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Recent performance of a method for forecasting Australian seasonal tropical cyclone activity

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The relationship between Australian region seasonal tropical cyclone numbers and prior values of the Southern Oscillation Index (SOI) is examined, with particular emphasis on the period after 1979. The first study indicating that the Southern Oscillation could be used to predict Australian tropical cyclone numbers was published in 1979, so later data provide an independent test of the relationship. Interannual variations of cyclone numbers have continued to be related with prior values of the SOI throughout the post-1979 period, and showed skill relative to persistence or climatological 'predictions'. However, the relationship has been confounded by secular changes in the numbers of cyclones, including a drop in cyclone numbers after 1986 that was not associated with a corresponding drop in the SOI. This would have led to substantial over-prediction of seasonal cyclone numbers in the seasons 1986/87–1990/91, although the changes in cyclone numbers from year to year would still have been predicted quite accurately. Use of the SOI to predict the change in cyclone numbers from last season to the coming season, rather than predicting the expected numbers directly from the SOI, could reduce the confounding effect of possible secular changes in cyclone numbers, the SOI, or of relationships between them.

Introduction

Nicholls (1979) proposed, on the basis of an empirical study, that Australian seasonal tropical cyclone activity was predictable using observations of Darwin pressure in the months leading up to the cyclone season. Darwin pressure is an index of the Southern Oscillation (e.g. McBride and Nicholls 1983). Subsequent studies (Nicholls 1984, 1985; Revel and Goulter 1986a, 1986b; Dong 1988; Hastings 1990; Solow and Nicholls 1990) have confirmed that Australian seasonal tropical cyclone activity is related to the El Niño-Southern Oscillation phenomenon, and predictable through the use of indices of the phenomenon. Solow and Nicholls (1990), for example, used September values of the Southern Oscillation Index (SOI), the normalised difference between atmospheric pressure at Darwin and Tahiti, as the predictor. They, and Nicholls (1985), demonstrated that the relationship has been operating since at least 1910.

There have been 12 cyclone seasons since the study of Nicholls (1979) indicated that an index of the Southern Oscillation could predict seasonal cyclone activity. No verification of the predictive relationship on these independent data has, as yet, been published. Impetus for verifying the recent performance of the SOI-cyclone relationship was also provided by Drosdowsky and Woodcock (1991) who observed that the September 1988 SOI would have led to a substantial over-prediction of cyclone numbers for the 1988/89 season, possibly indicating a change in the SOI-cyclone relationship. In the present paper the performance of the forecast method is analysed for the cyclone seasons 1979/80 to 1990/91. It should be noted that this is not a true independent test of the forecast method, since the forecasts were not prepared and issued in 'real-time', i.e., they are 'hindcasts'. Analysis of the 'performance' of the forecast method in recent years should, however, provide guidance on the accuracy possible in real-time forecasting.

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Data and methods

Numbers of tropical cyclones in the Australian region (105°E–165°E) have been taken from Lourensz (1981) for the seasons up to 1979/80. These have been supplemented from seasonal cyclone summaries (Rooney 1981; Lynch 1982; Bate 1983; Thom 1984; Kuuse 1985; Kingston 1986) for the seasons 1980/81 to 1985/86. Cyclone numbers for the last five seasons were obtained from files held by the Severe Weather Warning Services Program Office of the Australian Bureau of Meteorology. SOI values were provided by the Bureau's National Climate Centre.

Seasonal cyclone numbers were correlated with values of the SOI from months leading up to the cyclone season. Three-month means of the SOI (June to August and September to November) were used (Nicholls (1979) used the same three-month means of Darwin pressure). Data from the 1959/60 cyclone season up to the 1990/91 season are used, so that the behaviour in the period before Nicholls (1979) could be contrasted with the behaviour after 1979.

For some parts of the analysis, first differences of seasonal cyclone numbers were taken, i.e. the numbers of cyclones observed last year were subtracted from the numbers observed this year. First differences of the SOI were also calculated. This was done to reduce the effect of non-linear trends observed in the cyclone numbers. Such trends can confound linear regression/correlation studies.

