacific Ocean is unusually cool, helped to dampen global temperatures in 2021. As a result, Australian average daily maximum and minimum temperatures taken across the whole of 2021 were not extreme by 21st century standards. However, 2021 was one of the warmest La Niña years since records began in 1910[1].

Australian annual average daily maximum temperatures (1910-2021)

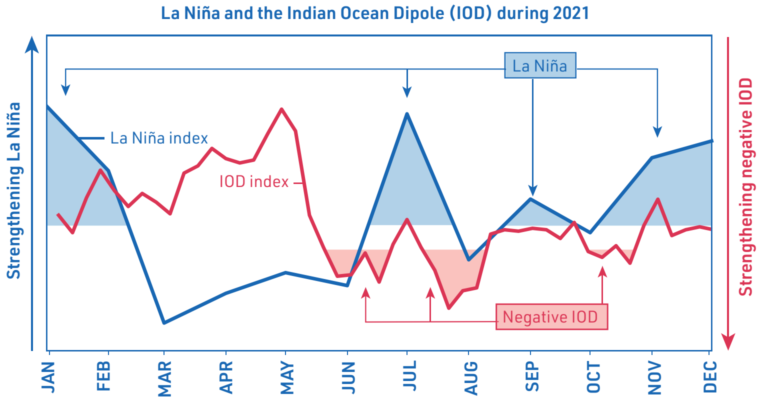


Data from Bureau of Meteorology (http://www.bom.gov.au/climate/change/#tabs=Tracker&tracker=timeseries)

Winter season temperatures were more extreme. The winter of 2021 was Australia's seventh warmest in terms of daily maximum temperatures since 1910 and the ninth warmest in terms of daily minimum temperatures, despite La Niña. Historically, warm winters have often occurred with the El Niño phase of the El Niño-Southern Oscillation (ENSO)[4], when the tropical Pacific Ocean is unusually warm, and the positive phase of the Indian Ocean Dipole (IOD)[5], which is associated with warming of the western tropical Indian Ocean and cooling of the east. The fact that neither of these phases were in place suggests that climate change played a role in the extreme winter temperature of 2021[6,7].

The effect of climate variability on Australian climate extremes is also an important part of CLEX's research. For example, CLEX is working to better understand how the oceans around Australia lead to rain over the continent[8]. The important role of these oceans in lifting Australian droughts[9] was demonstrated in 2021. Most of southeast Australia was in drought between 2017 and 2019 but above average rainfall in 2021 contributed to the gradual recovery that began in 2020. Levels in major water storages increased throughout 2021, except in parts of Queensland[10], where long-term rainfall deficits were finally alleviated in November. From January to March southeast Australia experienced above average rainfall due to a weakening La Niña and conditions over the Southern Ocean that favoured rain-bearing weather systems. After that, a negative IOD[11] developed, with cooling of the western tropical Indian Ocean and warming of the east, which directed moisture-filled air to the region. La Niña then returned and, concurrent with the negative IOD and rain-favouring conditions over the Southern Ocean, resulted in Australia's wettest November on record[12]. The wet conditions have made parts of Australia more vulnerable to flooding in 2022.

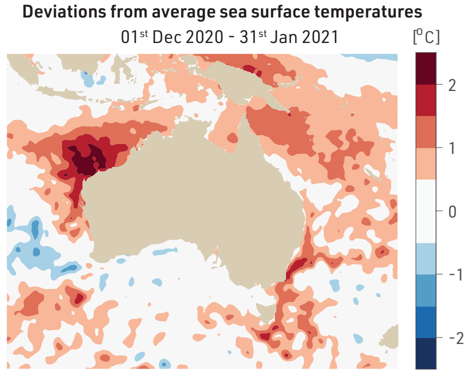
La Niña and the Indian Ocean Dipole (IOD) during 2021



La Niña (SOI) and IOD (DMI) data from Bureau of Meteorology (http://www.bom.gov.au/climate/influences/graphs/)

Marine Heatwave in Western Australia, December 2020 and January 2021

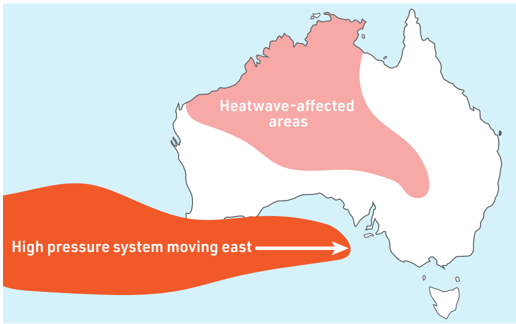
A marine heatwave is a prolonged period when the ocean is much warmer than usual for that time of year[13]. Marine heatwaves can damage marine ecosystems and the industries that rely on them[14]. In late 2020, a La Niña was underway, which tends to push warm water from the Pacific through the Indonesian archipelago, and south along the coast of Western Australia[15]. Temperatures reached 2-3°C above average off parts of the northwest coast during December 2020 and January 2021. Although it did not reach the same severity as the extreme 2011 marine heatwave[15], some coral bleaching was observed and impacts to fisheries may yet be felt. CLEX is working to understand how far in advance marine heatwaves off the coasts of Australia can be predicted[16]. This work is important because marine heatwaves are becoming longer and more frequent due to climate change[17].



