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Spatiotemporal Variability of Compound Droughts and Hot Extremes in East Australia

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Abstract

Droughts and hot extremes generate agricultural losses, forest death, and drinking water scarcity, especially when they happen simultaneously. In addition, drought appears to be linked to climate change in the same way that heat waves are. The rise in frequency and intensity of drought poses a severe danger, such as an increase in the number, size, and duration of bushfires. Even today, our understanding of how droughts and heat waves begin and evolve, as well as how climate change may affect these extreme events (droughts and heat waves), is limited. So far, numerous studies have been undertaken on the variability of individual droughts or hot extremes in Australia. However, the analysis of combined droughts and hot extremes, which might have even more significant effects than a single drought or hot extreme, is still inadequate. In this study, changes in the spatial extent of combined droughts and hot extremes in Eastern Australia have been investigated, considering daily precipitation and temperature data for 50 years between 1971 to 2021. For detecting and characterising the drought Standardised Precipitation Index (SPI) method has been used, and the hot extremes were evaluated based on the criterion given by the Australian Bureau of Meteorology (daily maximum temperature > 35 ⁰C). A linear regression method has been adopted to explore the trends of these climatic variables. All the stations have shown a general increase in combined drought and hot days. These findings demonstrate the variability of compound droughts and hot extremes and may provide helpful understanding to lessen the impact of extreme events in East Australia's region in the future.

Keywords: Combined extremes, Drought, East Australia, Hot days, Trend.

1. INTRODUCTION

Droughts and heat waves have significantly affected the environment and society worldwide during the past few decades, affecting human life, agriculture, ecosystems, and so forth (Lesk et al., 2016). One of the major impacts is the risk of water shortage in arid and semi-arid regions which will continually expand in the future (Noorisameleh et al., 2020). Wilhite (2000), reported that droughts generate an estimated US$6–8 billion in economic losses annually, while heat waves increased mortality rates around the world significantly. Therefore, it is crucial to increase our conception of the unpredictability of droughts and heat waves (or hot extremes) to lessen the potential impact on society and the ecology.

Numerous research has been conducted so far on the historical evaluation of droughts using various indices, and they have demonstrated the increased probability of droughts due to global warming (Vicente-Serrano et al., 2010). Some earlier research on dry hazards predominantly focused on two dry hazards only and their associated feedback mechanisms, i.e., among extremely high temperatures (or heatwaves) and drought, and among heatwaves and fire. For instance, Hao et al. studied (Hao et al., 2013) the concurrent phenomenon of dry and warm circumstances, revealing a clear increase in the frequency in the majority of places across the land areas worldwide. In another study, Ding et al.

examined the variation of both hot extremes and heat waves in China between 1961–2007 (Ding et al., 2010). They concluded that the northwest and eastern regions experienced a sharp increase in hot days and heatwaves in the last decade.

In Australia, the frequency of droughts or extremely hot weather occurrences has increased during the previous few decades; one of the major reasons is global warming (Spinoni et al., 2019). According to Australia's Bureau of Meteorology (BOM), the 2018 drought was the worst in southeast Australia since 1965. In one of the studies, Tian et al. (2019) claimed that due to low rainfall, declining soil moisture, rising temperatures, and increased evapotranspiration, south-eastern Australia, particularly New South Wales, Victoria, and Queensland, had an extreme drought during 2018 (Tian et al., 2019). Dewi et al. (2017) used combined rainfall and high temperatures for southeast Australia to characterise the climatology and variability of seasonal-scale droughts for 150 years period (Kirono et al., 2017). So far, considerable research has been conducted individually in the Australian region, the evaluation of compound droughts and hot extremes, which may induce even larger impacts than the individual drought or hot extreme, is still lacking in Eastern Australia.

Therefore, this work aims to examine the spatiotemporal variability of combined droughts and hot extremes in eastern Australia from 1971 to 2021 annually. To characterise the drought standardised precipitation index (SPI) and daily precipitation data were considered. The daily maximum temperature greater than 35 ºC criteria has been used to identify heat extremes or hot days. The findings indicate that compound droughts and heat extremes have significantly increased in spatial extent, with regional variations. These observations might clarify how to lessen the detrimental consequences of compound droughts and hot extremes in East Australia.