Results

Time series of the seasonal cyclone numbers and the September to November SOI are plotted in Fig. 1. Figure 2 shows the cyclone numbers plotted with June to August SOI. A cursory examination of the two figures indicates that fluctuations in cyclone numbers from year to year are related to the SOI, both before and after 1979. Table 1 lists correlations between the SOI and cyclone numbers calculated using different periods of data.

Positive correlations are observed both before and after the 1978/79 season, but the correlations in the latter part of the record are relatively low although still positive. Separation of the post-1979 record into two sections, before and after 1986, leads to higher correlations. The reason for this, and the lower correlations when all the post-1979 data are used, is clear from inspection of Figs 1 and 2. After the 1985/86 season the numbers of cyclones are consistently lower than would have been expected from the observed values of the SOI. This feature is also evident in Fig. 3 which is a scatter plot of the September to November mean SOI versus tropical cyclone numbers. In each season from 1986/87 to 1990/91 the observed number of tropical cyclones is lower than expected from the regression between SOI and cyclone numbers (i.e. the point representing each of these

Fig. 2 **Time series of the number of tropical cyclones in the Australian region and the June to August SOI.**

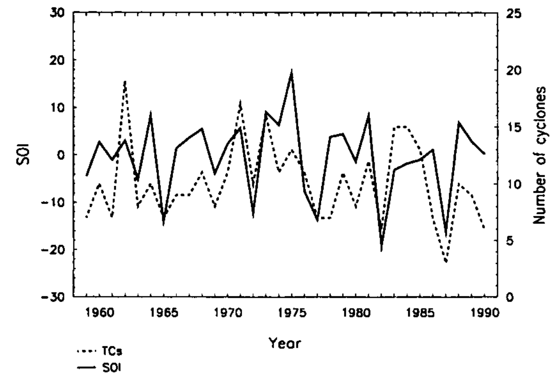


Table 1. **Correlations between SOI and Australian region seasonal tropical cyclone numbers. Correlations in italics are significant at 5 per cent.**

Seasons	*Jun–Aug SOI*	*Sep–Nov SOI*
1959/60–1990/91	*0.51*	*0.58*
1959/60–1978/79	*0.52*	*0.65*
1979/80–1990/91	0.49	0.45
1979/80–1985/86	0.52	*0.82*
1986/87–1990/91	*0.94*	0.82

Fig. 1 **Time series of the number of tropical cyclones in the Australian region and the September to November SOI.**

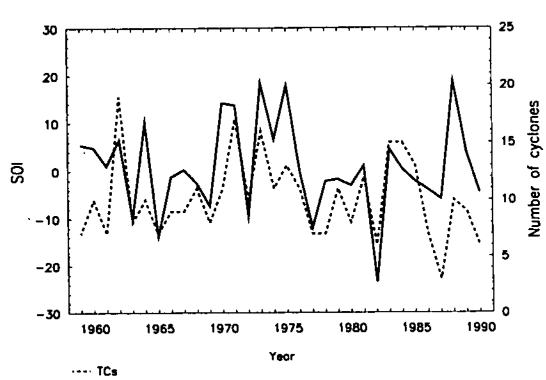


Fig. 3 Scatter diagram of Australian region tropical cyclone numbers versus September to November SOI. The full dots indicate seasons after 1986; open dots indicate data from the 1959/60 to 1985/86 seasons. The full line is the regression between the two variables, calculated using all the data shown in the figure.

