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The local dependency of precipitation on historical changes in temperature

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Abstract
Globally, mean and extreme precipitation will increase with climate change. This is largely controlled by moisture and energy availability which is linked to temperature. Therefore, changes in precipitation are regularly presented proportional to a change in mean global temperature, and temperature is often proposed as a covariate for projecting precipitation with climatic change. However, studies which investigate the association between precipitation and temperature largely focus on the day-to-day association between precipitation and temperature fluctuations at a gauged location, which is not necessarily equivalent to changes in precipitation at climatic spatial and time scales. To assess whether temperature changes may help inform changes in precipitation with climatic change, we evaluate the historical relationship between precipitation and annual temperature fluctuations. We find positive correlations between precipitation and mean annual dew point temperature. These associations are strongest for annual average precipitation and weakest for the shortest, most extreme precipitation. We find that the strength of this correlation is more strongly linked to the number of rain days, rather than the precipitation depth itself. When dry-bulb temperatures are used in place of dew point temperature, the association between precipitation and temperature is either negative or zero. As a strong association between wet day dry-bulb and dew point temperatures exists, changes in temperature may aid in understanding the changes to precipitation as global temperatures increase. However, as the precipitation-dew point correlation is not necessarily physically related to the precipitation depth but rather to precipitation occurrence; precipitation-temperature sensitivities need to be interpreted with caution.

Keywords Precipitation · Precipitation extremes · Temperature · Dew point · Trends · Climate change

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1 Introduction

It is accepted that, at a global scale, both mean and extreme precipitation intensity will increase with climatic change (Allen and Ingram 2002; Kirtman et al. 2013; O'Gorman 2015). The most common explanation for an increase in extreme precipitation follows from the Clausius-Clapeyron (CC) relationship. If the Earth warms and the atmosphere is warmer, the saturation vapor pressure will increase. Hence, in the absence of changes in relative humidity, there will be more moisture available for precipitation, and precipitation extremes could theoretically be assumed to increase at the same rate as the increase in saturation vapor (Trenberth et al. 2003; Trenberth 2011). This rate of increase is generally approximated as 7%/°C and termed "CC scaling". Mean precipitation is also expected to increase globally but at a rate less than 7%/°C, dictated by the availability of energy (Allen and Ingram 2002).

Sensitivities of extreme precipitation to the observed daily temperature, termed scaling, could be expected to replicate CC scaling. However, only in certain regions (Utsumi et al. 2011; Wasko et al. 2016) does the observed relationship match theory. Scaling above the CC relationship (Lenderink and van Meijgaard 2008; Busuioc et al. 2016; Lenderink et al. 2017), usually termed super CC scaling, is attributed to invigorating storm dynamics in convective systems (Trenberth et al. 2007; Lenderink et al. 2017). Below CC scaling, often negative, is attributed to either decreasing relative humidity with higher tropical temperatures (Drobinski et al. 2018, Hardwick Jones et al. 2010, Wasko et al. 2015) or higher temperatures being correlated with drier surface conditions (Trenberth and Shea 2005; Vautard et al. 2007). As dew point temperature is a more direct measure of the absolute humidity or atmospheric moisture in the atmosphere (Lenderink et al. 2011; Lenderink and van Meijgaard 2010) scaling more consistent with the increases expected per physical dependencies have been obtained using dew point temperature (Lenderink and van Meijgaard 2010; Lenderink et al. 2011; Panthou et al. 2014; Barbero et al. 2017b; Park and Min 2017; Ali and Mishra 2017; Wasko et al. 2018; Bui et al. 2019). A median global scaling of 6.1%/K (Ali et al. 2018) and 7.4%/K (Zhang et al. 2019) was found for the 95th percentile of precipitation with dew point temperature. Globally, the mix of increases and decreases in extreme precipitation trends better match dew point temperature scaling than dry-bulb temperature scaling (Zhang et al. 2019). As climate models generally predict dry-bulb temperatures to increase at the same rate as dew point temperatures, this gives credence to the usefulness of precipitation-temperature relationships, at least in part, informing future changes in precipitation extremes (Lenderink and Attema 2015). For short-duration precipitation extremes, climate models simulate near CC sensitivities of extreme precipitation (Muller et al. 2011; Kendon et al. 2014; Chan et al. 2016) though there is a large variance between studies (Bao et al. 2017; Zhang et al. 2017).

However, it is unlikely that changes in precipitation will be as straightforward as following temperature trends. For example, changes in both thermodynamic and dynamic contributions to changes in precipitation need to be considered (Trenberth et al. 2003; Pfahl et al. 2017). Large scale shifts in atmospheric circulations (Allan and Soden 2008; O'Gorman and Schneider 2009; Allan et al. 2014; Blenkinsop et al. 2015), such as the expansion of the tropics (Seidel et al. 2008), changes in the type and frequency of events (Molnar et al. 2015; Schleiss 2018), and changes in aerosol concentrations (Da Silva et al. 2019) may also change precipitation intensities. Historical trends place annual global increases in precipitation at approximately 2.4 mm/decade (Dai et al. 1997; Hartmann et al. 2013). This corresponds to the simulated increase of 2%/°C globally (Kharin et al. 2013; Allan et al. 2014) but results vary from region to region (Zhang et al. 2007; Allan et al. 2010). By the end of the century, a decrease in subtropical rainfall in the range of − 3 to − 9%/°C is projected with an increase in the deep tropics in excess of 12%/°C. Midlatitude mean rainfalls are projected to increase in the range of 3 to 9%/°C (Collins et al. 2013).