2. STUDY AREA AND DATA

The climate of Australia is diverse due to its huge geographical size. For this study, we have selected six stations, two in each state (QLD, NSW, VIC), one near the coast and the other in the inland area (Figure 1 and Table 1).

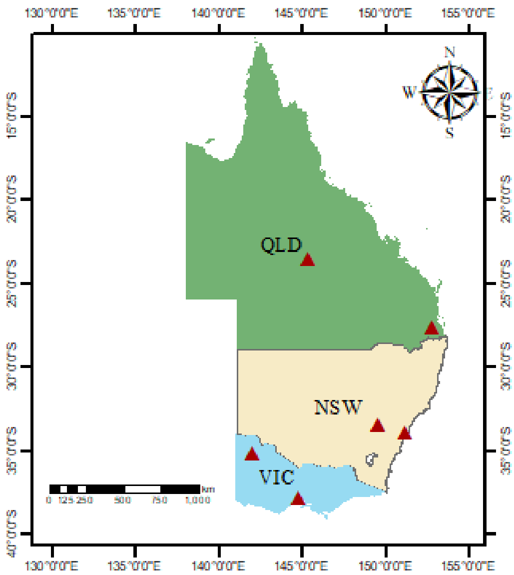

Figure 1. Location of six selected stations in East Australia

The daily precipitation and maximum temperature data have been collected from the Australian Bureau of meteorology covering the period between 1971 to 2021. The commonly used indicator SPI has been employed to characterise the meteorological drought. Table 2 displays the classification of SPI (Guttman, 1998).

Table 1: Description of selected stations

Station ID	Station Name	Latitude	Longitude
066037	Sydney Airport AMO	33.94 °S	151.17 °E
063005	Bathurst Agricultural Station	33.43 °S	149.56 °E
087031	Laverton RAAF	37.86 °S	144.76° E
076064	Walpeup Research	35.12 °S	142.00 °E
040004	Amberley AMO	27.63 °S	152.71 °E
036007	Barcaldine Post Office	23.55 °S	145.29 °E

Table 2: Categorisation of SPI (Guttman, 1998)

SPI values	≥ 2.0	1.5 ~ 1.99	1.0 ~ 1.49	− 0.99 ~ 0.99	− 1.0 ~ − 1.49	− 1.5 ~ − 1.99	≤ − 2.0
Moisture level	Extremely wet	Very wet	Moderately wet	Average	Moderately dry	Very dry	Extremely dry

3. METHODOLOGY

In this paper, the SPI drought index has been used which is a popular drought indicator that simply needs the amount of precipitation to calculate drought. It is a normalised score that expresses a difference from the mean for an event in standard deviation units. For our analysis, we employed the impact of droughts at 12 months SPI, thereby making it easier to analyse drought events over time (Janga Reddy & Ganguli, 2012). For the value of April, for example, is based on the total amounts of precipitation in April, March, and February. A positive SPI score implies above-average precipitation, whereas a negative one indicates below-average precipitation. A drought period is defined as a set of months that are consecutively below the SPI threshold of – 1 (McKee et al., 1993).

In Australia, a hot day is considered when the (daily maximum temperature) > 35°C (Bureau of Meteorology, 2022). The combination of droughts and hot extremes is defined as hot drought days in this study. Simple parametric tests have been used to accomplish the trend analysis. The linear regression has been used as a parametric analysis of yearly drought and hot days individually and combinedly.

4. RESULTS

Figure 2(a) - 7(a) depicts the annual trends in the frequencies of HDs from 1971 to 2021. In all the stations, the number of hot days (NHD) increased significantly, and the highest can be observed in the Barcaldine Post Office at 0.570 per year and the lowest in Sydney Airport AMO at 0.068 per year. The positive trend of HDs is consistent with the previous study (Pezza et al., 2012). They found a higher frequency of hot days appearing in most inland Australia.

