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# Southeast Australian thunderstorms: are they increasing in frequency?

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**Trends in warm season thunderday incidence are examined over southeastern Australia. There has been a significant increase in the number of thunderdays from 1941-2004, but much of this increase may have been a result of changes in observing practices in the mid 1950s. When data earlier than this are removed, some significant trends remain. There have also been smaller increases since 1970, mostly in the early part of the warm season (October-December). These increases may have been caused by changes in the atmospheric processes that affect this region. Examination of temporal trends in surface and 500 hPa temperatures and several instability indices since 1970 showed an increase in temperature and an increase in the number of days that instability is present in the atmosphere, as measured by the Total Totals index. It is unclear whether these increases are caused by localised phenomena or changes in some larger scale meteorological processes caused by climate change or other large-scale processes. Significant issues remain regarding the homogeneity of the thunderday record.**

## Introduction

There is a developing consensus that the increase of greenhouse gases in the atmosphere is causing higher temperatures (e.g. IPCC 2001). It is unclear, though, how climate change might affect small-scale meteorological phenomena such as thunderstorms. Most research has been on the dynamics of thunderstorms, particularly severe ones, rather than long-term trends in their behaviour. IPCC (2001) concluded that there had been no systematic trends in thunderday frequency in the rather limited regions that had been examined, and a similar conclusion was reached in IPCC (2007). In Australia, a climatology of severe thunderstorms for New South Wales was compiled by Griffiths et al. (1993), and other climatologies have been compiled for other States (Grace et al. 1989; Harper et al. 2000). More recently, a nationwide analysis of thunderstorm distribution was undertaken by Kuleshov et al. (2002). In compiling their analysis, they noted that there were a number of inhomogeneities in the observational record of thunderdays, as well as an apparent difference between the quality of thunderday data at Bureau of Meteorology and non-Bureau stations. These issues and others have made the analysis and interpretation of the thunderstorm record problematical, in Australia and elsewhere (Doswell 2005).

As a result, few trend analyses have been performed. Kuleshov et al. (2002) found no overall systematic trends in thunderdays at analysed stations from 1970-1999, although they indicate that in the earlier part of that period, a number of stations had fewer thunderstorms than in the later part. For cool-season

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tornadoes, Kounkou (2007) used reanalyses to examine trends in favourable environments, finding a slight increase since 1960 in the western part of Australia, but many such trends are likely to have been due to changes in the quality and type of observational data ingested into the reanalyses. Nevertheless, a systematic analysis of thunderstorm trends in southeastern Australia, and their possible causes, has not been performed. This study examines temporal trends of warm-season thunderdays and instability indices associated with thunderstorms recorded at several Australian Bureau of Meteorology stations. The data are examined for the presence of inhomogeneities, and relationships between thunderstorm occurrence and instability indices are examined to determine the physical reasons for any detected trends.

Several authors have identified atmospheric instability indices associated with thunderstorm development (Doswell 1985; Rasmussen and Blanchard 1998; Craven et al. 2002; Brooks et al. 2003). These indices include the following:

- Convective Available Potential Energy (CAPE; in J/kg), the maximum energy available to an ascending parcel of air;
- Lifted Index (LI; Galway 1956), the temperature of a parcel lifted to 500 hPa subtracted from the temperature of the surrounding environment at 500 hPa. The more negative the LI is, the more unstable the atmosphere. This index is also calculated at 700 hPa; and
- Total Totals (TT; Miller 1972), an index that combines the temperatures and dew-points at 850 hPa and 500 hPa to establish thunderstorm development potential:

$$T_{850} + Td_{850} - 2T_{500} \qquad ...1$$

where $T_{850}$ is the temperature at 850 hPa, $Td_{850}$ is the dew-point at 850 hPa and $T_{500}$ is the temperature at 500 hPa. Many other indices have been proposed as indicators of thunderstorm formation, but the ones listed above are among the most widely used and will be examined in this analysis.

For index values above certain thresholds, convective instability is to be expected. Hanstrum et al. (2002) investigated the thresholds for case studies in Australia that produced multiple tornadoes. They examined instability indices for both cool season (Apr-Sept) and warm season (Oct-Mar) events, finding distinct differences in the amount of instability that produced a severe event in the two seasons. They concluded that the amount of CAPE needed for a severe event in the cool season was at least 500 J $kg^{-1}$ less than in summer. Other indices such as LIs at 700 and 500 hPa were less negative for cool season severe thunderstorm events than their summer counterparts.

Here, we focus on warm season thunderstorm and index trends. The data and methodology are discussed in the next section, followed by a discussion section and brief concluding remarks.

## Data and methodology

Data reliability is a critical issue in a study of this kind. Changnon (2001) compiled phenomena reports and correlated them with synoptic observations of thunderdays, but crucially he restricted his analysis to official meteorological stations with trained observers. This study does the same, limiting the data analysis to those stations that have a long reporting history by Bureau staff and that have a minimum of seven observations per day. This eliminated the problems noted by Brooks et al. (2003), who found that volunteer-only stations tended to exaggerate storm occurrences. This also eliminates the problem noted by Kuleshov et al. (2002; their Appendix A) of differences in the data archiving practices between Bureau and non-Bureau stations prior to 1987. The sites chosen for the examination were all staffed by Bureau Technical Officers and data from these sites are considered of high quality (Brewster and Hicks 2002).