Increases in daily precipitation extremes show a linear association with a global mean temperature of 5.9 to 7.7%/°C (Westra et al. 2013a), generally matching climate model projections (Collins et al. 2013; Kharin et al. 2013). Similarly, Barbero et al. (2017a) found a sensitivity of historical increases in the intensity of annual maximum precipitation across the USA of 6.9%/°C with global temperature. As a function of Australian land surface temperature, Westra and Sisson (2011) found an increase of 5.6% per degree of warming in 6-min rainfall, and a sensitivity of 9.7%/K for 10-min rainfall was found in Japan (Fujibe 2013). However, in the USA, when local temperatures were matched to historical precipitation increases, the association reduced to 0%/°C (Barbero et al. 2017a).

Past research has focused on either (a) the day-to-day variations in extreme precipitation and temperature (Lenderink and van Meijgaard 2008) which are often fraught with the possibility of statistical artefacts (Wasko and Sharma 2014; Bao et al. 2017; Zhang et al. 2017; Schleiss 2018; Roderick et al. 2019) or (b) the linear association of historical changes in precipitation with global mean temperature change (e.g. Westra et al. 2013a; Barbero et al. 2017a). Global temperatures are not necessarily physically associated with historical changes in precipitation (Barbero et al. 2017a) and there is little physical evidence that day-to-day precipitation-temperature sensitivities are relevant to changes in precipitation on climatic time scales (Zhang et al. 2017). Of the few studies that investigated local historical dependencies of precipitation on temperature, changes of extreme rainfall and dew point temperature have shown strong similarities for both the Netherlands (Lenderink et al. 2011; Lenderink and Attema 2015) and Hong Kong (Lenderink et al. 2011), though not necessarily for all seasons analyzed (Lenderink et al. 2011). Here, we build on these studies by performing a pan-Australian study to investigate whether, on a local scale, historical changes in precipitation follow changes in temperature.

2 Data and methods

Data were obtained from the Australian Bureau of Meteorology climate station network. The daily precipitation data consist of over 17,770 stations, the sub-daily precipitation data 1489 stations, and the temperature data 1830 stations. Analysis was restricted to precipitation records with a minimum of 30 years overlapping daily average dry-bulb and dew point temperature measurements. For daily precipitation, analysis was restricted to sites with less than 10% missing data resulting in 113 stations. This was relaxed to 20% missing for sub-daily precipitation leaving 85 stations across Australia. These restrictions ensure spatial coverage of major climatic zones.

Australia is tropical in the north with summer dominant precipitation. In southern Australia the climate is dominated by cool/temperate climatic conditions and winter dominant precipitation. Inland, Australia is arid with little rainfall. Annual rainfall varies between approximately 1800 mm along the eastern coast to less than 200 mm in the central regions. For reference, the Köppen climate classification is presented in Fig. 2c (Peel et al. 2007).

Historical changes in precipitation and temperature were calculated at annual levels based on calendar years. That is, the mean precipitation, daily maxima, and hourly maxima were calculated on an annual basis and compared with dry-bulb and dew point temperatures averaged across the entire year. As we are aiming to use temperature as an indicator of climatic change, where possible, mean temperature is calculated using the entire record, and not just wet days. The use of an annual temperature will not reflect the conditions of storm development but is able to provide a proxy for the moisture budget. Further, using annual temperatures ensures that any dependencies identified can be related to climate model projections of annual temperature. This is consistent with the presentation of changes in precipitation relative to changes in temperature as per IPCC reporting (Collins et al. 2013). The criteria for including an individual year in the analysis were less than 20% missing data in that calendar year for the annual analysis and less than 20% missing for the target season for the seasonal analysis. The fraction of wet days as a proportion of the duration of interest, that is annual or seasonal, was also calculated. Wet days are defined as those exceeding 1 mm.

3 Results

The mean annual precipitation anomaly with dry-bulb and dew point temperature anomalies is presented in Fig. 1a for Melbourne, located in the temperate south-east of Australia (see Fig. 2c for location). Melbourne was chosen for its exceptionally long temperature record length. Despite this, the dew point record only commences from the mid-1950s (which is typical of most Australian sites). The dry-bulb temperature anomaly oscillates until approximately 1950 when a stark rise in averages temperatures of approximately 2°C is observed. Although the precipitation record also oscillates, it remains centred around zero and does not follow the dry-bulb temperature increase. In contrast, the dew point temperature anomaly closely follows the precipitation anomaly. This observation is supported by the negative correlation (−0.23) between dry-bulb temperature and precipitation, and positive correlation (0.56) between dew point temperature and precipitation. A similar behavior is observed for daily (Fig. 1b) and hourly (Fig. 1c) annual precipitation maxima, at least for limited periods. However, the calculated correlation between dew point temperature and precipitation for daily maxima is less (0.33) and for hourly maxima is near zero (0.03). It appears that annual precipitation extremes have some association with mean annual dew point temperature, but this varies with the temporal aggregation of precipitation considered.

