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Recent Trends in Australian Region Tropical Cyclone Activity

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With 7 Figures

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Summary

The number of tropical cyclones observed in the Australian region (south of equator; 105–160° E) has apparently declined since the start of reliable (satellite) observations in the 1969/70 season. However, the number of more intense cyclones (with minimum pressures dropping to 970 hPa or lower) has increased slightly. The numbers of weak (minimum pressures not dropping below 990 hPa) and moderate systems (minimum pressures between 970 and 990 hPa) have declined. Possible reasons for these different trends are discussed. The decline in the number of weaker cyclones may at least partly reflect improved understanding of the nature of some weak systems. The decline in the number of cyclones more intense than 990 hPa primarily reflects the downward trend in the Southern Oscillation Index (SOI). Previous work has demonstrated that the number of tropical cyclones observed in the Australian region each cyclone season is related to the value of the SOI prior to the start of the cyclone season. This relationship is clearest with the number of moderate cyclones. The SOI is only weakly related to the number of intense or weak cyclones. The increase in the number of intense cyclones is not attributable to the trend in the SOI. Nor is there clear reason, at present, to suspect that it is artificial (i.e., due to changes in observing or analysis techniques).

1. Introduction

Landsea et al. (1996) reported a downward trend, since mid-century, in the annual number of intense hurricanes in the Atlantic basin. Chan and Shi (1996) found that, since the mid-1970s, western North Pacific tropical cyclone activity has increased. The focus on such trends reflects the interest in the possible effects of an enhanced greenhouse effect on tropical cylone activity, and the need to understand natural, long-term variability. Here we examine trends in tropical cyclone activity in the Australian region (south of equator; 105–160° E), including cyclones that formed in the region and those that move into the region after forming elsewhere, to enable comparison with the trends identified by Landsea et al. (1996) and Chan and Shi (1996). As background, some factors affecting tropical cyclone numbers in this region are discussed below.

The observational network has changed during the period of recorded tropical cyclone activity. The improvements to the network, including the introduction of satellite observations, have led to an increase in the number of cylones observed. The cyclone season of 1960/70 is suggested by Holland (1981) as the first reliable year due to the availability of geostationary satellite pictures during (and since) that season. Holland observed that apparent trends in the numbers of tropical cyclones prior to that date would be likely due to changes in observing systems. Therefore, only the cyclone seasons from 1969/70 to 1995/96 are considered here. Inclusion of earlier data in a search for trends would clearly produce artificial trends, simply reflecting the improved observational network.