Changes in observing practices can cause artificial trends to be introduced into climate data. The observational record at the Bureau sites was examined to determine if there were any changes in practices that might contribute to data inhomogeneities over the selected analysis period. Two possible influences were identified. A change to the manner in which thunderday observations are reported occurred with the release of the *Australian Meteorological Observers Handbook* (Bureau of Meteorology 1954), which stated that the reporting of thunderdays in the phenomena section of the manual could now include all thunder being heard at the station. Previously, storms needed to be located within five miles of the station to be reported. Thus this change should cause an artificial increase in the number of observed thunderstorms after the mid-1950s, as thunder can be commonly heard at greater distances than five miles. Nevertheless, consultation with Bureau personnel suggests that this change to observing practices should have been introduced into Bureau observational practices in 1954 or 1955, so any trends after this time could not be due to this effect. Additionally, in 1994, the procedure for recording thunderstorms was slightly modified by entering a code of ‘no or yes’ instead of ‘blank or 1’. This was implemented to avoid any confusion regarding whether the observation had been overlooked or not. This change will have no effect on our results but is merely mentioned for completeness.

The stations in southeast Australia chosen for detailed analysis were Laverton, Mt Gambier and Wagga Wagga. These are considered of high quality and meet the guidelines of Changnon (2001) and Brewster and Hicks (2002), and also have daily temperature and wind sonde measurements at 9 am and 9 pm so that instability indices could be calculated. Both thunderday and index trends were examined at these locations. It was decided that it would be useful to extend the analysis of thunderdays to include other Bureau of Meteorology observation stations for a comparison across a wider area of southeast Australia. The additional stations analysed were Mildura, Adelaide Airport and East Sale (Fig. 1).

Thunderday data were available for varying time periods at each selected station: Laverton, from 1941 to 1998; Mt Gambier, 1943-1991; Wagga Wagga, 1943-2003; Mildura, 1947-2000; Adelaide, 1956-2001; and East Sale, 1944-2001. The varying time periods of the data were caused by a number of factors. In 1998, radiosonde launches were moved from Laverton to Melbourne Airport. After 1991, observations at Mt Gambier were reduced to fewer than seven observations per day, thus reducing their reliability. In addition, the trend analysis was extended to the most up-to-date data available in the archive at the time of analysis, and this end year varied from station to station.

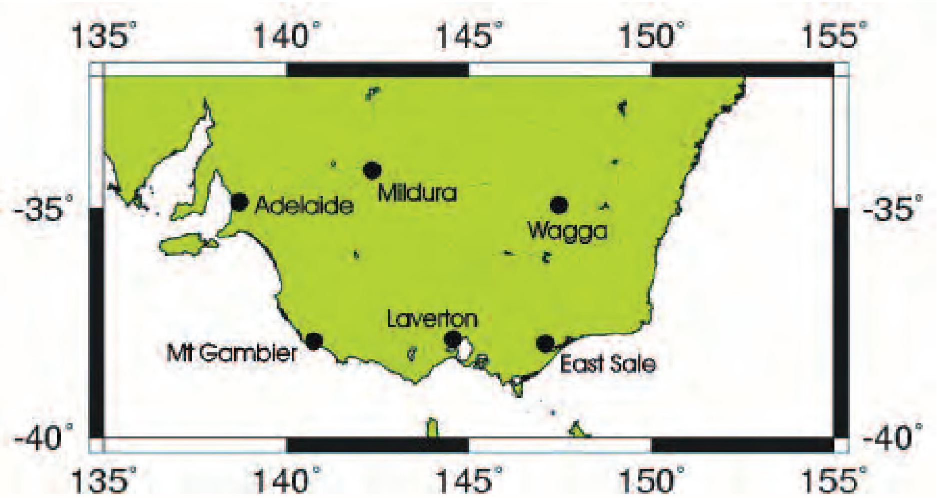
The Bureau of Meteorology Helindex software (Smith 1997) was used to compute parameters from the sonde data such as CAPE, LIs, TTs and vertical wind shear, the vector difference between winds in the lower and upper troposphere. Surface to 3 km shear of greater than 12 m/s is considered convectively important for thunderstorm development (Craven et al. 2002). Indices were calculated beginning in 1970, the commencement of electronic archiving of sonde data. After initial investigation, it was decided to omit CAPE from this study. The reason for this is that prior to 1987, the Bureau archived sounding data at the standard levels only, which give insufficient vertical resolution for a good discrimination of trends in CAPE. Thus trends based on thresholds for CAPE prior to 1987 would be erroneous and any analysis after 1987 is an insufficient period for establishing long-term changes.