Data from National Oceanic and Atmospheric Administration (https://doi.org/10.25921/RE9P-PT57)

Heatwaves in Western Australia, Summer 2021 – 2022

Heatwaves are the second deadliest natural hazard in Australia[18] and can negatively impact infrastructure, agriculture and ecosystems. Western Australia experienced a series of heatwaves. The first was in the Pilbara from 30th November to 6th December 2021, when Marble Bar experienced six continuous days of maximum temperatures above 45.5°C, 5°C warmer than average. The heat was associated with low pressure across northern Australia and a high-pressure ridge to the south. The high eventually moved east, leading to individual daily maximum temperatures more than 8°C warmer than normal occurring across much of southern Western Australia from 8th to 11th December.

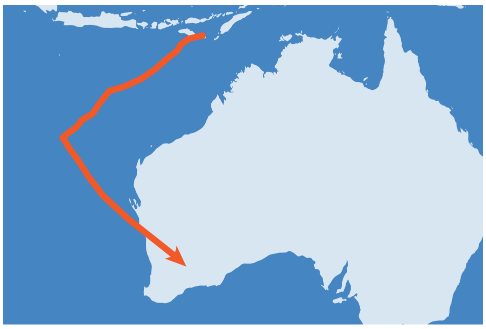


Schematic of the Pilbara heatwave of November-December 2021

Further heatwaves occurred in the Pilbara, starting on 17th December and 12th January, and in the south-west, starting on 23rd December and 18th January. These led to several records, including the equal hottest day in Australia of 50.7°C, at Onslow on 13th January, and Perth recording six days in a row above 40°C. CLEX is researching links between heatwaves and weather systems[19], soil moisture[20] and climate change[21].

Tropical Cyclone Seroja, April 2021

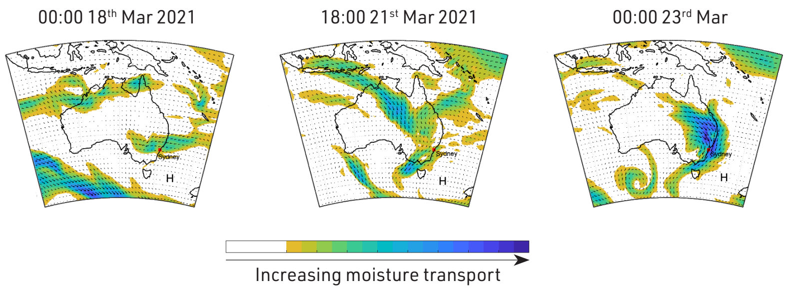
After causing deaths and destruction in Indonesia, Tropical Cyclone Seroja made landfall in Western Australia on 11th April 2021, where it destroyed about 70% of the infrastructure in the town of Kalbarri, making 1500 people homeless and causing electrical blackouts. Seroja was a highly unusual Category 3 cyclone. Indonesia, where Seroja originated, is too close to the equator for frequent cyclone genesis - only seven tropical cyclones have formed there in the past 20 years[22]. Another peculiarity of Seroja was that it made landfall in Western Australia so far south from its origin. Historically, Category 3 cyclones have only made landfall in the area about once every 190 years on average[23].



Tropical cyclone track from http://www.bom.gov.au/cyclone/history/seroja.shtml

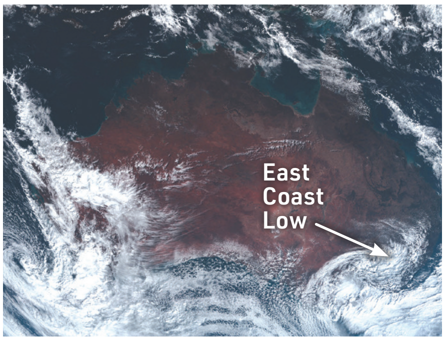
Flooding in Eastern Australia, March 2021

Between the 17th and 24th of March 2021, eastern Australia experienced record-breaking rainfall and widespread flooding; more than 400mm of rain fell in some locations. The cause was a confluence of moisture in the atmosphere from two different sources. A high-pressure system in the Tasman Sea pushed moist air over the coast from the east. From the west, moisture was transported from the Indian Ocean by an Atmospheric River. Atmospheric Rivers are streamers of moist air in the lower atmosphere that transport water vapour from the Tropics. They can cause heavy rainfall, flooding, landslides, strong winds and heavy snowfalls[24,25,26]. New research by CLEX has shown that the probability of weather events like the one that caused the extreme rainfall in March 2021 could increase by 80% over Sydney by the end of the 21st century due to climate change[27].



