Extreme rainfall deficit in southern coastal Australia signals a return to drought, low dam levels and declining stream flows

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Brief communication

Extreme rainfall deficit in southern coastal Australia signals a return to drought, low dam levels and declining stream flows

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Abstract: Southern coastal Australia is situated between 30° and 38°S and is the longest east-west mid-latitude coastline (4,300km) in the Southern Hemisphere. It includes over 35% of Australia's total population. Approximately 75% of this coastline, west of Melbourne, has a Mediterranean climate dominated by cold frontal systems that produce cool season (April to October) rainfall. Historically, this area has been devastated by droughts, particularly since the early 1990s. Over the last 24 months since early 2023, extreme drought has returned with dam levels falling as stream flows plummett. Using observational and reanalysis data of the Southern Hemisphere atmosphere, we provide an explanation for the sustained southern Australian coastal drying since the 1990s, and particularly over the most recent decade. Significant changes in the atmospheric circulation are shown to be responsible for the observed rainfall decreases. Both the subtropical and polar jets have contracted poleward, reducing the frequency and intensity of the embedded rain-producing systems affecting Australia's southern coastline. These atmospheric circulation changes have become highly noticeable in the current 2016-2025 decade and are attributed to an amplification of Australian climate drivers, from accelerated global and local atmospheric and ocean warming. Consequently, there are more frequent and intense droughts, with major reductions in stream flows and dam levels. The current extreme drought conditions are affecting water sustainability in cities and regional communities in southern coastal Australia, decreasing agricultural production, threatening ecosystem survival, contributing to more frequent and severe heatwaves, and increasing the frequency and length of bushfire seasons.

Keywords: drought; southern coastal Australia; global and ocean warming; atmospheric circulation changes; low dam and river levels; climate drivers

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1. Introduction

1.1 Background

In the two years since early 2023, almost all southern coastal Australia has experienced serious to extreme rainfall deficiencies, leading to severe to exceptional drought conditions (Figure 1a). Most of southern Australia had already experienced a long-term decline in rainfall [e.g., 1,2]. Even Tasmania, which mostly lies poleward of 40°S, is drought affected. These persistent rainfall deficiencies also have produced well below average soil moisture levels (Figure 1b). Low streamflow heights have reduced water storages, leading to widespread reliance on transporting hay and

