*Aust. Met. Mag.* 47 (1998) 183-189

# The relationship between tropical cyclones near Western Australia and the Southern Oscillation Index

**L. W. Broadbridge and B. N. Hanstrum**
Regional Office, Bureau of Meteorology, Perth, Australia

(Manuscript received June 1997; revised December 1997)

**An examination of tropical cyclone activity near the Western Australian coastline during the cyclone seasons from 1960/61 to 1996/97 inclusive showed distinct seasonal and regional characteristics consistent with variations in the average value of the Southern Oscillation Index (SOI) during the months prior to the cyclone season, as well as changes in the average SOI value from the previous year.**

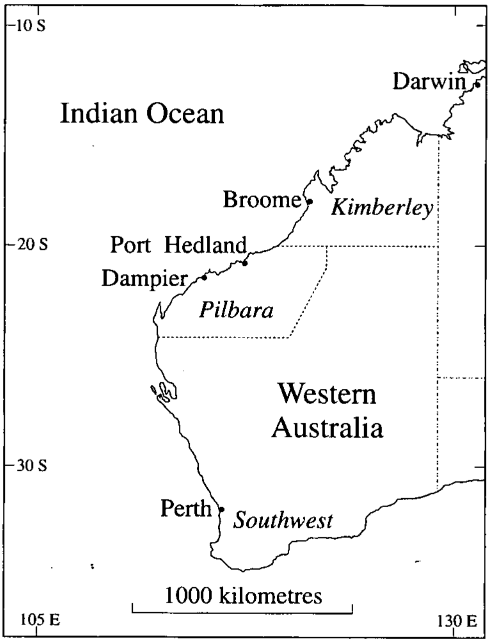
**Important findings of this study were: an overall increase in tropical cyclone frequency (and coastal impacts) with strong positive SOI values; a greater number of coastal impacts when the SOI value was positive together with a large positive SOI change; a large increase in probability of early season (prior to Christmas) activity with positive SOI; and a preference for more late season (April/May) events to occur following negative SOI years. Although there were fewer tropical cyclones in the negative SOI years, a higher percentage of these were severe. As a result the number of coastal impacts by severe tropical cyclones was similar following both positive and negative SOI years.**

## Introduction

Each day natural resources valued at around A$20 million are mined in the Pilbara region (see locality map, Fig. 1). Extensive exploration for mineral resources and development of mining infrastructure is ongoing. All of these activities are highly sensitive to a tropical cyclone impact, and special warning arrangements are in place for industries to ensure that timely preparations can be carried out in the event of a tropical cyclone threat.

Through the 1980s, rumours of the nature of the coming tropical cyclone season were always rife in the lead-up to each season. There was also much interest in the likelihood of pre-Christmas tropical cyclones because work cycles and community preparedness activities are tied into a pattern that encompasses the Christmas holiday period. Hence guidance on the likelihood of pre-Christmas tropical cyclones was eagerly sought. Another demand came from the pastoral industry. As much of the rain in the Pilbara and Kimberley regions (commonly called the Northwest or northwest Australia) is caused by tropical cyclones, some knowl-

**Fig. 1** **Map showing location of places referred to in the text.**




*Corresponding author address:* Mr L. Broadbridge, Bureau of Meteorology, PO Box 1370, West Perth, Western Australia 6872, Australia.

edge of likely cyclone activity in the coming wet season can aid pastoralists with their planning.

The pioneering work of Nicholls (1979, 1984, 1985) provided the Bureau of Meteorology's Perth Regional Office with a basis for providing a tropical cyclone outlook service for northwest Australia. Nicholls (1979) showed that enhanced (reduced) tropical cyclone activity in the Australian region (105°E-165°E) followed low (high) values of Darwin pressure in the months leading up to the cyclone season. Later studies by Nicholls (1984,1985) confirmed that Australian seasonal tropical cyclone activity is related to the El Niño-Southern Oscillation phenomenon. Other studies also show the links between the Southern Oscillation and tropical cyclone activity in the Australian region. Examples include Revell and Goulter (1986), Hastings (1990) and Evans and Allan (1992).

From 1986 onwards, confidential outlooks for the coming season were provided to key members of the mining industry in the Pilbara. A prediction of a late start to the 1987/88 tropical cyclone season and a below-average number of cyclones during that season (based on higher pressures at Darwin during the winter of 1987) proved reliable.

