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Impacts of ENSO on Australian rainfall: what not to expect

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ABSTRACT

In eastern Australia we expect to experience wet conditions during La Niña and dry during El Niño events. We explore how well these expectations match historical outcomes by assessing, for spring, how much rain fell during past La Niña and El Niño events. We use a tercile framing and find that for rainfall averaged across eastern Australia, La Niña approximately doubles the chance of spring rainfall being in the wet tercile whereas El Niño approximately doubles the chance of a dry spring. Also of note is that during La Niña, the dry tercile is mostly vacant and during El Niño, the wet tercile is mostly vacant, indicating that one should not expect dry conditions in La Niña or wet in El Niño for eastern Australia as a whole. At individual locations across Australia, the results vary, and in some cases, including the eastern seaboard, La Niña or El Niño events do not change the odds of wet and dry springs significantly beyond chance expectations. For example, in the Sydney region, the normal chance of experiencing a wet tercile spring is 33% and this increases only slightly in a La Niña to 38%, suggesting that La Niña is not a strong indicator for wet conditions in this region. These outcomes may help to manage our expectations for the likely rainfall outcomes during future El Niño–Southern Oscillation (ENSO) events.

Keywords: Australian climate, Australian rainfall, climate extreme, drought, dry, El Niño, ENSO, extreme probability, flood, La Niña, rainfall extremes, wet.

1. Introduction

The El Niño–Southern Oscillation (ENSO) has a well-documented association with Australia's rainfall variability, with La Niña events linked to wet conditions across the continent and El Niño to dry (McBride and Nicholls 1983; Risbey *et al.* 2009; Chung and Power 2017). Key examples of this relationship are the very wet spring of 2010, which coincided with a La Niña (Hendon *et al.* 2014) and the extreme dry of 1982, associated with El Niño (van Rensch *et al.* 2019). Wet conditions across Australia, particularly eastern Australia, over 2021–22 have also been linked to back-to-back La Niña events (e.g. Bureau of Meteorology 2022) and, as such, the declaration of a third La Niña was met with concern from already flood affected communities (Taylor and Haines 2022).

The relationship between ENSO and Australia's climate is complex, though, such that not all La Niña events have been associated with wet conditions or El Niño events with dry. Spring 2020, for example, was dry despite the occurrence of a La Niña (Lim *et al.* 2021), whereas during the El Niño of 1997, Australia experienced mostly average rainfall conditions (van Rensch *et al.* 2015). These outcomes motivate the question: how often does Australia experience wet conditions in a La Niña or dry in an El Niño? We seek to answer this question by identifying the historical occurrence of wet and dry periods in Australia during La Niña and El Niño conditions. Understanding these probabilities may help manage expectations of the likely rainfall outcome for Australia during future ENSO events.

2. Methods

We focus on the austral spring (September–November) period, given that spring rainfall in Australia has the highest correlation with ENSO variability (Risbey *et al.* 2009;

Chung and Power 2017). We split the rainfall data into terciles. For the 1950–2021 period, years with spring rainfall totals in the third tercile (i.e. years with spring totals equal to or greater than the 66th percentile) are considered wet, and years with spring rainfall totals in the first tercile (years with spring totals equal to or less than the 33rd percentile) are dry. All years between these values are considered to have average spring rainfall totals. Partitioning the data in this way means that, absent external influences, there is ~33% chance each that any spring could be wet, dry or average.

Various thresholds have been used to identify La Niña and El Niño events (e.g. Trenberth 1997). Here we identify La Niña and El Niño years using terciles. A year is classified as La Niña when the spring Niño3.4 index value is in the first tercile (i.e. years with an index value equal to or less than the 33rd percentile or ~ -0.41) whereas El Niño years are years with a spring Niño3.4 index value in the third tercile (i.e. years with an index value greater than or equal to the 66th percentile or ~0.44). All years in between are considered neutral ENSO years. For our 72-year analysis period (1950–2021), this means we have 24 La Niña, 24 El Niño and 24 neutral springs. Although our ENSO event threshold differs from that of the Australian Bureau of Meteorology, who currently use a threshold of Niño3.4 at ± 0.8 to identify ENSO events, the results we present are not largely sensitive to the threshold value, as discussed below.