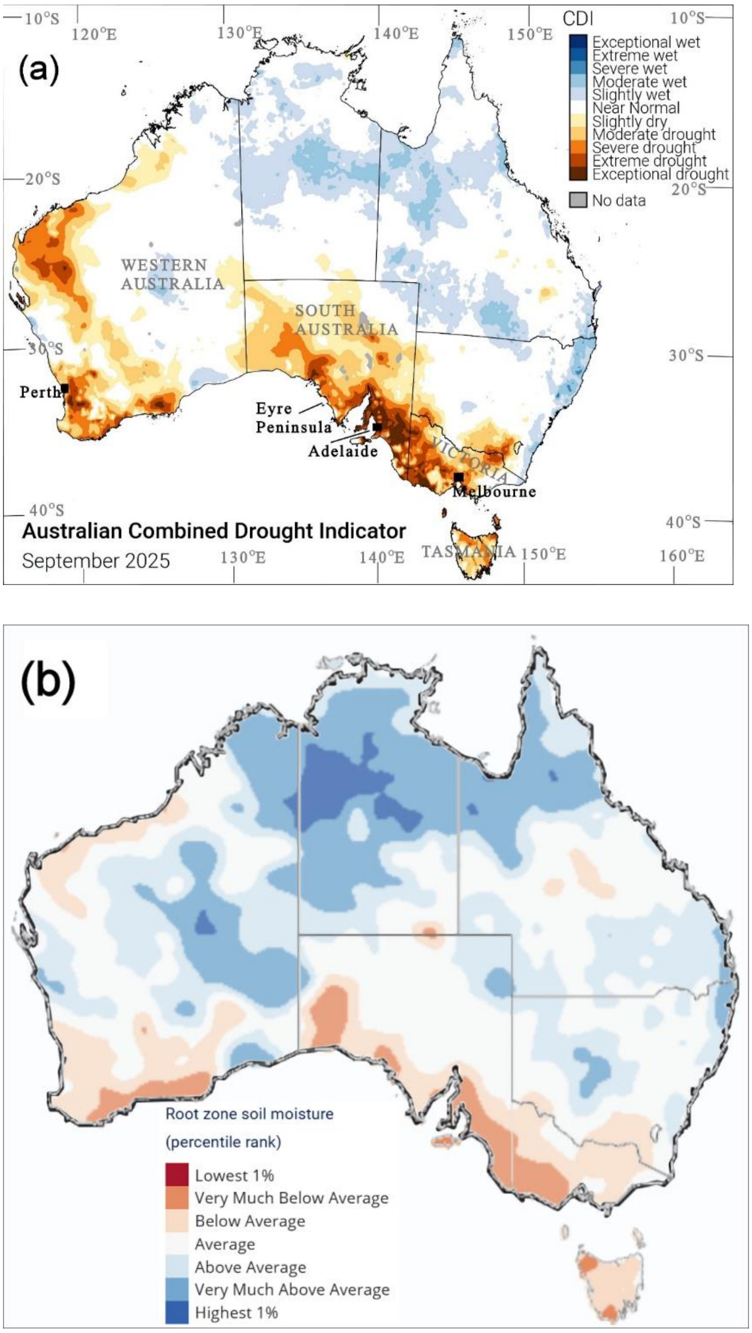


Figure 1 (a) Australian Combined Drought Indicator (CDI) for the last 24 months ending September 2025.

The CDI uses a combination of precipitation, soil moisture, evaporation and NDVI satellite data to produce a drought indicator tailored for Australia – available at:- https://nacp.org.au/drought_monitor , (b) Root zone soil moisture map. Month to date 12 October 2025. Available at:- https://awo.bom.gov.au/products/historical/soilMoisture-rootZone/

purchasing extra feed for livestock. In some key farming regions, farmers have delayed or cancelled planting their crops. Brief cool season rainfall in July 2025 provided some local relief to several agricultural areas. However, the impact was short-lived, as in major cities, Adelaide and Melbourne, the July rainfall accounted for only 20-30% of the total rainfall received from January to September 2025.

Consequently, despite some areas of southern Australia temporarily showing limited improvement, the drought continues. Because of the drought, the 2024 annual averaged sub-soil moisture was very low over almost all southern coastal Australia and was spreading inland (Figure 1b). It has remained at similarly very low levels throughout 2025. In stark contrast, most of northern Australia was not in drought and root zone soil moisture levels ranged from average to the highest one percentile.

Both Adelaide (35°S) and Perth (32°S) are located at lower latitudes than Melbourne (38°S) (see Figure 1a). In Adelaide, as of January 2025, the extreme dry conditions in the previous two years have resulted in greatly reduced levels of water inflows to Adelaide's reservoirs. Total reservoir levels dropped to 44% at the beginning of the dry warm season, their lowest in more than 20 years. Adelaide's single desalination plant has quadrupled its output from January to the present, to meet demands. Perth, which has experienced a long-term rainfall decrease since 1970 [3], has routinely been operating two desalination plants since 2012, and currently is building a third plant, given its continuing rapid increasing need for fresh water. Melbourne, which is by far the largest southern Australian coastal city, received just over 300 mm through September 2025, with winter and spring rainfall failing to produce the usual sharp increase in water storage levels during 2025. Melbourne's desalination plant was initially activated for just 10 months in 2022, to increase the supply of fresh drinking water. However, the continuing dry conditions in 2024 and 2025 motivated the state government to again utilize the desalination plant in April 2025. As of September 2025, with the warm months approaching, Melbourne's water storages were at approximately 74% capacity, the lowest since the Tinderbox Drought of 2017-2019 [4], at this time of the year. Given Melbourne's rapidly increasing population, it is estimated that up to 65% of Melbourne's water may need to come from manufactured sources, such as desalination and recycling. That is an increase from 2020 when 25% of Melbourne's water was desalinated and 10% recycled.