The mean annual precipitation anomaly with dry-bulb and dew point temperature anomalies for Darwin is presented in Fig. 1d. Darwin is in the northern tropics of Australia and has a strongly seasonal climate with summer dominant rainfall. There is no clear correspondence between precipitation and either dry-bulb or dew point temperature. The dry-bulb and dew point temperatures appear to be correlated, but the correlation between the mean precipitation and dry-bulb temperature is weakly negative (−0.12), and for dew point temperature only slightly positive (0.14). Darwin exhibits much weaker evidence for a correlation in the variations of precipitation with either dry-bulb or dew point temperature. Similarly, the annual daily maxima (Fig. 1e) and hourly annual maxima (Fig. 1f) show little correspondence to either dry-bulb or dew point temperature. This is similar in part to results for Hong Kong, where, in the wet season, limited correspondence of precipitation and dew point temperature

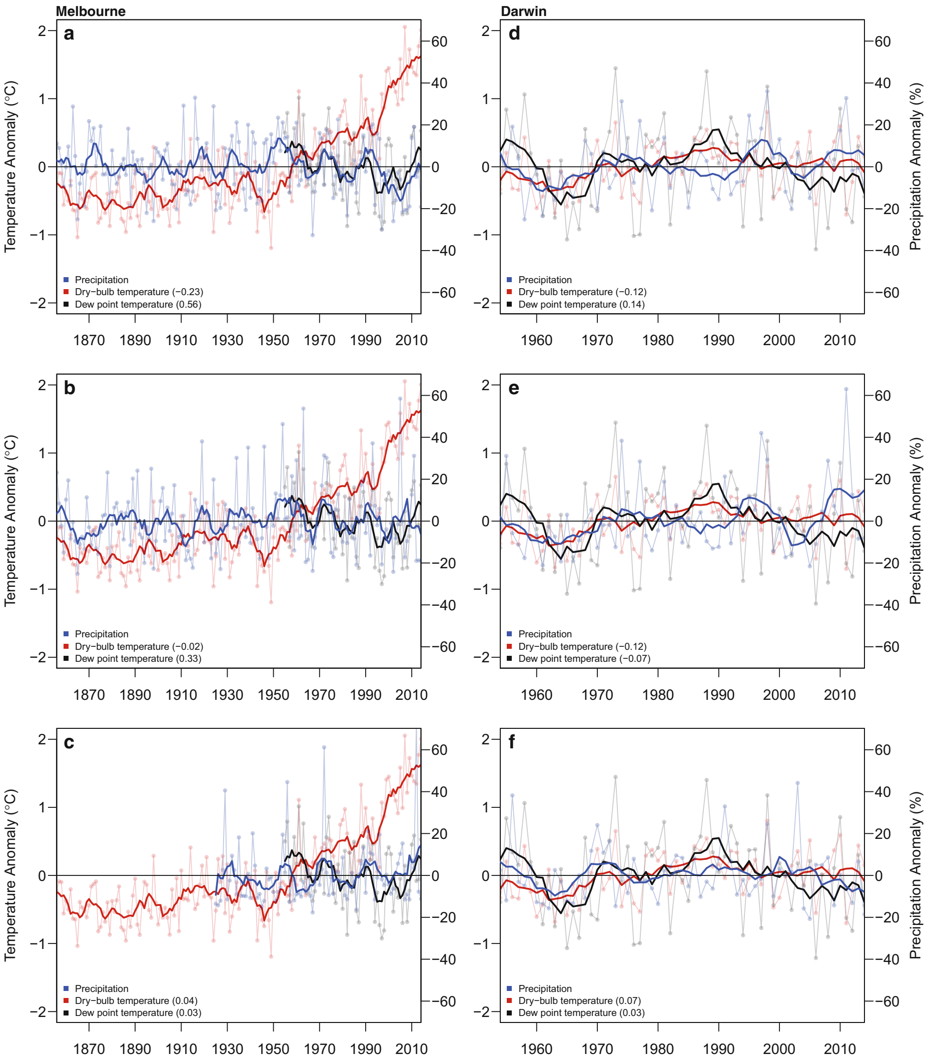

Fig. 1 Historical variations in precipitation and temperature for Melbourne and Darwin. **a** Melbourne mean precipitation. **b** Melbourne annual daily maxima. **c** Melbourne annual hourly maxima. **d**, **e**, **f** Corresponding figures for Darwin. Anomalies are calculated based on the mean of the entire observed record. The precipitation anomaly is standardized on the maximum observed rainfall after subtraction of the mean. Thick lines are a moving average of 7 years. The Pearson correlation of precipitation with temperature calculated on the raw anomalies is presented in brackets in the legend. The location of Melbourne and Darwin is presented in Fig. 2c

anomalies was identified (Lenderink et al. 2011). Although there is evidence for local correspondence in the variations of extreme precipitation and annual mean dew point temperatures for Melbourne, it is not clear if these correlations are universal.

