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Climate Systems
National Environmental Science Program
Extreme climate: dry, wet, hot-and-dry
Extreme events explained

What made eastern Australia so wet from 2020 to 2022?

Extreme rainfall can occur across a range of timescales, including:

- short, heavy bursts that can cause flash floods
- slow-moving weather systems that bring several days of heavy rain, leading to widespread river flooding
- months or seasons of persistent heavy rain, often linked to global climate patterns like La Niña, which push more moisture and rain into the country.

As the climate warms and the atmosphere holds more moisture, the characteristics of these events are likely to change.

NESP Climate Systems Hub researchers have been working to understand the changes in long-duration rainfall extremes by focussing on the wet conditions that impacted eastern Australia from 2020 to 2022.

Understanding the behaviour of and interactions within our climate system, especially under a warming climate, provides critical information to support evidence-based climate adaptation and decision-making.

Key findings

- Climate drivers influence eastern Australia's highly variable rainfall. La Niña, negative Indian Ocean Dipole (IOD), and positive Southern Annular Mode (SAM) phases typically promote more rainfall in spring, while El Niño, positive IOD, and negative SAM phases generally mean less rain and drier, warmer conditions in spring. Each driver on its own can influence rainfall significantly, and when they co-occur, their impacts are further strengthened.
- Under climate change, most models project a decline in winter-spring rainfall in southeastern Australia, and the influence of ENSO on rainfall is likely to strengthen. This would suggest increased drying during El Niño years but extreme La Niña-related rainfall may increase.

The triple La Niña and extremely wet conditions of 2020 to 2022

From 2020 to 2022, eastern Australia had much more rain than usual. In these years, three La Niña events occurred in a row, only the third occurrence of a triple La Niña since the 1950s. La Niña - a phase of the El Niño–Southern Oscillation - is one of Australia's key climate drivers. It refers to the extensive cooling of the central and eastern tropical Pacific Ocean. It typically leads to shifts in weather patterns across our region.

Particularly in 2021 and 2022, the La Niña events, in conjunction with other climate drivers such as negative Indian Ocean Dipole (IOD) and positive Southern Annular Mode (SAM) events, contributed to extremely wet conditions along Australia's east coast.

This culminated in 2022, which was very wet for the year across much of the country (Figure 1) and when southeast Australia received its highest spring season rainfall on record. Widespread flooding across Queensland, New South Wales, Victoria and Tasmania led to significant damage, affecting communities, livelihoods, our natural environment and impacting multiple sectors such as transport, agriculture and infrastructure.

What decision makers wanted to know

Through a hub co-design process, decision makers from areas most affected by the wet conditions shared perspectives about how their organisations were impacted by the extremely wet conditions and the types of decisions they were making during this time.

They said they wanted to know more about these types of events and how they are projected to change in future, with a focus on two broad areas:

- What is the role of climate drivers?
- What is the role of climate change?

Hub scientists combined new and existing research to address these questions.