Adapted from Reid et al. (2021) (https://doi.org/10.1029/2021GL095335)

Storms in Southeast Australia, June and October 2021



Himawari-8 satellite image from the Bureau of Meteorology retrieved from the National Computational Infrastructure

Image of forest damage near Daylesford in June 2021 supplied by Lily Langham

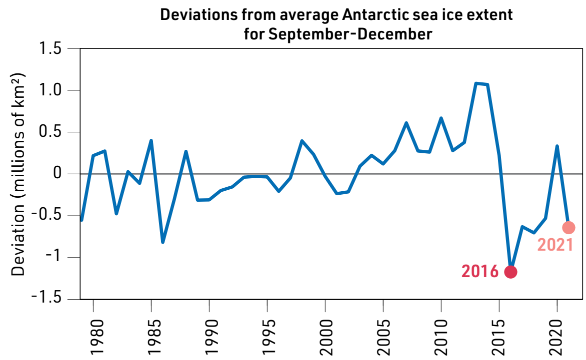
A storm caused widespread wind damage across southeast Australia between 9th and 11th June 2021, with gusts exceeding 100 km/h in some areas. The storm also caused flash flooding in parts of eastern Victoria, with 3-day rainfall totals ranging between 100-300 mm, approximately twice the average rainfall total for June[28]. The combination of wet soils from the rainfall, and the unusual wind direction (from the southeast) led to large areas of damaged forests, power outages to more than 200,000 premises and two deaths. This event was driven by an intense coastal low-pressure system, known as an East Coast Low[29], which formed along a strong cold front that passed over the southeast on the 7th and 8th June.The East Coast Low was clearly visible in satellite images.

Another severe windstorm occurred on 28th and 29th October 2021, bringing localised heavy rain and damaging wind to southern Victoria and Tasmania. Winds gusted to 146 km/h in the extreme south of Victoria and parts of Melbourne recorded their strongest October wind gusts for more than a decade. Approximately 526,000 Victorian homes and businesses, almost 25% of Victorian properties, were without power on the morning of the 29th[30]. The event was mainly driven by a rapidly intensifying low-pressure system, which developed on a low-pressure trough moving eastwards from South Australia.

Some types of weather system that bring extreme winds to southeast Australia, such as cold fronts and East Coast Lows, may be in decline during the cooler months of the year[31,32]. However, the link between damaging winds and human-induced climate change is unclear[33]. Ongoing research by CLEX aims to better understand and model the processes that lead to severe winds in Australia and estimate the potential effects of climate change.

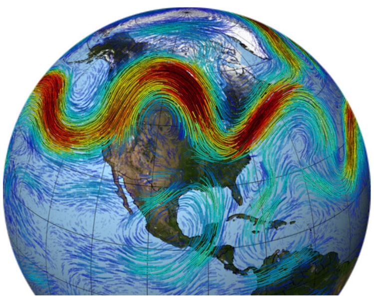
Low Antarctic Sea Ice, Spring and Summer 2021 - 2022

Antarctic sea ice affects global climate by reflecting sunlight, influencing air-sea interactions and ocean circulation. Sea ice also provides habitat for krill, a keystone species in the Southern Ocean food web. Despite global warming, Antarctic sea ice coverage increased from 1979 until the mid 2010s. Then, in 2016, an unprecedented decline in sea ice occurred during spring, leading to sustained record low sea ice coverage[34,35,36]. Since then, sea ice has slowly rebounded, and in mid 2021 was again above average. However, in spring 2021 sea ice once again decreased rapidly, with total coverage at its third-lowest level for spring. Continued rapid loss has led to record low coverage in late summer 2021-22. The causes of the 2016 and 2021-22 declines are being investigated. Weather patterns over the Southern Ocean were certainly important, with remote influences from the tropics and warmer ocean surface temperatures linked to the 2016 decline[34,35,36] possibly also relevant for the 2021-22 decline. Given the far-reaching implications of Antarctic sea ice on global climate, it is important to understand drivers of these recent extremes and the role that global warming has played.



Data from National Snow and Ice Data Center (https://doi.org/10.7265/N5K072F8)

Heatwaves, Fires and Floods in the Northern Hemisphere Summer of 2021



NASA image sourced from National Oceanic and Atmospheric Administration (https://scijinks.gov/jet-stream/)

There were a series of high-impact weather events in the Northern Hemisphere in June and July 2021. An extreme heatwave affected western North America, sparking wildfires and causing deaths and economic losses. Heavy rainfall in western Europe resulted in flooding, leading to loss of life and property damage. Parts of China experienced record-breaking amounts of rainfall that paralysed economic hubs. These events, while extraordinary in their impact, were caused by a common atmospheric mechanism: Rossby waves[37,38]. These waves are the main drivers of weather outside the Tropics (including in the Southern Hemisphere[39]). They form as undulations in the jet stream, a band of strong winds in the upper atmosphere. High- and low-pressure systems are carried along by the jet. However, when Rossby waves grow very large they break, much like ocean waves, causing highs and lows to remain stationary over one location for some time. This can contribute to strong heating of the Earth's surface or flooding from stalled rain systems.

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