In the spring of 1988, in the knowledge of a return to lower pressures at Darwin and encouraged by the success of the earlier outlooks provided to industry, it was decided to make public the outlook for the 1988/89 season. This occurred during the annual pre-season education and publicity tour of the Northwest conducted in October/November 1988. The outlook of a high probability of above-average tropical cyclone activity and a high likelihood of a coastal crossing before Christmas received much media and public attention. Severe tropical cyclone *Ilona* crossed the Pilbara coast near Dampier on 16 December 1988 and the outlooks gained immediate credibility and acceptance in the minds of people in the Northwest.

Nicholls (1992) tested the performance of his earlier results using data from the tropical cyclone seasons from 1979/80 to 1990/91. He found that the relationship between the Southern Oscillation Index (SOI) and tropical cyclone numbers had been confounded by apparent changes in tropical cyclone numbers, including a secular drop in tropical cyclone numbers after 1986 that was not associated with a corresponding decrease in the SOI. He was able to show that by using the first differences of SOI values (i.e. changes from year to year), and first differences of tropical cyclone numbers, the effects of the secular change in tropical cyclone numbers could be reduced and that these differences were more strongly and consistently related than the absolute SOI values and tropical cyclone numbers.

This study looks specifically at tropical cyclone activity off the coast of Western Australia and tropical cyclone impacts on the Western Australian coastline rather than the Australian region as a whole. It explores the relationship between the year-to-year, intraseasonal and regional variations with the SOI values during the months preceding the tropical cyclone season. The conclusions are designed to assist with preparation of the annual tropical cyclone season outlook for northwest Australia.

## Data and methods

Details of tropical cyclone centre locations and central pressure estimates as well as monthly values of the SOI were obtained from the Bureau of Meteorology's National Climate Centre. Tropical cyclones within the region 105°E-130°E and south of 10°S with central pressure of 996 hPa or less were selected from the cyclone database for the period 1960/61 to 1996/97. Although 'best track' data were available since 1910, the post-1960 period was chosen since this era encompasses meteorological satellite data when the confidence in detecting a tropical cyclone away from the Western Australian coastline and estimating its intensity increased significantly. This is consistent with the findings of Holland (1981). A tropical cyclone impact on the Western Australian coast was defined to be an event that produced at least gale-force winds on the coast. A severe tropical cyclone was defined to be one that had a central pressure of 970 hPa or less at some time during its lifetime. This central pressure value typically corresponds to winds of hurricane strength. Similarly, a severe tropical cyclone impact was defined to be one with central pressure on the coast estimated to be 970 hPa or less.

Trenberth (1976) used three-monthly mean values of the SOI to eliminate short-period fluctuations of the SOI unrelated to the Southern Oscillation (SO). Three-month means of the SOI have also been used by Nicholls (1979, 1992), Rimmington and Nicholls (1993) and others. In this study, three-month means of the SOI for the period July to September each year are used, and the values obtained are given the term 'SOI value'. First differences of the SOI values were also calculated (i.e. the SOI value from last year was subtracted from the SOI value in the current year) in order to examine how changes in the SOI value may also relate to tropical cyclone activity. These are referred to as the 'SOI trend'.

The approach used was similar to that adopted by Rimmington and Nicholls (1993) who correlated wheat yields in Australia with three-month SOI values near the time of sowing and the SOI trend (i.e. the change in the SOI value over the preceding 12 months). The distinct modal changes in the SO typically occur during the southern hemisphere late summer/autumn period, and subsequent winter/spring values of the SOI are generally more stable. Hence it was considered sufficient to examine the links between tropical cyclones and the July-September SOI value and the SOI trend.

Another approach was demonstrated by Zhang and Casey (1992) who examined the relationship between phases of the SO and Australian rainfall. A similar approach regarding the relationship between phases of the SO and tropical cyclone occurrence near Western Australia was not considered in this study, although it may be investigated in the future.