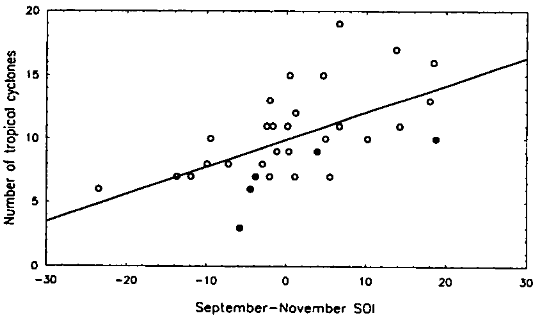
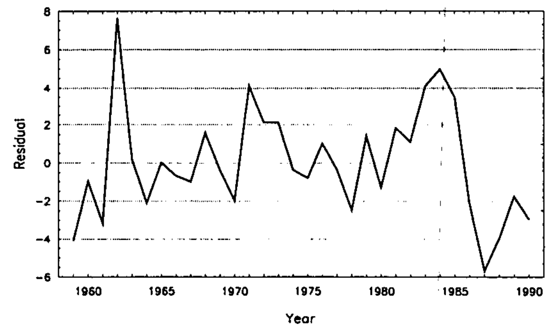


Fig. 4 Residuals (i.e. observed-predicted) of seasonal tropical cyclone numbers from the regression on September to November SOI.

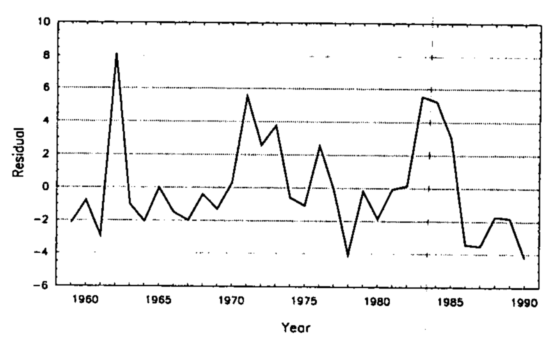


years falls below the linear regression line shown in the figure). Thus the behaviour noted by Drosdowsky and Woodcock (1991) for the season 1988/89, i.e. a substantial over-prediction of cyclone numbers from prior values of the SOI, would have occurred in each of the past five years.

The change in the SOI-cyclone relationship after 1986 was further investigated by calculating the linear regression between September to November SOI and cyclone numbers, and calculating the residuals from this regression. Data from the 1959/60 to 1990/91 seasons were used. The residuals from this regression are plotted in Fig. 4. An increasing trend towards positive residuals is evident up to the mid-1980s. From 1986 there is a sudden drop to substantial negative residuals (i.e. over-prediction). A similar trend in the residuals when June to August SOI values are used as the predictor is also evident, although somewhat less clearly (Fig. 5). In both figures the 1962/63 season stands out as an outlier from the long-term trends in residuals. The apparent anomalous behaviour of this season has been noted by Nicholls (1985) and Solow and Nicholls (1990).

There is some indication of non-stationarity in the time series of cyclone numbers (Fig. 1), as well as in the residuals. A general tendency for increased numbers (apart from the anomalous 1962/63 season) from the 1959/60 season up to the mid-1980s, followed by a sharp drop in numbers following the 1985/86 season can be seen. Possible causes for these trends in cyclone numbers, and in the relationship between cyclone numbers and the SOI, are discussed in the next section. First, however, ways of calculating the relationship between cyclone numbers and the SOI, after minimising the possible confounding effects of secular changes, are considered.

Fig. 5 Residuals (i.e. observed-predicted) of seasonal tropical cyclone numbers from the regression on June to August SOI.



One way of dealing with such secular changes is to calculate non-linear trends then calculate anomalies of cyclone numbers in each season from this trend function. Such an approach was used by Nicholls (1985). Here the first differences of cyclone numbers (i.e. the change in cyclone numbers from the last season to the present season) and the first differences of September to November SOI are calculated. The first differences of the two series are then correlated. Calculation of first differences is a frequently-used technique to reduce non-stationarity in time series.

Time series of the first differences of September to November SOI and the first differences of cyclone numbers are shown in Fig. 6. Examination of the cyclone numbers series indicates that the use of differences has removed the non-linear trends. The figure also does not suggest, in con-

Fig. 6 Time series of first differences (coming season minus last season) of seasonal tropical cyclone numbers, and of September to November SOI.

