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RESEARCH ARTICLE

Spatial and temporal variability of wet spells and their role in wet and dry summers and winters in Australia

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Abstract

Using three-hourly ERA5 and ERA5-Land reanalyses from 1979 to 2024, we determine the characteristics of wet spells in Australia in summer (October–March) and winter (April–September), focusing on northern and southeast Australia. Wet spells in summer account for up to 90% of seasonal precipitation in northern Australia, with a frequency of 20%–30% and a mean duration of 8–10 hours. In winter, wet spells of similar frequency contribute up to 96% of precipitation in southeast Australia, with a mean duration of 12–17 hours. Wet spells lasting six hours to one day account for the largest fraction (50%–60%) of seasonal precipitation in summer, whereas 12-hour to two-day wet spells contribute the most (50%–70%) in winter. Wet spells longer than 12 hours account for nearly 90% of the three-hourly extreme precipitation events with a mean intensity of 3–4 mm·3-h^{-1}. Shorter spells are associated with light showers with a mean intensity of 0.5–2 mm·3-h^{-1} and contribute 10%–30% of extreme events. The increase in seasonal precipitation during wet years is primarily due to an increase in the frequency of wet spells in northern Australia. In contrast, increases in both wet-spell frequency and intensity are important in southeast Australia. In both regions, wet spells longer than 12 hours contribute the most to the change in precipitation between wet and dry seasons. The synoptic environments for subdaily wet spells in northern Australia are tropical convection and monsoon low-pressure systems. Longer wet spells show patterns similar to active monsoon bursts with a well-developed monsoon trough. In southeast Australia, the synoptic patterns for subdaily spells resemble extratropical lows and fronts, while longer wet spells are mostly associated with cut-off lows.

KEYWORDS

Australia, precipitation variability, wet spells

1 | INTRODUCTION

The discrete nature of precipitation makes it a unique climate variable, often characterized by consecutive periods of precipitation and no precipitation, commonly referred as wet and dry spells. The frequency, intensity, and duration of wet and dry spells primarily characterize seasonal precipitation variability and extreme weather events, such as floods or droughts, that seriously affect agriculture (Gobin & Van De Vyver, 2021; Malik et al., 2002), water quality (Van Vliet & Zwolsman, 2008; Wang et al., 2018), and human health (Goh et al., 2017). Persistent precipitation for several hours or days potentially leads to a water surplus and increases the possibility of floods. In contrast, prolonged sequences of dry spells lead to a water deficit, possibly resulting in droughts. Thus, the climatology and the variability of wet and dry spells provide valuable information for agriculture, hydrology, water resource planning, and disaster risk management.

Being a semi-arid country, Australia's water availability is highly sensitive to small changes in seasonal precipitation. The interannual variability of seasonal precipitation is linked to large-scale modes of variability such as the El Niño–Southern Oscillation (ENSO) (Chiew et al., 1998; Cowan et al., 2023; Power et al., 1999; Risbey et al., 2009), the Indian Ocean Dipole (IOD) (Ashok et al., 2003; Liguori et al., 2022; Risbey et al., 2009), the Madden–Julian Oscillation (MJO) (Cowan et al., 2023; Ghelani et al., 2017; Wheeler et al., 2009), and the Southern Annular Mode (SAM) (Cowan et al., 2013; Hendon et al., 2007; Mbigi & Xiao, 2024), even though these modes explain no more than a few tens of percent of the annual variance (Risbey et al., 2009). These modes are thought to influence the seasonal precipitation patterns in space and time by modulating the synoptic systems (Hauser et al., 2020; Moron et al., 2019; Pepler et al., 2021; Tozer et al., 2023). Of course, these synoptic systems produce rain and, ultimately, the sequence of wet and dry conditions that define the seasonal precipitation variability. As these wet and dry spells are the building blocks of seasonal precipitation and its variability, to understand how seasonal precipitation varies interannually, we need to know how wet and dry spells vary in space and time.

Previous studies on wet and dry spells in Australia have been focused primarily on dry spells and their implications for drought (Breinl et al., 2020; Lisonbee et al., 2022; Taschetto et al., 2016; Ummenhofer et al., 2009; Verdon-Kidd & Kiem, 2013; Verhoeven et al., 2022; Wang et al., 2018). These studies, based mainly on daily data, investigate the changes in the frequency and duration of dry spells in relation to drought onset and its severity. A few other studies have examined the characteristics of both wet and dry spells and their implications for precipitation variability and predictability (Cook & Heerdegen, 2001; Moron et al., 2025; Muita, 2013; Ratan & Venugopal, 2013). However, studies on the contribution of the frequency and intensity of wet spells of different duration to the interannual variability of precipitation in Australia are still limited. Nor have previous studies used subdaily data.

This study builds on our previous work (Pariyar et al., 2024), where we used a moisture budget framework to link weather processes with seasonal precipitation variability in Australia. We showed that the relationship between evaporation minus precipitation ($E-P$) and vertically integrated moisture divergence (VIMD) differs markedly between wet and dry seasons. The two terms are more strongly correlated during wet seasons, which feature a higher frequency of three-hourly negative $E-P$ events. However, these wet spells vary in duration and intensity, and identifying dominant time-scales and their contribution to seasonal precipitation variability is key to understanding precipitation characteristics and associated weather processes. Therefore, in this study, we extend the analysis by examining how variations in both the frequency and intensity of wet spells of different duration contribute to seasonal precipitation variability across Australia. Further, we investigate the synoptic environments associated with wet spells of varying duration to better link the observed variability to the underlying weather processes. These new insights improve our understanding of how changes in wet-spell characteristics across multiple time-scales shape seasonal precipitation variability in Australia, knowledge that is essential for enhancing seasonal precipitation prediction and supporting applications in agriculture, hydropower, and water resource management. Specifically, this study aims to address the following research questions:

- What are the spatial patterns of variability in the frequency, intensity, and duration of wet spells across Australia during wet and dry summers and winters?
- How do changes in the frequency and intensity of wet spells of different duration differ between wet and dry summers and winters?
- What synoptic-scale weather processes are associated with wet spells of varying duration?

The paper is organized as follows: First, we highlight the advantages of using precipitation minus evaporation to define wet and dry spells. Next, we provide an overview of the spatial and temporal characteristics of wet and dry spells over Australia in summer (October–March) and winter (April–September). We then examine the spatial and temporal characteristics of wet spells of different duration followed by a discussion on their synoptic environments. Finally, we quantify the contribution of frequency and intensity to changes in precipitation between wet and dry summers and winters. A discussion and summary are presented in the final section.

2 | DATA AND METHODS

We use the hourly ERA5 precipitation datasets from 1979 to 2024 (Hersbach et al., 2020; https://cds.climate.copernicus.eu/datasets/reanalysis-era5-single-levels?tab=download). For evaporation, we use the total evaporation (amount of water evaporated from the earth's surface including transpiration from vegetation) from ERA5-Land, as it better represents the land surface processes (Muñoz-Sabater et al., 2021), and closes the moisture budget more precisely. Note that the precipitation data for ERA5 and ERA5-Land are identical. These datasets are available at $0.25° \times 0.25°$ horizontal resolution. We also use hourly ERA5 datasets for the mean sea-level pressure and 500-hPa geopotential height to represent the synoptic environment. To maintain consistency with our previous work (Pariyar et al., 2024), we compute three-hourly means from the hourly data and base our analysis on these averages. We note that using hourly data instead does not lead to significant differences in the key conclusions of this study, as precipitation associated with wet spells shorter than three hours contributes only a small fraction of the total precipitation. We perform the analysis separately for the summer and winter seasons, where summer is defined as the period from October to March, and winter as the period from April to September.