For the precipitations, significant negative trends were spread over all the stations ranging between -0.032 (Sydney Airport AMO) to -0.014 (Barcaldine Post Office) per year. In contrast, positive non-significant trends were found at Bathurst Agricultural Station. Hence, Barcaldine Post Office experiences a greater number of hot days and lesser total monthly precipitation per year, the opposite can be seen for the Sydney Airport AMO.
In Figure 2(c) - 7(c), the time series for the SPI12 are determined, and the values of the linear regression slope are also shown. If the p-value is less than 0.05, the null hypothesis (no trend) is rejected and considered a significant trend at a 5% significance level. The p-value and the slope value of trend test results are displayed in Figure 2-7. The key factor used to define the drought index is precipitation. Hence there is a connection between precipitation and the SPI. The slope of the precipitation for all the stations shows a downward trend, except the Bathurst Agricultural Station experienced a non-significant positive trend of 0.001 per year.

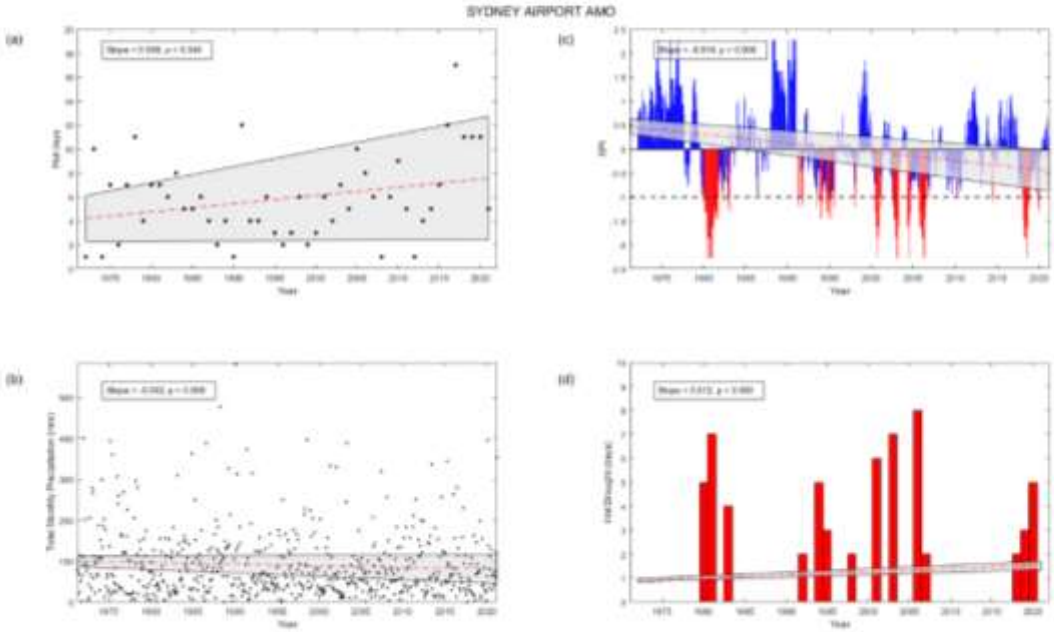

Figure 2. Differences in the regional extent of drought (SPI), hot extreme (NHD) and compound droughts and hot extremes (SPI & NHD) during 1971-2021 in Eastern Australia

