Predictability of Interannual Variations of Australian Seasonal Tropical Cyclone Activity

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ABSTRACT

The number of tropical cyclones observed in the Australian region during a single cyclone season has ranged from one to nineteen since 1909. Previous studies, using limited data sets, have suggested that interannual variations in the number of cyclones are related to the Southern Oscillation and that an index of the Southern Oscillation (e.g., Darwin pressure) can be used to predict the number of cyclones expected in the coming season. This study uses a 74 year time series of tropical cyclone numbers, from the 1909/10 season to the 1982/83 season to confirm this. Strong and stable correlations are found between cyclone numbers and Darwin pressures before and during the cyclone season. Even stronger relationships are found between Darwin pressure and the number of cyclone days in a cyclone season. The correlations are strong and stable enough to allow prediction of seasonal cyclone activity from several months prior to the start of the tropical cyclone season. A simple equation for predicting seasonal cyclone activity is derived.

1. Introduction

Tropical cyclones are observed in the Australian region (105–165°E) every year. The tropical cyclone season generally runs from November to April although occasional cyclones are observed earlier or later. The number observed in a single cyclone season has ranged from one (in the 1909/10 season) to 19 (in the 1962/63 season). A time series of the number observed is shown in Fig. 1. This figure has been prepared from the data presented by Lourensz (1981) for cyclone seasons from 1909/10 to 1979/80, supplemented by Rooney (1981), Lynch (1982) and Bate (1983) for the last three seasons shown.

A nonlinear trend is evident in Fig. 1 with more cyclones being observed in more recent years, presumably due mainly to improvements in observing systems and networks. Around this trend strong variations in cyclone activity occur. Nicholls (1979), using data from 1950–74, produced evidence of a relationship between these interannual variations in tropical cyclone numbers and Darwin pressure in the winter (June–August) preceding the cyclone season. Darwin pressure is closely related to the Southern Oscillation phenomenon so Nicholls (1984a) also examined the relationships of cyclone numbers with two other variables associated with the Southern Oscillation, sea-surface temperatures in the east equatorial Pacific and around the north Australian region. That study used data from 1964–82 and from 1913–37 and confirmed that cyclone numbers in the Australian region were related to the Southern Oscillation and were predictable from data observed some months prior to the start of the cyclone season. Shapiro (1982) and Gray (1984a,b) have related Atlantic tropical storm numbers to large-scale atmospheric conditions, including the Southern Oscillation, and Gray derived predictive equations for seasonal tropical storm activity.

Nicholls (1979, 1984a) used fairly small amounts of data. There has been concern that some lag relationships suggested as bases for seasonal prediction might not be stable (e.g., Ramage, 1983; McBride and Nicholls, 1983; Nicholls, 1984b). The complete record of Australian tropical cyclone numbers from 1909/10–1982/83 has been examined therefore to determine the strength and stability of the lag relationship between Darwin pressure and cyclone numbers.

The relationship between Darwin pressure and the number of cyclone days observed in each cyclone season has also been studied. A cyclone day is defined as a day when, at 0900 LST, a tropical cyclone was observed in the Australian region. If two tropical cyclones were observed at 0900 on a particular day, that day counts as two cyclone days. The number of cyclone days in a season could be a better measure of cyclone activity or threat than cyclone numbers. Figure 2 shows the time series of the number of cyclone days from 1909/10–1982/83. As was the case with the time series of cyclone numbers (Fig. 1), a strong nonlinear trend, due to improving observational systems, is clear.

Section 2 discusses the data and methods used, including the technique for removing the nonlinear trends in the cyclone time series. The results of correlating cyclone numbers and cyclone days with Darwin pressure, using the whole 74 year record and