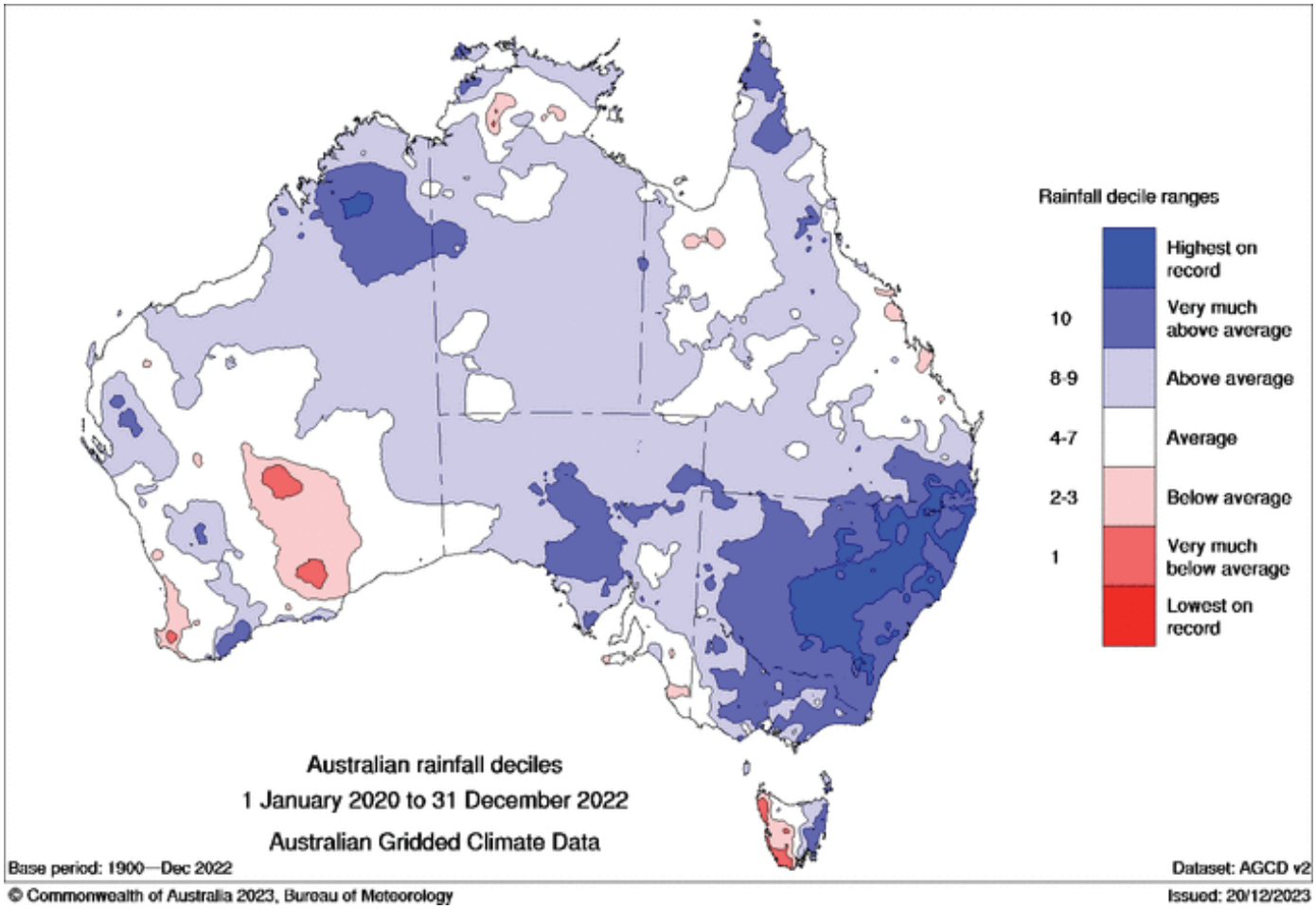

Figure 1: Australian rainfall from January 2020 – December 2022. This map shows rainfall deciles, where dark blue indicates the highest rainfall on record, and dark red indicates the lowest rainfall on record. Parts of southeastern Australia received their highest recorded rainfall during spring of 2022. Image credit: Bureau of Meteorology.

The role of climate drivers

Eastern Australia's highly variable rainfall is heavily influenced by several climate drivers, particularly in winter and spring. La Niña, negative IOD, and positive SAM phases typically promote more rainfall over eastern Australia. Meanwhile, El Niño, positive IOD, and negative SAM phases generally mean less rain and drier, warmer conditions in spring. While each of these drivers in isolation can influence rainfall significantly, when these phases occur together, their impacts are further strengthened.

La Niña's influence on Australian rainfall is generally more consistent than El Niño. This means La Niña-driven events are typically wetter than El Niño-driven events are dry.

Rainfall-increasing Phases

- ✓ La Niña
- ✓ Negative IOD
- ✓ Positive SAM

Rainfall-decreasing Phases

- ✓ El Niño
- ✓ Positive IOD
- ✓ Negative SAM

The climate driver phases which typically increase or decrease winter-spring rainfall, particularly over eastern Australia.

While each of these drivers in isolation can influence rainfall significantly, when these phases occur together, their impacts are further strengthened (see Figure 2).

To quantify the influence of La Niña and El Niño on eastern Australian rainfall in spring, and better understand this influence, hub researchers applied a sophisticated attribution technique. Climate attribution techniques allow scientists to isolate the amount of influence that a particular factor has on the frequency, magnitude, and intensity of extreme events.

We found the following patterns across records spanning the past 6 decades:

- 81% of spring months that had experienced heavier than normal monthly rainfall occurred during La Niña years.
- 59% of spring seasons where rainfall was slightly below average, or were moderately dry, occurred during El Niño years.
- By contrast, extremely dry spring months, with well below average rainfall, are equally likely to happen during El Niño and La Niña years.

New hub research shows rainfall tends to increase year by year over northern and eastern Australia during triple La Niña events as seen from 2020 to 2022.