The majority of sites across Australia (97%) show strong positive correlations between mean precipitation and dew point temperature (Fig. 2a). Sites with positive correlations that are statistically significant represent 73% of the sample and none of the sites with negative correlations are statistically significant (Fig. 2a, Fig. 4a). There does not appear to be any

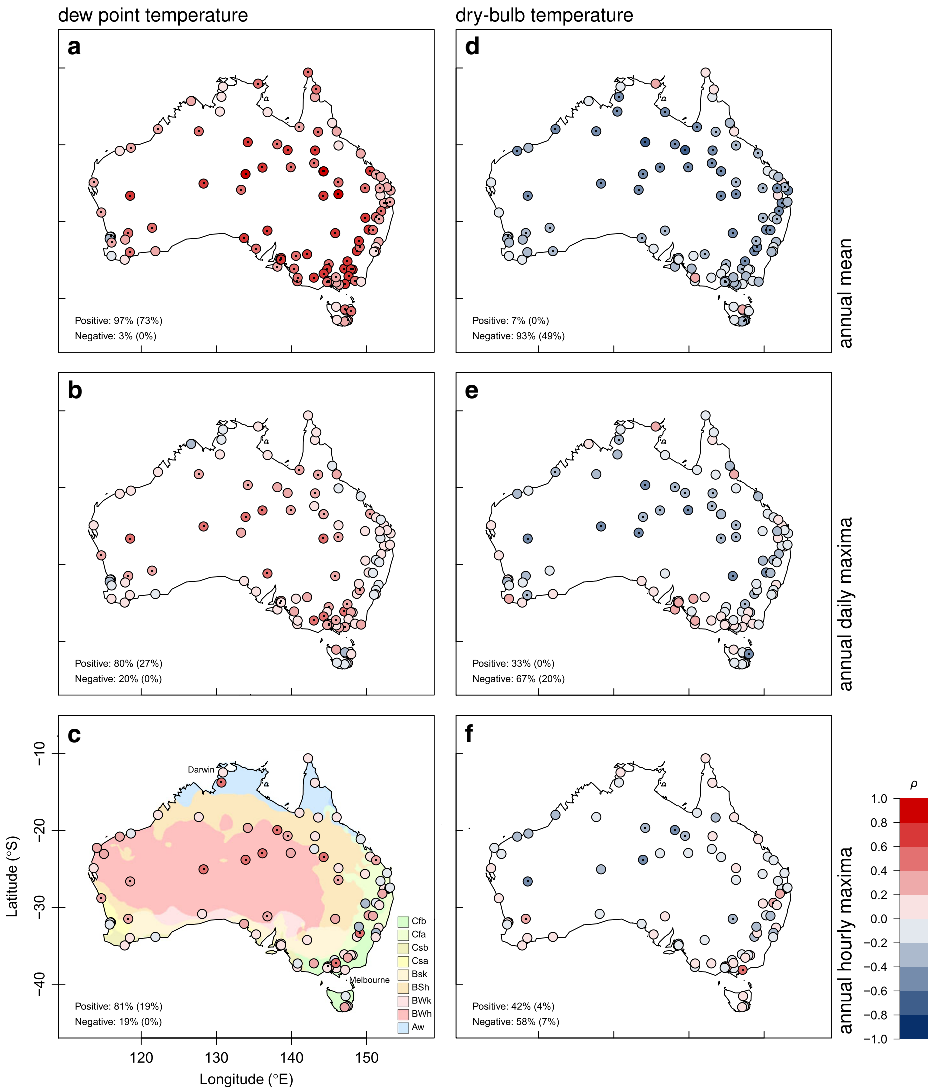

Fig. 2 Correlation (ρ) of annual variations in precipitation and temperature for Australia **a** mean precipitation with dew point temperature, **b** annual daily maxima with dew point temperature, and **c** annual hourly maxima with dew point temperature. **d**, **e**, **f** Corresponding results using dry-bulb temperature. **c** The Köppen climate classification (Peel et al. 2007). Sites that are statistically significant at the 5% level are identified by a black dot. The percentage of sites that are positive and negative is indicated in each panel with the number in brackets presenting the percentage of sites that are statistically significant at the 5% level

differences across climatic regions suggesting that, despite variability, the positive associations are universal. This could be expected by physical reasoning. Dew point temperature by definition is the temperature the air must be cooled (at constant pressure and moisture content) for saturation to occur (Wallace and Hobbs 2006). The less the air must be cooled, the more moisture is in the atmosphere. Hence, a higher temperature is physically associated with greater atmospheric moisture (Lenderink and van Meijgaard 2010) and a greater likelihood of precipitation (assuming a constant climate and no moisture limitations) resulting in a positive statistical association between mean precipitation and mean annual dew point temperature. Likewise, annual daily maxima are positively associated with the mean annual dew point temperature at a majority (80%) of sites (Fig. 2b), although the magnitude of this positive association is now smaller (Fig. 4b), and also a smaller proportion of sites are statistically significant (27%).

