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Severe thunderstorms in the Brisbane region and a relationship to the El Niño Southern Oscillation

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The number of severe thunderstorm days in the most populated region of southeast Queensland and its relationship to El Niño Southern Oscillation (ENSO) have been examined. On a seasonal scale, ENSO has some impact in setting the background for synoptic patterns that are favourable or unfavourable for severe thunderstorm development. A climatology of severe thunderstorm days for the most populated area of southeast Queensland (inner Brisbane) was constructed using data from 1956 to 2000. Using these data and Southern Oscillation Indices (SOI) for each severe thunderstorm season, it was demonstrated that severe thunderstorm days are about 60 per cent more likely in neutral SOI years than in positive SOI years. When these data were partitioned into post and pre-1977 (approximately the year the inter-decadal Pacific Oscillation became positive and a downward trend in the SOI was observed) the pre-1977 data showed an even more impressive result with severe thunderstorm days being nearly 130 per cent more likely in neutral years than in positive SOI years. Post-1977 data showed severe thunderstorm days as being only about 23 per cent more likely in neutral years than positive SOI years. Composites of climate anomalies were constructed using the NCEP/NCAR reanalysis data for the various phases of ENSO and compared to previously published composites. The composites consist of fields of 850 hPa to 500 hPa lapse rates and sea-level pressure. Analysis of the composites shows anomalous atmospheric stability in positive ENSO years, with no conclusive results for the other composite combinations.

Introduction

The number of severe thunderstorm days and its relationship to the El Niño-Southern Oscillation (ENSO) in the most populated region of southeast Queensland (SE Qld) has been the subject of speculation amongst both meteorologists and the local media for some time. Severe thunderstorms account for ten per cent of all thunderstorms but ninety per cent of all damage and injury (Bureau of Meteorology 1995). Approximately sixty per cent of the population of Queensland resides along the coastal strip containing the Gold Coast, Brisbane and the Sunshine coast in southeast Queensland (Callaghan 1996) with Brisbane being the fastest growing capital in Australia. Therefore a method of predicting the num-

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ber of severe thunderstorm days per season will benefit the inner Brisbane population and in particular the emergency services and insurance agencies. The motivation for this particular study is to investigate the effectiveness of the SOI as a possible seasonal predictor for severe thunderstorm numbers in the Brisbane region. A risk assessment study of severe thunderstorm impacts in southeast Queensland was undertaken by Harper (1997) for SUNCORP General Insurance, highlighting previous work on severe thunderstorms by the Queensland Bureau of Meteorology. The report included a climatology of severe thunderstorms in southeast Queensland for the period 1967 to 1995 based mostly on Bureau of Meteorology data.

The most complete description of severe thunderstorm occurrence and behaviour in the region is by Callaghan (1988) with later updates such as Callaghan (1996). In an unpublished study, Callaghan (2000) drew attention to the notable severe thunderstorms in the greater Brisbane region and a possible relationship with the SOI, although no firm conclusions were drawn.

As ENSO sets a slowly varying background state for the circulation patterns that deliver the conditions conducive to severe thunderstorms, the numbers of severe thunderstorm days per thunderstorm season were compared with a quantifiable ENSO parameter, the SOI. The inter-decadal variability and other trends of ENSO were also explored (with a brief review of recent published work) and then related to the severe thunderstorm day numbers.

As this dataset may be considered small, an alternative method for testing whether these results were due to random chance was adopted, using a randomisation test that is a computer-intensive method of reshuffling observed data. This technique is described in the methods section of this paper, with the detailed philosophy behind randomisation tests to be found in Howell's resource of statistical material (Howell, D.C. 2003. Statistical Home Page. University of Vermont. http://www.uvm.edu/~dhowell/StatPages/StatHomePage.html).