## Results and discussion

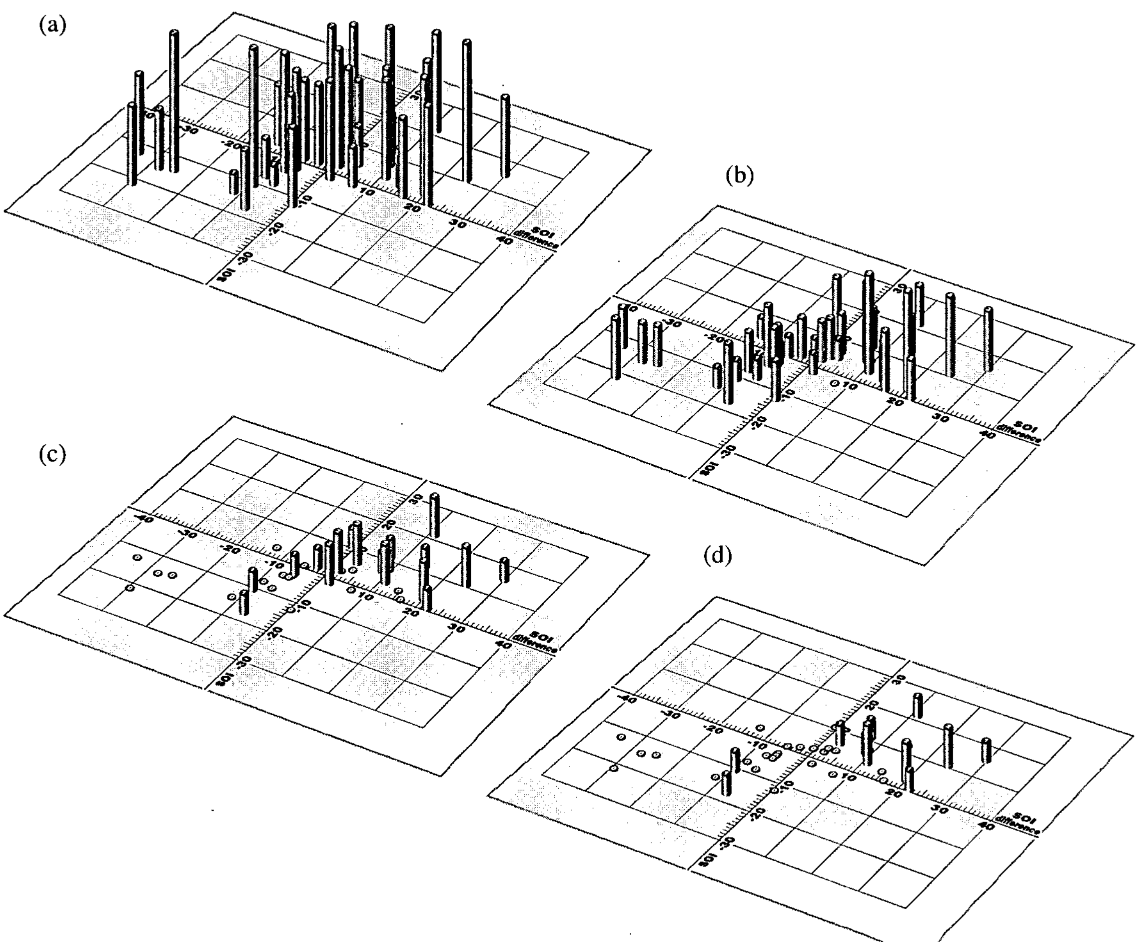
### Seasonal frequency of tropical cyclone events in relation to SOI values and SOI trends

The strength of the relationships between SOI values and tropical cyclone numbers discussed by Nicholls (1992) was tested for the northwest Australian tropical cyclone dataset. Table 1 lists correlations including those

**Table 1. Correlation between first differences of SOI values and first differences of seasonal tropical cyclone numbers, and correlation between SOI values and actual cyclone numbers. (All are significant at 5 per cent.)**

| *Period* | *Differences* | *Cyclone numbers* |
|---|---|---|
| 1959/60-1990/91 (Sept/Nov SOI) | 0.72 | 0.58 (Australian region) (Nicholls, 1992) |
| 1960/61-1990/91 (Sept/Nov SOI) | 0.40 | 0.32 (NW Australia) |
| 1960/61-1996/97 (Jul/Sept SOI) | 0.33 | 0.28 (NW Australia) |

**Fig. 2** **Cyclone numbers versus SOI value and SOI difference (SOI trend): (a) for all cyclones; (b) for all coastal impacts; (c) for pre-Christmas cyclones; and (d) for pre-Christmas coastal impacts.**



achieved by Nicholls (1992) for comparison. The correlations between SOI trends and first differences of seasonal tropical cyclone numbers off Western Australia are also stronger than those between SOI values and actual seasonal tropical cyclone numbers. However the correlations for the Australian region are significantly stronger than those for the Western Australian region. This is most likely due to the smaller number of tropical cyclone numbers per season and hence the greater impact on the correlation due to anomalous seasons (Neville Nicholls, personal communication).