Notably, in the Eyre Peninsula, which is a vital food and energy production area west of Adelaide (Figure 1), water availability is far worse because of the exceptional drought conditions over the past 24 months. Most of the region's water is currently pumped from the Murray River and from groundwater aquifers. The aquifers were at historic lows in early 2025, having steadily declined since the 1960s. Decreased annual rainfall, greater evaporation rates, rapid urbanization, and a loss of native vegetation all being contributing factors. When groundwater levels drop below sea level, saltwater enters and pollutes the water, endangering the numerous fragile ecosystems located in the region. A possible solution currently being considered is the building of a desalination plant that has large filters to prevent bulky items and animals from being drawn into water pipes. Inflows into the Adelaide reservoirs over the last year or two have been their lowest since approximately 1982. The normally free flowing Breakout Creek had dried up by the end of summer, in March 2025 (Figure 2).

Figure 2 Breakout Creek at the western end of Adelaide's Torrens River in March 2025. It was one of many pools and waterways that dried up and left fish stranded. Photograph: Green Adelaide

1.2 Drought Impacts on Perth, Adelaide and Melbourne

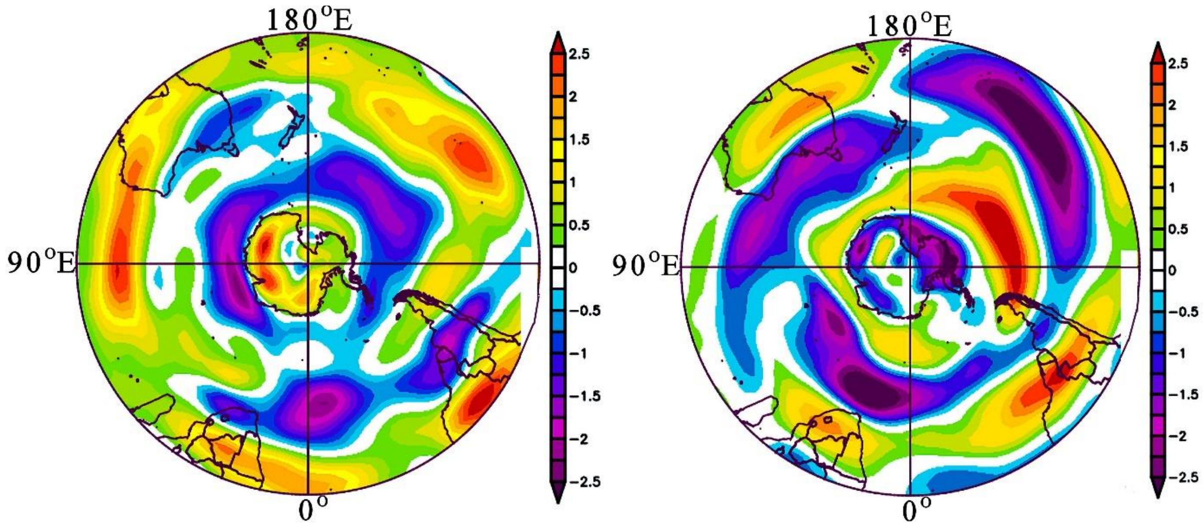
As mentioned above, both Perth and Adelaide have typical "Mediterranean" climates characterized by cool, wet winters and hot, dry summers. The cool season precipitation of southern coastal Australia is dominated historically by a westerly wind regime, embedded with rain-bearing cold fronts. Melbourne, located farther south than both Perth and Adelaide, also is subject to winter westerly winds, but receives year-round precipitation from frontal and low-pressure systems. However, the cool season westerly wind regime has contracted poleward since the 1990s, along with the polar and subtropical jet streams [5]. These atmospheric circulation changes have reduced the cool season rainfall because the frontal systems are now being steered poleward. Since the 1990s, and particularly in the last decade, northerly or northwesterly winds have dominated Melbourne's cool-season weather. In the upper atmosphere, small circulations of cold air also direct north to northerly winds and act to destabilize the atmosphere because of changes in the jet streams. Thunderstorms or heavy showers can form ahead of the north to northwesterly winds over Melbourne, but they rapidly cease in the following dry, westerly airflow. There are typically long periods of dry weather between the days before and after this type of rain event. Melbourne lies mostly in a rain shadow due to high terrain to its west and north, and, compared with Perth and Adelaide, Melbourne receives considerably less winter rainfall from both pre-frontal northerly winds and post-frontal westerly winds. However, the decreasing number of cool season rainfall frontal systems is also affecting the cities of Adelaide and Perth as the westerlies move southward. To explain the recent impacts of the above tropospheric circulation features on precipitation, results are presented of dramatic changes in the SH and Australian regional circulations that have occurred in the recent decade.