The trends for the remaining indices were analysed in three stages. The first stage was to extract the daily values for the instability indices calculated by Helindex. Multiple entries were deleted so that one daily value remained; in about 90 per cent of cases, this was a morning reading. The second stage was to develop thresholds so that temporal trends of the indices could be established. Current thresholds of indices for the prediction of severe thunderstorm development are as follows:

| | |
|---|---|
| TT ≥ 51 | (BMTC 1995) |
| LI at 700 hPa and 500 hPa ≤ -2 | (BMTC 1995) |
| Shear ≥ 12 m $s^{-1}$ | (Craven et al. 2002) |

Since severe thunderstorms are relatively rare events, in order to maximise the statistical detectability of any trends, the thunderday trends analysed in this paper include both severe and non-severe thunderstorms. For this reason, the established severe storm thresholds were lowered so that the indices could represent all forms of thunderstorms. After consultation with Bureau of Meteorology forecasters, the index thresholds for non-severe storms were set as follows:

**Fig. 1 Locations mentioned in the text.**



TT ≥ 49
LI at 700 hPa and 500 hPa ≤ 0
Shear ≥ 10 m $s^{-1}$

Trends in the number of days that these conditions were satisfied were calculated for all warm season (W) thunderdays (October-March). To examine sub-seasonal trends, the data were further divided into early warm season (EW, October-December) and late warm season (LW, January-March). Once the temporal trends for the indices were established, they were correlated with thunderdays at Laverton, Mt Gambier and Wagga Wagga, in order to establish a physical mechanism for any detected trends in thunderdays. Detrended correlations with indices were calculated over a reference period of 1970-2000, although not all stations had data available over this entire period, as previously discussed.

## Results

### Thunderdays

Annual numbers of all warm season thunderdays from 1941-2004 at Laverton, Mt Gambier and Wagga Wagga are shown in Fig. 2, and trends for all analysed stations are shown in Table 1. The stations shown in Fig. 2 all demonstrate upward trends in observed thunderdays, and most stations analysed in Table 1 show significant upward trends when the entire period of record is analysed. If the period before 1956 is removed from the data, to account for the change in observing practices noted previously, significant upward trends remain at Laverton, Mt Gambier and Adelaide Airport.

Because of concerns regarding data homogeneity, a break-point statistical analysis (e.g. Fawcett 2004) was performed on all warm season thunderday data, for the entire available period of record for each station. At Mt Gambier and East Sale, breaks were identified around 1960, which tends to support a mid or late fifties change in observing practices. Breaks at Wagga Wagga and Mildura occurred in the early 50s, while Laverton showed a break at 1968 (Fig. 3). The size of the discontinuity at Laverton is large: values that are above average before 1968 become well below average after 1968. This points to a possible inhomogeneity in the data-set of unknown origin. Finally, Adelaide had insufficient data in the 1950s to investigate possible inhomogeneities at that time.

When the period since 1970 is analysed, thunderdays for the warm season as a whole appear to be increasing at four of the six selected stations, although with the exception of Adelaide Airport, these trends are not significant. Most of this increase appears to be occurring in the early part of the warm season, as

**Fig. 2** **Trends in warm season thunderdays from 1941-2004, for (a) Laverton; (b) Mt Gambier; and (c) Wagga Wagga. Line of linear regression best fit is also indicated.**

(a)

