The relationship between the subtropical ridge and Australian temperatures

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The intensity and latitude of the subtropical ridge over eastern Australia is strongly associated with southeast Australian rainfall, particularly during the cool months of the year. We show that the subtropical ridge also exerts a strong influence on temperatures across much of Australia, with warmer daytime temperatures and more warm extremes across southern Australia when the subtropical ridge is stronger than average, which is largely independent of the relationship between the subtropical ridge and rainfall. A strong subtropical ridge is also linked to warmer than average minimum temperatures over southern Australia throughout much of the year, except from May to August when a strong ridge is associated with cooler mean minimum temperatures and an increased frequency of cool nights. This relationship, and the observed strengthening of the subtropical ridge during autumn and winter in recent decades, can partially explain the weaker warming trends in minimum temperatures in southeast Australia compared to elsewhere in the country over the period 1960–2016.

1 Introduction

The subtropical ridge (STR) is a ridge of high pressure systems in the global midlatitudes that is the surface representation of the descending branch of the Hadley Cell (Chen et al. 2014; Nguyen et al. 2013). The seasonal progression of the latitude of the STR, from its most poleward locations during the summer months to more equatorward positions during the winter, plays an important part in seasonal rainfall patterns throughout the midlatitudes. In Australia, the more northward position of the ridge during the winter months allows rain-bearing cold fronts and low-pressure systems to deliver winter rains to southern Australia (Drosdowsky 2005).

Both the intensity and latitude of the STR vary interannually, with these variations strongly linked to rainfall variability in southeast Australia (Drosdowsky 2005; Timbal and Drosdowsky 2013; Ashcroft, Karoly and Gergis 2014; Maher and Sherwood 2014), as well as broader circulation anomalies (Pittock 1973). During June 2017, the STR was both much stronger and further south than typical for winter, contributing to record-low rainfall totals in southern Australia (Australian Bureau of Meteorology 2017).

In addition to record-low rainfall totals, the anomalously strong STR during June 2017 was associated with above-average daytime maximum temperatures and well below-average overnight minimum temperatures across much of southeastern Australia. Compared to the well-established links between STR and rainfall, there is less understanding of how the STR influences Australian temperature patterns, although a relationship between frost days and the STR has been previously identified for southern Australia (Crimp et al. 2016; Crimp, Nicholls, et al. 2018).

An increase in intensity of the STR in recent decades has been associated with decreases in southeast Australian rainfall (Timbal and Drosdowsky 2013), and has been proposed as a driver in the observed increase in frost days in parts of this region (Dittus et al. 2015; Crimp et al. 2016). The observed increase in frost days in the southeast has occurred despite the overall annual trend towards warmer minimum temperatures and a decrease in cold extremes on a national scale (Alexander...
and Arblaster 2017). Expansion of the Hadley Cell and associated poleward movement of the STR has also been linked to drying in Australia’s southeast (Cai, Cowan and Thatcher 2012; Nguyen et al. 2015).

This paper presents a detailed assessment of the relationship between the STR and Australian temperatures during the period 1910-2016, and the role of the subtropical ridge in long-term temperature trends. It builds on recent work by Crimp et al. (2018b) which focused on minimum temperature variability across Australia since 1960 using the Scientific Information for Land Owners (SILO) gridded temperature product, and a reanalysis-derived index of the STR. Instead, we employ homogenised temperature datasets to minimise the effect of non-climatic changes on results (Trewin 2013; Ashcroft, Karoly and Gergis 2012) and subtropical ridge data calculated directly from Bureau of Meteorology pressure observations, allowing results to cover more than 100 years of records.

Section 2 describes the datasets used. Section 3 presents the relationships between the intensity and position of the STR and mean maximum and minimum temperatures across Australia, and the extent to which these relationships can be attributed to the link between STR and rainfall. Section 4 delves further into this relationship by examining the link between extreme temperature indices and STR variability. Finally, Section 5 focuses on the months May to August when a strong subtropical ridge is associated with cool overnight temperatures and assesses the role of the increasing intensity of the STR on recent trends in minimum temperatures over southeast Australia in this season.