We aim to identify whether ENSO conditions significantly change the odds of it being wet or dry beyond the normal 33% chance (i.e. 8 out of 24 springs are wet or dry). To this end, we assess the significance of our results using the binomial test, which is relevant when there are two outcomes of an experiment. For our study, the outcomes are 'wet' and 'not wet' or 'dry' and 'not dry'. Using the binomial test, for a sample size of 24 and probability of success of 33%, we find that 12 or more springs or 4 or less springs are significant for a *P*-value ~0.05. That is, for a sample of 24 springs, if 50% (12/24) or more of those springs are wet or dry or ~17% (4/24) or less are wet or dry, the results are significant according to a binomial test. Given that our sample sizes do not change, these significance levels remain the same for all analyses presented below.

3. Do ENSO events change rainfall odds in eastern Australia?

Fig. 1 presents total spring rainfall averaged across eastern Australia states (Queensland, New South Wales, Victoria and Tasmania) and the Niño3.4 index, averaged across spring months. It is evident in Fig. 1 (coloured dots) that El Niño and La Niña events of varying magnitude occur throughout the 1950–2021 period. We focus initially on La Niña and note that during La Niña the 'dry' tercile is mostly

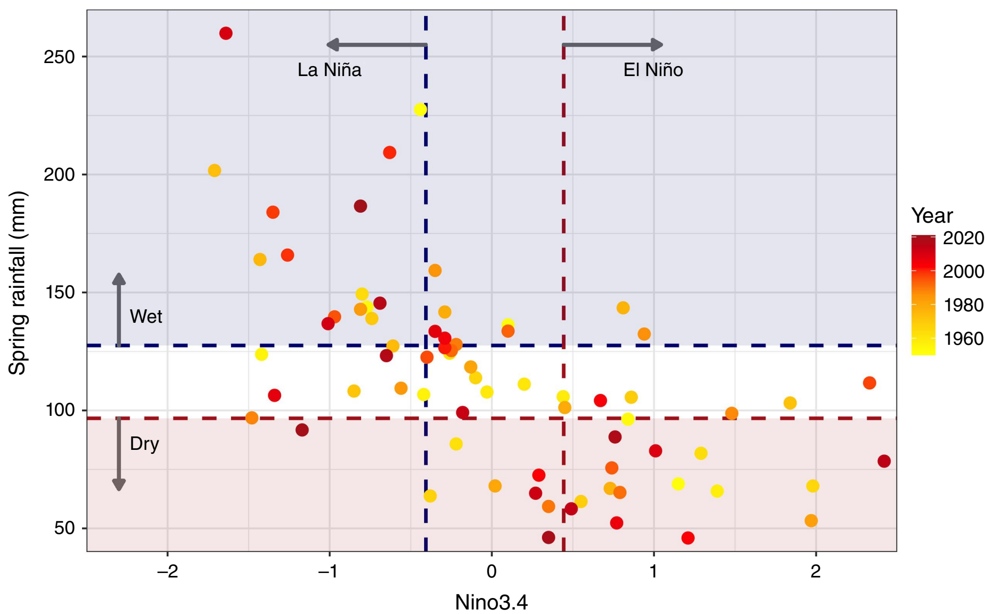

Fig. 1. Total spring rainfall averaged across eastern Australia states (Queensland, New South Wales, Victoria and Tasmania) and Niño3.4 index averaged across spring months. Dots are coloured according to their year, as indicated in the legend. The wet (third) rainfall tercile is indicated by the horizontal dashed blue line. The blue shaded box indicates rainfall totals above the wet tercile value. The dry (first) rainfall tercile is indicated by the horizontal dashed red line. The red shaded box indicates rainfall totals below the dry tercile value. Rainfall and ENSO terciles are calculated over the 1950–2021 period.

empty, which means that eastern Australia typically experiences average to wet conditions during La Niña events. Of the 24 La Niña springs, 15 are wet (spring totals in the third tercile) and 9 are average to dry (spring totals less than the 66th percentile). In line with our tercile framing, this means that, all else equal, any spring normally has a 33% chance of being wet but in La Niña that value increases to ~63% for eastern Australia (15/24), which is significant according to a binomial test. On the other side, during El Niño the 'wet' tercile is mostly empty, which means that eastern Australia typically experiences average to dry conditions during El Niño events. Of the 24 El Niño springs, 16 are considered dry and 8 are average to wet. This means that the normal 33% chance of being dry increases in El Niño to ~67%, which is also significant according to a binomial test. During neutral ENSO periods ~30% (7/24) of springs are dry and ~30% (7/24) are wet and just over 40% are average. A change to the threshold for ENSO event identification, for example, increasing the threshold to ±0.8, would not change the key results described above. That is, that La Niña significantly increases the chance of wet and decreases the chance of dry conditions, and El Niño significantly increases the chance of dry and decreases the chance of wet conditions in eastern Australia.