2. Data and Methods

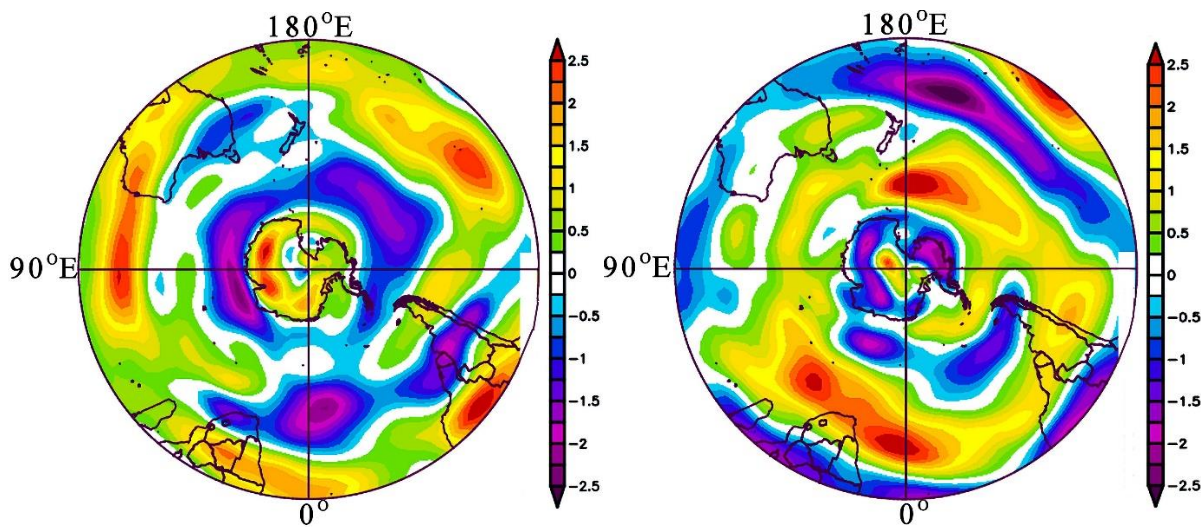
To capture the wind structure and speed of the branches of the subtropical jet (STJ) and polar front jet (PFJ) in the Southern Hemisphere (SH), composite monthly u-Component anomalies at 250 hPa were derived from the reanalysis data sets provided by the website of the National Center for Environmental Prediction (NCEP) and National Center for Atmospheric Research (NCAR) developed by [6]. The main April–September wet season interval was selected to compare the pre- and post-1990 circulation anomalies and then to focus on the most recent decade 2016–2025.