It is more difficult to physically link maximum daily precipitation and annual temperature as the precipitation intensity will depend on the climatic conditions at the time of precipitation occurrence. Because of this, the analysis is repeated using the dew point temperature from wet days only (Figure S1b) as per Lenderink and Attema (2015), and using the dew point temperature from the coincident day (Figure S1c). These two measures of temperature are arguably more physically associated with the recorded precipitation. However, there is almost no difference in the association regardless of whether all days or just wet days are used in calculating annual average temperature (Figure S1a-b). Similarly, there is little difference in the associations calculated between annual daily maximum and annual dew point temperature, and when the coincident dew point temperature (that is, the temperature on the day of precipitation occurrence) is used instead (Figure S1a, Figure S1c). But here, the effective time scale investigated is reduced to daily and the usefulness of temperature as an indicator of climatic change becomes less of a focus. As presented in the methods, we wish to see if temperature is an indicator of changes in precipitation in the context of climatic time scales; hence, we continue our analysis using annual average temperature.

Despite the lesser physical link, there is a causal explanation for the positive correlation presented between annual daily maxima and mean annual dew point temperature (Fig. 2b). On average, if a year has high dew point temperatures, more rain days are likely, as evidenced by the very strong positive correlations between the proportion of wet days and the mean annual dew point temperature (Fig. 3a). Hence, there is a greater chance of precipitation and higher maximum precipitation intensity. This statistical association is confirmed by the strong universal correlation between the mean precipitation and annual daily maxima (Figure S2a). A year that has more precipitation is more likely to exhibit greater precipitation extremes. Although the physical link between annual precipitation maxima and mean annual temperature is not as explicit as it is for the mean precipitation, it represents a causality which corresponds to the statistical correlations presented (Lenderink et al. 2011).

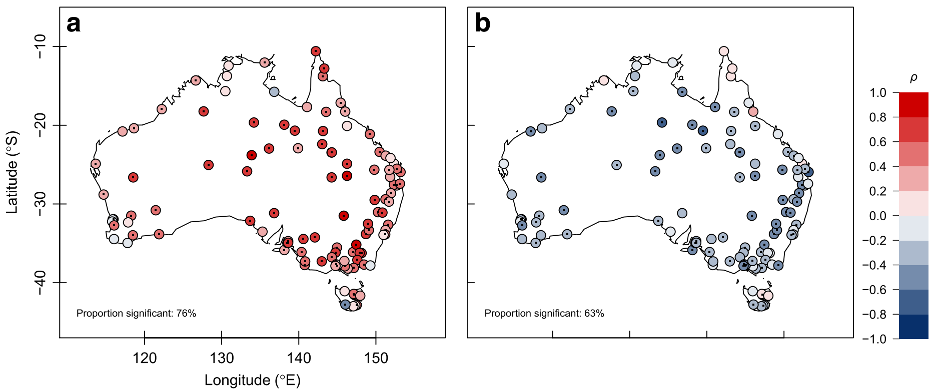

Fig. 3 Correlation (ρ) between the proportion of wet days and mean annual dry-bulb and dew point temperature. **a** Dew point temperature. **b** Dry-bulb temperature. Wet days are defined as days with more than 1 mm of precipitation. Sites that are statistically significant at the 5% level are identified by a black dot. The proportion of sites that are statistically significant is also presented

At the shorter duration of 1 h, the correlation between the extreme precipitation remains (Fig. 2c) but again is less than for daily precipitation (Fig. 2b). Correspondingly, the correlation between mean annual precipitation and annual hourly maxima (Figure S2b) is less than that calculated for mean annual precipitation with daily hourly maxima (Figure S2a). As the extreme precipitation duration decreases the likelihood it is determined by local convective processes increases, lessening the link to moisture availability and annual dew point temperature. For the interested reader, Figure S2c presents the correlation between annual daily maxima and annual hourly maxima which is similar to the correlation between mean precipitation and annual hourly maxima (Figure S2b).

When dry-bulb temperatures are higher, we may also expect greater mean and extreme precipitations, due to increases in the moisture-holding capacity of the atmosphere; however, this is not the case presented here (Fig. 2d–f). Prolonged dry-days, and conditions with less precipitation, are generally associated with drought and higher temperatures, as evidenced by the negative correlation between the number of wet days and mean annual dry-bulb temperature (Fig. 3b). This causality appears to dominate the correlation between mean annual precipitation and dry-bulb temperature resulting in strong negative correlations (Fig. 2d) consistent with studies using seasonal rainfalls (Nicholls et al. 2004; Trenberth and Shea 2005). Even when only wet days are used in calculating annual average temperatures, the correlations remain broadly negative. Similarly, for annual daily (Fig. 2e) and hourly (Fig. 2f) precipitation maxima, the correlation with dry-bulb temperature is generally negative.