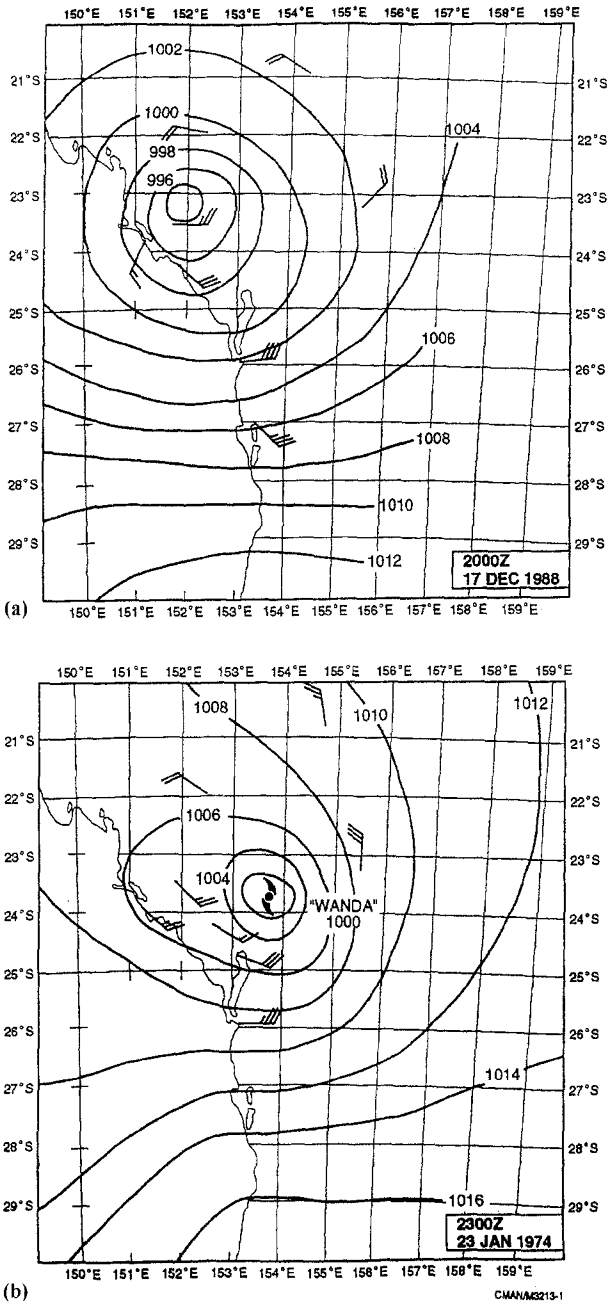

Fig. 1. Synoptic analysis of (a) a cyclonic system on 17 December 1988 with minimum central pressure of 998 hPa, and (b) Tropical Cyclone Wanda on 23 January 1974, with minimum central pressure of 1000 hPa

Even in the period since 1969/70, however, the observational network has not remained constant. Improved access to digital satellite data by tropical cyclone analysts, as well as the installation of coastal and off-shore radar stations, may have affected the number of cyclones observed. These improvements may have led forecasters to avoid identifying a system as a cyclone unless the evidence that a cyclone had formed was compelling. Previously, some systems may have been identified as cyclones when the observational evidence was incomplete.

The understanding, by analysts, of the nature of tropical systems has improved over the period examined in this paper. A growing awareness has developed amongst forecasters of a type of system that does not possess the traditional tropical cyclone inner-core structure, but rather has the band of maximum winds well removed from the centre. In the past, these systems may have more readily been identified as cylcones whereas recently this has tended to happen only if the system adopts a more classic tropical cyclone structure. This change in approach is illustrated in the two cyclonic systems (one from 1974: the second from 1988) shown in Fig. 1. Both systems had broad pressure gradients and the strongest winds well removed from the vortex centre. However, the 1974 system was considered to be a tropical cyclone and named "Wanda", while the 1988 system was not named as a tropical cyclone.

The relationship between the number of tropical cyclones in the Australian region and the Southern Oscillation Index (SOI) is well-known (e.g., Nicholls, 1979, 1984, 1985, 1992; Revel and Goulter, 1986a, b; Dong, 1988; Hastings, 1990; Solow and Nicholls, 1990; Evans and Allan, 1992; Basher and Zheng, 1995). This relationship can be used to predict cyclone activity. Low values of the SOI, typically associated with an El Niño, during the Southern Hemisphere spring usually indicate that the ensuing cyclone season will have fewer than normal cyclones. During such years cyclone activity usually increases in the central South Pacific (Revel and Goulter, 1986a, b; Hastings, 1990; Basher and Zheng, 1995). A downward trend in the SOI should, therefore be accompanied with a decline in cyclone activity in the Australian region, if all other factors remain the same. There has been a downward trend in the SOI in this period (e.g., Trenberth and Hoar, 1996).

So, any trends in observed numbers of tropical cyclones in the Australian region could reflect trends in the SOI, or be the result of changes in observational systems or reflect improved understanding of tropical systems, or even of changes in definition of a tropical cyclone. As well, there may also be underlying trends due to a changed climate, perhaps associated with the general global warming of the past few decades. Air temperatures across Australia have generally increased since mid-century (Torok and Nicholls, 1996). The possible explanation of any observed trends by the factors noted earlier (changes in observational networks, changes in understanding or definition of tropical systems) needs to be considered before we conclude that these trends are the result of an underlying climate change.

2. Trends in Cyclone Activity

Time-series of the total number of tropical cyclones, along with the number with minimum pressures higher than 990 hPa ("weak" cyclones), the number with minimum pressures less than or equal to 970 hPa ("intense" cyclones), and the number between 970 and 990 hPa ("moderate" cyclones), in each year since the 1969/70 season, are shown in Fig. 2. The total number of cyclones shows a significant downward trend. The correlation with the year was −0.43, significant at 5%. The number of weak and moderate cyclones also declined (correlations with year were −0.35 for weak cyclones and −.56 for moderate cyclones). However, the number of intense cyclones increased, although the correlation with year (0.17) was weak and not significant.