3. Results

The dominant rain season for southern coastal Australia is April to September, reflecting the most equatorward position of the mid-latitude, zonal (or westerly) wind regime that brings the rain-bearing cool season frontal systems. It is also the time when climatologically the well-known upper-level tropospheric split-jet is present in the Australia-New Zealand region, between 90^{O} E and 180^{O} E [7]. This is evident with the STJ when the 1965 to 1995 u-component of the 250 hPa wind anomaly, relative to 1991 to 2020 climatology across northern tropical Australia, and the weaker PFJ branch anomaly, spans the mid-latitudes south of Australia (Figure 3a – left panel). A previous study by the authors of this jet structure covering the 55 years from 1965 to 2020 shows that since the 1990s both branches have shifted poleward by approximately 5^{O} latitude [5]. Compared with the 1965 to 1995 anomaly, the 2006 to 2015 decadal anomaly still shows the split-jet with the STJ branch across northern tropical Australia and the PFJ positioned in the mid-latitudes of the Australia-New Zealand region (Figure 3a – right panel). However, there is a dramatic change in position and structure of the STJ branch of the split jet, when the 1965 to 2015 anomaly (Figure 3b; left panel) I s compared with the 2016 to 2025 anomaly (Figure 3b; right panel). The split-jet structure present in Figure 3b (right panel) has shifted approximately 10^{O} poleward and is reduced to a branch over the subtropical jet east Indian Ocean and another branch over southeast Australia between longitudes approximately 140^{O} E to 170^{O} E. This major change from 2016 is consistent with the largest increase in rate of global warming and is likely related to a rapid decrease in Antarctic Sea-ice over the same period [8].



3(a)



3(b)

Figure 3. Southern Hemisphere tropospheric circulation anomalies. NCEP/NCAR Reanalysis 250 hPa u-component wind anomalies April to September for, (a) 1965–1995 (left panel), 2006–2015 (right panel), (b) 1965–2015 (left panel), 2016–2025 (right panel).

Consequently, regional atmospheric changes have affected southern Australia. First, the contraction polewards of the STJ and PFJ means that fewer cool season frontal producing rain systems are affecting southern coastal Australia leading to an April to September decrease in precipitation including the cities of Perth, Adelaide and Melbourne. [9] identified that upper-level vortices (cut-off lows) have been dominated by those developing equatorward of a polar jet southwest of Western Australia, since the 1990s, and heading northeast over the Australian continent. Those developing south of the polar jet are captured in the westerlies between about 40-50^{O} S. latitude. In both April to July and August to November the surface manifestation of the upper cut-off lows is mainly a low pressure trough in the easterlies, which normally provides little low- to mid-level moisture in southern Australia, unless aided by favourable phase combinations of the Indian Ocean Dipole (IOD), ENSO, the southern annular mode (SAM) with teleconnections to phases of local and remote drivers such as the Atlantic Meridional Oscillation (AMO), the Pacific Meridional Mode (PMM), Tasman Sea SSTs. Prior to the 1990s, there were few cut-off lows equatorward of the PFJ [9]; cut-off lows formed on the polar side of the STJ when a PFJ merged with the STJ to cause Rossby wave breaking. For example, numerous east coast lows (ECLs) have formed off the east coast since the 1990s and are usually captured by the westerlies south of Sydney [10]. In the most recent decade, 2016-2025, when an upper-level vortex developed on the equatorward side of the PFJ south of Western Australia, it usually moved northeast toward southeast Australia and interacted with the STJ, producing upper-level instability. However, rain does not occur until the upper-level vortex reaches a deep, moist layer below it, which has formed from onshore northeast winds directed over Australia's east coast. Little or no rain occurs in southern coastal areas or southern inland areas until the combination of the upper-level instability and deep, moist layer results in heavy, southeast coastal and inland precipitation, typically in short, thunderstorm-type events. These events can persist for days due to slow movement of the upper vortex and the continued moist onshore flow underneath. An example is the Flash Drought (FD) in eastern inland Australia in November 2023 whereas, at that time, the coast experienced flooding [11]. Notably, the Australian region was not alone in receiving decreased precipitation and drought has occurred due to poleward contraction of the jet stream. Drought has been a feature of southern coastal Africa in recent years. One example being Cape Town's critically low water storage event during the 2015-2017 drought [12]. The jet stream, previously located equatorward of the South African southern coast (Figure 3b; left panel), shifted poleward of the southern coast (Figure 3b; right panel), again, reducing the chance of cool season rainfall.