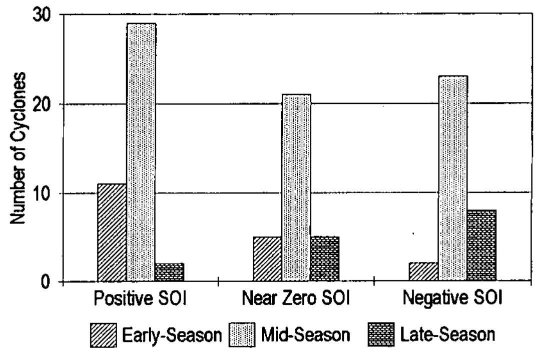
An examination of a plot of the SOI values and the SOI trends against tropical cyclone numbers in each of the 37 seasons (Fig. 2(a)) shows a tendency for the more active seasons to occur when both the SOI value and the SOI trend are positive. However two active seasons in 1972/73 and 1993/94 (seven events in each) occurred with significantly negative SOI values (-14.1 and -10.8 respectively). Figure 2(b) identifies a tendency for the seasons with the highest number of coastal impacts to occur with positive SOI values together with large positive SOI trends. It is also interesting to note that all of the seasons with large negative SOI trends had either two or three coastal impacts.

The graphs of early-season (pre-Christmas) tropical cyclones (Fig. 2(c)) and early-season coastal impacts (Fig. 2(d)) clearly show a strong preference for these events to be associated with both positive SOI values and positive SOI trends.

### Intraseasonal variability

The SOI values were ranked in ascending order and divided into three groups of eight corresponding to the most negative SOI years, the most positive SOI years, and the years when the SOI values were closest to zero. These are shown in Table 2. The relationship between SOI values and the intraseasonal variability of tropical cyclone numbers was examined by looking at tropical

**Fig. 3 Seasonal distribution of cyclones for positive, near zero and negative SOI values.**




cyclone occurrences in each of the three SOI value categories. The tropical cyclone season was divided into three time periods defined as early-season (pre-Christmas), mid-season (Christmas to end of March) and late-season (April and May).

A graph of the seasonal distribution of tropical cyclones in these categories is shown in Fig. 3. In the negative SOI years there were 33 tropical cyclones in the eight seasons. The frequency distribution of tropical cyclone numbers was skewed towards the later part of the season. In the years when the SOI was near zero there were 31 events. These events were approximately normally distributed. In the positive SOI years there were 42 tropical cyclones. In contrast to the negative SOI years the distribution of events for the positive years was skewed towards the early part of the season with 11 tropical cyclones in that period compared to only two late season tropical cyclones.

Table 3 lists correlations between the SOI values and tropical cyclone numbers for the different periods of the

**Table 2. Ranking of eight years each of most positive, nearest zero and most negative SOI values.**

| *Positive SOI years (SOI value)* | *Zero SOI years (SOI value)* | *Negative SOI years (SOI value)* |
|---|---|---|
| 1975 (+21.4) | 1968 (+1.6) | 1993(-10.8) |
| 1988 (+15.4) | 1961 (+1.0) | 1977(-12.1) |
| 1964 (+11.7) | 1983 (+0.8) | 1976(-12.6) |
| 1971 (+10.8) | 1966 (+0.3) | 1972(-14.1) |
| 1973 (+10.6) | 1992 (-1.6) | 1987(-14.6) |
| 1974 (+10.3) | 1980 (-1.8) | 1965(-16.1) |
| 1981 (+7.6) | 1990 (-2.4) | 1994(-17.5) |
| 1996 (+6.3) | 1963 (-2.9) | 1982(-21.4) |

**Table 3. Correlations between first differences of SOI values and first differences of cyclone numbers and correlations between SOI values and actual cyclone numbers for various periods of the cyclone season. Correlations in italics are significant at five per cent.**

| | *Differences* | *TC numbers* |
|---|---|---|
| Whole season | *0.33* | *0.28* |
| Early season | *0.65* | *0.54* |
| Mid season | 0.20 | 0.22 |
| Late season | *-0.34* | *-0.42* |

tropical cyclone season. The strongest correlations occur in the early-season. Mid-season correlations were weak and not significant at the five per cent level. A significant negative correlation was evident in the late-season.