We compare daily ERA5 precipitation with the Australian Gridded Climate Data (AGCD) version 1.0.0 (Evans et al., 2020) in terms of mean and variability at each grid point during summer and winter (Figures S1, S2). The mean is calculated by averaging daily precipitation over the entire study period, while variability is quantified using the standard deviation. ERA5 reproduces the spatial structure and magnitude of mean, variability and rainy days in both seasons, with pattern correlations exceeding 0.8 and normalized root-mean-squared errors (NRMSE) below 10%. The NRMSE is calculated as the RMSE divided by the AGCD mean value and expressed as a percentage. These metrics are computed only for regions with climatologically high precipitation, based on the Australian Bureau of Meteorology's definition of arid regions — those with mean precipitation below 250 mm for southern Australia and below 350 mm for northern Australia.

The use of evaporation data from ERA5-Land is primarily due to its finer horizontal resolution (~9 km) and its ability to better represent land surface processes through enhanced soil moisture and lake representations (Muñoz-Sabater et al., 2021). Many previous studies have validated ERA5-Land evaporation against in situ observations (Pelosi et al., 2020; Xin et al., 2022; Zolfaghari et al., 2025), satellite-based datasets (Liu et al., 2023, 2025; Muñoz-Sabater et al., 2021), and land surface models (Li et al., 2023; Xu et al., 2024) across various regions of the world, and have consistently reported promising results. A recent study compared the Global Land Evaporation Amsterdam Model (GLEAM) with ERA5-Land evaporation and found good agreement between them in terms of mean spatial patterns both globally and regionally (Miralles et al., 2025). The study further evaluated the mean seasonal cycle and temporal evolution of daily evaporation at an Australian open woodland savanna site in Howard Springs using 10 years of in situ data. The temporal evolution of ERA5-Land evaporation showed remarkable similarity with the in situ observations, along with a comparable mean seasonal cycle. This promising ability of ERA5-Land to capture the spatial and temporal variability of evaporation provides confidence in its application for this study.

To gain better insights into ERA5's ability to capture regional precipitation variability, we compute the weighted area average for northern (11° S–17° S, 127° E–136° E) and southeast (30° S–37° S, 145° E–153° E) Australia (Figures S1, S2). The average was calculated only over land, with weights based on grid cell area. The daily ERA5 time series shows a strong correlation with AGCD, with correlation coefficients above 0.9 in both seasons. These results indicate that ERA5 captures the spatial and temporal variability of precipitation very well and is therefore suitable for our analysis.

We define wet (dry) spells as consecutive three-hourly periods during which the precipitation minus evaporation ($P-E$) values are positive (negative). It is worth noting that our previous study (Pariyar et al., 2024) used $E-P$, in order to remain consistent with the sign convention of VIMD. In the present study, however, we use $P-E$ for convenience such that positive values represent wet spells and negative values represent dry spells. Past studies have defined wet or dry spells from precipitation only, often with a threshold to exclude light precipitation. These thresholds are either an arbitrary constant value for all grid points of interest (Huang et al., 2017; Mahbod et al., 2023; Ren et al., 2022; Wang et al., 2021), or a spatially varying threshold based on percentiles (Singh & Ranade, 2010). Given the subjective nature of the threshold chosen for wet and dry spells, the results can be sensitive to the choices made (Ratan & Venugopal, 2013). To address this limitation, we use evaporation as a threshold because precipitation greater (less) than evaporation physically suggests a water surplus (deficit) condition.

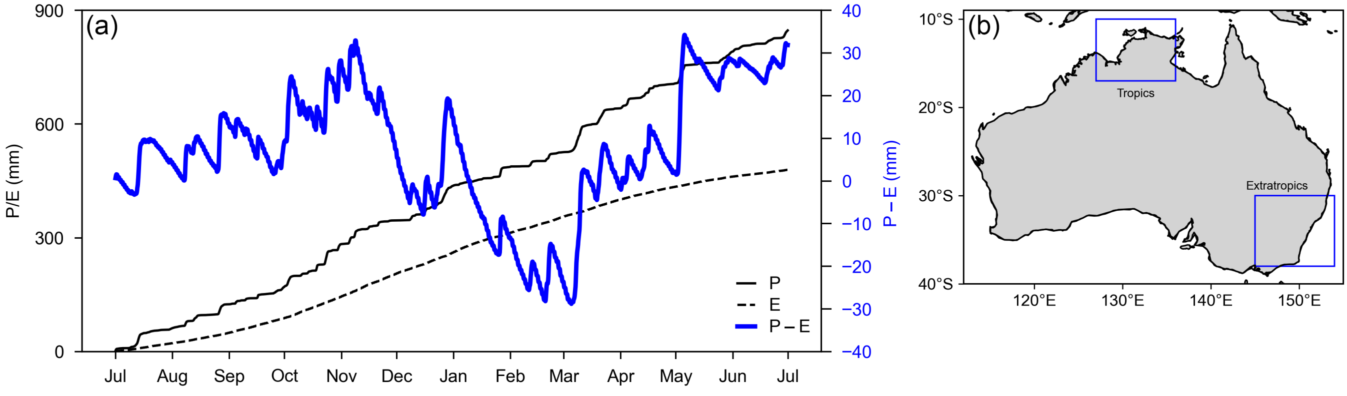

FIGURE 1 (a) Three-hourly cumulative time series of precipitation (thin solid line), evaporation (dashed line), and precipitation minus evaporation (thick solid line) from July 1999 to June 2000 for southeast Australia (30° S–37° S, 145° E–153° E). (b) Two regions selected for regional analysis: Northern Australia (11° S–17° S, 127° E–136° E) and southeast Australia (30° S–37° S, 145° E–153° E). [Colour figure can be viewed at wileyonlinelibrary.com]

The use of $P-E$, rather than precipitation alone, is common in hydrological investigations because it more accurately represents hydroclimate variability, with broader relevance to drought assessment, agriculture, and water security (Byrne & O'Gorman, 2015; Greve & Seneviratne, 2015). To illustrate this, we present the three-hourly cumulative time series of P, E, and $P-E$ from 1 July 1999 to 30 June 2000 for a region in southeast Australia (30° S–37° S, 145° E–153° E; Figure 1b) (Figure 1a). It is evident that $P-E$ captures the variability of wet and dry conditions more clearly than P alone. While the cumulative time series of P and E indicates that annual precipitation exceeds evaporation, the cumulative $P-E$ time series more directly reveals periods of sustained wetting and drying.

3 | RESULTS

3.1 | Cumulative $P-E$ time series

Figure 2 shows the three-hourly annual cumulative $P-E$ from 1 July to 30 June for the five wettest and five driest years between 1979 and 2024, for two regions in Australia: northern (11° S–17° S, 127° E–136° E) and southeast (30° S–37° S, 145° E–153° E) Australia (Figure 1b). We chose these regions because they exhibit larger seasonal contrasts in precipitation between wet and dry seasons, which we will discuss in subsequent sections. The wet and dry years are determined from annual anomalies of $P-E$, with years defined as 1 July to 30 June. We analyse the five wettest and driest years to examine differences in the characteristics of wet and dry spells. We calculate annual cumulative values from 1 July to capture the seasonal precipitation cycle in northern Australia, with the same starting date applied to southeast Australia for consistency and because of its less pronounced seasonal cycle.

