Understanding Australia’s rainfall

ARC Centre of Excellence for Climate Extremes Briefing Note 19

Australia’s rainfall can vary dramatically from one year to the next. A range of atmosphere, ocean and land processes, from the equator to the poles, work together to influence our rainfall.

This briefing note summarises the current understanding of Australia’s rainfall, including regional and global influences, extremes, historical trends and expected future changes. It draws upon decades of national and international scientific research and highlights how research carried out by the ARC Centre of Excellence for Climate Extremes (CLEX) is improving our collective understanding to help Australia cope with extremes now and in the future.

- **Australia’s rainfall varies strongly by region and season, driven by a diverse set of weather systems whose location and frequency are influenced by large-scale climate variability.**
- **Australia’s rainfall is characterized by periods of extremely heavy rainfall and drought, leading to substantial impacts on our environment and society.**
- **According to the IPCC Sixth Assessment, there is medium confidence that heavy rainfall will increase across some parts of Australia. Despite this, parts of southern Australia are expected to spend more time in drought in the future.**

Drivers of Australia’s rainfall

Regional influences

Australia’s rainfall varies significantly across the country and through the seasons. The tropical north of Australia receives most of its rainfall in summer during the monsoon and is typically dry in winter. In contrast, many parts of southern Australia receive more rainfall in winter than in summer, and much of inland Australia remains relatively dry throughout the year.

Rainfall occurs when a weather system causes moisture in the atmosphere to ascend, allowing it to condense and precipitate. In southern Australia, weather systems responsible for rainfall include extratropical cyclones, fronts, troughs, and thunderstorms. High-pressure systems (including blocking highs, Figure 1) can prevent rain-bearing systems from moving, resulting in persistent rainfall in regions such as coastal eastern Australia; these systems also suppress rainfall in their immediate vicinity, and can contribute to the development of drought[1]. For the northern parts of Australia, tropical cyclones and monsoon depressions are also important. The contribution each of these weather systems makes to rainfall, and how rainfall is further influenced by land-atmosphere feedbacks (Box 1), differs by region and season[2–4] and can vary from year to year.

The high-pressure systems, and the low-pressure systems and their accompanying fronts, are characteristic of the weather in southern Australia and are embedded in global-scale waves in the atmosphere called Rossby waves (Figure 1). These waves form on the jet stream, a band of strong westerly winds in the upper atmosphere. Processes related to the jet stream and Rossby waves play an important role in connecting weather between tropical and extratropical Australia. CLEX researchers are investigating the physical mechanisms responsible for weather extremes in the tropics and extratropics and the effect of a warming world on these mechanisms.

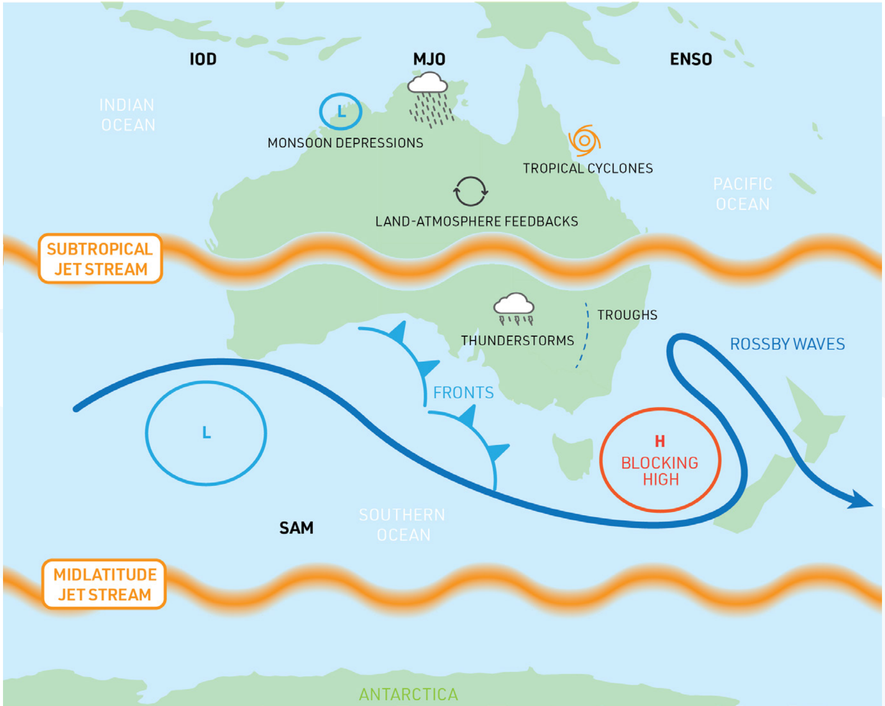

Figure 1: Key processes influencing Australian rainfall

BOX 1 **LAND-ATMOSPHERE FEEDBACKS**

Australia's day-to-day weather is also influenced by the exchange of water, energy and momentum between the land surface and the overlying atmosphere. Changes in the land surface will affect the atmosphere, and vice versa, creating what is known as land-atmosphere feedbacks. These feedbacks modify the lower atmosphere to affect the formation of clouds and rainfall[5]. Despite the expectation that land-atmosphere feedbacks will play an increasingly important role in Australian rainfall in future[6], they remain poorly observed, incompletely understood and inadequately represented in weather and climate models[7–9]. CLEX researchers are working to understand the role played by land-atmosphere feedbacks in intensifying drought and heatwaves in Australia.