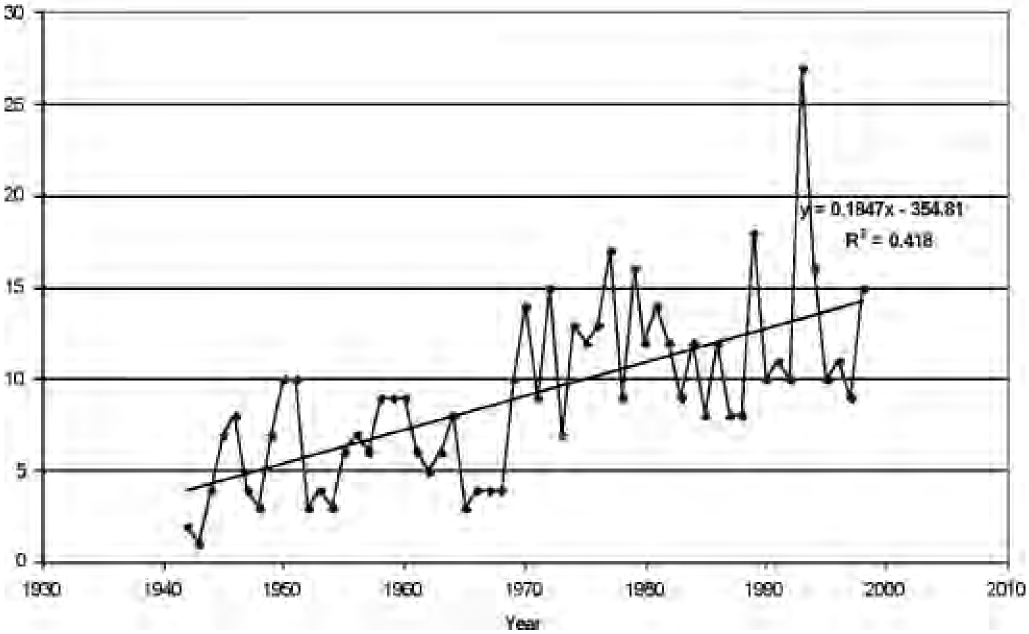


**Fig. 2 Continued.**

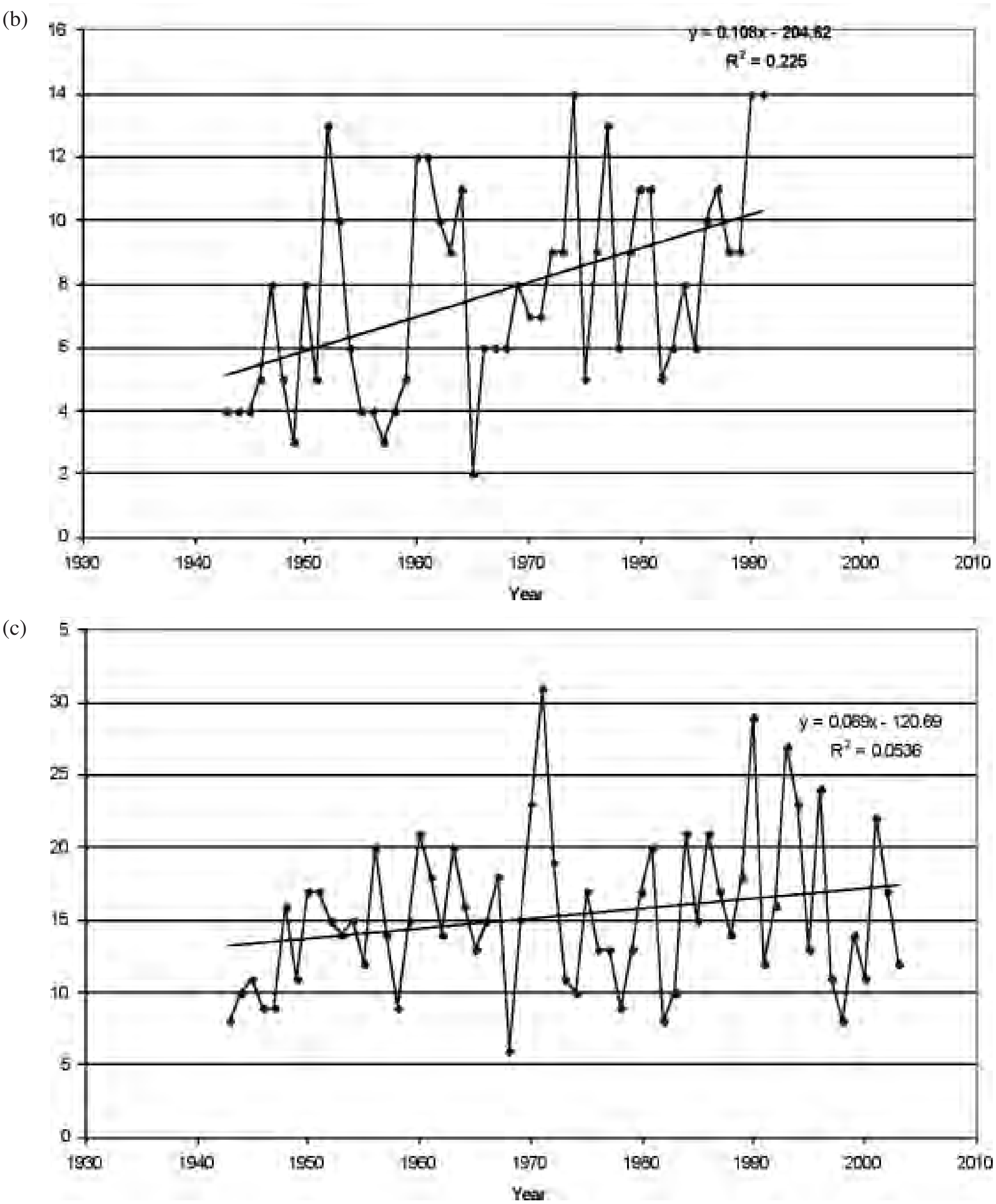


Table 1 shows that trends in the late part of the warm season are mostly negative.

### Thunderstorm indices

The thunderday trends since 1970 at the locations mentioned above, while not large, seem to suggest that the overall increase in thunderdays may not be localised phenomena, but may be caused by changes in some meteorological process that affects the southeastern Australian region as a whole. Accordingly, trends in thunderstorm indices were examined in order to elucidate possible forcing mechanisms that could be causing the trends in thunderdays.

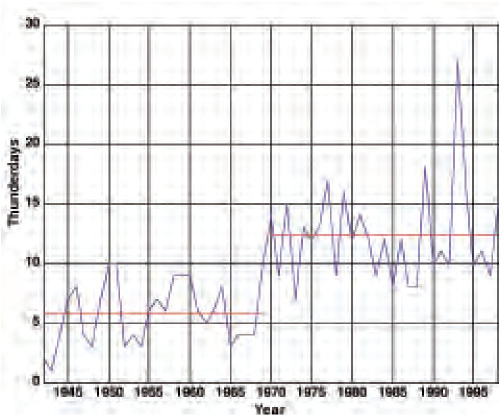
**Table 1. Trends per year in number of days of observed conditions as specified in the table. Trends in bold type are significant at the 95% level (two-tailed test). W refers to the entire warm season (October-March), EW to October-December and LW to January-March.**