2 Data

Daily maximum and minimum temperature (9am to 9am) between 1910 and 2017 are sourced from version 2 (v2) of the Australian Climate Observations Reference Network – Surface Air Temperature (ACORN-SAT) dataset (Trewin 2018). This dataset contains homogenised daily temperature data from 112 locations across Australia and can be used for assessment of long-term changes in climate and temperature extremes. The analysis was also conducted using version 1 of ACORN-SAT, with very similar results, although improvements in v2 resulted in slightly stronger warming trends across southeast Australia. Monthly gridded temperature anomalies relative to 1961–1990 are also obtained from ACORN-SATv2 at a 0.25° resolution across Australia, while monthly rainfall between 1900 and 2017 on a 0.25° resolution grid is derived from the Australian Water Availability Project (AWAP; Jones et al. 2009). Numbers of cold nights (TN10) and warm days (TX90) are calculated from the monthly 10th and 90th percentiles for the full period of record at each station, consistent with recommendations from the WMO Expert Team on Climate Change Detection and Indices (Zhang et al. 2011), with nights below 2°C also used as an indicator of frost, consistent with previous studies such as Crimp et al. (2018b).

The intensity (STRI) and position (STRP) of the STR over eastern Australia are calculated from Bureau of Meteorology monthly mean sea level pressure (MSLP) station data following the method of Drosdowsky (2005) and Timbal and Drosdowsky (2013) and are available from 1890. This is calculated over a single longitude band representing eastern Australia (145-150°E) for consistency with previous studies on rainfall relationships, rather than using a longitudinally-varying approach such as taken by Crimp et al. (2018b). Following the convention of Timbal and Drosdowsky (2013), "positive" STRP in this dataset refers to a more poleward (southward) position of the STR. Figure 1 shows the updated seasonal mean STR indices between 1890 and 2017.

![Figure 1](image-url)  
Figure 1  Seasonal mean STR position (left) and intensity (right) calculated as per Timbal and Drosdowsky (2013) for 1890–2017. Pale lines show the raw data, and dark lines show 21-year centred running means.
Across eastern Australia, the correlations between our eastern Australian STR and a longitudinally-varying version calculated using the same approach from the NCEP-NCAR reanalysis are greater than 0.6 in all months for longitudes between 135 and 155°E. Correlations are above 0.8 during the winter months, with weaker but still significant correlations for STRP (r>0.4, >0.7 in winter months). Consequently, using a single STRI/STRP index is expected to be broadly representative of conditions across eastern Australia. The STR data and data from ACORN-SAT v2 are used in conjunction with homogenised historical temperature and atmospheric pressure observations for southeastern Australia (Ashcroft, Karoly and Gergis 2012, 2014) in section 4 to examine trends in temperature and the STR from 1885 to present. The atmospheric pressure data from Ashcroft et al. (2014) is highly correlated with STR, particularly in the winter months (r =0.91 for May–August average), so was deemed suitable as a historical representation of STR.

Correlations are performed using Spearman's ranked approach and assessed for statistical significance at p<0.05 after using the false discovery rate to correct the effects of simultaneous multiple test results that can occur when applying statistical tests over gridded spatial data (Wilks 2016). Partial correlations are performed between the residuals after linear regression against the confounding variable, while multiple linear regressions are used to identify long-term trends with the influence of a variable removed. In all cases, seasons refer to the austral meteorological seasons of summer (December-February; DJF), autumn (March-May; MAM), winter (June-August; JJA) and spring (September-November; SON).

Composite figures are created for each season by identifying months within that season where the monthly STRI or STRP is above the historical 90th percentile (or below the 10th percentile) for that month, and then calculating the mean monthly anomaly (compared to a standard 1961-1990 average). Statistical significance is assessed using a t-test against an anomaly of 0 (i.e. the 1961-1990 average), with results only shown where there are at least five months over which to composite averages. Composites were also calculated for months above the 75th or below the 25th percentile of STRI/STRP and showed similar but weaker spatial patterns. In all cases, a positive STRI refers to a stronger (higher) maximum MSLP than normal, while a positive STRP refers to the position being anomalously southward (higher latitude), consistent with Drosdowsky (2005); in the case of STRP this is the inverse of the definitions used in Crimp et al. (2018b).

### 3 Impact of STR position and intensity on Australian temperature

Both the intensity and position of the STR are strongly associated with Australian temperatures throughout the year (Figure 2). A stronger STR is associated with warmer maximum temperatures in southern Australia during all seasons, with the region of strongest correlations extending into central Australia during the cool months when the ridge is located towards the equator. This pattern is restricted to southern coastal regions during summer when the average latitude of the STR is closest to the poles (38°S). Similarly, a poleward (positive) STRP is associated with warmer maximum temperatures across southern Australia in all seasons except summer. In contrast to southern Australia, maximum temperatures in parts of northern Australia are negatively correlated with both STRI and STRP, particularly in eastern Queensland during spring and summer.