4. Climate Driver Attribution of Precipitation

Continued global warming (GW) and interaction with other climate drivers that has altered the southern hemisphere (SH) and regional atmospheric circulation can help explain how this now dramatic Melbourne drying and continued southern coastal drying further west, has occurred over recent years. First, the persistent ocean warming in the southwest Pacific Ocean and around Australia represents part of the negative phase of the Pacific decadal oscillation (PDO), the leading mode of North Pacific sea-surface temperature (SST) variability [13] and the leading mode of basin wide Pacific SST variability called the inter-decadal Pacific oscillation (IPO). Briefly, the positive phase of the IPO characterizes a pattern of warm SST anomalies in the eastern Pacific Ocean cold SST anomalies in the western Pacific Ocean, while the IPO negative phase reverses the SST anomaly pattern. The negative phase has been locked in for more than three decades and is associated with the long-term drought in southwestern USA. Historically, it changes phase every 15–30 years due to processes internally generated by the climate system [14–16]. Statistical and dynamic models that simulate these internal processes predicted that the large 2015 El Niño reversed the sign of the locked in negative phase of the PDO [17]. However, it remains unchanged including the impact of drought on southwestern USA. [13] isolated the anthropogenic influences from internally generated forcings of the PDO and found that, in observations, external forcing accounts for 53% of total multidecadal PDO amplitude, whereas in models, external forcing only accounts for 7% of total multidecadal PDO amplitude. They suggest this error may also affect low frequency modes of climate variability throughout the extratropical northern hemisphere (NH), and potentially globally [18–20]. The patterns of SST Pacific warming that are generated internally resemble those now externally generated by human emissions in the negative PDO phase and those generated externally by aerosol emissions in the positive PDO phase prior to the 1990s [13]. Second, negative phase PDO-IPO results in an anomalous poleward shift of the subtropical high-pressure ridge in the Australia-New Zealand region [21]. Combined with the May to October anomalous 700 hPa high pressure anomalies in the mid-latitudes of the Australia-New Zealand region since the 1990s [11] sources of atmospheric moisture have decreased along the southern Australian coast throughout the year. The cool season months of April to September when frontal and low-pressure systems provide most of the cool season rainfall have joined the normally drier warm season months of October to April. Currently, a strong stratospheric warming event (SSW) is exacerbating the drying across southern Australia [22]. An SSW affects the SH low level atmospheric circulation by extending the westerly winds from the high polar latitudes to the mid-latitudes, in addition to increasing their speed. The impact on southeast Australia is to enhance the drying. The strong negative IOD is not producing the usual increase in spring rainfall as in past events of 2022 or 2016 because GW interaction with other climate drivers has diminished the impact of a negative IOD on increasing rainfall across southern Australia [23].

5. Reduced stream flows and water levels

In addition to the southern Australian coastal areas, the extensive river systems and dams which occupy most of inland southeast Australia in the Murray-Darling Basin (MDB), are currently experiencing reduced water supply through spring, thereby continuing the inevitable, long-term impacts of GW, and currently are enhanced by the impact of the naturally occurring SSW event. The MDB has been drying since the 1990s because the catchment rainfall in all dams, in both the north and south MDB, has decreased significantly during April-May and now continues to dry through June to September, even with average or slightly below average rainfall [24,25]. Consequently, spring and summer soil and vegetation moisture levels in southern coastal areas and adjoining regions further north will be very low. Sufficient soil moisture must be present in spring leading into summer to prevent moisture levels becoming too low. This cycle continues and progressively worsens, unless it is punctuated by several successive wet years such as in the double La Ninas of 2010–2012 and 2020–

2022 when late spring to summer extremely high rainfall totals produced devastating floods in southeast inland Australia [26,27].

6. Conclusion

The main findings of this research contribute to an understanding of the climate change impacts of drought in southern Australia due to important SH and Australian regional circulation changes in the recent decade compared with previous decades. Water availability along southern coastal and southern inland Australia continues to decline. Good agricultural yields in those regions depend on timely rainfall during their growing seasons, typically from winter through spring. The current drought has devastated livestock numbers across southern South Australia with farmers relying on donated feed being trucked in from other states. Both Adelaide and Melbourne have planned incremental increases in water supplies from their desalination plants this year. This scenario looks set to continue in years to come.

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