We now focus on an individual location in eastern Australia to illustrate that the large area expectations above do not always translate to smaller regions. We focus on Sydney as it is a high population centre on Australia's eastern seaboard. The region also experienced wet conditions in both spring 2021 and 2022, coinciding with La Niña events (e.g. Bureau of Meteorology 2021). In Fig. 2 we present the same analysis as in Fig. 1 but for a ~5- × 5-km grid cell that encompasses Sydney. In La Niña, the Sydney region has ~38% chance of experiencing a wet spring (9/24 years). This is only slightly higher than the normal chance that spring will be wet in the region (i.e. 33%). In El Niño, the chance of being in the dry tercile increases from 33 to 46% (11/24 years). These results suggest that unlike the broader eastern Australia region, La Niña does not significantly change the odds of experiencing a wet spring in the Sydney region, nor El Niño a significant increase to the odds of a dry spring.

4. Wet and dry rainfall odds across Australia during La Niña and El Niño events

The example above shows that, while eastern Australia as a whole experiences a notable change in the odds of wet and dry conditions during ENSO events, the Sydney region does not. We now explore how this applies more broadly across Australia. We present four cases that identify the following: the percentage of wet springs in La Niña years (Fig. 3*a*), the percentage of dry springs in La Niña years (Fig. 3*b*), the percentage of dry springs in El Niño years (Fig. 3*c*) and the percentage of wet springs in El Niño years (Fig. 3*d*). White colours in Fig. 3 indicate regions where there are near 'normal' (~33%) odds of experiencing wet or dry tercile conditions during the ENSO phase indicated in each subplot. Orange and red colours indicate regions where the odds of wet or dry conditions in the given ENSO phase have increased significantly (according to the binomial test) beyond normal odds, and blue colours indicate where the odds of wet or dry conditions in the given ENSO phase have decreased significantly below normal odds. That is, the high

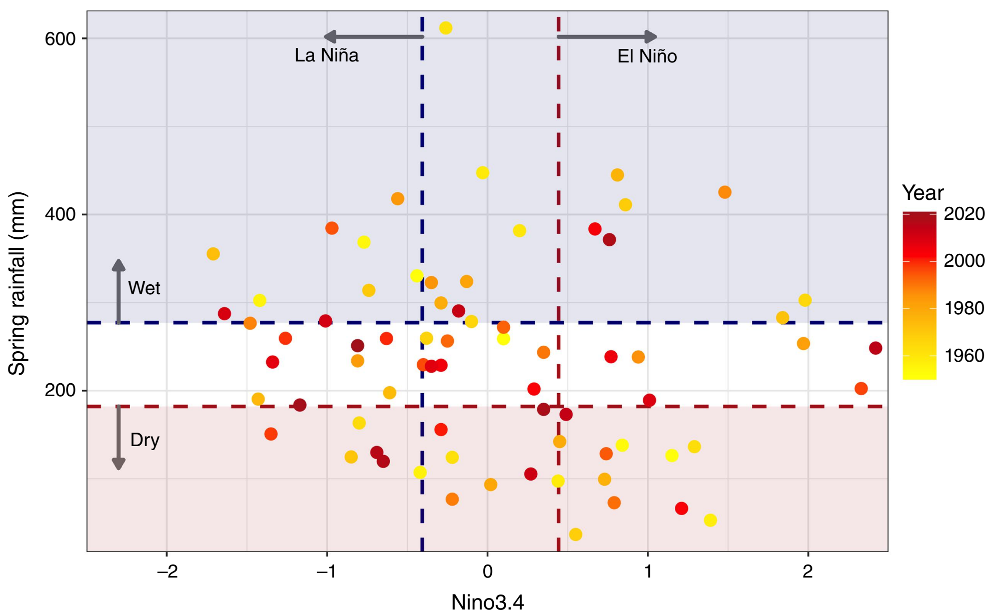

Fig. 2. As in Fig. 1 but for total spring rainfall for the Australian Gridded Climate Dataset grid cell that encompasses Sydney (33.9°S, 151.2°E). The location of Sydney is indicated in Fig. 3.