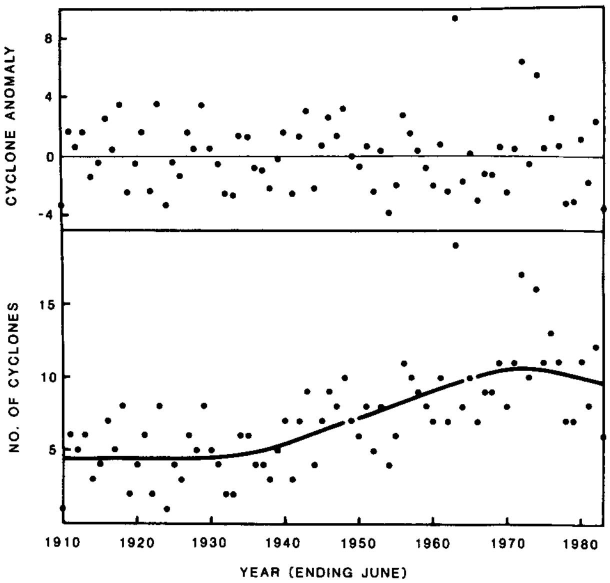

FIG. 1. Top: Time series of anomalies of the number of tropical cyclones observed. Bottom: Time series of numbers of tropical cyclones observed in the Australian region (105–165°E) from 1909/10 season to 1982/83 season (dots) and cubic spline fitted to the time series.

various subsets of the data, are then presented and discussed.

2. Data and methods

As noted in Section 1, the time series of tropical cyclone numbers and days exhibit strong nonlinear trends associated with improvements in the observing system. In the early years approximately five cyclones were observed each year; since the advent of meteorological satellites in the 1960s the typical number of cyclones has been about ten. These trends had to be removed before relationships between cyclone activity and the Southern Oscillation could be examined.

The trends were removed by fitting cubic splines to the time series. The IMSL routine ICSSCV, which uses statistical considerations to determine the amount of smoothing required (Craven and Wahba, 1979), was used to fit the splines. The splines fitted to the time series of cyclone numbers and cyclone days are shown in Figs. 1 and 2.

Anomalies of cyclone activity for each cyclone season were then calculated by subtracting the smoothed cyclone numbers (or days), as provided by the spline, from the actual number of cyclones (or cyclone days). The time series of anomalies of tropical cyclone numbers and cyclone days are shown in Figs. 1 and 2. These time series of anomalies of tropical cyclone activity have been related to Darwin 0900 mean sea level pressure, representing the Southern Oscillation. Pressure data for Darwin are not available from a single location for the complete period 1909–83. Prior to 1942 the data came from the Darwin Post Office, and subsequently from Darwin Airport.

The Darwin data were used to calculate three month means. Then the anomalies in cyclone activity were correlated with the three month average pressures before, during and after the cyclone season. The three month periods used in this analysis started with the January–March prior to the cyclone season and ended with the October–December following the end of the cyclone season (i.e., about 21 months later). This was first done using the entire 74 year data set.

Then the stability of the relationships between Darwin pressure and cyclone activity was examined by recalculating the correlations on subsets of data. The first subsets examined divided the data into the two periods when pressure data came from different locations; i.e., 1909/10–1941/42 and 1942/43–1982/83. As a further test of the stability of the relationships, the data were divided into ten year subsets starting with 1913/14–1922/23 and finishing with 1973/74–1982/83. Then the correlations calculated on these ten year subsets were calculated and compared.

3. Results

The correlations between anomalies of cyclone numbers from the cubic spline long-term trend and three month average Darwin 0900 mean sea level pressure, calculated on the 1909/10–1982/83 data set, are shown in Fig. 3. The approximate extent of the cyclone season is represented by the thick horizontal bar. The central month of the three month average of Darwin pressure is indicated on the abscissa.

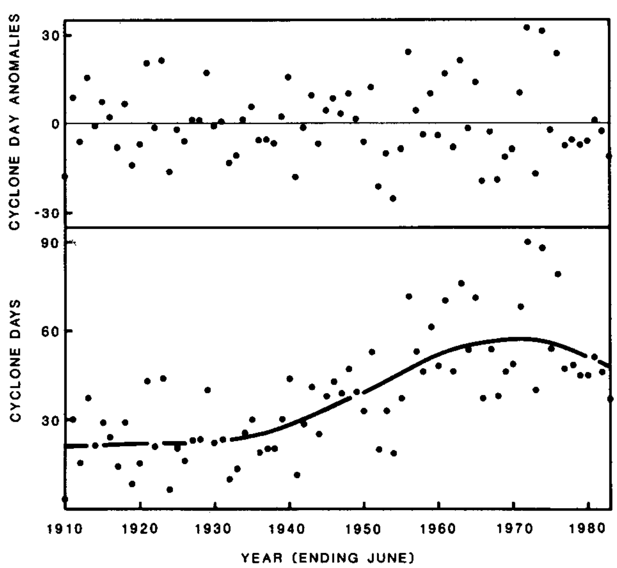

FIG. 2. Top: Time series of anomalies of the number of tropical cyclone days observed. Bottom: Time series of numbers of tropical cyclone days observed in the Australian region (105–165°E) from 1909/10 season to 1982/83 season (dots) and cubic spline fitted to the time series.