## Regional variations

Tracks of the tropical cyclones that occurred in each of the three SOI value categories for each of the stages of the tropical cyclone season are shown in Fig. 4. Figure 4(a) clearly shows the higher frequency of early-season events for the positive SOI years when the whole of the northwest coast is at risk from a tropical cyclone impact. However, when the SOI value was near zero or negative the early-season coastal impacts were confined to the west Kimberley region. In the mid-season period (Fig. 4(b)) there appears to be a preference for tropical cyclones to travel further southwards along the west coast as SOI values increase. Late in the season (Fig. 4(c)) there were more tropical cyclone events that threatened the southern part of the west coast for the

**Fig. 4(a) Tracks of early-season tropical cyclones for positive SOI values (top), near zero SOI values (middle), and negative SOI values (bottom). Circles denote tropical cyclone genesis locations. Filled circles indicate that the tropical cyclone reached severe intensity for a period during its lifetime.**

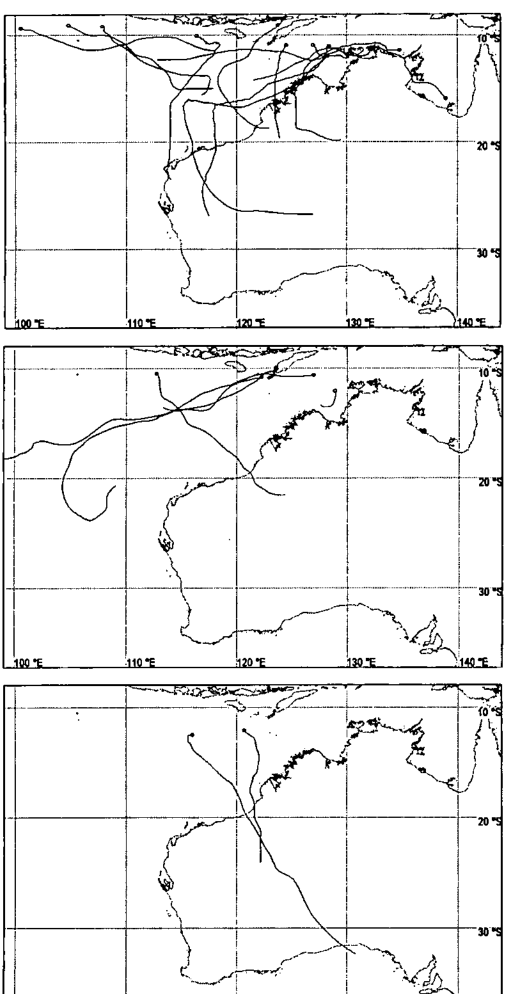



**Fig. 4(b) As for Fig. 4(a) except tracks are mid-season events.**

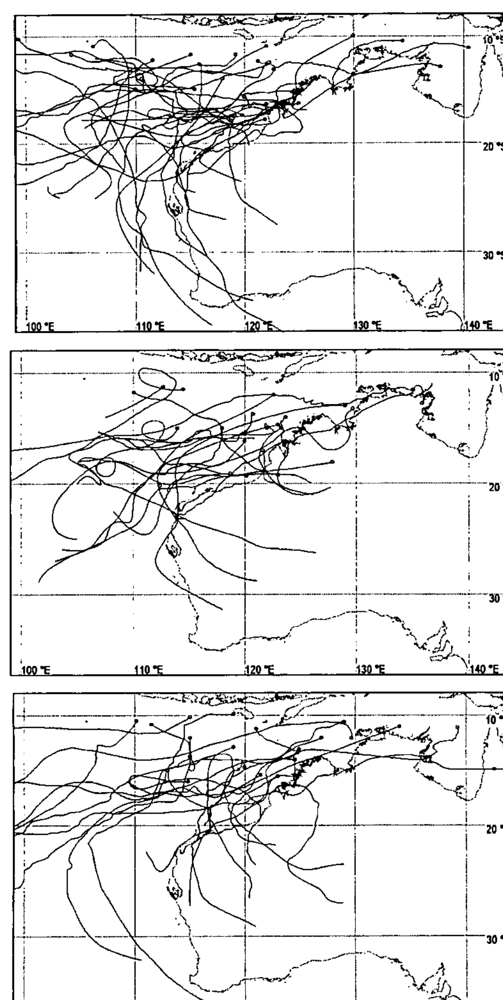
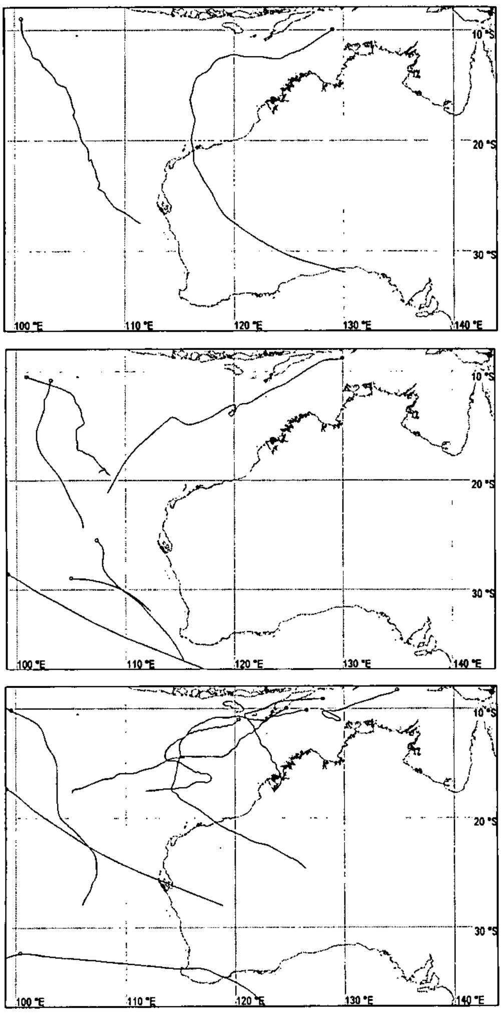


**Fig. 4(c)** As for Fig. 4(a) except tracks are late-season events.




near zero and negative SOI values. The preference for late-season events with negative SOI values has implications for the more heavily populated southwest parts of Western Australia. This is a period when the region is most vulnerable to impact from a so-called 'cyclone capture event' (Foley and Hanstrum 1994).