| | | *Laverton* | *Mt Gambier* | *Wagga Wagga* | *Mildura* | *Adelaide Airport* | *East Sale* |
|---|---|---|---|---|---|---|---|
| Thunderdays* | W | **0.185** | **0.108** | 0.069 | 0.029 | **0.082** | **0.164** |
| | EW | **0.110** | **0.064** | 0.010 | **0.056** | **0.114** | **0.081** |
| | LW | **0.076** | **0.042** | **0.063** | -0.104 | -0.015 | **0.092** |
| Thunderdays (1956- ) | W | **0.186** | **0.122** | 0.013 | -0.033 | **0.082** | 0.071 |
| | EW | **0.112** | **0.092** | -0.017 | 0.047 | **0.111** | 0.034 |
| | LW | **0.071** | 0.010 | 0.033 | **-0.075** | -0.015 | 0.022 |
| Thunderdays (1970- ) | W | 0.039 | **0.125** | **-0.048** | 0.060 | **0.130** | -0.034 |
| | EW | 0.045 | **0.091** | **-0.021** | 0.057 | **0.124** | 0.066 |
| | LW | -0.012 | -0.026 | -0.008 | -0.022 | 0.067 | -0.032 |
| Total-Totals days > 49 (1970- ) | W | 0.136 | **1.114** | 0.783 | -- | -- | -- |
| | EW | 0.034 | 0.760 | **0.569** | -- | -- | -- |
| | LW | 0.053 | 0.149 | 0.216 | -- | -- | -- |
| Shear days > 10 m $s^{-1}$ (1970- ) | W | 0.499 | **3.618** | **2.516** | -- | -- | -- |
| | EW | 0.134 | 0.353 | **1.457** | -- | -- | -- |
| | LW | 0.309 | **3.057** | **1.199** | -- | -- | -- |
| Days LI500 < 0 (1970- ) | W | -0.065 | -0.309 | **-1.975** | -- | -- | -- |
| | EW | -0.043 | -0.109 | -0.519 | -- | -- | -- |
| | LW | -0.004 | -0.365 | **-1.116** | -- | -- | -- |
| Days LI700 < 0 (1970- ) | W | -0.052 | -0.233 | **-1.566** | -- | -- | -- |
| | EW | 0.017 | -0.116 | -0.412 | -- | -- | -- |
| | LW | -0.044 | -0.170 | **-0.899** | -- | -- | -- |
| T850 (1970- ) | W | 0.020 | 0.033 | 0.046 | -- | -- | -- |
| | EW | 0.047 | **0.065** | 0.043 | -- | -- | -- |
| | LW | -0.004 | 0.005 | 0.048 | -- | -- | -- |
| Td850 (1970- ) | W | -0.067 | **-0.103** | -0.043 | -- | -- | -- |
| | EW | -0.023 | -0.065 | -0.014 | -- | -- | -- |
| | LW | **-0.132** | **-0.172** | -0.073 | -- | -- | -- |
| T500 (1970- ) | W | 0.033 | 0.036 | 0.027 | -- | -- | -- |
| | EW | 0.044 | 0.034 | 0.025 | -- | -- | -- |
| | LW | 0.023 | 0.052 | 0.018 | -- | -- | -- |
| T850* | W | 0.002 | 0.028 | 0.002 | -- | -- | -- |
| | EW | 0.011 | **0.065** | 0.014 | -- | -- | -- |
| | LW | -0.003 | 0.015 | 0.000 | -- | -- | -- |
| Td850* | W | **-0.070** | **-0.080** | -0.009 | -- | -- | -- |
| | EW | **-0.075** | -0.047 | -0.006 | -- | -- | -- |
| | LW | **-0.051** | **-0.123** | -0.013 | -- | -- | -- |
| T500* | W | **0.015** | 0.020 | 0.018 | -- | -- | -- |
| | EW | **0.020** | 0.026 | 0.021 | -- | -- | -- |
| | LW | 0.010 | 0.024 | 0.017 | -- | -- | -- |

*Laverton 1941-1998; Mt Gambier 1943-1991; Wagga Wagga 1943-2003; Mildura 1947-2000; Adelaide 1956-2001; East Sale 1944-2001.

Trends in TT, surface to 3 km shear and LIs at 700 and 500 hPa were examined and compared to the trends for thunderdays at Laverton, Mt Gambier and Wagga Wagga. Trends in TT values since 1970 (Table 1) are positive at all selected locations, with statistically significant trends at Mt Gambier and Wagga Wagga. Similarly, increased numbers of high shear days were found at all locations, with statistically significant increases at Mt Gambier and Wagga Wagga. In contrast, trends in days of high instability as indicated by the Lifted Index are mostly negative, implying decreased convective development, particularly at Wagga Wagga.