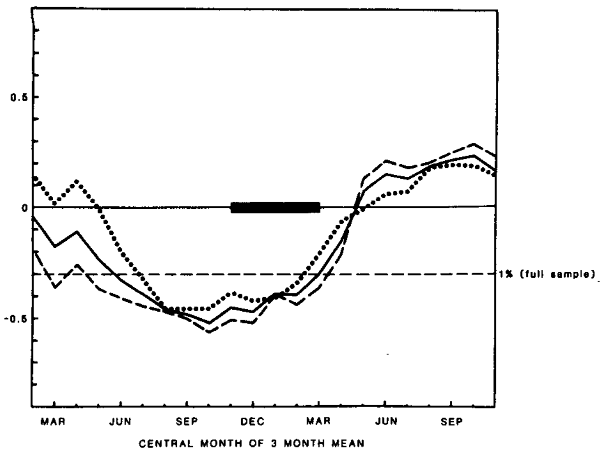

FIG. 3. Correlations between anomalies of the number of tropical cyclones in the Australian region and three-month means of Darwin 0900 mean sea level pressure. Data from 1909–83 (full line), 1909–41 (dotted line) and 1942–83 (broken line). Thick horizontal bar indicates approximate extent of cyclone season. The 1% significance level for the full sample (1909–83) is shown as the thin dashed line.

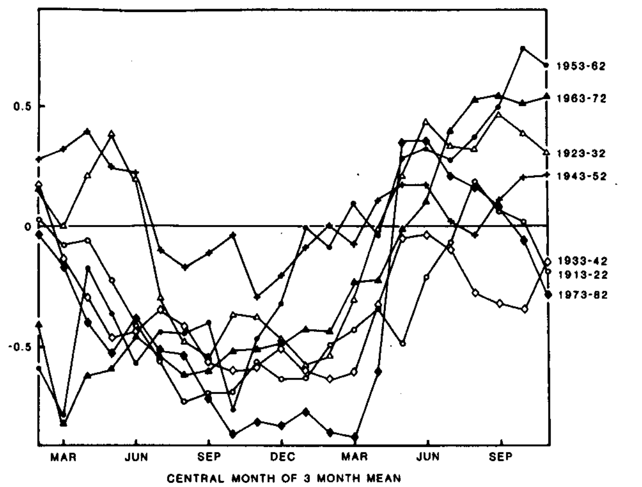

FIG. 4. Correlations between anomalies of the number of tropical cyclones in the Australian region and three-month means of Darwin 0900 mean sea level pressure. Correlations calculated using seven separate ten-year samples.

Highly significant correlations exist with Darwin pressures during and before the cyclone season. For instance, the correlation with July–September pressure is −0.47, significant at 0.01%. Low Darwin pressure during winter and spring indicates that more cyclones than usual can be expected in the ensuing cyclone season, and vice versa.

Also shown on Fig. 3 are the correlations calculated when the data are divided into the periods when the pressure was recorded at Darwin Post Office (prior to 1942) and at the Darwin Airport. The correlations on the two subsets are almost identical. In both subsets, years with low Darwin winter and spring pressures tend to be followed by cyclone seasons with above average cyclone activity.

Further evidence of the stability of the correlations is provided by Fig. 4 which shows the correlations for each of seven distinct ten-year subsets of the data. The general pattern is similar in each subset with negative correlations with pressures before and during the cyclone season and weak or positive correlations with pressures in the months after the end of the cyclone season. The magnitudes of the correlations with pressure in winter and spring prior to the cyclone season, and during the cyclone season, are very similar, except for the 1943/44–1952/53 subset. For instance, the correlations with July–September pressures in the other subsets range from −0.41 to −0.72. The correlation on the 1943/44–1952/53 subset is −0.16. Examination of the data in this subset suggests that the weak correlation is due to one outlier, the 1943/44 season. Removal of this outlier and recalculation of the correlations using 1944/45–1952/53 data produced correlations with a pattern and magnitudes similar to the other six ten-year subsets.