## Severity of tropical cyclones

The intensity of the tropical cyclones in each of the three SOI categories was also examined. Table 4 shows that although there were more tropical cyclones in the positive SOI category the percentage of severe tropical

**Table 4. Numbers of tropical cyclones and severe tropical cyclones for the three categories of SOI value.**

| | *All TCs* | *Severe TCs* | *All impacts* | *Severe impacts* |
|---|---|---|---|---|
| *Positive SOI* | 42 | 16 | 22 | 9 |
| *Near zero SOI* | 31 | 14 | 12 | 5 |
| *Negative SOI* | 33 | 20 | 15 | 9 |

cyclones in this group (38 per cent) was less than for the negative SOI category (61 per cent). A chi-squared test of the difference between these two proportions was significant at the 90 per cent level, but not quite at the 95 per cent level. It also shows that although more coastal impacts occur with positive SOI, the number of severe coastal impacts was the same for both positive and negative SOI values.

The larger percentage of weaker tropical cyclones in the positive SOI years may be explained by changes in the broadscale circulation patterns over Australia associated with contrasting phases of the SO. Williams (1987) investigated the strength and nature of the relationship between the SOI and the upper tropospheric variables of wind and geopotential height across Australia on a month-by-month basis. The results show that in the strongly positive SOI years the low-level (high-level) westerly flow (easterly flow) over northern Australia is considerably stronger than in the negative SOI years. This implies that the deep tropospheric shear in these years is greater, thereby reducing the potential for tropical cyclone intensification.