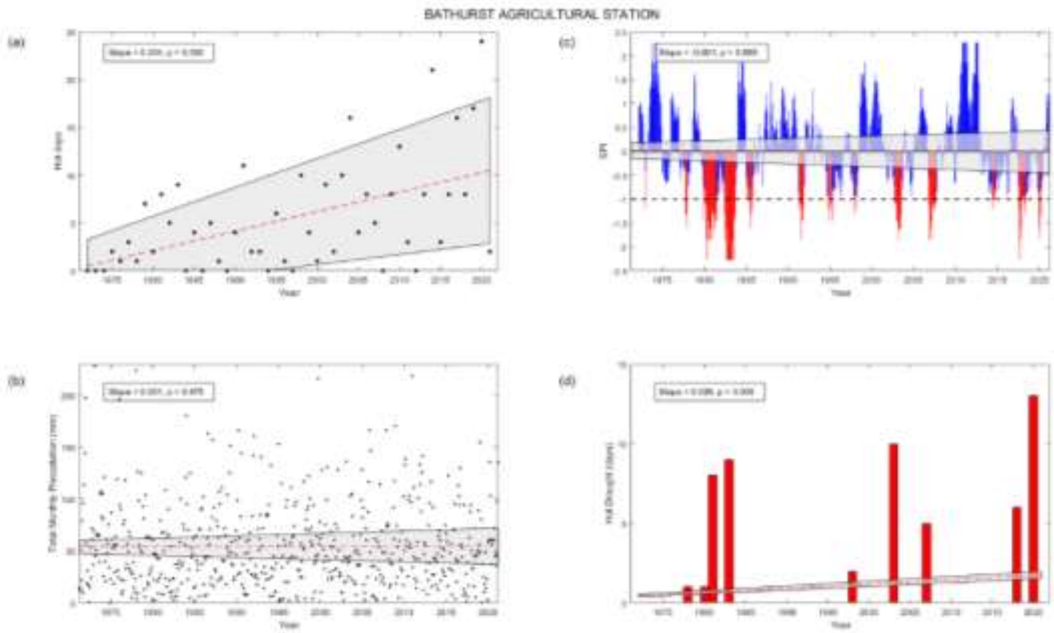

Figure 3. Same as Figure 2, except for Bathurst Agricultural Station

Similarly, the SPI value of all the stations shows a decreasing trend, indicating the severity is getting more severe over time. The lowest decrease can be seen in Bathurst Agricultural Station at 0.001 per year. Additionally, the finding of the significant trend of the spatial extent of drought is also consistent with previous studies (Rashid & Beecham, 2019). Thus, for individual extremes, NHD and SPI both showed a significantly increasing trend in the spatial extent at 95% confidence interval.