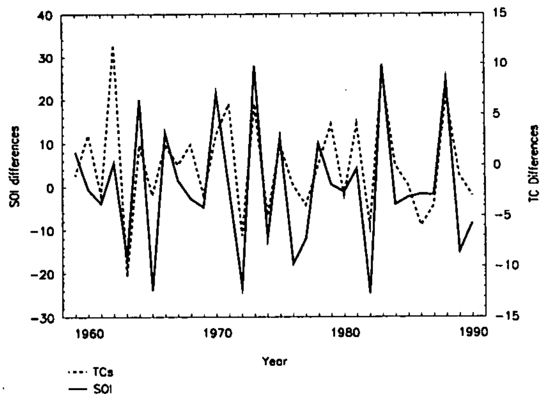


Table 2. Correlations between first differences of September to November SOI and first differences of seasonal tropical cyclone numbers, calculated using various periods of data. Correlations in italics are significant at 5 per cent. The correlations of September to November SOI with actual cyclone numbers (from Table 1) are listed for comparison.

Period	*Differences*	*Cyclone numbers*
1959/60–1990/91	*0.72*	*0.58*
1959/60–1978/79	*0.67*	*0.65*
1979/80–1990/91	*0.82*	0.45
1979/80–1985/86	*0.90*	*0.82*
1986/87–1990/91	*0.75*	0.82

trast to Fig. 1, marked secular changes in the relationship between the two series. Calculation of correlations between the two series (Table 2) confirms this. All the correlations between the first differences are significant. The use of first differences has removed the apparent secular change in 1986 which reduced the strength and significance of the correlations in the case of the actual cyclone numbers. This has led to a substantial increase in the correlation calculated with all seasons 1959/60 to 1990/91, as well as increasing the consistency, strength and significance of the post-1979 correlations. The correlations between the differences are actually higher in the 'independent', post-1979 period than in the earlier period.

The 'skill' of the hindcasts of cyclone numbers has been assessed by calculating the root mean square errors. Even though the apparent secular changes in cyclone numbers have confounded, to some extent, the predictive relationship with the SOI, the use of the SOI to predict cyclone numbers would have resulted in forecasts with more skill over the independent seasons 1979/80 to 1990/91 than other methods of estimating cyclone numbers. Table 3 lists root mean square errors of predictions of cyclone numbers calculated with a regression on September to November SOI. The regression relationship was calculated only using data from the 1959/60 to 1978/79 seasons. Also shown in the table are root mean square errors that would have occurred for persistence and climatological predictions. The persistence prediction assumes the number of cyclones in the coming season will equal the number observed in the previous season. The climatological prediction assumes that the number of cyclones in the coming season will equal the long-term average number. Here the long-term number is assumed to equal the 1959/60 to 1978/79 mean of 10.4.

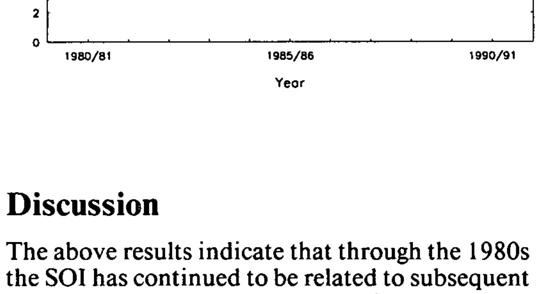
Table 3. Root mean square errors for predictions of seasonal tropical cyclone numbers for the seasons 1979/80 to 1990/91. Regression predictions were produced using regression relationships derived using 1959/60 to 1978/79 data. One regression forecast simply regressed cyclone numbers against September to November SOI. The other regression method regressed first differences, then added last year's cyclone numbers to the predicted difference in cyclone numbers. Persistence forecasts assume cyclone numbers in the coming season will equal the number observed in the last season. Climatological predictions assume the number of cyclones in the coming season will equal the 1959/60 to 1978/79 mean of 10.4.

Prediction method	*Root mean square error*
Climatological predictions	3.71
Persistence predictions	4.77
Regression on Sep–Nov SOI	3.26
Regression (predict change in cyclone numbers then add last year's numbers)	2.79

The use of the regression relationship between September to November SOI and cyclone numbers would have produced forecasts with RMS errors smaller than persistence or climatology on the 'independent' seasons 1979/80 to 1990/91 (although not significantly better). So, skilful forecasts would have been possible, even though the confounding effects of the secular changes in cyclone numbers would have tended to reduce the skill of the regression forecast.