The strength of the correlations between cyclone numbers and Darwin pressure, and their stability when calculated on small subsets, confirms that these relationships, which were previously noted on smaller data sets, are real. Even stronger relationships were found with the number of cyclone days. Figure 5 shows the correlations of Darwin three month averages of 0900 mean sea level pressure with the anomalies, from the cubic spline long-term trend, of the number of cyclone days. The correlations tend to be larger in magnitude than those with cyclone numbers (Fig. 3). The correlation, calculated on the entire 74 year sample, between Darwin July–September pressure

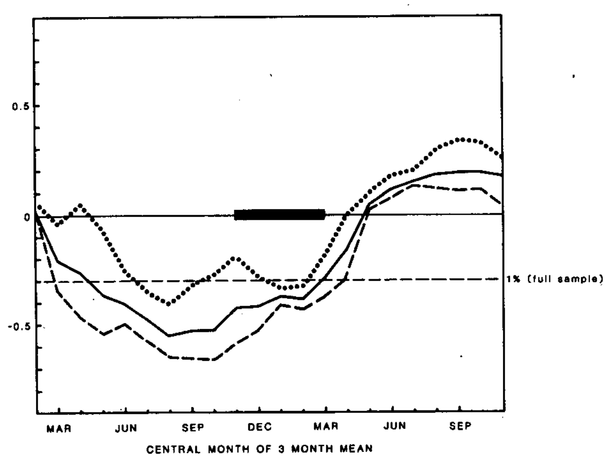

FIG. 5. Correlations between anomalies of the number of cyclone days in the Australian region and three-month means of Darwin 0900 mean sea level pressure. Data from 1909–83 (full line), 1909–41 (dotted line) and 1942–83 (broken line). Thick horizontal bar indicates approximate extent of cyclone season. The 1% significance level for the full sample (1909–83) is shown as the thin dashed line.

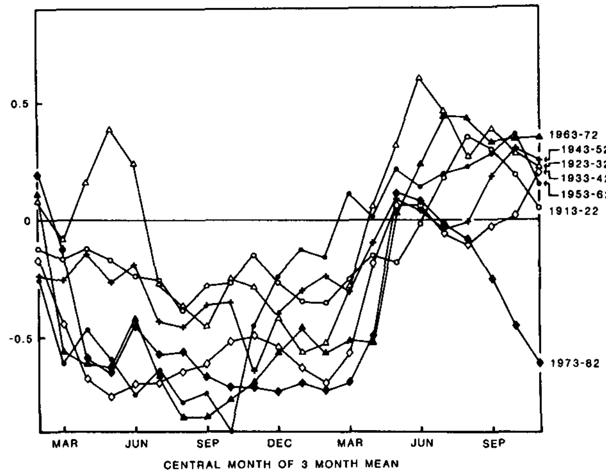

FIG. 6. Correlations between anomalies of the number of tropical cyclone days in the Australian region and three-month means of Darwin 0900 mean sea level pressure. Correlations calculated using seven separate ten year samples.

and the number of cyclone days in a cyclone season is −0.54.

Also shown on Fig. 5 are the correlations for the two subsets of data 1909/10–1941/42 and 1942/43–1982/83. As was the case with the subset correlations with cyclone numbers (Fig. 3), the correlations on the two subsets show similar patterns. However the correlations are substantially smaller in magnitude on the earlier subset. This may represent inaccuracies in the number of cyclone days observed during the earlier years when offshore observation of tropical cyclones was poor.

The correlations with cyclone days using the seven separate ten-year subsets of data are shown in Fig. 6. Again, the pattern and magnitude of the correlations are similar. The later subsets, when offshore observations of tropical cyclones were better, tend to show the strongest correlations.

The strength and stability of the relationships of cyclone numbers and days with Darwin pressure prior to the start of the cyclone season (e.g., July–September) suggest that development of a scheme to produce operational predictions of seasonal cyclone activity would be reasonable. This has been done using the last 25 years data. Over this period long term trends in the number of cyclone days observed have been relatively small, as demonstrated by the fairly flat cubic spline over that period in Fig. 2. Therefore, actual numbers of cyclone days, rather than anomalies from the cubic spline, were regressed against Darwin pressures prior to the start of the season. The period used for the Darwin pressures was the mean of July, August and September. Since even early cyclone seasons do not generally start until well into November, the use of data up to the end of September still provides considerable lead time for a forecast. Of course, Figs. 5 and 6 indicate that equations using only earlier data could be prepared, although at some loss in accuracy.