The correlations for Australia are quantified annually and for individual seasons in Fig. 4. The correlations with dew point temperature are presented in the left column (Fig. 4a–c) and with dry-bulb temperature in the right column (Fig. 4d–f). Moving from top to bottom, the rows present the correlations for the precipitation daily mean, daily maxima, and hourly maxima. The proportion of statistically significant sites is also presented. There are positive correlations between mean precipitation and dew point temperature (Fig. 4a) regardless of the season. When only statistically significant sites are considered, the correlations are almost exclusively positive. For daily (Fig. 4b) and hourly (Fig. 4c) maxima, the correlations are less on average but remain positive. The correlations between the mean precipitation and dry-bulb temperature are overwhelmingly negative (Fig. 4d). Similarly, for dry-bulb temperature, the association is weaker for daily (Fig. 4e) and hourly (Fig. 4f) maxima. For hourly maxima, there is evidence the correlation is zero (Fig. 4f). The exception is the winter season where the correlation between dry-bulb temperature and all the precipitation statistics is slightly positive, particularly for sites that are statistically significant. However, the number of sites showing statistical significance is very small. Similar correlations with dew point temperature were obtained when only wet days were used, with dry-bulb temperature correlations even weaker than those presented in Fig. 4.

The correlation of mean precipitation, maximum daily precipitation, and maximum hourly precipitation, with dew point temperature, is strongly positive across Australia for all seasons. Therefore, it follows, if variations in historical dew point are similar to dry-bulb variations, historical dependencies may help understand precipitation changes for a future warmer climate. However, the anomaly time series presented for Melbourne (Fig. 1a) gives little evidence for this assertion as the increasing trend dry-bulb temperature was not replicated by the dew point temperature, but for Darwin (Fig. 1d), the two temperature time series appear to be correlated suggesting there may be a basis for informing changes in precipitation based on temperature.

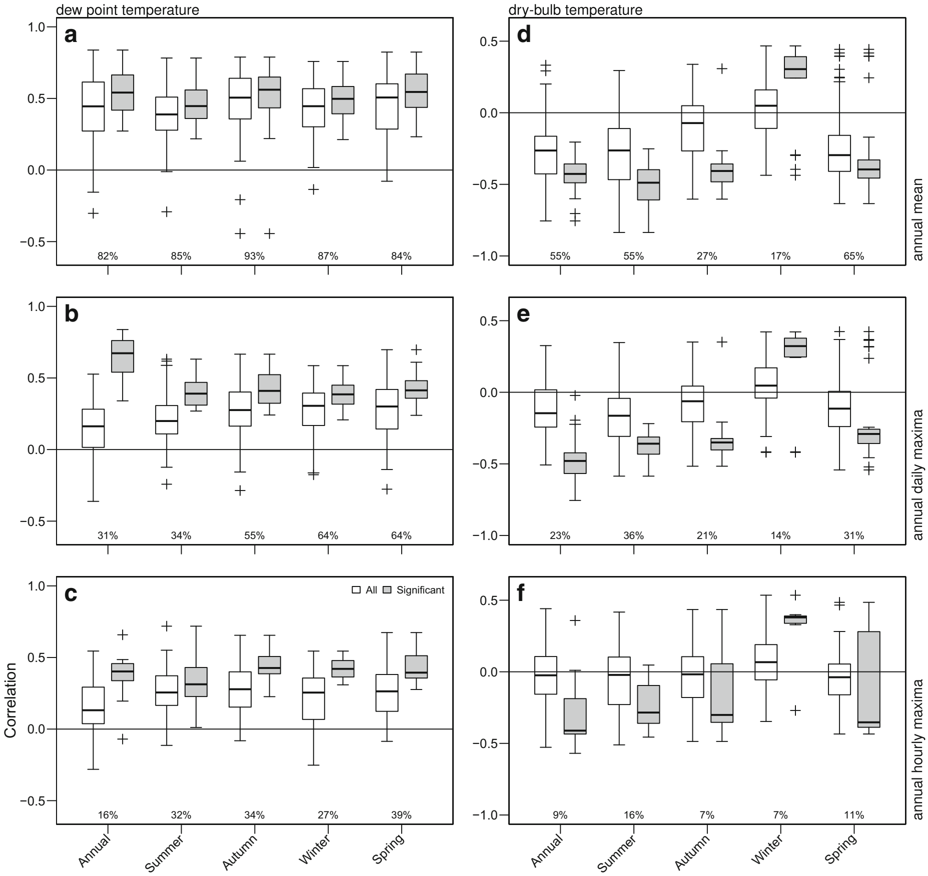

Fig. 4 Correlations of annual variations in precipitation and temperature on an annual and seasonal basis. **a** Mean precipitation with dew point temperature. **b** Annual daily maxima with dew point temperature. **c** Annual hourly maxima with dew point temperature. **d**, **e**, **f** Corresponding results but with dry-bulb temperature. Correlations for all sites are presented in white; correlations that are statistically significant at the 5% level are presented in grey. The proportion of statistically significant sites is presented as a percentage above the horizontal axis