Wet years in both regions are characterized by a series of steep upward slopes of $P-E$ (wet spells) followed by slow and gradual negative trends (dry spells). The steep upward slopes represent short-duration heavy precipitation events, whereas the more gradual downward slopes are the decaying phase of precipitation events with light or no precipitation. These episodes of steep increases in $P-E$ cumulative are largely missing in dry years, and as a result, the $P-E$ cumulative is mostly negative throughout the year. One of the main differences between northern and southeast Australia is the frequency of wet spells. In southeast Australia, wet spells are more frequent and are considerably shorter (Figure 2a), whereas in northern Australia, wet spells are longer and less frequent (Figure 2b). These differences are interesting, and a detailed analysis of spatial and temporal variation of wet and dry spells in terms of their frequency, intensity and duration provides valuable information about precipitation characteristics and their association with weather processes. Therefore, in the subsequent sections, we will present the key characteristics of wet and dry spells, their synoptic patterns, and variations in wet and dry years across Australia in summer and winter.

3.2 | Climatological features of wet and dry spells

Figure 3 shows the climatology of the precipitation contribution, frequency, and mean duration of wet and dry spells in summer and winter. The precipitation contribution (PCP) refers to the percentage of total precipitation associated with wet or dry spells in summer and winter.

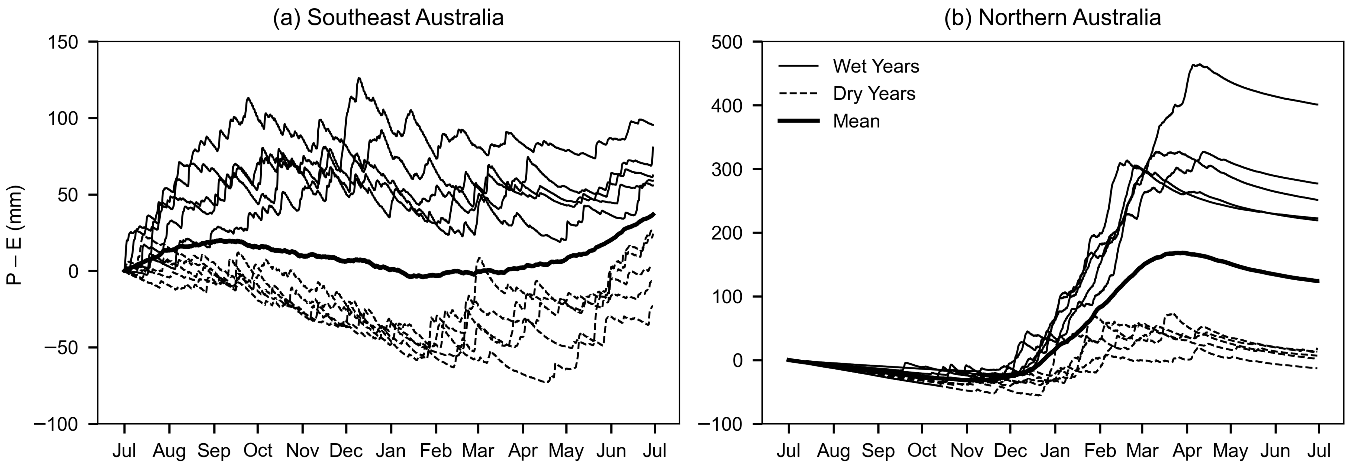

FIGURE 2 Three-hourly cumulative precipitation minus evaporation ($P - E$) from 1 July to 30 June for the five wettest (thin solid line) and five driest (thin dashed line) years between 1979 and 2024, averaged over southeast and northern Australia (red boxes in Figure 1b). The thick solid line denotes the mean cumulative $P - E$ across all years.

Likewise, the frequency (FRQ) represents the percentage of three-hourly observations occurring within wet or dry spells. The mean duration indicates the average length of all wet and dry spells in days, expressed in days.

Wet spells are more frequent along the coasts in both seasons, whereas dry spells dominate the interior of the continent. In summer, wet spells account for more than 90% of seasonal precipitation, occurring 20%–30% of the time with a mean duration of 8–10 hours (Figure 3a–c). In contrast, dry spells account for only a small fraction (up to 10%) of the seasonal precipitation, with a mean duration of 5–15 days around the central parts of the continent and shorter duration (1–3 days) along the northern and eastern coasts (Figure 3e,f). The mean longest summertime dry spells (6–15 days) are observed in the central part of the country (Figure 3f). These regions are primarily influenced by the subtropical high-pressure ridge, resulting into clear skies, high temperature, and sporadic precipitation patterns (McMahon et al., 2008). Further, these regions host some of Australia's largest lakes, such as Lake Eyre with very high evaporation rate (Hope et al., 2010). The combination of limited precipitation and intense evaporation from the water bodies contributes to prolonged dry spells.

In winter, wet spells are most frequent in southeastern Australia, with considerably longer spells (12–17 hours) and higher contribution to the seasonal precipitation (up to 96%) (Figure 3g–i). On the other hand, the frequency of dry spells substantially increases in northern Australia, with mean duration ranging between 10 and 15 days (Figure 3j,k), contributing up to 30% of seasonal precipitation (Figure 3l). Winter is the dry season in northern Australia, with only 10%–15% of the annual precipitation occurring during this period, which is often characterized by prolonged dry conditions, sometimes lasting up to 167 consecutive days without precipitation (Bureau of Meteorology, 2009). Although a considerable fraction of precipitation in northern Australia occurs during these dry spells, their contribution to the total annual precipitation is minimal. Since a large proportion of seasonal precipitation is associated with wet spells in both seasons, we focus our analysis solely on wet spells.

3.3 | Wet-spell characteristics

To investigate the characteristics of wet spells in more detail, we classify them into eight categories based on their duration. Figures 4 and 5 show the climatology of the total precipitation contribution, frequency, and intensity of wet spells with different duration. We compute the precipitation contribution and frequency of wet spells as before. For the mean precipitation intensity (INT), the method is as follows: (i) for each category, we compute the mean precipitation for each wet spell; (ii) from the mean duration of individual spells, we compute the mean for all wet spells for the entire period.

Wet spells of six hours to one day contribute the largest fraction of seasonal precipitation in northern Australia in summer (Figure 4c,d). About 50%–60% of summertime precipitation is attributed to these categories, with a seasonal frequency of 30%–40% (Figure 4i,j). The mean intensity for this category ranges between 2 to 3 mm·3-h^{-1} (Figure 4o,p). Unlike northern Australia, wet spells of 12 hours to two days dominate the seasonal precipitation in southeast Australia, contributing 50%–70% of seasonal precipitation (Figures 4d,e, 5d,e). However, there are seasonal differences. The precipitation contribution is slightly higher in winter because of more frequent wet