Hub researchers found that even though the La Niña temperature patterns in the equatorial Pacific do not get progressively stronger during a triple La Niña, soil moisture levels tend to progressively increase during spring and summer. These wetter soils can lead to more moisture in the air, subsequently increasing the likelihood of rainfall in each subsequent year under La Niña conditions.

Triple La Niña events are more common than triple El Niño events.

Other influences

In each spring season of 2020 to 2022, a negative IOD and positive SAM event co-occurred with the La Niña, exacerbating the extremely wet conditions.

We also investigated the relationship between SAM, El Niño/La Niña and stratospheric wind patterns high above Antarctica (known as the stratospheric polar vortex), to better understand the influence of these winds on SAM and associated southeastern Australian rainfall.

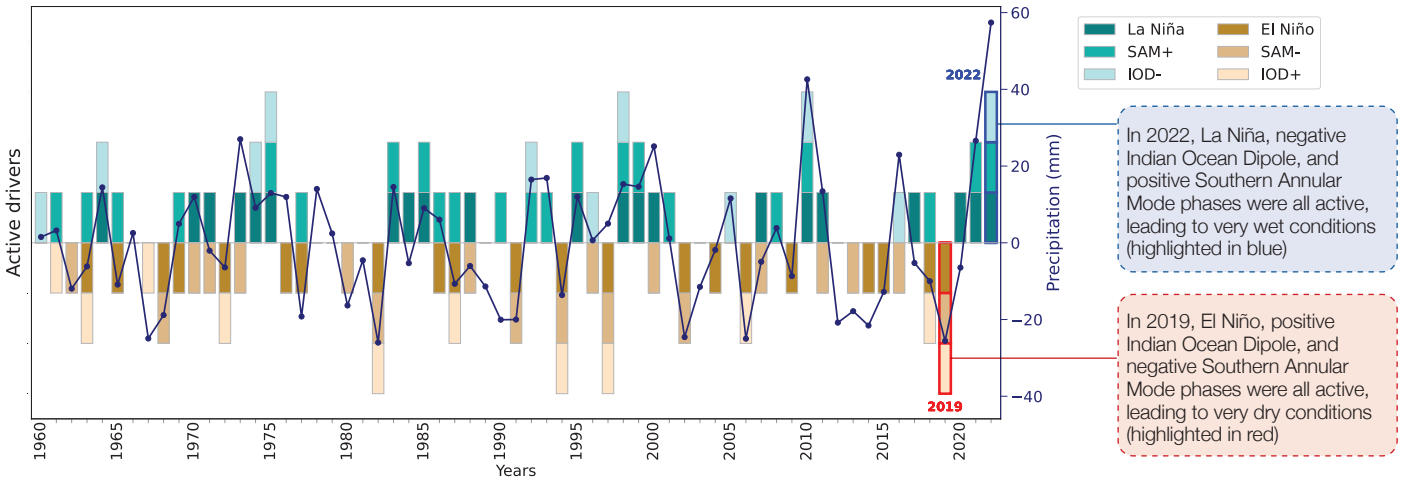

Figure 2: Timeline of the phases of El Niño/La Niña, positive/negative Indian Ocean Dipole, and positive/negative Southern Annular Mode active during spring from 1959–2022. The solid line shows changes from the average spring rainfall in the Murray–Darling Basin during these seasons. In winter-spring, El Niño, positive Indian Ocean Dipole, and negative Southern Annular Mode phases typically promote dry conditions over southeastern Australia (brown bars). In 2019, all three were active, leading to very dry conditions (highlighted in red). La Niña, negative Indian Ocean Dipole, and positive Southern Annular Mode phases promote wetter conditions over southeastern Australia (teal bars). In 2022, all three were active, leading to very wet conditions (highlighted in blue). Image credit: Dr Ghyslaine Boschat, Bureau of Meteorology.