To further investigate the possible link between the number of severe thunderstorm days and ENSO, the response of broadscale atmospheric variables to ENSO was studied using composites. Previously, Karoly (1989), Drosdowsky and Williams (1991) and Mullan (1996), used composites of seasonal mean and anomaly fields to describe circulation features associated with ENSO events using various datasets (operational numerical analyses, rawinsonde station data etc). That technique was adopted here, as a way of quantifying seasonal tendencies of some atmospheric variables assessed as significant in the development of severe thunderstorms. In this study, the National Centers for Environmental Prediction – National Center for Atmospheric Research (NCEP-NCAR) reanalysis dataset was utilised using the National Oceanic Atmospheric Administration-Co-operative Institute Research Environmental Sciences (NOAA-CIRES) Climate Diagnostics Center (CDC) website.

Broadscale conditions for severe thunderstorm development in the southeast Queensland region identified by Callaghan (1988) included an unstable environment, strong vertical shear and various lifting mechanisms. The general broadscale conditions for severe thunderstorm development are well documented (e.g. Bureau of Meteorology 1995). For this initial investigation, stability was investigated by constructing composites of anomalies for 850 hPa to 500 hPa lapse rates and sea-level pressure for years where the SOI was more than +3.0.

The following sections describe the data used and details of the approach adopted to investigate the relationship between severe thunderstorm days and ENSO, followed by results and conclusion.

Climatology

This study adopts the Australian Bureau of Meteorology definition of a severe thunderstorm as described by the Weather Services Handbook (Bureau of Meteorology 1992). A thunderstorm is classified as severe if it produces any of the following:

- hail with diameter ≥ 2 cm at the surface;
- wind gusts of ≥ 90 km/h (≈ 48.5 knots) and /or reports of wind gusts causing significant structural damage;
- tornado(es);
- heavy rainfall that causes flash flooding, and/or an hourly rainfall rate equalling or exceeding the 1 in 10 year recurrence threshold.

Two sources of raw data were used in this study: (a) the severe thunderstorm database maintained by the severe weather section of the Queensland Bureau of Meteorology, and (b) paper-based files of each severe thunderstorm reported in the region pre-1967. To eliminate bias in numbers of severe thunderstorm reports caused by increasing population density with time, an area was chosen which was densely populated during the entire study period of 1956 to 2000. This was achieved by using the Queensland Year Book's (Solomon 1956) distribution of population. The approximate area chosen is shown in Fig. 1(a) - a rectangle approximately 15 km east/west and 30 km north/south, also including the satellite township of Ipswich. Areas outside this region showed significant population increases during the study period and hence were excluded.

Fig. 1(a) **Location of area used for study. Inset map shows the approximate area used for severe thunderstorm observations.**

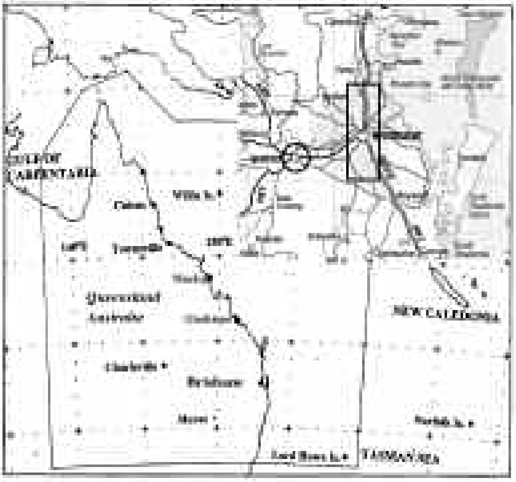
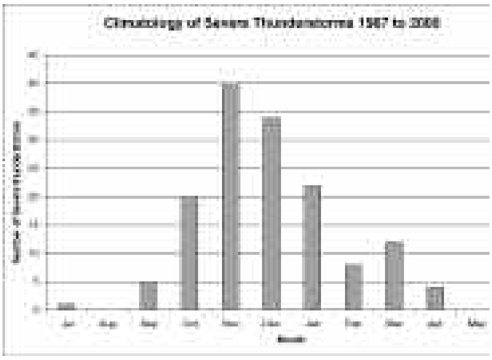


Fig. 1(b) **Climatology of severe thunderstorm days in the Brisbane region.**



The climatology revealed the four-month period of October to January as the peak severe thunderstorm season, with March exhibiting a secondary peak (Fig. 1(b)). For the purposes of this study, the severe thunderstorm season was defined as the months between October and March inclusive.