**Fig. 3** **Break-point analysis for Laverton warm season thunderdays, showing discontinuity in the data record around 1968.**



### Comparison between index and thunderday trends

A comparison was made between trends in thunderstorm incidence and instability to identify possible forcing factors for the observed thunderstorm trends. Figure 4 shows the changes in thunderstorm and index values over the period since 1970. There are some gaps in the data of unknown origin; a possible explanation relates to the changeover from manual to electronic archive (R. Hicks, Bureau of Meteorology, personal communication). Figure 4 shows that there is substantial interannual and even some decadal variability superimposed upon the trends calculated in Table 1. For instance, days of high Total Totals values at Wagga Wagga were common in 1970, became less frequent in the late 1970s, and have gradually increased since then. To assess the strength of the interannual relationship between thunderdays and the stability indices, detrended correlations were performed between warm season detrended values of thunderdays, TTs, shear and LIs for Laverton, Mt Gambier and Wagga Wagga for the period 1970-2000. The results (Table 2) indicate that none of the indices were well correlated with thunderdays at Laverton, but seasonal variations in both LIs were well correlated with thunderdays at Mt Gambier, and well correlated with LI at 700 hPa at Wagga Wagga.

A multiple regression analysis was also performed to determine whether an effective predictor of interannual thunderstorm variation could be constructed from variations in the indices. Three indices were chosen as predictors: TT, shear and LI500. The results (Table 3) show that no effective predictor could be constructed using this technique for Laverton, but that significant relationships were constructed for both early and late warm seasons at Mt Gambier and warm and late warm seasons at Wagga Wagga. This suggests that instability is closely related to warm season thunderstorm incidence at Mt Gambier and Wagga Wagga, but that other factors play a more important role at Laverton.

### Comparison between long-term trends and thunderday trends

As mentioned above, sonde data for instability calculations were available only from 1970. To investigate possible longer-term climate effects on thunderstorm incidence, trends were calculated in seasonally averaged 850 hPa temperature and dew-point, and 500 hPa temperature over the entire period of thunderday record (Table 1). A fairly consistent pattern of drying and warming is seen at all three stations. While surface warming would tend to increase instability, all other things being equal, drying would tend to decrease it, as would increases in 500 hPa temperature. There is no clear signal in these trends that would explain the increases in thunderstorm incidence since 1956, unless surface warming is dominating the instability over this time. We discuss this issue further in the next section.

## Discussion

There are strong trends in thunderstorm incidence in the observed thunderday record over southeastern Australia from the late 1940s onwards. When the early part of this record before 1956 is excluded, due to changes in observational practices introduced from 1954 onwards, some of these trends remain. When the analysis is repeated for data from 1970 onwards, the significant trends largely disappear, except at Adelaide Airport. This may simply be an effect of sample size for some stations, for example Mt Gambier. Kuleshov et al. (2002) also found an upward trend at this station in their analysis of the period 1970-1999. After 1970, most thunderday trends in the data analysed in this study are upward, particularly in the early half of the warm season, but they are mostly not significant.

There are some indications that the environment in this region has been trending towards more unstable conditions since 1970, although these trends are not uniform across all indices. The trends since 1970 in the number of days of high Total Totals values are upwards, with increases in values at all three stations. There are also increases in the number of days of high

**Fig.4** **Comparison between trends in thunderdays and index trends for: (a) Laverton; (b) Mt Gambier; and (c) Wagga Wagga.**