The relationship between the subtropical ridge and minimum temperatures is more complex. There are strong positive correlations between both the intensity and position of the subtropical ridge and minimum temperatures across most of southern Australia during spring and summer, as well as in southwestern Australia and parts of eastern Australia during the autumn. In contrast, during winter there are strong negative correlations between both STRI and STRP and minimum temperatures throughout a large region extending between northwest and southeast Australia (Figure 2j,n). Monthly correlations between STRI and average minimum temperatures across southeastern Australia (Table 1) reveal statistically significant negative correlations for every month between May and August (and significant positive correlations between October and March). The relationship between the STR and minimum temperatures in northwest Australia is not the focus of this paper, although it is worth noting that Trewin et al. (2015) found that winters with large numbers of cool nights in northwest Australia typically had a strong STR in Australian longitudes.

Both maximum and minimum temperatures tend to be associated with rainfall, as cloudy and rainy conditions are associated with decreased shortwave radiation and thus cooler daytime temperatures. In contrast, rainy periods tend to be associated with warmer than average overnight temperatures, particularly in southern Australia (Hope and Watterson 2018). However, partial correlations between the STR and both maximum and minimum temperatures with the co-relationships with rainfall removed remain similar in magnitude to those calculated directly (Figure 3). A notable exception is for minimum temperatures in parts of southeast Australia during autumn and winter, where the association between a strong subtropical ridge and below-average rainfall explains a large proportion of the relationship with cool overnight minima.
Figure 2  Spatial correlations between Australian temperatures in ACORN-SATv2 and the subtropical ridge for four seasons between 1900 and 2016: (a-d) Maximum temperature (Tx) and STR intensity (STRI); (e-h) Maximum temperature and STR position (STRP); (i-l) Minimum temperature (Tn) and STR intensity; and (m-p) Minimum temperature and STR position. Solid lines indicate statistically significant correlations for \( p<0.05 \) after correcting for the false discovery rate. A grey dashed line indicates the seasonal mean position of the STR.

3.1 Co-impact of STR intensity and position on Australian temperatures

In most months, the intensity and position of the STR are significantly correlated, with correlations greater than 0.6 between July and November, although correlations drop below 0.2 between January and March (Timbal and Drosdowsky 2013). Consequently, extremes of STRI and STRP tend to coincide in most seasons, except for some instances of weak but poleward STRs during summer (Figure S3).

The combination of a strong and poleward STR, or weak and equatorward, tends to enhance the impacts on maximum temperatures during most seasons, although the STRI has a strong influence on temperatures regardless of the position of
the subtropical ridge. During spring for example, large parts of southern Australia have average maximum temperatures as much as 2°C above average in months when both STRI and STRP are above the 90th percentile (Figure 4).

In most seasons, the relationship between STRI and minimum temperatures is stronger than for STRP, and STRP plays only a small role in anomaly patterns. Notably, during the summer months (December-February) a weak STR is associated with cooler mean minimum temperatures across southern Australia in years where the STR is anomalously equatorward as well as when it is anomalously poleward (Figure S6). The exception is autumn, where parts of southern and eastern Australia see very different temperature patterns associated with extremes of STRI depending on the position of the subtropical ridge (Figure 5).

4 The relationship between the STR and temperature extremes

While several studies have investigated variability in temperature extremes and heatwaves in Australia (Perkins, Argüeso and White 2015; Min, Cai and Whetton 2013), relationships between heat extremes and the subtropical ridge have not previously been investigated, although the related subtropical ridge high has been associated with weekly temperature extremes in most seasons in southeast Australia (Marshall et al. 2013). Figure 6 shows the correlations between the STR and seasonal numbers of hot days (above the monthly 90th percentile) and cold nights (minimum temperature below the monthly 10th percentile) across Australia. Nation-wide, the correlation patterns generally replicate those observed for mean maximum and minimum temperatures, with a positive STRI associated with an increased number of hot days in southern Australia, particularly during the spring months (Figure 6c), but fewer warm days on parts of the northeast coast.

A strong STRI is also associated with a decrease in the number of cool days across southern Australia, with the spatial area of influence extending further northward than observed for hot days (Figure S7). In contrast, in parts of eastern Australia a strong STRI is associated with fewer hot days and more cool days during spring and summer. In northern Australia there is little relationship between a strong STR and the number of cool days, despite the decrease in hot days when the STR is strong, indicating the STR has varying effects on different parts of the temperature distribution. The position of the STR also has a stronger influence on the numbers of cool days in southern Australia than it does on hot days, particularly in the autumn.