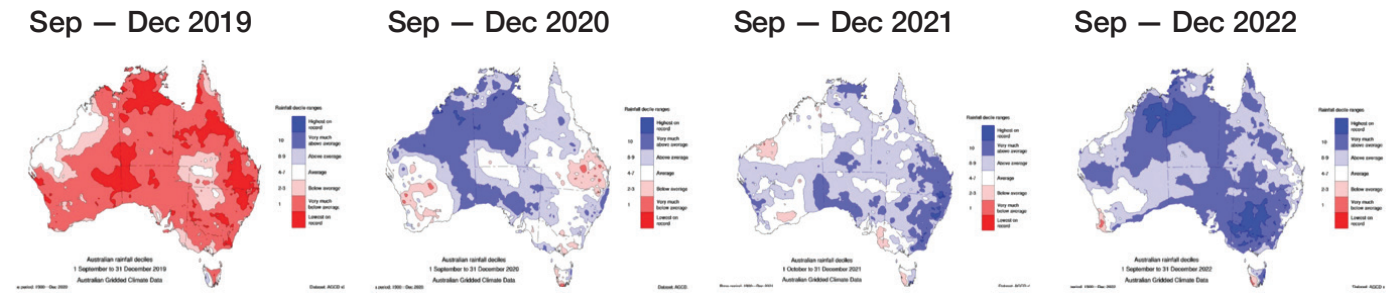

Figure 3: Australian rainfall during September to December from 2019 to 2022. These maps show rainfall deciles, where dark blue indicates the highest rainfall on record, and dark red indicates the lowest rainfall on record. For this period in 2019, it was the driest on record in many regions. In the three-year period between 2020 and 2022, rainfall across eastern Australia became progressively wetter, culminating in parts of southeastern Australia receiving their highest recorded rainfall during spring of 2022. Image credit: Bureau of Meteorology.

The research found that a strong polar vortex, such as occurred in 2020, 2021 and 2022, can strengthen a positive SAM event. When this occurs alongside a La Niña and a negative IOD, the likelihood of increased rainfall is further amplified.

Conversely, an El Niño co-occurring with a positive IOD, weaker polar vortex and negative SAM can lead to significantly dry conditions, as was seen in the months preceding the Black Summer of 2019–20.

Figure 3 shows the extreme swing between dry and wet conditions over the 2019–2022 period. In the three-year period between 2020 and 2022, rainfall across eastern Australia became progressively wetter, culminating in parts of southeastern Australia receiving their highest recorded rainfall during spring of 2022.

Darling River, NSW, in July 2022. Image: Arthur Chapman.

The wet spring of 2022 and the role of climate change

The year 2022 was a year of rainfall extremes across Australia, especially along the east coast. For eastern Australia, spring was the second wettest on record, and the wettest on record for the Murray–Darling Basin catchment area, which recorded almost 60 mm/month of rainfall on average. This is almost double the maximum recorded monthly rainfall during spring outside of a La Niña year (35 mm/month). Hub researchers found that the unprecedented rainfall over eastern Australia during spring 2022 was more than 5.5 times more likely to occur because it was a La Niña year.

In a world without human-induced global warming, southeastern Australia would have received around 16% less rainfall during spring 2022 – suggesting that climate change did play a role.

Focusing specifically on southeastern Australia, hub researchers were able to isolate the relative influences of La Niña and the negative IOD, positive SAM, and human induced warming in contributing to the unprecedented rainfall in spring 2022.

In this region, they found that the positive SAM, reinforced by the strong polar vortex, strongly exacerbated the extremely wet conditions. Even with La Niña and negative IOD ocean conditions, without the positive SAM, spring 2022 would have been wet, but not as extreme.

Further experiments showed that in a world without human-induced global warming, southeastern Australia would have received around 16% less rainfall during spring 2022 – suggesting that climate change did play a role during this time.

In the Brisbane River flood event of February 2022, a river crane was destabilised and became a threat to people, buildings and infrastructure. Image credit: Stephen Dann.

What can we say about the future?

Projected changes to Australia's climate drivers

Climate models are our best available tool to understand future changes. A recent evaluation of the latest generation of climate models, as part of version 6 of the Coupled Model Intercomparison Project (CMIP6), show this new generation of models are better able to simulate ENSO (El Niño–Southern Oscillation) and the IOD's influence on Australian rainfall, particularly in spring. How the properties of ENSO, IOD, and SAM will change is an area of active research.

Most CMIP6 models project an increase in ENSO variability by the end of the 21st century. On the other hand, IOD events are projected to weaken. Some models project a 30% increase in consecutive (back-to-back or multi-year) La Niña events under a high emissions scenario, though there is still considerable variation when all model outputs are compared.

Decision makers with risks associated with extreme rainfall should consider the implications of a scenario in which an increase in multi-year La Niña events happens in the future.

Projections show an overall drying trend, with an increase in very wet rainfall during La Niña years.

Most CMIP6 models project an increase in ENSO variability by the end of the 21st century.