A scatter diagram of the number of cyclone days versus July–September pressure is shown in Fig. 7 using data from 1958/59–1982/83. The relationship between high (low) pressures and low (high) numbers of cyclone days is clear. The correlation on this subset of data was −0.68. The same data are plotted as time series in Fig. 8, with the scale of cyclone days reversed. The fluctuations in the two series parallel each other in a remarkably close way, except for the 1978/79 and 1981/82 seasons.

The linear regression relating Darwin July–September 0900 mean sea level pressures to the number of cyclone days in the coming cyclone season is:

$$\text{Cyclone days} = 224.5 - [11.6 \times (\text{pressure} - 1000 \text{ mb})]$$

Thus for each extra millibar of pressure observed, the number of cyclone days expected decreases by nearly 12. Significant skill can be expected from forecasts derived using this equation. The expected error of the forecasts was estimated by cross-validation on the 1958/59–1982/83 data. A forecast of the number of cyclone days was prepared for each of the 25 years using the Darwin July–September pressure observed in the year in question and a linear regression of cyclone days versus Darwin July–September pressure derived from the other 24 years data. Thus the data sample used to derive the prediction equation did not include data from the year for which the forecast was made. The mean absolute error of the 25 forecasts

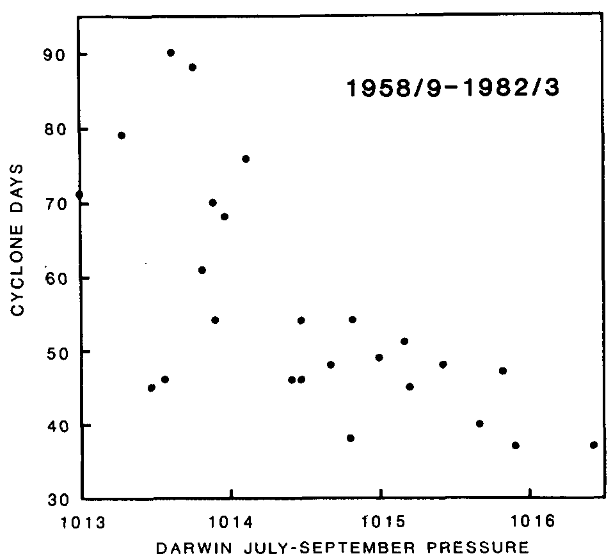

FIG. 7. Scatter diagram of the number of cyclone days observed in the Australian region over a cyclone season vs mean Darwin 0900 mean sea level pressure for July–September prior to the cyclone season. Data for the seasons 1958/59–1982/83.

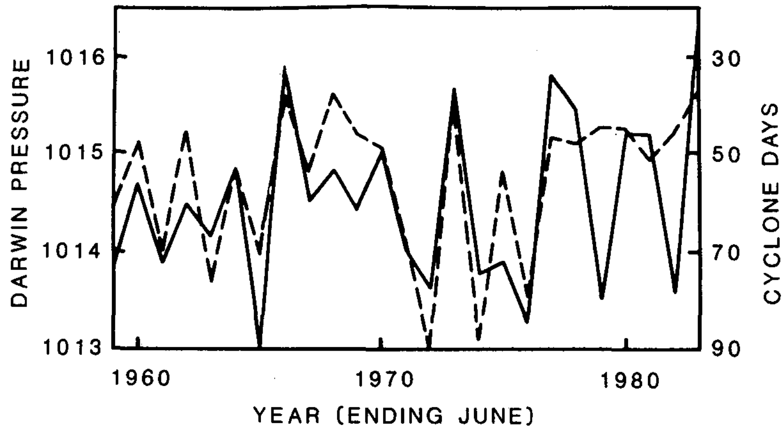

FIG. 8. Time series of the number of cyclone days observed in the Australian region over a cyclone season (broken line, scale reversed) and mean Darwin 0900 mean sea level pressure for July–September prior to the cyclone season (full line). Data for the seasons 1958/59–1982/83.