Global influences

Behind our day-to-day weather are variations in the global atmospheric circulation. These variations disturb the large-scale circulation of the atmosphere and the location and frequency of weather systems. Different modes of climate variability impact rainfall around Australia throughout the year.

El Niño-Southern Oscillation (ENSO): a coupled ocean-atmosphere phenomenon that is manifested through differences in sea surface temperatures across the eastern and western tropical Pacific Ocean. This fluctuation of warmer and cooler water across the Pacific causes large-scale changes in the atmosphere that drive year-to-year rainfall variability in northern and eastern Australia[10]. Rainfall in these regions is typically below average during El Niño (positive phase) and above average during La Niña (negative phase)[10] although the impact varies regionally[11], between events[12–14], and on multidecadal timescales according to the Interdecadal Pacific Oscillation (IPO)[15]. For instance, eastern Australian rainfall is more sensitive to sea surface warming in the central, rather than eastern, Pacific Ocean[13]. La Niña events can also occur in consecutive years, known as 'double-dip' events when occurring two years in a row. CLEX researchers are working to understand the role played by the double-dip La Niña in the extreme flooding experienced in New South Wales and Queensland in March 2022.

Indian Ocean Dipole (IOD): manifests as the difference in sea surface temperatures on either side of the tropical Indian Ocean[16]. In its negative phase, the eastern Indian Ocean northwest of Australia is warmer than usual, which promotes increased rainfall across parts of western and southern Australia during winter and spring[17]. The impact on rainfall is generally reversed during the positive phase of the IOD when the western Indian Ocean is warmer than usual[18]. However, IOD events often happen at the same time as ENSO events, making separation of their individual roles challenging[19]. Ongoing research by CLEX aims to transform our understanding of how climate processes in the tropical Indian Ocean interact with those of the Pacific Ocean to affect Australia's weather. This understanding is needed to improve seasonal weather predictions and long-term climate projections relevant to Australia's drought, flood and fire risk[20].

Madden-Julian Oscillation (MJO): a large-scale wave in the atmosphere that can bring clouds and rainfall as it travels eastward along the equator from the Indian Ocean to the western Pacific Ocean. The MJO varies on shorter timescales than ENSO and the IOD, with an approximately 30-90 day cycle. When the MJO is near Australia (phases 5 and 6), it promotes above average rainfall in northern Australia during the wet season[21] and influences tropical cyclone activity[22].

Southern Annular Mode (SAM): describes shifts in the midlatitude jet stream further north and closer to Australia (negative phase) or polewards away from Australia (positive phase). Rain-producing weather systems such as fronts and cyclones also shift north and south with changes in the SAM[23]. The SAM therefore influences rainfall across southern and eastern Australia and Tasmania with varying impacts on rainfall depending on the season and region[24]. Furthermore, winds and ozone high up in the atmosphere over Antarctica have been linked to east Australian rainfall variability in spring and summer[25,26]. CLEX researchers are working to improve our understanding of how both Antarctic ozone and human-induced climate change interact with the SAM to drive extremes in Australia's climate.

Extremes

Extreme rainfall

Extreme rainfall events can cause flooding and have major impacts, particularly when part of a compound event (Box 2), so it is important that we understand their causes.

There are two main ingredients needed for rainfall to occur: atmospheric moisture and ascending air, so that condensation may occur.

When there is an abundance of moisture in the atmosphere, extreme rainfall can occur[27]. Moisture transport into a region can be enhanced via atmospheric rivers[28] (long, narrow conduits of moisture in the atmosphere) and during different phases of the large-scale modes of climate variability[29]. The ocean is the largest source of moisture for Australia's rainfall, although evapotranspiration from the land surface also plays a part in some regions[30,31].

BOX 2 | COMPOUND EVENTS

Compound events are combinations of weather and climate hazards that can be more impactful than those occurring in isolation[36]. Extreme rainfall can have particularly severe socio-economic impacts when occurring as part of a compound event. For example, the extensive flooding in Queensland and New South Wales in early 2022 showed characteristics of a compound event[36]. With catchments already saturated from previous wet weather, several extreme rainfall events occurring in close succession led to damaging flooding over large areas. Moreover, strong onshore winds associated with the extreme weather elevated coastal sea levels, inhibiting the drainage of flood waters to the ocean, further compounding the impacts of the extreme rainfall. Scientific understanding of these and other compound events remains incomplete, however. As such, CLEX is leading research on compound events to help Australia assess and prepare for the risks they pose.