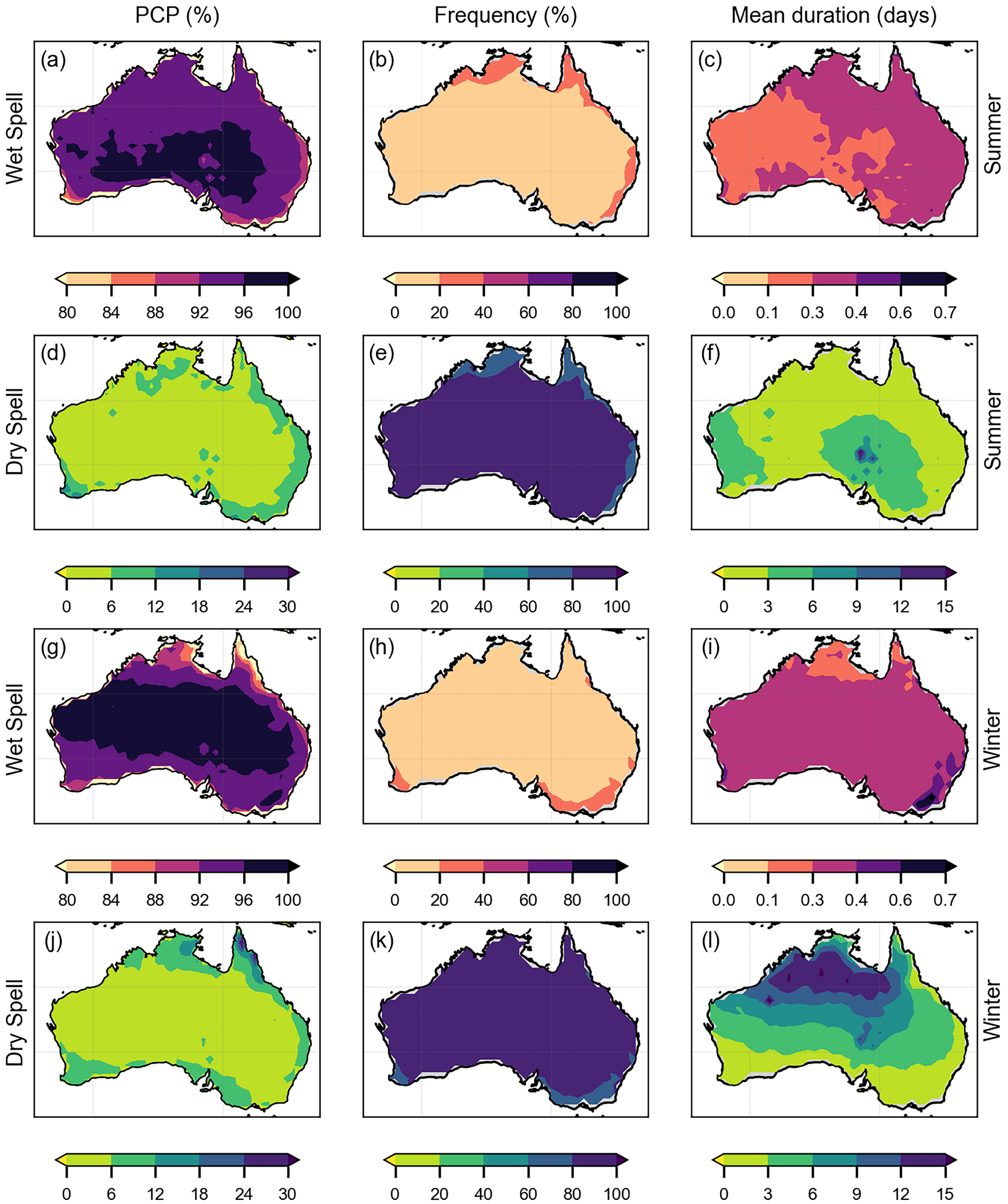

FIGURE 3 Contribution to seasonal precipitation (%, left), the fraction of frequency (%, middle) and mean duration (days, right) of wet and dry spells in summer (October–March, top two) and winter (April–September, bottom two). [Colour figure can be viewed at wileyonlinelibrary.com]

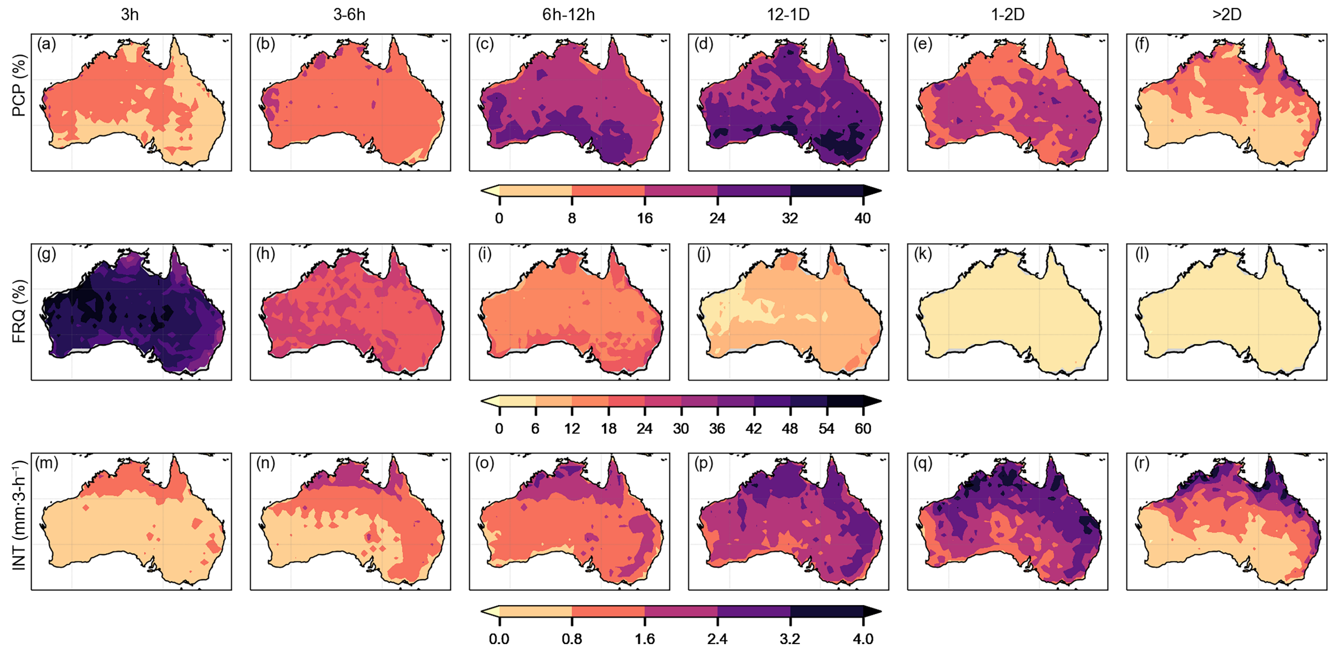

FIGURE 4 Contribution to seasonal precipitation (PCP, %, top), the fraction of frequency (FRQ, %, middle), and precipitation intensity (INT, mm·3-h^{-1}, bottom) for wet spells with different duration in summer (October–March) [Colour figure can be viewed at wileyonlinelibrary.com]