Much of the decline in the number of weak cyclones occurred abruptly, in the mid-1980s. Before and after 1985 there is little evidence of trends. The mean number of weak cyclones between 1969/70 and 1984/85 was 2.4; the mean number since the 1985/86 season has been 1.1. This difference in mean numbers of weak cyclones between the two periods is significant at the 5% level. The abrupt nature of this decline suggests that the drop may be artificial, reflecting the changes in the understanding of tropical cyclones (and of naming of cyclones) noted above. Also supporting the artificial nature of this decline is the change in relationship between cyclone numbers and the SOI, in the mid-1980s, noted by Nicholls (1992). Since the mid-1980s, there has been a bias in the number of tropical cyclones predicted by the SOI values. The sudden nature of this change is also suggestive of an artificial cause, rather than a climate change that might be anticipated to be gradual. The change in the number of moderate cyclones (with minimum pressures between 970 and 990 hPa), on the other hand, did not occur as a step (Fig. 2).

The weak increase in the number of more intense tropical cyclones has been more gradual and sustained over the period examined here. This suggests that this trend is perhaps less likely to be artificial. The threshold of 970 hPa used here for intense tropical cyclones equates, in the Australian region, to tropical cyclones with an eye identifiable from satellite imagery. This should mean that the number of intense tropical cyclones is less likely to have been affected by changes in interpretation or observation networks, since the advent of routinely available geostationary satellite images. However, the possibility that the slight upward trend in the number of intense tropical cyclones is due to artificial effects cannot be entirely discounted.

3. Relationship Between Tropical Cyclone Activity and the Southern Oscillation

As noted earlier, the relationship between cyclone numbers and the SOI means that the recent downward trend in the SOI might be expected to be accompanied by a downward trend in cyclone numbers. The correlations of the numbers of tropical cyclones in various categories, with monthly values of the SOI, are shown in Fig. 3. Correlations were also calculated between cyclone numbers and three-month SOI averages. There was little difference between the correlations with monthly averages and the correlations with three-monthly averages. All the categories of tropical cyclones are positively correlated with the SOI after February, but the strongest correlation is with the number of moderate systems. Both weak and strong cyclones were less clearly (and not significantly) related to the SOI. However, at least in the case of intense tropical cyclones, the lack of strength in the relationship with the SOI is partly due to the confounding effect of the positive trend in the cyclone numbers. This trend is the opposite to that which might be expected from the SOI (which has exhibited a negative trend over the period examined here). This is examined further in the next section.