As observed for mean temperatures, the influence of the STRI on these patterns is typically stronger than the STRP, with similar spatial patterns of changes in extreme frequency associated with strong (or weak) STRI regardless of the position of the STR, and little change in extreme temperatures associated with STRP during months where the intensity is close to normal (not shown). The exception is during the spring and (to a lesser extent) summer, where a southward STR is associated with an increased frequency of hot days across most of northeast Australia when the intensity of the STR is close to normal, consistent with Figure 4. In contrast, there is little change to the frequency of cool days during these months.

Table 1 Monthly correlations between temperature and rainfall averaged over southeast Australia (135-155°E, 32.5-40°S) and monthly STRI, 1910-2016. Bold text indicates correlations that are statistically significant for p<0.05

<table>
<thead>
<tr>
<th>Month</th>
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A strong or southward STR is also associated with a decrease in the frequency of cool nights across large areas of eastern Australia during autumn and spring, particularly on the east coast (Figure 6l,m,k,o). Correlations between STRP and the frequency of cool nights in autumn in particular are stronger than observed for mean minimum temperatures (Figure 2). The mean pattern thus reflects the varying impacts of STRP throughout the temperature distribution, with a relatively weak effect of the STRP on the number of warm autumn nights (Figure S7).

Similarly, during the winter months there is a strong association between a strong or southward STR and an increased frequency of cold nights (Figure 6j,n) but little change in the number of warm nights (Figure S7j,n). The increased frequency of cool winter nights is particularly strong in months where the STR is both strong and anomalously southward (not shown). In contrast, the strength and intensity of the subtropical ridge during spring and summer are more strongly associated with warm nights than they are cold (Figures 5/S7k,o), with a decrease in the number of warm nights across large areas of southern Australia when the STR is weak, regardless of its position (not shown).
Figure 4  Maximum temperature composites (anomaly relative to 1961-1990 average in °C) for combinations of monthly STRI and STRP above the 90th or below the 10th percentile of all years (1910-2016), combined across the three spring months September-November. Solid lines show where anomalies are significantly different to zero using a t test for p<0.05. For other seasons see supplementary figures S1-3.

5 Relationship between STRI and changes in cool winter nights in southeastern Australia

There has been little change in the average position of the subtropical ridge between 1890 and 2017 (Figure 1a), with a marginally significant southward trend of 0.15 degrees/decade during spring (p=0.048). In contrast, there have been statistically significant increases in the average STRI during all seasons except summer (Figure 1b), with the largest increase of 0.19 hPa/decade observed during winter (p<0.0001). This intensification of the subtropical ridge has been previously associated with cool season drying trends by Timbal and Drosdowsky (2013). The combination of a strengthening STRI and negative correlations between STRI and winter minimum temperatures (Figure 1j,n) provides a potential explanation for what can be considered a paradoxical increase in cold winter nights, despite a large-scale warming trend (Crimp, Jin, et al. 2018).
Figure 5  Minimum temperature composites (anomaly relative to 1961-1990 average in °C) for combinations of monthly STRI and STRP above the 90th or below the 10th percentile of all years (1910-2016), combined across the three autumn months March-May. Solid lines show where anomalies are significantly different to zero using a t test for p<0.05. For other seasons see supplementary figures S4-S6.

May to August is the period where the relationship between southeastern Australian rainfall and the subtropical ridge is strongest (Figure 7a, Table 1), while May to July are the only months where the correlation between mean southeastern Australian rain and Tn is greater than 0.4 (Table 1). The negative correlations between minimum temperatures and STR in southeast Australia (Figure 7b) can thus largely be explained by the association between the subtropical ridge and rainfall (Figure 7c).