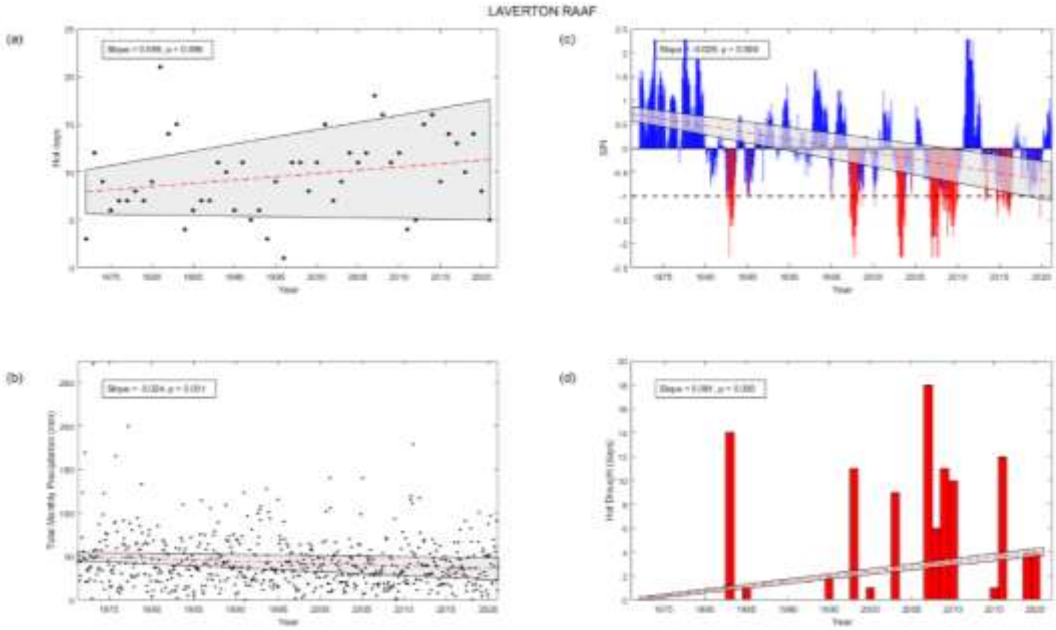

Figure 4. Same as Figure 2, except for Laverton RAAF

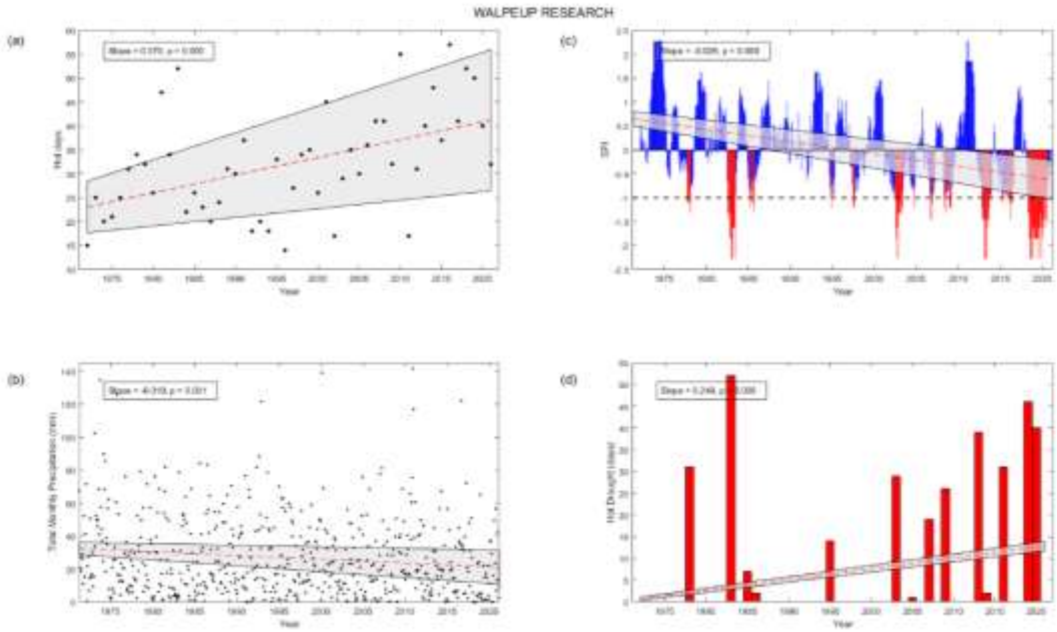

Figure 5. Same as Figure 2, except for Walpeup Research

Figure 2(d) - 7(d) displays the trend of compound droughts and hot extremes. The slope values indicate that Barcaldine Post Office has the highest Hot Drought (Days) of 0.466 per year, whereas Sydney Airport AMO shows the lowest slope value of 0.012 per year at a 95% confidence interval. Especially after the year 1995, all of the stations are showing a greater number of increments on hot drought days. These patterns suggest that the considerable rise in NHD and decline in precipitation may be responsible for increased spatial extent of compound droughts and heat extremes.