The above results differ from the climatology of thunder days as observed at the Brisbane Regional Office and Archerfield (a Brisbane suburb) Airport both of which record maximum thunderdays during December, with no secondary peak. The broader peak in the severe thunderstorm season may be related to some severe thunderstorm triggers that mainly occur during the transitional month of November, as detailed by Callaghan (1988). Callaghan (1988 and 1996) proposes a strong association between thunderstorm intensity and low-level coastal plain convergence (for example, convergence associated with synoptic flow and the penetration inland of the northeast sea breeze), which may explain the peak of severe thunderstorm days occurring in November, when sea breeze strength is at a maximum, as opposed to being coincident with the December peak in the number of thunder days. Instability is also increased during both November and March, as southern cold fronts penetrate far north over the hot land, potentially exacerbating the contrast between cold mid-tropospheric level temperatures and warm low-tropospheric level temperatures, more than in the summer months of December and February.

Data and method

Severe thunderstorm days and SOI

On a seasonal scale, ENSO has some impact in setting the background for synoptic patterns that are favourable or unfavourable for severe thunderstorm development. To investigate this hypothesis, days on which severe thunderstorms were observed over the study period were counted as severe thunderstorm days and were categorised according to the ENSO seasons. These were classified as El Niño (EN), Neutral (NU) or La Niña (LN) seasons by using SOI thresholds of –3.0 and +3.0, such that a season with an SOI less than or equal to –3.0 was labelled EN, an SOI greater than or equal to +3.0 was LN and other years NU. The SOI was averaged over the severe thunderstorm months (October to March) to obtain a figure representative of each season. The monthly SOI data were obtained from the Bureau of Meteorology National Climate Centre. These thresholds lead to a similar categorisation of seasons as that based on other ENSO indices (examples are defined online at http://ggweather.com/enso/years.htm). Most seasonal years, as defined above, compared to the agreed list of La Niña or El Niño years by the Bureau of Meteorology's National Climate Centre. They also mostly agreed with the NOAA National Weather Services Climate Prediction Center's list of cold and warm episodes. However, it appears that databases of ENSO episodes vary across institutions and research centers as different methods are employed to define an episode.

As previously mentioned, the motivation behind this research is to investigate the effectiveness of the SOI as a possible seasonal predictor for severe thunderstorm numbers in the Brisbane region. In real time, a pre-season average SOI would be required. The decision to use severe thunderstorm days as a parameter, rather than individual severe thunderstorm reports, was made with the original hypothesis in mind, namely, that ENSO affects the probability of a given day being conducive to severe thunderstorms, rather than forcing the individual severe thunderstorms.

As highlighted earlier, this dataset may be considered small due to the few years used and the results found may be considered due to random chance. Nicholls (2001) highlights the problem of using a null hypothesis (H_0) significance test on a small dataset such as the dataset used for this study: null hypothesis significance testing is affected as much by the size of the sample as by the strength of the effect (correlation) being tested. To try to address this, an alternative method for testing whether these results were due to random chance was adopted, using a randomisation test that is a computer-intensive method of reshuffling observed data. The data were reshuffled ten thousand times, with a test statistic generated and then compared to the corresponding statistic for each randomisation, giving a probability. This randomisation procedure is a process involving resampling the data without replacement (Lunneborg 2000). The program used for shuffling the data and creating a probability was adopted from Howell's statistical resource.

Composites

To investigate the atmospheric variables involved in producing the broadscale situations conducive to severe thunderstorms, composites of anomalies in the LN years were constructed using data from the NOAA-CIRES Climate Diagnostics Center website, which employed the NCEP-NCAR reanalysis. Details of the NCEP-NCAR reanalysis project are found both in the NOAA-CIRES Climate Diagnostics center website and in Kalnay et al. (1996).