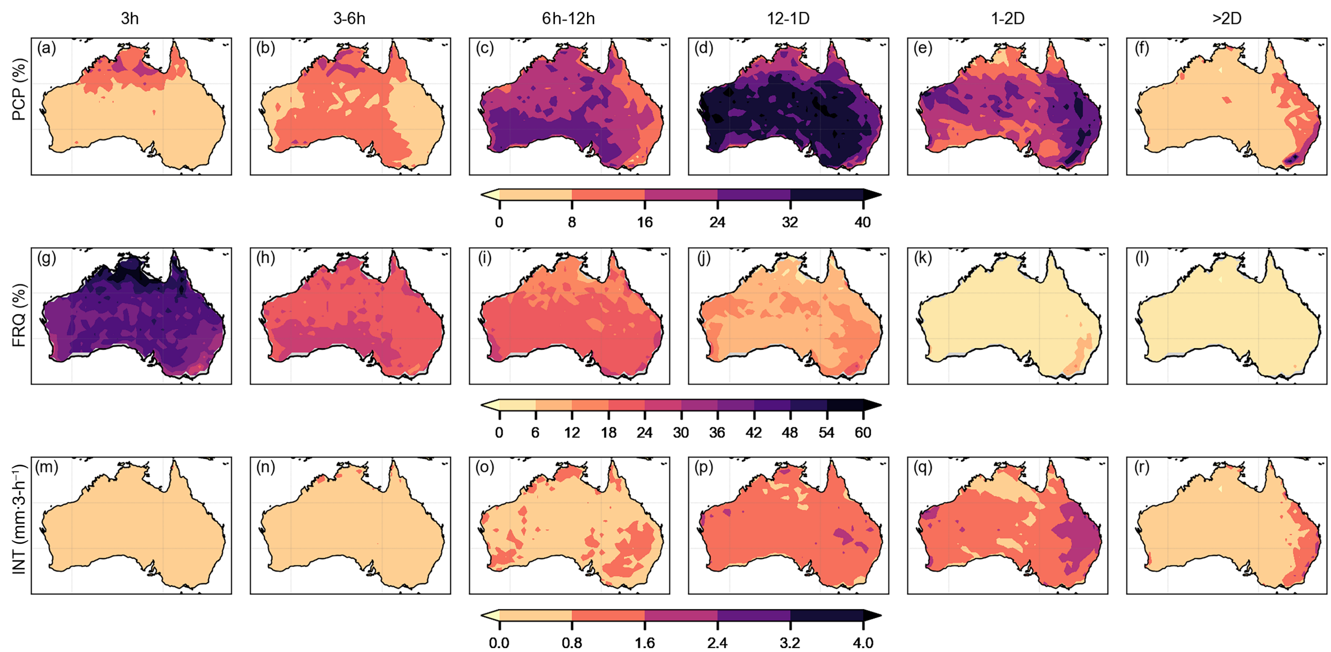

FIGURE 5 Contribution to seasonal precipitation (PCP, %, top), the fraction of frequency (FRQ, %, middle), and precipitation intensity (INT, mm·3-h^{-1}, bottom) for wet spells with different duration in winter (April–September). [Colour figure can be viewed at wileyonlinelibrary.com]

spells (Figures 4d,e, 5d,e), but the intensity is larger in summer (Figures 4p,q, 5p,q), which is compensated by reduced wet-spell frequency (Figures 4j,k, 5j,k). Notably, there is a westward shift in precipitation contribution from longer to shorter wet spells between six-hour to two-day spells in southeast Australia. For example, the contribution of one- to two-day wet spells is largest along the east coast (Figures 4e, 5e), whereas the contribution of six- to 12-hour wet spells is largest along the southern and south-eastern coasts (Figures 4c, 5c). This spatial discrepancy is

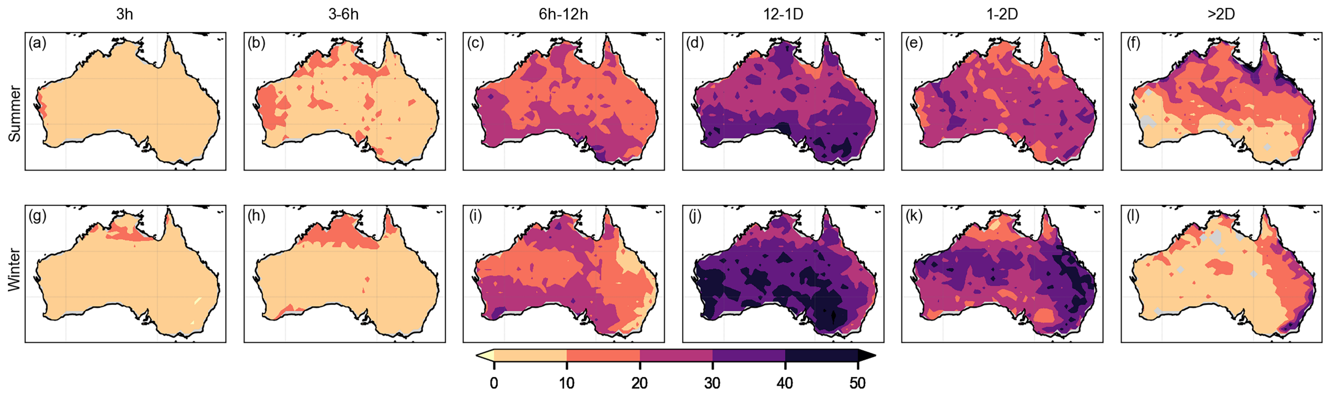

FIGURE 6 Fraction of extreme events (%) associated with different categories of wet spells in summer (October–March, top) and winter (April–September, bottom). Extreme events are defined as values exceeding the 99th percentile of three-hourly precipitation minus evaporation ($P-E$), calculated separately at each grid point for summer and winter. [Colour figure can be viewed at wileyonlinelibrary.com]

noteworthy and needs further investigation to identify the underlying causes.

Although wet spells shorter than six hours are the most frequent (60%–70%), they contribute only 10%–30% of seasonal precipitation in both seasons because of relatively low precipitation intensity (0.5–1.5 mm·3-h^{-1}) (Figures 4a,b,g,h,m,n, 5a,b,g,h,m,n). Despite being rare (<10%), wet spells over one day contribute up to 30% of seasonal precipitation in northern Australia in summer because of their higher intensity (Figure 4e,f,k,l,q,r). Wet spells over one day contribute 20%–40% of seasonal precipitation in southeast Australia in summer (Figure 4e,f,k,l,q,r). In winter, these wet spells contribute up to 60% of seasonal precipitation (Figure 5e,f,k,l,q,r).

It is evident that the mean precipitation intensity is higher for longer spells, suggesting their association with extreme events. To test this inference, we compute the fraction of three-hourly extreme precipitation events in each event duration category (Figure 6). We define extreme precipitation events as three-hourly $P-E$ values above the 99th percentile at each grid point for all months in summer and winter separately. We compute the fraction of extreme events by counting the frequency of extreme events in each category, which is normalized by the total number of extreme events.

In general, longer wet spells are associated with a higher number of extreme events in both seasons. About 60% to 90% of extreme events are related to wet spells over 12 hours in both seasons (Figure 6d–f, j–l), whereas short spells (<12 hours) contribute 10%–30% of extreme events (Figure 6a–c,g–i). Notably, 12-hour to one-day spells account for the largest fraction of extremes (30%–40%) in summer in both northern and southeast Australia (Figure 6d). In contrast, wet spells of 1one to two days share the largest fraction of extremes in the southeast Australia in winter (Figure 6k). Many previous studies on extreme precipitation based on subdaily datasets have shown that intense precipitation events contribute a large fraction of seasonal precipitation in Australia (Barbero et al., 2019; Guerreiro et al., 2018; Osburn et al., 2021). Because these studies typically define extreme events without considering the duration of the wet spells in which they occur, they might give the impression that these extremes are isolated events. However, our results indicate that a large fraction of extreme events actually occur during wet spells lasting more than 12 hours, rather than in isolation.

Interestingly, a considerable fraction of extreme events (30%–40%) is associated with wet spells over two days along northern and northeastern coasts in summer (Figure 6f) and southeastern coasts in winter (Figure 6l). In northern Australia, monsoon bursts commonly last between one and 12 days and may explain these extreme precipitation events and associated wet spells (Drosdowsky, 1996; Moise et al., 2020; Shaik & Cleland, 2010). Consistent with the precipitation contribution from wet spells, there is a clear westward shift in the wet spells and extreme precipitation association in southeast Australia. For longer wet spells (more than two days), wet spells account for a larger fraction of extreme events along the east coast (Figure 6e,k), whereas shorter wet spells (six to 12 hours) contribute to extremes in southern and southwestern coasts (Figure 6c,i).

It is evident that longer spells are important for seasonal precipitation because of their high intensity, despite being rare. For example, wet spells lasting more than one day occur fewer than 10 (two) times in summer in northern (southeastern) Australia (not shown). In winter, they occur 10–15 times in southeastern Australia. Likewise, wet spells longer than two days occur fewer than five times in summer. Given the rarity of these longer wet spells, and their significant contribution to seasonal total precipitation, any change in their frequency can have a considerable impact on interannual variability. We will discuss this in more detail in Section 3.5.