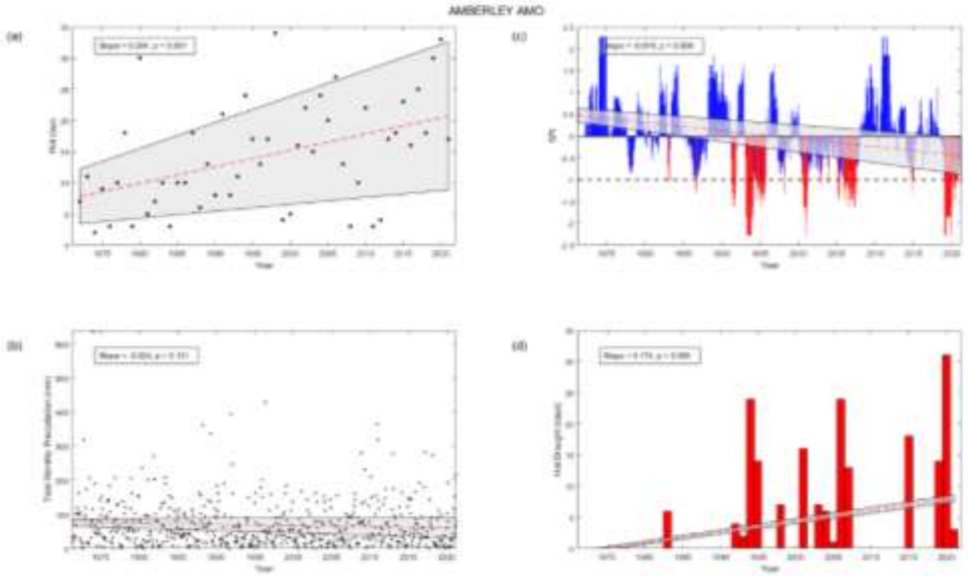

Figure 6. Same as Figure 2, except for Amberley AMO

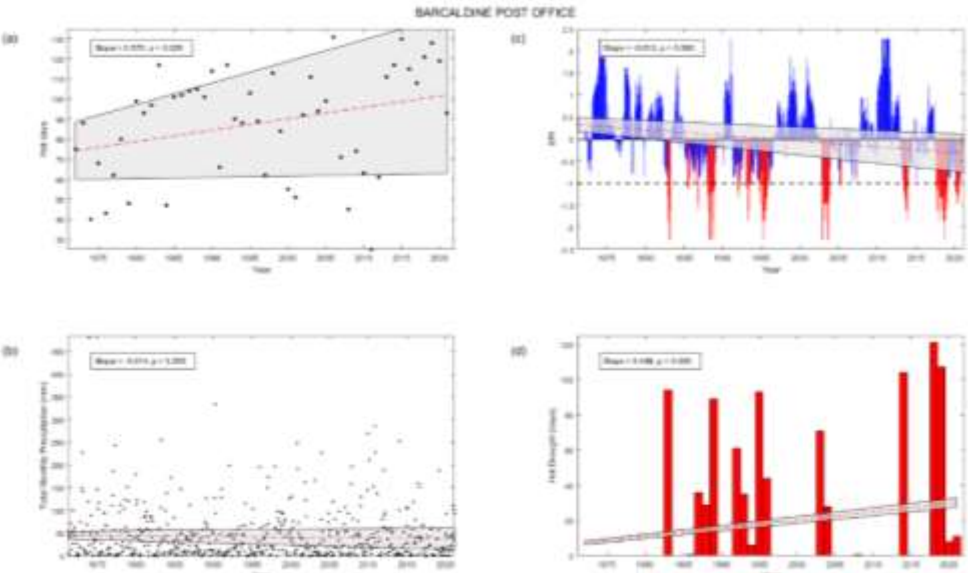

Figure 7. Same as Figure 2, except for Barcaldine Post Office

5. CONCLUSIONS

Trend analysis results show a general rise for the hot extremes, SPI, precipitation, and hot drought days for the six selected stations in East Australia. The overall trends in those climate variables agree well with the results of previous studies. The greatest number of hot days, SPI and hot drought days were found in the Barcaldine Post Office, whereas the smallest number of those events were found in Sydney Airport AMO. The upward slope is found to be 0.466 days per year for the Barcaldine Post Office, and the lowest slope is 0.012 per year for Hot drought days for Sydney Airport AMO. Thus, compared to the coastal region, the arid region (inner part of east Australia) has a greater impact on Hot droughts. Further study will include many stations to examine temporal and spatial changes in the whole Australian region, which might help to provide useful techniques for locating hotspots and evaluating hazard patterns that can help figure out how various natural disasters are related to one another. Also, can assist policy decision-makers and disaster managers in taking some actions for reducing the impact of extreme events.

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