The relationship between STRI and minimum temperatures in southeast Australia is particularly evident for cool extremes. Figure 8a shows the composite minimum temperature anomaly (compared to 1961-1990) for months between May and August where STRI is in the strongest 10% of months. In these months, the average minimum temperature is as much as 1°C below average in parts of southeast Australia, with large areas more than 0.5°C below average. This is associated with a statistically significant increase in the frequency of very cold nights (below the 10th percentile) at 13 stations in southeast Australia (Figure 8c), with a median increase of 1.1 nights/month (~35%) but up to 4 additional cold nights at Rutherglen. At 18 stations there is a statistically significant increase in the number of frost nights (Figure 8b), defined by minimum temperatures of 2°C or below, with a median 2.9 extra frost nights per month when the STR is strong.
Figure 6 Correlations between the subtropical ridge and Australian hot and cold temperature extremes from ACORN-SAT station temperature data for four seasons between 1900 and 2016: (a-d) Number of days with maximum temperature above the monthly 90th percentile (Tx90) and STR intensity (STRI); (e-h) Number of days with maximum temperature above the monthly 90th percentile (Tx90) and STR position (STRP); (i-l) Number of days with minimum temperature below the monthly 10th percentile (Tn10) and STR intensity; and (m-p) Number of days with minimum temperature below the monthly 10th percentile (Tn10). Solid triangles indicate where the correlation is statistically significant for $p<0.05$. Upward pointing triangles indicate positive correlations and downward-pointing triangles indicate negative correlations, with the colour scale varying such that red indicates warmer conditions for positive STR.

In contrast to warming minimum temperatures across most of eastern Australia since mid-century, trends have been weak in parts of the southeast during May to August (Figure 9a) (Alexander and Arblaster 2017). This area of weak warming can be largely explained by the intensification of the subtropical ridge during this period (Figure 9b), which has greater explanatory power than the concurrent decreasing trend in rainfall (Figure 9c). However, rainfall declines are a better explanation of the weak trends in southwestern Western Australia, where there is little relationship between minimum temperatures and the STRI index calculated for eastern Australia.
Figure 7  Spatial correlations between STR intensity in May-August, 1910-2016 with a) AWAP rainfall and b) ACORN-SATv2.6 minimum temperatures, and c) Partial correlation between minimum temperature and STRI after accounting for the rainfall relationship. Solid lines indicate statistically significant correlations for p<0.05 after correcting for the false discovery rate.

Figure 8  a) Minimum temperature anomaly (°C), b) Frost night anomaly (nights <=2°C) and cold night anomaly (number of nights below the 10th percentile) for months between May-August, 1910-2016 when the subtropical ridge is in the strongest 10% of values for that month.

Figure 9  a) Linear trend in May-August mean minimum temperature from ACORN-SAT between 1960 and 2016 (°C/decade), and the trends from multiple linear regressions incorporating b) STRI and c) rainfall. Solid lines indicate where the trend is statistically significant for p<0.05.
Figure 10 shows an extended timeseries of mean minimum temperatures across southeastern Australian stations (see Table S1) for May to August between 1885 and 2016, using stations with historical and modern data in the region displaying the strongest relationship between Tn and STRI. There has been a long-term increase in minimum temperatures over the past century, but the rate of increase has slowed somewhat in recent decades, consistent with Figure 9a and Dittus et al. (2015). As was shown in Figure 9b, when the relationship with the coincident increase in regional pressure is removed, the observed increase in mean minimum temperatures during recent decades is stronger.

Removing the covariability with STRI also results in warmer Tn anomalies for the early to mid-20th Century. Timbal and Drosdowsky (2013) identified strong STRI values during this period, particularly during austral winter, supporting the argument that more intense STR values are associated with cooler Tn across southeastern Australia. Interestingly, the early to mid-20th century response in Tn is not seen if we use the homogenised pressure dataset as a representation of STRI instead. This could reflect some inconsistencies in the pressure network used to develop the STRI index, as all available stations in southeastern Australia are used to calculate the index regardless of length or quality (Timbal and Drosdowsky 2013). It may also indicate that the homogenisation approach of Ashcroft et al. (2014) could have inadvertently removed some of the genuine pressure variability in this period. However, results using either the homogenised MSLP dataset or the STRI are very consistent for the period 1960-2016, which is the period used for trend analysis in this paper.

The behaviour of extreme minimum temperatures in the cooler months (Figure 11a) broadly parallels that of means (Figure 9a). Whilst the number of May–August days with minimum temperatures below the 10th percentile has decreased significantly over much of Australia, particularly the eastern half, over the 1960-2016 period, there is an area in inland southeast Australia, focused on northern Victoria and southern inland New South Wales, where trends over this period have been generally near zero. This area of weak trends is less pronounced, although still apparent to some extent, when the effect of STRI is removed (Figure 11b). As observed for mean minimum temperatures, accounting for the influence of changes in AWAP rainfall at the co-located grid point also partially explains these weaker trends (Figure 11c), but to a lesser extent than accounting for the intensifying STRI (Figure 11b).
Figures 9a and 11a show that trends in extreme cold minima during May-August are broadly similar to trends in mean minimum temperatures, and do not support the hypothesis of an accelerated cooling in extreme cold nights. This can also be observed when assessing trends in the temperature of the coldest night of the year (TNn) across 13 ACORN-SAT stations in inland southeast Australia (not shown). At some stations these trends differed from trends in the mean, such as at Mildura where TNn has had no trend over the 1960-2016 period, whilst mean June-August minima have warmed at a rate of 0.11 °C per decade, but the lack of a spatially coherent signal may indicate that those individual locations are influenced by local factors such as changes in land use.