Changes to rainfall associated with these climate drivers

Climate model projections of future rainfall changes related to these climate drivers are mixed.

In general, winter-spring rainfall is projected to decrease across Australia. However, the influence of ENSO on rainfall and temperature is also projected to strengthen. These two factors would work together to strengthen the amount of drying expected during El Niño years.

In the case of La Niña years, these two factors counteract with each other as seen in a previous hub study looking at Australian drought and how it will be impacted by El Niño over the coming century. That study showed that while seasons that typically experience moderate rainfall are projected to get drier during La Niña years, extreme La Niña-related rainfall is projected to increase (Figure 4).

Many climate models also project a positive SAM trend, which could bring about an increase in SAM-related rainfall over eastern Australia in summer and spring.

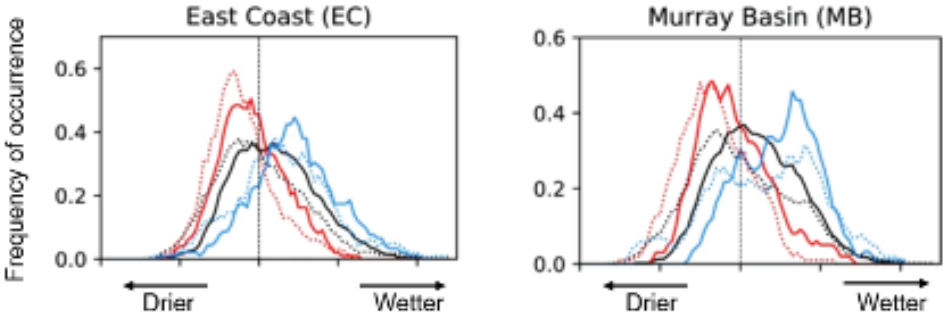

Figure 4: Projected winter-spring rainfall changes during all years (black), only El Niño years (red), and only La Niña years (blue), for the East Coast and Murray Basin Natural Resource Management clusters. Solid lines indicate modelled historical (1900–2005) rainfall values, and dashed lines indicate future (2006–2100) rainfall values under a high emissions scenario. **Projections show an overall drying. This is shown by a general shift of all curves towards drier conditions with the dashed lines to the left of the solid lines. However, there is an increase in the very wet rainfall values during La Niña years, whereby the dashed blue lines sit to the right of the solid blue lines, on the far right of the figures.** Image credit: Adapted from Figure 7 of Delage & Power (2020). Reproduced under Creative Commons Licence http://creativecommons.org/licenses/by/4.0/

Next steps and knowledge gaps

Knowing more about how multi-year ENSO events interact with other climate drivers and Australian rainfall can have important implications for forecasting and predictions around climate extremes.

Hub findings and research in this area provide important insights for decision makers, especially those planning for and managing responses to extremely wet periods, flooding, and the possibility of record-breaking rainfall in the future.

While we have made significant advances in our understanding of climate drivers and the large-scale impacts on rainfall, climate drivers are complex phenomena and there remains gaps in our understanding.

There are many computational challenges faced by climate modellers in pursuit of improving simulations of climate processes and improving certainty in rainfall projections.

Overcoming these challenges can be aided by improving computational functionality and capability, as well as improving representation of physical processes in the models.

Key knowledge gaps and next steps are set out below.

Knowledge gap	Opportunities
Climate drivers modulate rainfall on seasonal timescales, but short-lived (hourly to daily) heavy rainfall events are associated with synoptic weather systems.	This is the focus of ongoing research across Australia and globally particularly around how climate drivers influence smaller-scale weather patterns, such as thunderstorms, which ultimately affect local rainfall.
Improving simulation of ENSO, IOD, SAM, the polar vortex, and their influences on Australian rainfall.	Development of the next generation of Australia's climate model, the Australian Community Climate System Simulator (ACCESS), is underway. The Climate Systems Hub will be one of many contributors to this enhancement and in conjunction with other ongoing research may facilitate this improvement.
Quantifying the role of natural year-to-year variability in models and in observations, and how this is affected by climate change.	This is an area of active research across Australia and globally. With attribution techniques improving, scientists are more likely to be able to quantify the influence of climate change on the frequency, magnitude, and intensity of extreme events.
Improving our ability to translate coarse-resolution output from global climate models to useable, on-ground local information. This can help inform, for example, flood risk and other management decisions.	Researchers from the Australian Climate Service and elsewhere are working towards improving both global climate models and regional downscaling systems to provide more accurate projections on local scales.

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