## Summary of findings

An analysis of the relationship between tropical cyclone events off northwest Australia and tropical cyclone impacts onto the Western Australian coastline and the SOI value and SOI trend prior to the season in the period from 1960/61 to 1996/97 revealed the following characteristics:

(a) an increase in tropical cyclone frequency (and coastal impacts) with strongly positive SOI values;
(b) a greater number of coastal impacts when the SOI value was positive together with a large positive SOI trend (greater than +10);
(c) two to three coastal impacts whenever there was a large negative SOI trend;
(d) a marked increase in the number of early-season (pre-Christmas) tropical cyclones with both positive SOI values and positive SOI trends. (The strongest correlations between SOI values and SOI trends are with early-season tropical cyclone activity.);

(e) more late-season tropical cyclones with negative SOI values than with positive SOI values;

(f) the early-season tropical cyclone impact zone includes both the Kimberley and Pilbara coasts when SOI values are positive, whereas it is confined more to the Kimberley coast with near zero and negative SOI values;

(g) there is insignificant correlation between mid-season tropical cyclone activity and the SOI values;

(h) a higher percentage of severe tropical cyclones with negative SOI values (61 per cent) compared to those with positive SOI values (38 per cent); and

(i) the chances of a severe tropical cyclone coastal impact are about the same with both positive and negative SOI values.

This study has tailored previous work on the relationship between the SOI prior to the season and tropical cyclone numbers in the Australian tropics by focussing specifically on tropical cyclones off northwest Australia and on tropical cyclone impacts onto the Western Australian coastline. The results provide a basis for the preparation of an annual tropical cyclone season outlook for northwest Australia.

## Acknowledgments

We are grateful to Mr Kevin Smith from the Severe Weather Section of the Bureau of Meteorology in Perth for extracting and manipulating the cyclone data from the NCC database and for assistance with preparation of the figures. Cyclone tracks were generated using the Australian Tropical Cyclone Workstation.

A detailed and comprehensive internal review of an earlier draft of the paper by Mr Roger Tapp from the Climate and Consultative Services (CCS) of the Perth Office was greatly appreciated. Mr Tony Jennings, also from CCS, prepared the location map.

## References

Evans, J.L. and Allan, R.J. 1992. El Niño/Southern Oscillation modification to the structure of the monsoon and tropical cyclone activity in the Australasian region. *Intl J. Climatol., 12, No. 6*, 611-23.

Foley, G.R. and Hanstrum B.N. 1994. The capture of tropical cyclones by cold fronts off the West Coast of Australia. *Weath. forecasting, 9, No. 4*, 577-92.

Hastings, P.A. 1990. Southern Oscillation influences on tropical cyclone activity in the Australian/South-West Pacific region. *Intl J. Climatol. 10, No. 3*, 291-8.

Holland, G.J. 1981. On the quality of the Australian tropical cyclone data base. *Aust. Met. Mag., 29*, 169-81

Nicholls, N. 1979. A possible method for predicting seasonal tropical cyclone activity in the Australian region. *Mon. Weath. Rev., 107*, 1221-4.

Nicholls, N. 1984. The Southern Oscillation, sea-surface-temperature, and interannual fluctuations in Australian tropical cyclone activity, *J. Climatol., 4*, 661-70.

Nicholls, N. 1985. Predictability of interannual variations of Australian seasonal tropical cyclone activity. *Mon. Weath. Rev., 113*, 1144-9.

Nicholls, N. 1992. Recent performance of a method for forecasting tropical cyclone activity. *Aust. Met. Mag., 40*, 105-10.

Revell, C.G. and Goulter, S.W. 1986. South Pacific tropical cyclones and the Southern Oscillation. *Mon. Weath. Rev., 114*, 1138-45.

Rimmington, G.M. and Nicholls, N. 1993. Forecasting wheat yields in Australia with the Southern oscillation index. *Aust. J. Agric. Res. 44*, 625-32.

Trenberth, K.E. 1976. Spatial and temporal variations of the Southern Oscillation. *Q. Jl R. met. Soc., 102*, 639-53.

Williams, M. 1987. Relations between the Southern Oscillation and the troposphere over Australia. *BMRC Research Report No. 6*, Bur. Met., Australia.

Zhang, X.G. and Casey, T.M. 1992. Long-term variations in the Southern Oscillation and relationships with Australian rainfall. *Aust. Met. Mag., 40*, 211-25.