6 Discussion and conclusions

This paper has demonstrated, for the first time, the strong relationships between average maximum temperatures across southern Australia and the intensity of the subtropical ridge throughout the year. We also identified a clear seasonality in relationships between the subtropical ridge and minima in southeast Australia, with strong negative correlations during the months May to August, extending into northwestern Australia, but positive correlations in spring and summer. Relationships between STRP and temperatures were similar to those for STRI, particularly in the cool season where there is a high correlation between these indices. These relationships are largely independent of the relationships between STR and Australian rainfall, so may be associated with the effect of changes in the STR on Australian pressure and wind patterns, as well as the frequency of high pressure systems (Pepler, Dowdy and Hope 2018). The exception is parts of southeast Australia, where negative correlations between STRI and minimum temperatures during winter are largely the result of the relationship between STR and rainfall.

These spatial patterns are different to those presented in Crimp et al. (2018b), who presented no significant relationships between STRI and minimum temperatures across most of Australia in most seasons between 1960 and 2015, and significant negative correlations in southeast Australia during March-May between 1985 and 2015. One reason for this could be that we use a single definition of the STR for the whole country based on BoM data, rather than using a variable 'local STR' definition that is derived from the NCEP reanalysis as done in Crimp et al. (2018b) However, the correlations between STR values using the NCEP reanalysis and using BoM data are high over eastern Australia, and up to +0.98 for STR intensity and +0.83 for STR position at 150°E, so this is unlikely. Our correlation patterns are also very similar between all years 1910-2016 and the reduced period 1960-2015 used in Crimp et al. (2018b), so the different periods are unlikely to be a factor.

Data homogeneity is another potential explanation. Crimp et al. (2018b) used the unhomogenised SILO data set (Jeffrey et al. 2001), whereas this study (and Dittus et al. 2015) use the homogenised ACORN-SAT data set (Trewin 2013, 2018). Whilst post-1960 differences in minimum temperatures between un-homogenised and homogenised data sets are small at the national scale (Fawcett et al. 2012), in inland southeastern Australia they are substantial, largely because a substantial number of sites in the region moved from towns to (generally cooler) out-of-town locations during the 1990s and early 2000s. This is reflected in post-2000 State-averaged minimum temperatures for New South Wales being generally about 0.5 °C cooler in winter months in the (unhomogenised) AWAP data set (Jones, Wang and Fawcett 2009) than in the homogenised ACORN-SAT dataset.

![Figure 11](image-url)  
Figure 11  
a) Linear trend in May-August number of days with minimum temperature below the monthly 10th percentile (Tn10) between 1960 and 2016 (days/decade), and the trends from multiple linear regressions incorporating b) STR intensity and c) rainfall. Solid triangles indicate where the trend is statistically significant for p<0.05.
During May to August there is an area of strong negative correlations between STRI/P and minimum temperatures that extends between northwest and southeast Australia, associated with the strong relationship between STRI and rainfall during these months. This relationship was also apparent for extreme temperatures, with a statistically significant increase in the frequency of cold and frost nights as well as a decrease in the average minimum temperature during months May-August when the STRI is above the 90th percentile. Outside of these months, a strong subtropical ridge is typically associated with an increase in the frequency of warm temperature extremes in southern Australia and a decrease in cool extremes, particularly during the spring months.

Parts of southeast Australia have seen relatively little increase in average minimum temperatures, and weak trends in extreme low minimum temperatures, during the period 1960–2016. This can be largely explained by the increasing trend in STRI, with more spatially coherent changes observed when using a multiple linear regression. The effect of STRI on southeast Australian temperature trends is larger than that observed when accounting for decreasing rainfall trends, which was previously identified as playing a major role in observed increases in frost days in southeast Australia (Dittus et al. 2015). As the STR is predicted to strengthen and continue to move further poleward in the coming decades (Grose et al. 2015), this independent STR-temperature relationship will be of relevance to temperature sensitive sectors of the community.

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