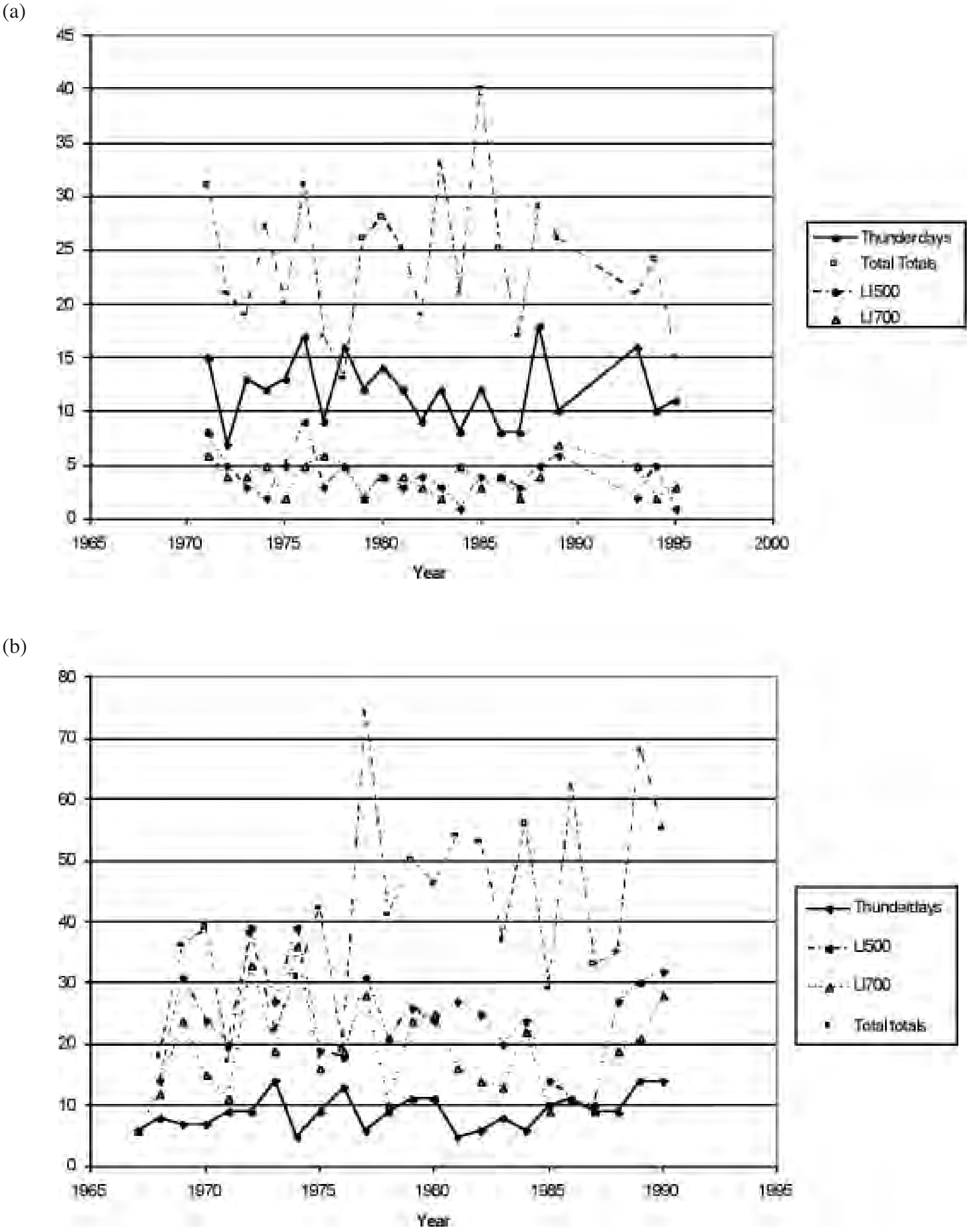


**Fig.4 Continued.**

(c)

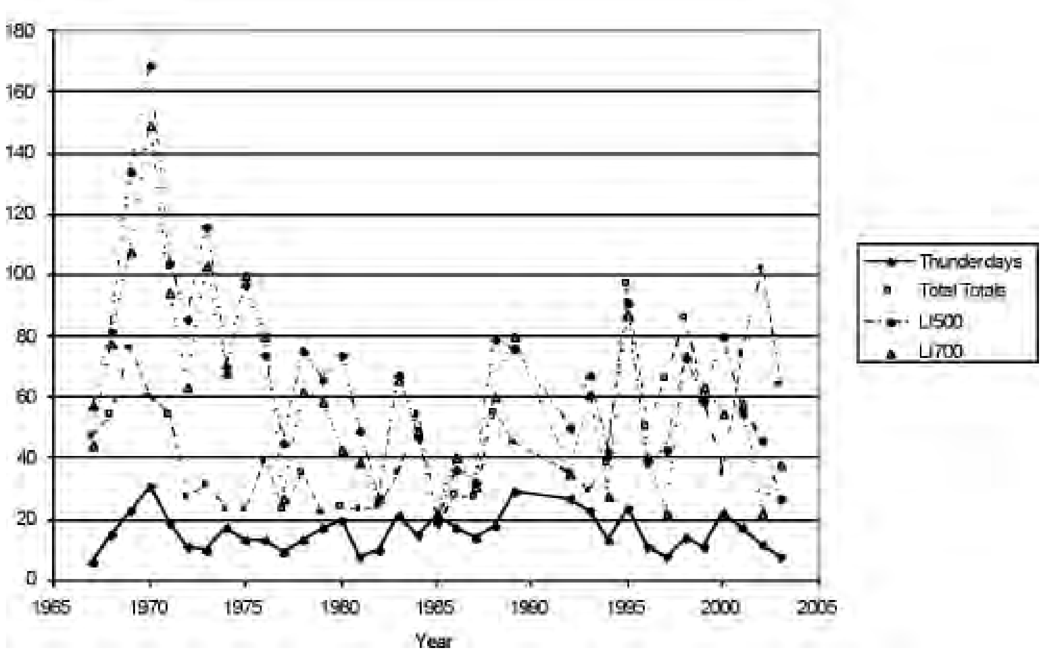


**Table 2. Detrended Pearson correlations between thunderdays and days of significant instability over the period 1970-2000. Bold values are significant at the 95% level (two-tailed).**

| | *Laverton* | *Mt Gambier* | *Wagga Wagga* |
|---|---|---|---|
| Total Totals > 49 | 0.135 | 0.219 | 0.343 |
| Shear > 10 m $s^{-1}$ | -0.123 | 0.020 | 0.148 |
| LI 700 < 0 | 0.207 | **0.690** | **0.543** |
| LI 500 < 0 | 0.363 | 0.499 | 0.284 |

**Table 3. p values of multiple regression analysis predicting thunderdays with values of TT, shear and LI500. Bold values are significant at the 95% level.**

| | *Laverton* | *Mt Gambier* | *Wagga Wagga* |
|---|---|---|---|
| Warm | 0.441 | 0.097 | **0.033** |
| Early warm | 0.140 | **0.008** | 0.116 |
| Late warm | 0.147 | **<0.001** | **<0.001** |

shear, but there are mostly decreases in the number of days of negative Lifted Index values (i.e. days of more lifting potential). Results of correlation analysis suggest that Lifted Index values were most correlated with actual thunderday incidence. Multiple regression analysis suggested that a strong association could be constructed between thunderday incidence and a suite of indices, with the Lifted Index being the strongest contributor.