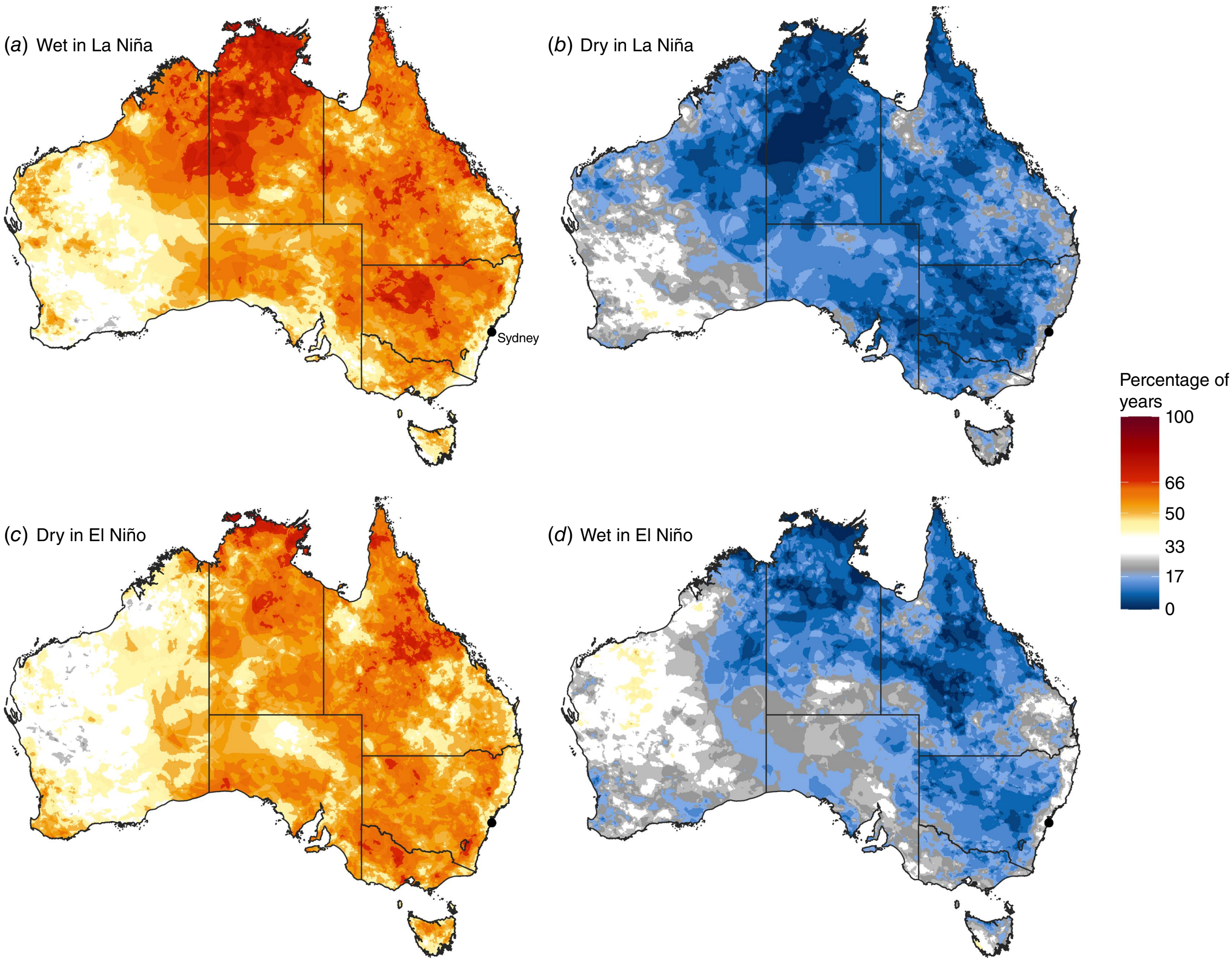

Fig. 3. (*a*) Percentage of La Niña years with spring rainfall in the wet (third) tercile. (*b*) Percentage of La Niña years with spring rainfall in the dry (first) tercile. (*c*) Percentage of El Niño years with spring rainfall in the dry tercile. (*d*) Percentage of El Niño years with spring rainfall in the wet tercile. The 17% and 50% marks indicate significant levels (see Section 2). The 33% and 66% marks indicate normal odds and double normal odds respectively. The white colour indicates near normal (33%) chance. Sydney is indicated by the black dot.