The correlation between mean annual dry-bulb and dew point temperature for all days (Fig. 5a) and wet days only (Fig. 5b) is presented across Australia. There is a positive association between the dry-bulb and dew point temperature for coastal regions which in general have greater annual precipitation and a greater number of rain days. In comparison, arid regions inland experience less precipitation and exhibit a negative association between annual average dry-bulb and dew point temperature. This means that, in arid regions, where moisture is limited, as the dry-bulb temperature increases, the relative humidity decreases and the dew point temperature decreases also. But in coastal regions, an increase in dry-bulb temperature is also associated, on average, with an increase in moisture through evaporative processes and hence an increase in dew point temperature.

When wet days are considered, it can be assumed that the environment is not moisture limited. As a result, there is a strong positive association at almost all locations between dry-bulb temperature and dew point temperature. When there is a higher climatic dry-bulb

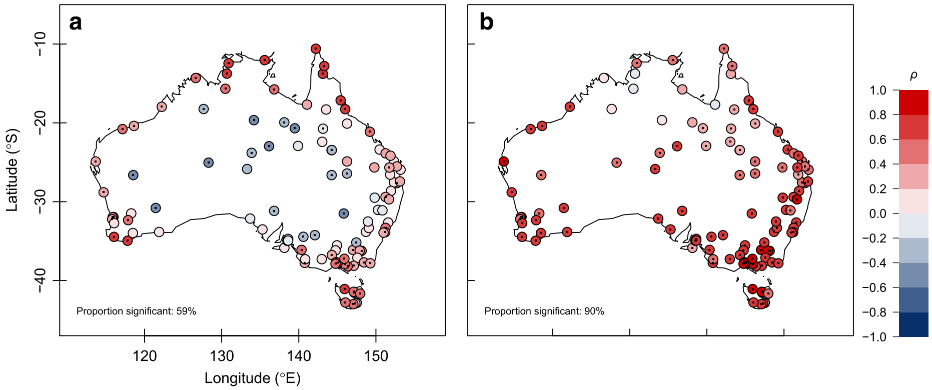

Fig. 5 Correlation (ρ) between annual temperature means. **a** Dry-bulb and dew point temperature. **b** Dry-bulb and dew point temperature using wet days only. Wet days are defined as days with more than 1 mm of precipitation. Sites that are statistically significant at the 5% level are identified by a black dot. The proportion of sites that are statistically significant is also presented

temperature, the dew point temperature (and moisture) is also higher. It is interesting to note that there are still some regions where the association between dry-bulb and dew point temperature on wet days is not positive. This region in the north of Australia almost exactly corresponds to the regions which are most limited in moisture availability (Wasko et al. 2015). It is expected, through the Clausius-Clapeyron relationship, that on average, a higher temperature will be physically associated with greater atmospheric moisture (Lenderink and van Meijgaard 2010; Lenderink et al. 2011). The results presented here support this assertion; on wet days, where a region is not moisture limited, the average dry-bulb temperature is positively associated with the dew point temperature on an annual (climatic) scale.

4 Discussion

Convective permitting models generally simulate increases in precipitation extremes at a rate of 7%/°C similar in magnitude to increases in surface water vapor (Muller et al. 2011; Chan et al. 2016). However, the rate of increase in precipitation extremes depends markedly on the model parametrization and grid scale (Kendon et al. 2014; Singh and O'Gorman 2014; Li et al. 2018). For example, in Australia, the projected ensemble mean increases of 9%/°C exceed increases in near-surface vapor (Bao et al. 2017). Small-scale simulations have found sensitivities of precipitation increase closer to 1.5 times the CC relationship (Singleton and Toumi 2013; Loriaux et al. 2013) and up to 2 times the CC relationship (Ban et al. 2014). With the complexity in understanding and modelling changes to precipitation in a future climate, particularly for short-duration extremes, there is an argument presented in the literature to instead use local historical precipitation-temperature dependencies to project changes to precipitation (Lenderink and Attema 2015; Hettiarachchi et al. 2018; Manola et al. 2018).

The aim of such approaches is to exploit the higher confidence in temperature predictions from climate models, while synthesizing local historical knowledge (Johnson and Sharma

2009; Westra et al. 2014; Zhang et al. 2017). This has been proposed in various forms, for example, using historical dew point scaling relationships in conjunction with predictions from regional climate models (Lenderink and Attema 2015), conditioning stochastic rainfall simulation on historical temperatures (Wasko and Sharma 2017), or disaggregation using observed temperatures among other climatic variables (Westra et al. 2013b). Temperature has also been proposed as a covariate for non-stationary design precipitation intensities (Agilan and Umamahesh 2017; Ali and Mishra 2017). However, if such approaches are to be valid, at the very least, historical precipitation fluctuations should match historical temperature fluctuations.