Results and discussion

Severe thunderstorm days and SOI: over all years

The days on which severe thunderstorms were observed over the study period were categorised as EN, NU or LN according to the ENSO phase in the season of occurrence. The results of this procedure are summarised in Table 1. The highest proportion of severe thunderstorm days has occurred in NU years while the lowest proportion has occurred in LN years, with about 60% more severe thunderstorm days likely in NU years than in LN years, and about 30% more in NU years than EN years. To test whether these results were due to random chance, the randomisation resampling technique was employed (Howell's statistical resource). The probability of a low proportion of severe thunderstorm days occurring during LN years due to random chance was 0.048. Since this is above the 95 per cent confidence level, it is unlikely that the low proportion occurring in LN years reflected random variations. Conversely, the probability that the difference between the EN years and the NU years being due to random chance was 0.60.

Composites

The composites of anomalies were generated for 850 hPa to 500 hPa lapse rates and sea-level pressure (in hPa) for the LN period and are displayed in Figs 2(a) and 2(b).

Figure 2(a) reveals anomalous stability over southeast Queensland for the LN phase. It is well documented that thermal instability is required for severe thunderstorms to develop (e.g. Bureau of Meteorology 1995). Figure 2(b) shows anomalous high pressure in the southern Tasman Sea and anomalous low pressure in the Coral Sea for LN years. This implies that the east coast of Queensland endures stronger and/or more persistent easterly flow during these years. This result is not new as authors Karoly (1989), Drosdowsky and Williams (1991) and Mullan (1996) for example, used composites to show sea-level pressure conditions during extreme SOI periods, which are consistent with this result. Under these atmospheric circulation characteristics, deep convection would be suppressed under the strong trade-wind inversion.

Severe thunderstorm days and SOI: pre and post 1977

ENSO events vary on inter-decadal time scales (e.g. Wang (1995); Wang and Ropelewski (1995); Allan et al. (1996); Wang and Wang (1996); Nicholls et al. (1996) and Plummer et al. (1997)). These papers describe long-term changes in sea surface temperature patterns in the tropical Pacific Ocean since 1950 that have in turn affected ENSO. Callaghan and Bonell (2004) also discusses the long-term sea surface temperature pattern changing around 1977, resulting in warming along the equator and eastern Pacific Ocean and cooling in the southwest Pacific Ocean. This long-term cycle of rising and falling sea surface temperatures is known as the Inter-decadal Pacific Oscillation (IPO) and can last up to 30 years (Power et al. 1999). Callaghan and Bonell (2004) also discusses the cumulative SOI as changing from a tendency to remain positive in the 20 years prior to 1977, to negative post-1977. Power et al (1999), highlight

Table 1(a). The number of severe thunderstorm days per SOI period categorised into EN, NU and LN according to ENSO phase in the season of occurrence.

SOI	*Number of years*	*Severe thunderstorm days*	*Total days*	*Severe thunderstorm-day proportion*
Less than -3	16	38	2916	0.0130
-3<0<+3	15	48	2734	0.0176
More than +3	15	30	2734	0.0110

Table 1(b). The number of severe thunderstorm days per SOI period categorised into EN, NU and LN according to ENSO phase in the season of occurrence before and after the year 1977.

SOI index	*Number of years*		*Severe thunderstorm days*		*Total days*		*Severe thunderstorm day proportion*	
	Pre-1977	*Post-1977*	*Pre-1977*	*Post-1977*	*Pre-1977*	*Post-1977*	*Pre-1977*	*Post-1977*
Less than -3	7	9	14	24	1276	1640	0.0110	0.0146
-3<0<+3	4	11	16	32	729	2005	0.0219	0.0160
More than +3	10	5	18	12	1822	911	0.0099	0.0132

Fig. 2(a) Composites of anomalies for the 850 hPa to 500 hPa lapse rate for LN period (SOI greater than +3). Shading corresponds with figures on contours.