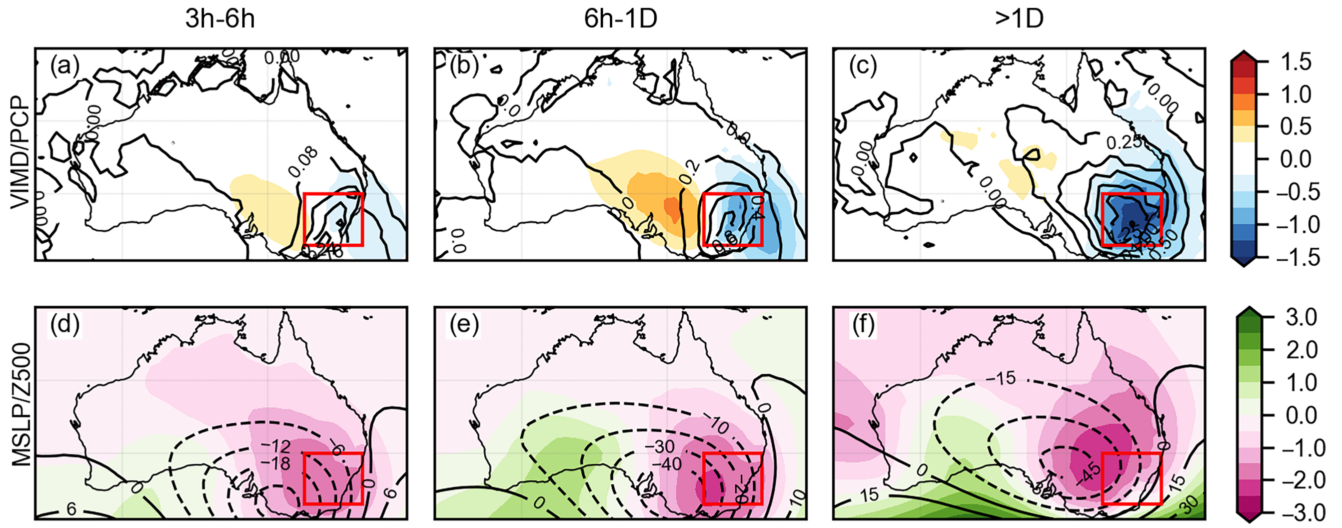

FIGURE 7 Anomaly composites of atmospheric variables for wet spells of 3–6 hours (left), six hours to one day (middle), and longer than one day (right) in southeast Australia in summer (October–March). Colour shading in panels a–c is for vertically integrated moisture divergence (mm·3-h^{-1}), and in panels d–f for mean sea-level pressure (hPa). Contours in panels a-c are for precipitation (mm·3-h^{-1}), and in panels d–f are for 500-hPa geopotential height (m). The solid contours are positive values, and the dashed are negative values. [Colour figure can be viewed at wileyonlinelibrary.com]

3.4 | Synoptic environment of wet spells

To illustrate the synoptic environment associated with wet spells of various duration, we compute the anomaly composites of VIMD, precipitation (P), mean sea-level pressure (MSLP), and 500-hPa geopotential height (Z). We compute the composites for two regions as described in the previous section. We compute the composites as follows: first, we define the wet spells of all six durations at individual grid points within the region. Then, we compute the composites by taking the time average for all wet spells in each category. We subtract the seasonal mean from the composites to get anomalies. We compute the mean composites by taking the mean of all composites for all grid points (only over land) within the specified region (marked as blue boxes in Figure 1b). For brevity, we show the results for three wet-spell categories instead of six (i.e., three to six hours, six hours to one day, and more than one day) as the composites are similar in each subcategory. Note that we show composites only for summer, as the composites in winter are very similar (Figure S3).

In southeast Australia, wet spells of three to six hours are characterized by moisture convergence to the northeast of maximum positive precipitation anomalies and divergence to the west (Figure 7a). The pattern is similar for six-hour to one-day spells, but the anomalies are more pronounced (Figure 7b). These features are associated with low surface pressure anomalies extending northwest from the maximum precipitation anomalies and upper-level negative geopotential height anomalies southwest of the maximum precipitation anomalies (Figure 7d). These synoptic patterns are typical of extratropical cyclones and their associated fronts, known producers of precipitation in southeastern Australia. Longer spells over one day show strong positive precipitation and moisture convergence anomalies over a large area (Figure 7c). The composites of MSLP show a low pressure with a centre northwest of the box (Figure 7f). This cyclonic flow is associated with upper-level negative geopotential height anomalies. Strong high-pressure anomalies are apparent on the poleward edge of the cyclonic anomalies. The synoptic pattern associated with longer spells resembles that of a cut-off low (Holgate et al., 2023, 2025; Jin et al., 2024; Katzfey & Mcinnes, 1996; Reeder & Smith, 1998). Cut-off lows are one of the major weather systems dictating precipitation variability, particularly heavy precipitation variability in southeastern Australia (Hauser et al., 2020). Cut-off lows are produced by anticyclonic Rossby wave-breaking and are often slow-moving as a result. This process manifests as cyclonic upper-level anomalies over eastern Australia and anticyclonic anomalies to the south and east of the continent (Barnes et al., 2023).

The synoptic pattern in northern Australia shows large-scale negative pressure anomalies for MSLP with negative geopotential height anomalies for all three wet-spell categories (Figure 8d–f), reminiscent of a monsoon trough (Hurley & Boos, 2015; Kilroy et al., 2016). For three- to six-hour spells, the MSLP anomalies show only a weak low-pressure system (Figure 8d) and the positive precipitation anomalies are also limited to land (Figure 8a). The patterns associated with these high-frequency wet

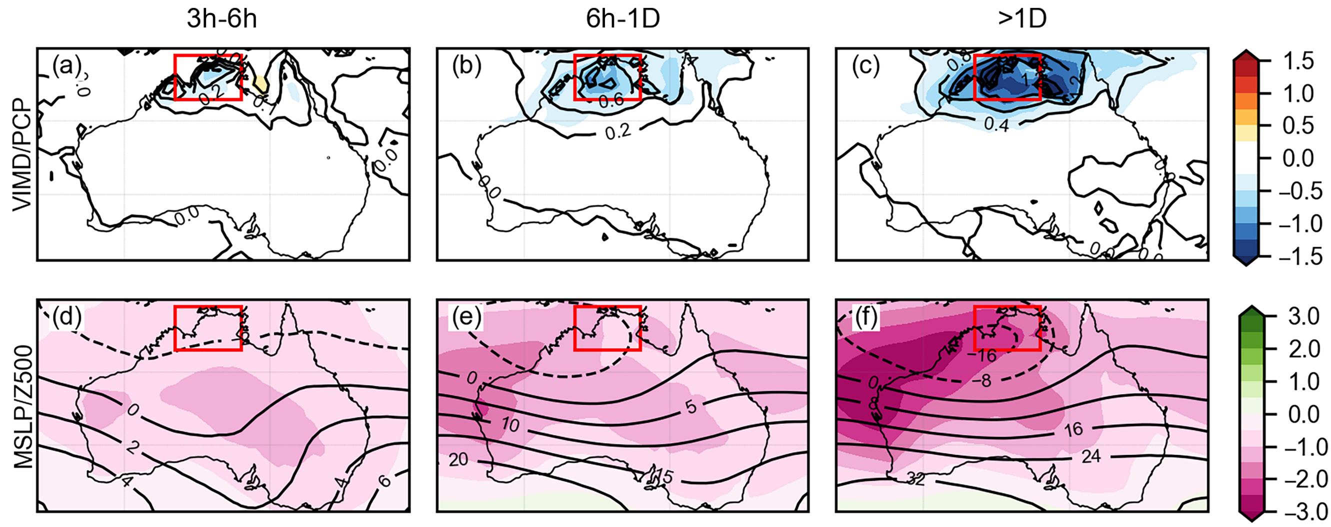

FIGURE 8 Anomaly composites of atmospheric variables for wet spells of 3–6 hours (left), six hours to one day (middle), and longer than one day (right) in northern Australia in summer (October–March). Colour shading in panels a–c is for vertically integrated moisture divergence (mm·3-h^{-1}), and in panels d–f for mean sea-level pressure (hPa). Contours in panels a–c are for precipitation (mm·3-h^{-1}), and in panels d–f are for 500-hPa geopotential height (m). The solid contours are positive values, and the dashed are negative values. [Colour figure can be viewed at wileyonlinelibrary.com]

spells suggest they are produced by tropical convection with weak large-scale dynamical forcing. For six-hour to one-day spells, the low-pressure system becomes stronger in the composites (Figure 8e), with stronger precipitation anomalies over a large region (Figure 8b). These long-duration wet spells are more likely associated with a monsoon low-pressure system. The monsoon low-pressure system is stronger in the case of wet spells over one day with a well-developed monsoon trough (Figure 8f), a typical synoptic environment for an active monsoon burst (Berry & Reeder, 2016; Narsey et al., 2017).