In order to explain the reasons for trends in the indices since 1970, trends in values of 850 hPa temperature, 850 hPa dew-point temperature and 500 hPa temperature were calculated and are shown in Table 1. These indicate that since 1970, overall in this region there has been warming and drying at 850 hPa, and warming at 500 hPa. This is consistent with the longer-term trends in the same variables mentioned above. Since these quantities are the components of the Total

Totals index, this suggests that the observed increase in Total Totals must be explained by a dominant increase in 850 hPa temperature, as the direction of change of the other variables implies a decrease in Total Totals values, which is not observed. The trends in the Lifted Index values must be dominated by drying conditions at lower levels, as there has been an increase in surface temperature as well as 850 hPa temperature over south-eastern Australia since 1970, but this would act to decrease the Lifted Index, not increase it. An increase in 500 hPa temperature would also act to increase the Lifted Index, so this may be a contributing factor.

The warming and drying of southeastern Australia over the past several decades would seem unfavourable for increased thunderstorm development, unless the observed surface warming were large enough to dominate the instability index calculations, as the Total Totals index appears to suggest. The main trend relationship appears to be between some increases in thunderstorm incidence and increases in the Total Totals values, whose increases appear to be dominated by low-level temperature increases. Note that previous work (Davis 2006) found that thunderstorm incidence in this region was positively correlated with the SOI. Given that the SOI trends since the 1950s have been negative, this would not provide an explanation for an increase in thunderstorm incidence.

The question of remaining data inhomogeneities is a difficult one. Break-point analysis identified a very obvious discontinuity in the thunderday record at Laverton around 1968, which may be the cause of the significant upward trend in this variable since 1956. There is no obvious cause for this discontinuity, however. Upward trends in thunderday incidence since 1956 at Mt Gambier are still evident even if data from before the analysed break year of 1959 are discarded (not shown). Significant upward trends remain at Adelaide Airport after 1970. Thus not all of the thunderday trends can be easily explained by data discontinuities.

Projections of the effect of climate change indicate that temperatures in southeastern Australia will continue to warm, while it is also likely that the region will be drier (e.g. CSIRO 2001). Thus the trends identified in the present study may continue. Niall and Walsh (2005) noted, though, that simulations with the CSIRO Mark 3 climate model (Gordon et al. 2002) indicated no significant increase in days of extreme Total Totals values (> 55 °C) over southeastern Australia in a warmer world. These Total Totals values are considerably in excess of the threshold values chosen in the present study, however, as Niall and Walsh (2005) examined future projections of damaging hail incidence rather than typical thunderstorm behaviour.

Thunderstorm formation requires not only a source of instability, but also high atmospheric moisture levels and a trigger, such as a cold front (e.g. Kuleshov et al. 2002). Significant future trends in triggering events such as cold fronts could change the number of convective events even if instability remained unchanged. Simmonds and Keay (2000) note that mid-latitude cyclone numbers appear to be decreasing south of the continent but becoming more intense, and projections of future climate indicate that this is likely to continue, with mid-latitude storm tracks located generally further south than at present (Cai et al. 2003). The possible effect on cold front numbers and intensities in southeast Australia in a warmer world is unknown. It is also possible that some portion of the trends in thunderday incidence shown here could be caused by changes in frontal activity rather than instability, although the two are likely to be strongly correlated. Without a synoptic climatological frontal and trough analysis, however, this hypothesis remains speculative.

Another issue that could affect our analysis is the possibility of sonde instrument changes over the period of the data record affecting the temperature trends analysed here. There have been several changes in Australian sonde devices over the past 30 years (B. Trewin, Bureau of Meteorology, personal communication) and studies have shown that these can affect data homogeneity (e.g. Free et al. 2002; Lanzante et al. 2003; Durre et al. 2006).

## Conclusion

There has been a significant increase in the number of thunderdays in southeastern Australia from 1941-2004, some of this probably due to a documented change in observing practices around 1955. Nevertheless, some of these trends remain when data after 1956 are analysed. Smaller increases have also occurred since the late 1960s. Increases are most pronounced in the early part of the warm season (October-December). Analysis of trends in instability indices suggest that there is an accompanying upward trend in days with high Total Totals values and high shear, although trends in Lifted Index values over this time have been tending towards less instability. The trends in the Total Totals values are ascribed to the increase in lower tropospheric temperature that has occurred since the late 1960s in this region. As projections of climate change indicate a continued increase in surface temperatures, this may have a similar effect on Total Totals values that are characteristic of thunderstorm incidence.

A similar analysis of thunderday trends in other regions of Australia is recommended to establish if the increase is Australia-wide or isolated to particular areas of the country. Comparison of trends in instability indices derived from large-scale reanalysis and trends in radiosonde data at other locations should be performed. Further research is required to establish a direct link between the increase in atmospheric instability and the driving mechanism causing the changes, whether climate change or changes in some large-scale meteorological process.

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