prepared in this way was 9.4 days. This error should be compared with the mean absolute error of 19.5 days for a "persistence" forecast; i.e., a forecast that the number of cyclone days in the coming cyclone season will equal the number observed in the previous cyclone season, and a mean absolute error of 12.7 days for a "climatological" forecast, i.e., a forecast that each year the number of cyclone days in a season will equal the 25 year average number (55). The regression forecasts are substantially more accurate than persistence or climatological predictions. Forty percent of the regression forecasts had errors less than five days in magnitude, compared to only 20% of the persistence or climatological forecasts. Seventy-three percent of the regression predictions had errors of less than ten days while only 56% and 33% of the climatological and persistence forecasts, respectively, had errors less than this. The regression forecasts produced errors smaller in magnitude than the persistence forecasts in 19 of the 25 cases and smaller than the climatological forecasts in 18 cases. The regression forecasts were significantly better (2% level, one-sided Wilcoxon signed-rank test on the magnitudes of the errors) than either persistence or climatology.

4. Conclusions

In this paper, the relationships between Australian tropical cyclone activity and Darwin pressures before, during and after the tropical cyclone season have been investigated. Strong and stable relationships have been found between cyclone activity and Darwin pressure prior to the start of the season, confirming a suggestion made earlier on the basis of smaller data sets (Nicholls, 1979, 1984a). The relationships are strong and stable enough to enable prediction of expected seasonal cyclone activity some months prior to the start of the season. Linear regression has been used to derive a simple forecast equation for seasonal cyclone activity.

The accuracy to be expected from this forecast equation is quite good (Fig. 8). Nevertheless, better forecasts are probably possible. Nicholls (1984a) found, on a limited sample, that sea-surface temperatures around north Australia were a better predictor of seasonal cyclonic activity than were Darwin pressures. The strong possibility that sea-surface temperatures may produce a better method of forecasting Australian region seasonal tropical cyclone activity justifies continuing efforts to improve the historical, and current, record of sea-surface temperatures in this region. Nonlinear, or multiple, regression techniques might also provide better predictions than seem possible using simple regression.

The accuracy expected from seasonal forecasts of tropical cyclone activity might also improve if better quality control measures were introduced on the historical time series of cyclone activity. In this paper all available data were used, without questioning their quality. Yet in some years there is doubt about the accuracy of the tropical cyclone activity reported. For instance, in the first season for which cyclone activity data were available (1909/10) only one cyclone, and only three cyclone days, were reported (Figs. 1 and 2). This was the lowest report in the 74 years. It may be that this value is unrealistically low due to inadequacies in the observing network or analyzing system symptomatic of any new system. More recently, the 19 cyclones analyzed in the 1962/63 season were easily the highest total for any season (Fig. 1). It may be that some degree of overanalysis contributed to this high total. A suspicion that this might be true arises from examination of Fig. 29 of Lourensz (1981) where three cyclones are located within 150 km of each other at the same time. This seems unlikely behavior. Both 1909/10 and 1962/63 are outliers in the statistical analysis reported in this paper. In scatter diagrams of cyclone numbers versus Darwin pressures, both these years lie well off the line of best fit. It seems possible that analysis errors, in one case underanalyzing cyclones and in the other overanalyzing, might have taken place. Improved quality control on the historical analyses of tropical cyclones might remove any such analysis errors. The actual relationships between Darwin pressures and cyclone activity thus may be even stronger than those found in the present analysis of the imperfect historical data.

Previous papers (Nicholls, 1979, 1984a) used the numbers of tropical cyclones as an index of cyclone activity or threat and concentrated on finding methods for predicting this quantity. In this paper the number of cyclone days observed in a season also was used as an index of cyclone activity. Better measures of cyclone threat could be envisaged, e.g., the number of days that cyclones were within a certain distance of the coast (say, 500 km). It is only such cyclones which constitute a major threat to Australia. Some indicator of the strength of a cyclone could also be included in a measure of the cyclone threat. Thus supertropical cyclones constitute more of a threat than do systems which just reach cyclone intensity. This should probably also be taken into account in deriving a cyclone threat index for seasonal prediction. Such indices, and the feasibility of their prediction, will be examined in future studies, as will the mechanisms that seemingly allow long-range prediction of tropical cyclone activity. Nicholls (1984a) has speculated on the causes of these relationships between Australian tropical cyclone activity and the Southern Oscillation.

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