Also listed in Table 3 is the error that would have resulted if the regression between the first differences of the SOI and the cyclone numbers had been used to predict cyclone numbers. In this approach, the regression relationship would have been used to predict the change in cyclone numbers between last season and the coming season. Then last season's cyclone numbers would have been added to this prediction to produce a prediction of the coming season's cyclone numbers. The skill of these forecasts over the independent period would have been greater (i.e. smaller RMS errors) than that achievable through direct prediction of cyclone numbers from the SOI, although still not significantly better than persistence or climatology. This approach would have reduced the confounding effects of secular changes in cyclone numbers, the SOI, or the relationship between them. The forecasts produced with this method do not result in, for example, consistent over-predictions of cyclone numbers in the 1986/87 to 1990/91 seasons (Fig. 7).

Fig. 7 **Time series of seasonal tropical cyclone numbers (full line) with predicted numbers from the regression between seasonal cyclone numbers and September to November SOI (dotted line), and from predictions based on regression between first differences of September to November SOI and first differences of cyclone numbers with last season's number added (broken line). Regressions calculated using data from the 1959/60 to 1978/79 seasons.**



Discussion

The above results indicate that through the 1980s the SOI has continued to be related to subsequent seasonal cyclone numbers. It is also clear, however, that two secular changes in the relationships have occurred between 1959 and 1991, and that these have confounded the SOI-cyclone relationship, somewhat reducing the skill. The differences from year to year of the SOI and cyclone numbers are related more strongly and consistently than are the absolute SOI values and cyclone numbers.

A secular increase in cyclone numbers occurred between 1959 and the mid-1980s, although with relatively lower numbers in the late 1970s. This trend is evident in the time series of cyclone numbers (Fig. 1). A parallel trend is not evident in the SOI. As a result, residuals calculated from the SOI-cyclone numbers regression also show a trend (Fig. 4).

This trend to more cyclones might be the result of improved access to satellite imagery. Improved access to polar-orbiting satellite imagery through the late 1960s and early 1970s, or changes in interpretation of the imagery, might account for the early part of the upward trend. Introduction of the Japanese geostationary satellite could have led to a further quantitative improvement in monitoring the Australian tropics. This might explain why the positive trend in the residuals continues up to the mid-1980s. It is possible, however, that the increasing trend in the residuals from the late 1950s to the early 1980s is the result of a real change in the relationship between the SOI and cyclone numbers, rather than improved and more frequent observations or changes in interpretation.

The sudden drop in negative residuals after the 1985/86 season might represent a real change in the SOI-cyclone relationship. Drosdowsky and Woodcock (1991) attributed the over-prediction in 1988/89 to an unusual development of the South Pacific convergence zone during January and February, with abnormally frequent tropical cyclone genesis in this area. Ready and Woodcock (1992) noted that a similar development occurred during the 1989/90 season. In this season four short periods of enhanced convection occurred near the date-line, during which several cyclones were generated. These intraseasonal events, with enhanced central Pacific cyclone activity, may have led to a reduction in the number of cyclones generated further west, i.e. around northern Australia. Such developments could account for the consistent negative residuals in the cyclone predictions after 1985 if they also occurred in the other three seasons. A physical reason for such a sudden change in the pattern of cyclone development in the South Pacific-Australian region does not immediately present itself.

The change in the relationship might, on the other hand, be artificial and result from spurious trends in either the SOI or cyclone numbers. A spurious trend in the SOI might result from, for instance, an inadvertent and unnoticed change in instrumentation or site. A secular change in tropical cyclone numbers might result from a change in interpretations of tropical depressions from satellite imagery, perhaps as a result of higher-quality imagery and other data.