3.5 | Wet and dry summer/winter characteristics

We extend our analysis to wet and dry summer/winter to understand how wet-spell frequency and intensity modulate seasonal precipitation variability on the interannual time-scale. To achieve this, we define the wet and dry summers/winters based on the weighted area average of three-hourly $P-E$ for all grids within Australia, with weights determined by grid area. We compute seasonal anomalies for each year from the $P-E$ time series and choose the top five wettest and driest summer and winter separately.

Figure 9 shows the change in total precipitation between wet and dry summers and winters (wet minus dry) and the contributions from changes in wet-spell frequency, intensity, and their combination. Note that we define the wet/dry summers and winters separately so they represent different years and therefore the year shown in Figure 2 are not necessarily the same as those shown in Figure 9. The contribution from the change in frequency is calculated as the difference in wet-spell frequency between wet and dry summers or winters, multiplied by the wet-spell intensity of either the wet or dry years. The contribution from the change in intensity is calculated as the difference in wet-spell intensity between wet and dry summers or winters, multiplied by the wet-spell frequency of either the wet or dry seasons. The combined contribution from changes in both frequency and intensity, calculated as the product of the change in wet-spell frequency and the change in wet-spell intensity, is negligible and therefore not shown. The sum of these three contributions equals the total change in precipitation. However, the sign of the combined term depends on whether the change in frequency or intensity is multiplied by the corresponding value from the wet or dry seasons when calculating the individual frequency and intensity contributions. This decomposition allows us to quantify the contribution of wet-spell frequency, intensity, and their combination to the total change in precipitation.

During the wet years in both seasons, most of Australia experiences above-normal precipitation; however, the magnitude of anomalies is larger in summer. In summer, the largest change in precipitation is evident in northern Australia, where the precipitation anomaly ranges from 300 to 600 mm (Figure 9a). On the other hand, in winter, the maximum changes in precipitation are in southeast Australia, where the precipitation anomalies range between 200 and 400 mm (Figure 9d). The

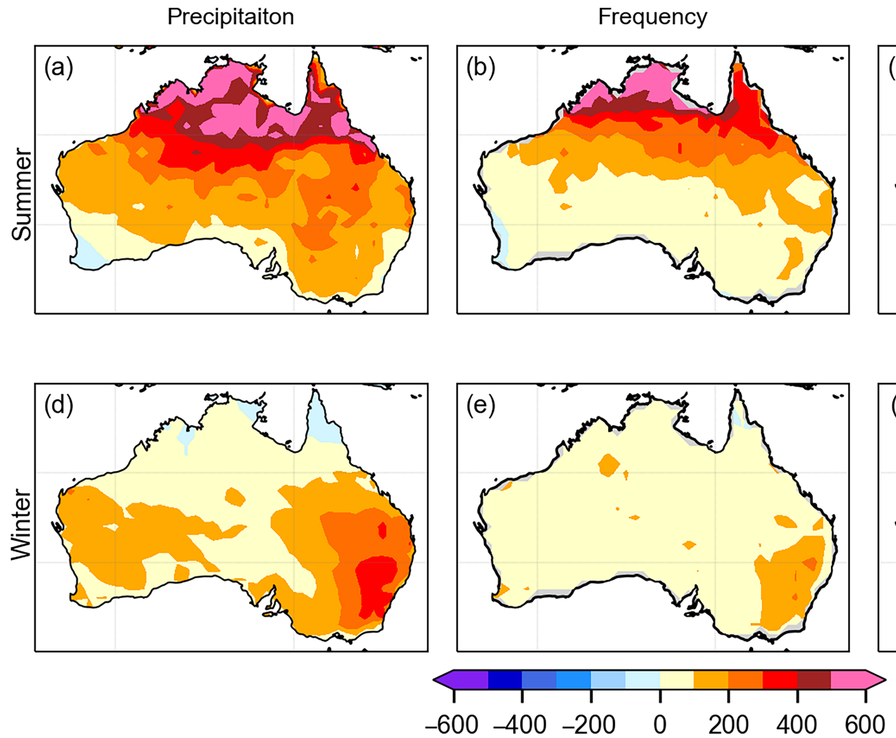

FIGURE 9 Precipitation change between wet and dry summers (October–March) and winters (April–September) (mm, left) and the contribution from change in wet-spell frequency (mm, middle) and intensity (mm, right) in summer (top) and winter (bottom). [Colour figure can be viewed at wileyonlinelibrary.com]