Across Australia, mean precipitation is increasing in the tropics and decreasing in the subtropics (Head et al. 2014; CSIRO and BOM 2016). Despite large spatial variability, rainfall extremes, such as daily annual maxima, show reasonably uniform increases across Australia, but few sites show statistical significance (Alexander and Arblaster 2017; Jakob and Walland 2016). Hourly precipitation extremes show some robust increasing trends (Guerreiro et al. 2018; Westra and Sisson 2011) with stronger trends in summer months compared with winter months (Zheng et al 2015). Since 1951, mean temperatures have increased at a rate of 0.1–0.2 °C per decade over most of Australia (Hughes 2003; Head et al. 2014), consistent with increases in global averages (Hartmann et al. 2013). This is also consistent with the annual trend across Australia in dew point temperatures of 0.12 °C per decade over a similar period (Lucas 2010). However, there is large spatial variability in dew point temperature trends (Lucas 2010).

We have exclusively investigated annual variations in precipitation with temperature as evidence for using temperature as an indicator of climatic change. We presented that, on average, precipitation extremes exhibit a positive association with annual average dew point temperature, and on wet days, the variation in annual dry-bulb and dew point temperature is

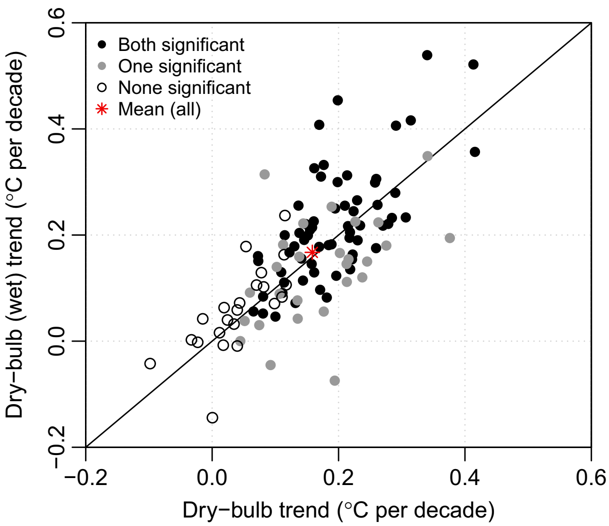

Fig. 6 Linear temperature trend for annual average dry-bulb temperature using all days, and wet days only. Each dot represents the trend at a single station. Statistical significance is tested on whether the slope of the linear regression line at the site is significantly different from zero. Wet days are defined as days with more than 1 mm of precipitation

closely linked. To complement this discussion, we regress the annual mean dry-bulb temperature for all days and for wet days and compare the historical trends (Fig. 6). There is a significant variability in temperature trends with a range approximately 0–0.5 °C per decade. However, the mean trend is approximately 0.2 °C per decade. This rate of increase is at the upper end of predictions and corresponds to an accelerating rate of increase in temperatures (Hartmann et al. 2013). There is evidence, that on a site-by-site basis, trends in annual average dry-bulb temperature match trends using wet days only. But the evidence is more compelling that the mean across all sites analyzed is similar. This is consistent with Lenderink and Attema (2015) who found that on regional and global scales, changes in temperature are similar regardless of the type of temperature metric used.

5 Conclusions

There would be little need for projecting precipitation based on temperature associations if precipitation trends were easy to identify or model (Groisman et al. 2005; Westra et al. 2013b; Westra and Sisson 2011; Zhang et al. 2017). Due to the large variability in observed trends and simulated projections (Singh and O'Gorman 2014; Zhang et al. 2017), a proposed alternative is to judiciously use observed precipitation-temperature sensitivities to help inform how precipitation extremes might change in a future warmer climate (Lenderink and Attema 2015). On global scales, the change in dew point temperature is closely related to the change in global mean temperature (Lenderink and Attema 2015). Here we presented evidence at a local level that variations in dew point temperatures are related to dry-bulb temperatures at the annual time scale, particularly for wet days, the days that are most of interest for extreme precipitation. However, the relationships were not as robust as those on the regional scale and depend on local moisture availability. Despite very poor relationships between precipitation and annual average dry-bulb temperatures, correlations exist between both mean and extreme precipitation and annual average dew point temperature at most sites across Australia. This corroborates previous studies which found associations between precipitation increases and regional or global temperatures (Westra and Sisson 2011; Westra et al. 2013a; Fujibe 2013; Barbero et al. 2017a). However, the results at the local level are not as robust and exhibit significant variability from site to site supporting the assertion that local temperature changes show limited association with increases in precipitation extremes (Barbero et al. 2017a).

Although the results presented here may provide evidence in support of the use of precipitation-temperature relationships for projecting future changes in mean and extreme precipitation, such relationships must be used judiciously. Studies investigating precipitation-temperature relationships may aid the understanding of changing precipitation extremes in a future warmer climate (Boucher et al. 2013) but should not be used as the sole indicator of changes in precipitation (Lenderink and Attema 2015). Rather, studies such as this one help inform the debate of how precipitation extremes may change in the future.

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Data availability Data used in this study can be obtained from the Australian Bureau of Meteorology from http://ww.bom.gov.au/climate/data/stations/.

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