Processes driving strong ascent and extreme rainfall differ across the country. In northern Australia, extreme rainfall has been linked to slow-moving monsoon lows[32] and tropical cyclones[33], while in southern Australia there are links to low-pressure systems higher up in the atmosphere[34] and Rossby waves[35]. Variability of extreme rainfall in Australia has also been linked to ENSO, IPO, IOD and SAM[33].

Human-induced climate change and natural climate variability affect the weather systems that control patterns of both the availability of moisture and the favourable locations for ascending air. Human-induced climate change can therefore increase or decrease the likelihood of extreme rainfall in different places. CLEX researchers are working to identify the mechanisms that cause shifts in moisture supply and weather systems favourable for extreme rainfall both at present and under future climate change.

Meteorological drought

Australia also experiences periods of intense meteorological drought; that is, sustained periods of lower-than-normal rainfall. In Australia, drought has been linked to modes of climate variability such as ENSO, IOD and SAM[37,38], a reduced frequency of synoptic features such as fronts and low-pressure systems[39], an increased frequency of high-pressure systems[40], and reduced moisture supply from the ocean[41].

Although droughts are a recurrent feature with known impacts on the Australian climate, many aspects of the physical processes that contribute to drought remain unknown. To improve our understanding and prediction of drought, further research is required to determine: the role of land-atmosphere feedbacks in amplifying drought; the causes of reduced moisture supply for rainfall; to what extent an absence of extreme rainfall-generating weather systems contributes to drought, and the relative contribution of long-term variability and human-induced climate change.

CLEX researchers are working to understand how well our climate models simulate relevant processes with the goal of improving predictions of future drought.

Changes: past, present and future

Historical trends

Past studies have reported trends in rainfall in different parts of Australia. Notable trends include increasing summer rainfall in Australia's northwest[42], with a tendency toward longer-duration rainfall events (>6 days)[43], and more frequent and intense extreme sub-daily rainfall[44]. In contrast, declining trends have been reported for the southwest[45] and the southeast[42] in the cooler months of the year. This includes a reduction in long-duration events, and an increase in shorter events (1-2 days)[43] and more extreme sub-daily events[44].

However, the highly variable nature of Australia's rainfall makes long-term trends difficult to detect. Historical trends in annual and seasonal mean rainfall in most regions of Australia, with the exception of the northwest, have been found to be within the bounds of what is expected from natural long-term variability[46]. Moreover, few significant trends in extreme rainfall frequency and intensity have been observed, with the exception of increases in northwest Australia[47].

Future rainfall extremes

Given the destructive nature of extreme rainfall, it is important that robust projections can be made for changes in the frequency, intensity and duration of such events.

Globally, the amount of moisture the atmosphere can hold will increase as the planet warms. This has the potential to lead to more extreme rainfall. However, changes to the positioning, persistence and behaviour of weather systems will likely modify this response[48] such that the regional patterns of change in Australian rainfall extremes remain uncertain[47,49]. As such, the IPCC sixth assessment report, representing the most up to date physical understanding of climate change, projects increases to heavy rainfall in some parts of Australia with medium confidence[50].

Greater certainty can be found, however, in the positive relationship between mean and extreme rainfall in Australia, which is expected to hold under future climate change[51]. This means that extremes are likely to increase except where mean rainfall decreases.

Moreover, greater understanding of future changes to regional weather systems is emerging. Weather systems associated with the Southern Hemisphere storm tracks are expected to shift further south and away from Australia[52], continuing the current wintertime drying in southern Australia[53] and, in particular, southwestern Australia[50]. In eastern Australia, low-pressure systems that extend deep into the atmosphere are projected to occur less often in future but produce rainfall that is more extreme[54]. Similarly, further north, tropical cyclones are expected to occur less often in the future[55] but contribute more strongly to extreme rainfall when they do occur[56]. Yet while extreme rainfall may change in the future, parts of southern Australia are expected to spend more time in drought[57].

Summary

Many years of work has improved our understanding of the causes of year-to-year variability in Australian rainfall and the different mechanisms that explain rainfall in different parts of the country. Unfortunately, how different modes of climate variability interact with weather systems, and how these lead to extreme events, is complex. How these processes will change in the future is so complex that our ability to predict exactly how rainfall extremes will be altered in most parts of Australia remains deeply uncertain.

The ARC Centre of Excellence for Climate Extremes recognises that improved understanding and improved ability to predict the future of Australian rainfall and its extremes is crucial to many sectors including agriculture, water resources, urban and infrastructure planning, emergency management and others. By bringing together researchers focussed on the large-scale modes of climate variability with researchers investigating weather and land surface processes, our goal is to improve the regional predictions of how rainfall extremes will change in the future.

Created by:

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