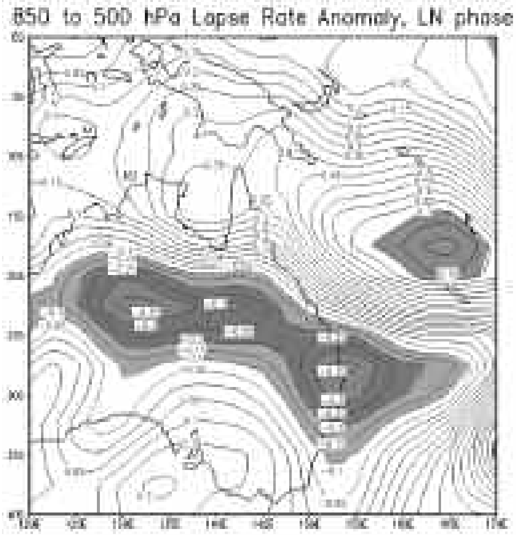
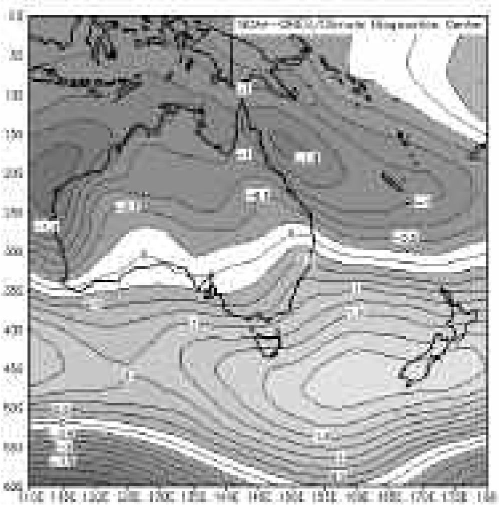


Fig. 2(b) Composites of anomalies for sea-level pressure (hPa) for LN period. (SOI greater than +3). Shading corresponds with figures on contours.



the importance of this tendency by showing that since 1977 there has been no robust relationship between year-to-year Australian climate variations and ENSO, with the reverse being true for variability in rainfall, surface temperature, river flow and domestic wheat crop yield before 1977.

The number of severe thunderstorm days in the ENSO seasons EN, LN or NU before and after 1977 are shown in Table 1(b). The highest proportion of severe thunderstorm days have occurred in NU years while the lowest proportion have occurred in LN years for both pre and post-1977. However, pre-

1977 about 130 per cent more severe thunderstorm days occurred in NU years than in LN years, while post-1977 only about 21 per cent more occurred in NU years. This suggests that the possibility of the SOI being an indicator of severe thunderstorm days may best apply when the Inter-decadal Pacific Oscillation is negative, supporting the findings of Power et al. (1999).

Again the data were repeatedly shuffled and randomly allocated to years in the study period. The probability of a low proportion of severe thunderstorms occurring during LN years before 1977 was found to be 0.0642. This is above the 90 plus per cent confidence level, demonstrating that it is unlikely that the low proportion occurring in LN years before 1977 reflected random variations. For post-1977 the probability was 0.33, indicating this result may be due to random variations.

Conclusions

The number of severe thunderstorm days that occurred in the most populated region of southeast Queensland and the relationship to ENSO have been examined. This was achieved by comparing the number of severe thunderstorm days over the defined severe thunderstorm season to the average seasonal SOI. It was shown that there is a significant relationship between fewer severe thunderstorm days in a season and a greater than +3.0 value of the SOI (LN) and between a much higher number of severe thunderstorm days and an SOI between –3.0 and +3.0 (NU). The pre-1977 data showed an even more impressive result with severe thunderstorm days being nearly 130 per cent more likely in neutral years than positive SOI years, which is coincidental with a negative Inter-decadal Pacific Oscillation. This implies that the possibility of using the SOI as an indicator of severe thunderstorm days may only apply when the Inter-decadal Pacific Oscillation Index is negative.

Further study may involve compiling composites for post and pre-1977 and using more variables.

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