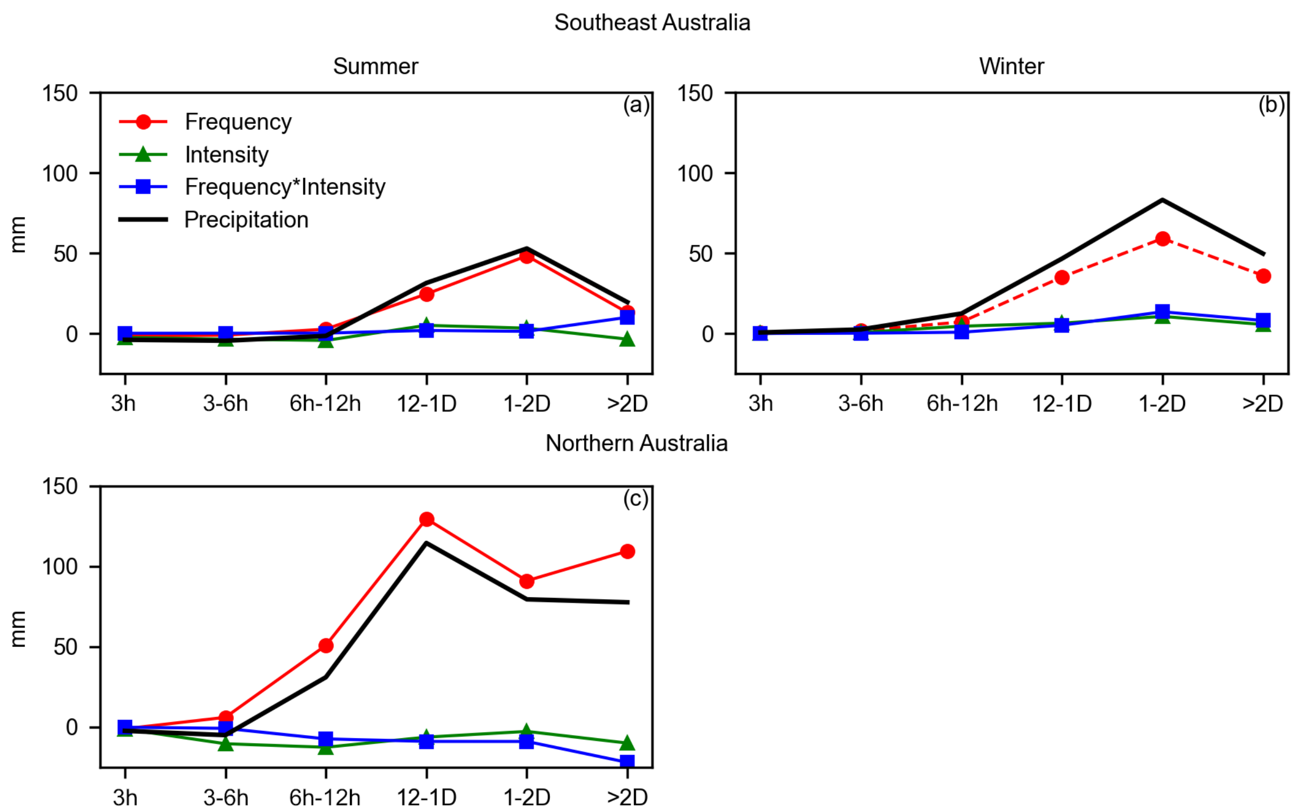

FIGURE 10 Change in precipitation (thick solid line) between wet and dry summers (October–March, left) and winters (April–September, right) for wet spells of different duration (black), the contribution from change in wet-spell frequency (solid line with circle), intensity (solid line with triangle), and both frequency and intensity (solid line with diamond) in the southeast (top) and northern Australia (bottom). [Colour figure can be viewed at wileyonlinelibrary.com]

decomposition of the change in precipitation into the contribution from the change in frequency and intensity of wet spells shows that the increase in wet years precipitation is primarily determined by the change in the frequency of wet spells in northern Australia (Figure 9b). However, in southeast Australia, though the frequency of wet spells dominates the change in precipitation, the contribution from precipitation intensity is also important, particularly for the east coast in winter (Figure 9b,c,e,f).

To understand the relative importance of wet spells of different duration to change in precipitation between wet and dry seasons, we decompose the contribution of wet-spell frequency and intensity into wet spells of different duration. The contribution of wet-spell frequency and intensity is computed for each category separately as described before. For convenience, we summarize the results for two regions where the change in precipitation is the largest, as described in the previous section. Figure 10 shows the change in precipitation between wet and dry summers/winters associated with wet spells of different duration, the contribution from change in frequency, intensity, and both frequency and intensity in northern and southeast Australia. The increase in precipitation during wet years is primarily attributed to wet spells over 12 (six) hours in southeast (northern) Australia. The maximum change in precipitation is associated with one- to two-day spells in both seasons (Figure 10a). These changes are dominated by an increase in the frequency of wet spells in summer. However, in winter, both frequency and intensity are important (Figure 10b). In northern Australia, the maximum change in precipitation is contributed to wet spells of 12 hours to one day, but wet spells over two days are equally important (Figure 10c). Unlike in southeast Australia, these changes are primarily contributed by changes in the frequency of wet spells. Wet spells shorter than six hours do not show significant changes between wet and dry years in both regions. This highlights the role large-scale and longer-lasting weather systems play in differentiating wet and dry years (Jin et al., 2024; Parker & Gallant, 2022).

4 | SUMMARY

The paper describes the characteristics of wet spells in Australia based on three-hourly ERA5 and ERA5-Land reanalyses from 1979 to 2024. We analyse the spatial and temporal distribution of wet spells of different duration from subdaily to daily time-scales, discuss their synoptic environment and examine their roles in dictating wet and dry summers and winters in Australia.

Our definition of wet spells is based on $P-E$. While the use of $P-E$ instead of precipitation alone is common in hydrological investigations, it has been applied less frequently in climate studies. Defining wet conditions using evaporation as a physically based threshold, rather than relying on arbitrary precipitation thresholds, provides a more meaningful distinction between wet and dry conditions. This approach is particularly valuable in regions like Australia, where precipitation exhibits large spatial variability across diverse climatic regimes.

On a daily time-scale, ERA5 captures precipitation characteristics quite well, both at the grid level and for regional averages across Australia, when compared to the AGCD database. The spatial structure of the mean and variability of precipitation is also well represented by ERA5, highlighting its usefulness for similar studies on precipitation characteristics in Australia. However, the precipitation variability captured by ERA5 on a subdaily time-scale, as shown here, is also important for seasonal precipitation and should be evaluated against subdaily observations to build confidence in ERA5's performance for high-frequency precipitation events.

Climatologically, wet spells dominate the seasonal precipitation in Australia, explaining more than 90% of it. Regionally, in summer, the contribution of wet spells to seasonal precipitation is larger in northern Australia than in southeast Australia, with comparable frequency and mean duration. In southeast Australia, with longer wet spells and higher frequency, the contribution of wet spells to seasonal precipitation is considerably higher in winter than in summer.

In summer, six-hour to one-day wet spells contribute the most to seasonal precipitation, whereas in winter, 12-hour to two-day wet spells contribute the most. Despite being the most frequent, wet spells shorter than six hours explain a small fraction of seasonal precipitation because of their considerably lower intensity. These short-lived wet spells are characterized by light showers for a few hours. For longer wet spells, as the precipitation intensity increases with duration, moderate to heavy precipitation for an extended period is expected, significantly contributing to seasonal precipitation. These longer wet spells contribute more to extreme precipitation events than shorter ones. As longer wet spells are few in numbers a small change in their frequency can therefore have significant role in seasonal precipitation anomalies, floods, and drought. For example, a study by Parker and Gallant (2022) showed that absence (presence) of just a week or two of moderate to heavy precipitation can develop (terminate) meteorological droughts. Given the rare nature of longer spells and their co-occurrence with a large fraction of extreme events, it is highly likely that these longer spells are the key for drought development and termination.

The change in precipitation anomaly between wet and dry summers and winters in Australia is primarily due to the change in the frequency of longer wet spells in northern Australia. In contrast, both the frequency and intensity are important in southeast Australia, particularly in winter. The increase in seasonal precipitation during wet years is primarily due to the higher frequency of wet spells lasting more than 12 hours in northern Australia. Although wet spells lasting more than 12 hours dominate the increase in southeast Australia, one- to two-day wet spells contribute the most. These changes are largely due to changes in the frequency of wet spells in summer, whereas changes in intensity are equally important in winter.

The synoptic conditions associated with subdaily wet spells in southeast Australia in both seasons resemble an extratropical low and frontal system, whereas longer wet spells show patterns similar to cut-off lows. Wet spells on a subdaily time-scale in northern Australia are associated with tropical convection and low-pressure systems. The synoptic environment for longer wet spells is a well-developed monsoon trough, like that for active monsoon bursts.

Our results show how sequences of wet spells on subdaily to daily time-scales produce the year-to-year seasonal precipitation variability in Australia. Though short-duration wet spells (less than one day) dominate the frequency distribution and contribute to the overall climatology, their frequency and intensity do not change much between wet and dry years. Longer wet spells (more than one day) seem particularly important for the variability despite being less frequent as their contribution to change in precipitation between wet and dry years is considerably large. This means an increase or lack of long-duration wet spells determines the interannual variability of precipitation in Australia and, therefore, has implications for seasonal precipitation predictability. Thus, it is important to investigate whether climate models can reproduce these characteristics. Likewise, how changes in wet-spell characteristics determine the changes in mean and variability of seasonal precipitation in Australia under future climate change is another interesting topic for future research.

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CONFLICT OF INTEREST STATEMENT

None of the authors have a conflict of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are openly available in ECMWF Climate Data Store at https://cds.climate.copernicus.eu/datasets/reanalysis-era5-single-levels?tab=overview.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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