Whatever the cause of the secular changes in the SOI-cyclone relationship, the larger and more consistent correlations and smaller RMS errors when first differences of cyclone numbers are correlated and regressed suggest a different approach to the prediction of seasonal cyclone numbers. The regression between, say, the change in September to November SOI and the first differences of cyclone numbers could be used to estimate the likely change in cyclone numbers between last season and the coming season. The actual number of cyclones observed last season could then be added to the predicted difference to provide a prediction of the likely number of cyclones for the coming season. This approach would reduce the effects of secular changes in the SOI-cyclone numbers relationship, whatever their cause. This approach would not have resulted in consistent over-prediction for the 1986/87 to 1990/91 seasons.

Conclusions

Examination of the recent performance of a method for forecasting Australian region tropical cyclone numbers using the SOI indicates that the SOI and cyclone numbers have continued to be closely related. Apparent secular changes in cyclone numbers not accompanied by changes in the SOI have, however, confounded the relationship. These changes would have led to consistent over-prediction of cyclone numbers with the SOI since the 1986/87 season.

This over-prediction commenced suddenly and may be the result of changes in interpretation of satellite imagery, inadvertent changes in the SOI, or a real physical change in the SOI-cyclone numbers relationship. Whatever the cause, it seems likely that secular changes in the relationship may continue to confound the use of the SOI in operational seasonal prediction of cyclone numbers. It is suggested, therefore, that the difference in cyclone numbers from last season to the coming season be predicted on the basis of the observed change in the SOI. The observed number of cyclones from the last season could then be added to this prediction to provide a forecast of the number of cyclones expected in the coming season. This approach provided more skilful forecasts of cyclone numbers over the period of 'independent' data from 1979/80 to 1990/91 than predicting seasonal cyclone numbers directly from observed SOI. The use of differences in this way may provide a means for avoiding deterioration of seasonal climate forecast systems in a changing climate, or in other circumstances which might lead to non-stationarity in predictive relationships.

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References

Bate, P. 1983. The Australian tropical cyclone season 1982–83. *Aust. Met. Mag., 31*, 209–16.

Dong, K. 1988. El Niño and tropical cyclone frequency in the Australian region and the northwest Pacific. *Aust. Met. Mag., 36*, 219–25.

Drosdowsky, L. and Woodcock, F. 1991. The South Pacific and southeast Indian Ocean tropical cyclone season 1988–1989. *Aust. Met. Mag., 39*, 113–29.

Hastings, P.A. 1990. Southern Oscillation influences on tropical cyclone activity in the Australian/Southwest Pacific region. *Int. J. Climatol., 10*, 291–8.

Kingston, G. 1986. The Australian tropical cyclone season 1985–86. *Aust. Met. Mag., 34*, 103–16.

Kuuse, J. 1985. The Australian tropical cyclone season 1984–85. *Aust. Met. Mag., 33*, 129–43.

Lourensz, R.S. 1981. *Tropical Cyclones in the Australian Region July 1909 to June 1980*, Bureau of Meteorology, Melbourne, Australia, 94 pp.

Lynch, K. 1982. The Australian tropical cyclone season 1981–82. *Aust. Met. Mag., 30*, 305–14.

McBride, J.L. and Nicholls, N. 1983. Seasonal relationships between Australian rainfall and the Southern Oscillation. *Mon. Weath. Rev., 111*, 1998–2004.

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.

Ready, S. and Woodcock, F. 1992. The South Pacific and Southeast Indian Ocean tropical cyclone season 1989–90. *Aust. Met. Mag., 40*, 111–21.

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

Revell, C.G. and Goulter, S.W. 1986b. Lagged relationships between the Southern Oscillation and numbers of tropical cyclones in the Southern Pacific region. *Mon. Weath. Rev., 114*, 2669–70.

Rooney, W. 1981. The Australian tropical cyclone season 1980–81. *Aust. Met. Mag., 29*, 143–53.

Solow, A. and Nicholls, N. 1990. The relationship between the Southern Oscillation and tropical cyclone frequency in the Australian region. *Jnl Climate, 3*, 1097–101.

Thom, D.E. 1984. The Australian tropical cyclone season 1983–84. *Aust. Met. Mag., 32*, 137–53.