proportion of orange–red in Fig. 3*a*, *c* indicates that for large parts of Australia there are significantly increased odds of experiencing wet springs in La Niña and dry springs in El Niño. This is the case for parts of northern and south-eastern Australia, including the Murray Darling Basin. For those same regions, coloured blue in Fig. 3*b*, *d*, there are significantly decreased odds of experiencing dry springs in La Niña or wet springs in El Niño.

Yellow, white and grey colours indicate regions where there is no significant change to the odds of a wet or dry spring in La Niña and El Niño events. This is the case for large parts of Western Australia, south-western Tasmania and southern and eastern coasts of mainland Australia, including the eastern seaboard, where Sydney is located. Other authors have described how the eastern seaboard does not have a strong relationship with ENSO compared to other regions in Australia (e.g. Pepler *et al.* 2014). The results described in Fig. 3, expressed here in likelihood terms, are in line with Australian spring rainfall and ENSO correlations presented by other authors (e.g. Risbey *et al.* 2009; Chung and Power 2017). That is, regions where the correlations are high, correspond to regions that experience significant changes to wet or dry odds in La Niña and El Niño, with the opposite the case for regions with low correlations.

5. Conclusion

When La Niña or El Niño events are declared we tend to expect wet or dry conditions in eastern Australia respectively. We explored how this expectation has played out historically, by answering the question: how often does Australia experience wet conditions in a La Niña or dry in an El Niño? We applied a tercile framing and identified whether the odds of being in the wet or dry tercile change in La Niña or El Niño events beyond normal odds. We showed that for eastern Australia as a whole, La Niña events approximately double the chance, beyond normal expectations, of experiencing a wet spring whereas El Niño events similarly double the chance of a dry spring (Fig. 1). Also important is that in La Niña, the dry tercile is mostly vacant and during El Niño, the wet tercile is mostly vacant, indicating that one should not expect dry conditions in La Niña or wet in El Niño for eastern Australia. These outcomes are also relevant to parts of northern and southern Australia (Fig. 3). Although La Niña and El Niño may be good indicators of wet and dry conditions in eastern Australia as a whole, at some locations in eastern Australia, including the highly populated eastern seaboard, and also Western Australia and south-west Tasmania, ENSO phase does little to shift the chance of wet or dry conditions beyond normal expectations (Fig. 3). For example, in the Sydney region, the normal 33% chance of experiencing a wet spring increases only slightly in a La Niña to 38%, suggesting that La Niña is not necessarily a good indicator for wet conditions in this location (Fig. 2). The results of this study may help manage expectations of the likely outcomes for Australia's rainfall during future La Niña and El Niño events.

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Data availability. This Niño3.4 index was downloaded from https://www.cpc.ncep.noaa.gov/products/analysis_monitoring/ensostuff/ONI_v5.php. Data are available for the 1950–present period. For this study, only Niño3.4 data for the spring (September–November) period were used. Rainfall data used in Fig. 1 were downloaded from http://www.bom.gov.au/climate/change/ (variable: Rainfall – Total, region: Eastern Australia, period: Spring). The data represent spring averaged rainfall across Queensland, New South Wales, Victoria and Tasmania. Rainfall data used in Figs 2, 3 are from the Australian Gridded Climate Dataset v2 provided by the Bureau of Meteorology (Jones *et al.* 2009; Evans *et al.* 2020). Further information about the data is available at (http://www.bom.gov.au/climate/austmaps/about-agcd-maps.shtml). Data for Fig. 2 are extracted for the grid box that encompasses Sydney (33.9°S, 151.2°E). Rainfall and ENSO terciles were calculated using the 1950–2021 period.

Conflicts of interest. The authors declare that they have no conflicts of interest.

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