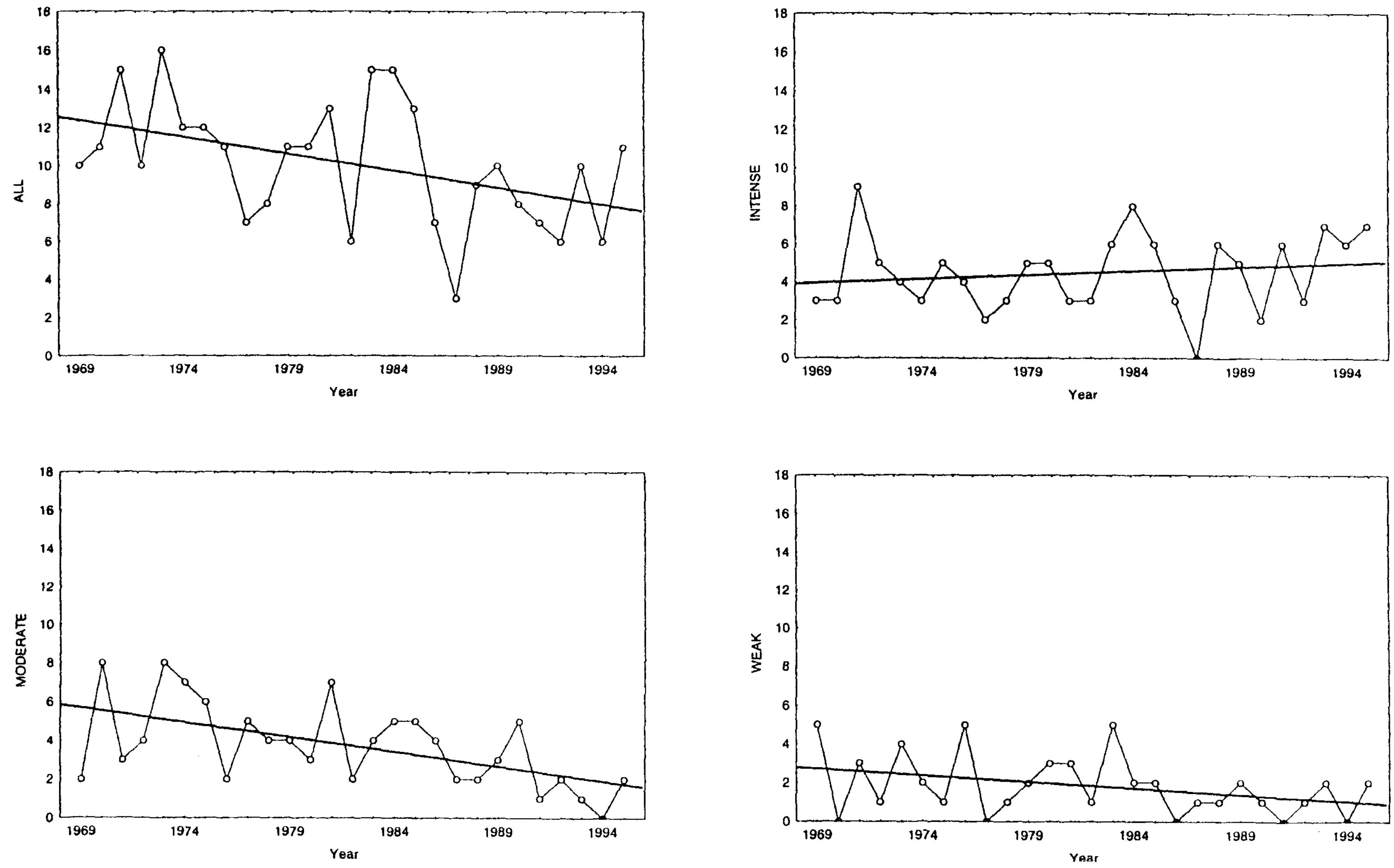

Fig. 2. Time series (top left frame) of the total number of tropical cyclones in the Australian region (105–106E). Also shown are time series of the number of intense cyclones (with minimum pressures less than or equal to 970 hPa-top right frame), the number of moderate cyclones (with pressures between 970 and 990 hPa-bottom left frame), and the number of weak cyclones (with minimum pressures greater than 990 hPa-bottom right frame). Linear trends for all time-series are shown as thick lines. The cyclone season starts around November and lasts until about May. The abscissa gives the year in which the cyclone season starts (e.g., the 1969/70 season is plotted against "1969")

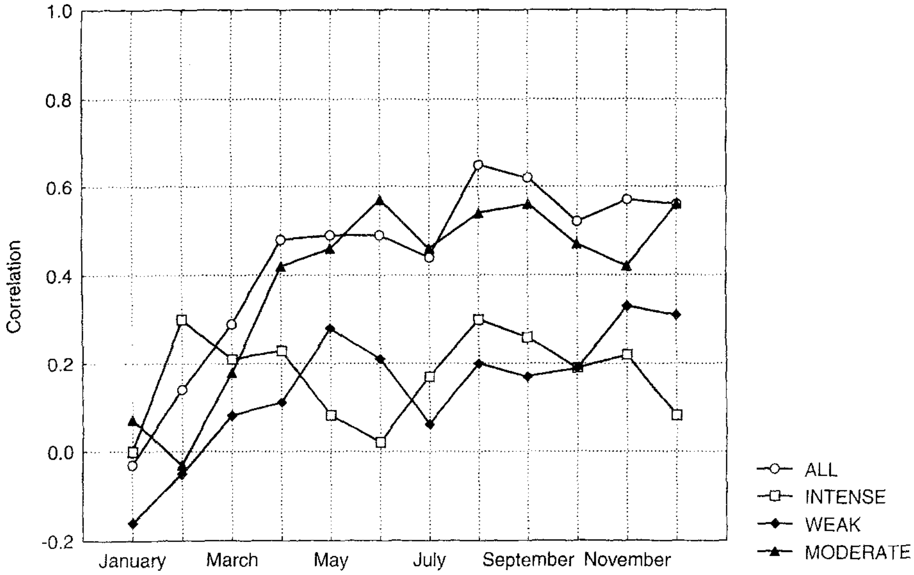

Fig. 3. Correlations between the time series of the number of cyclones in various categories (as defined in the caption to Fig. 2) and monthly mean values of the SOI

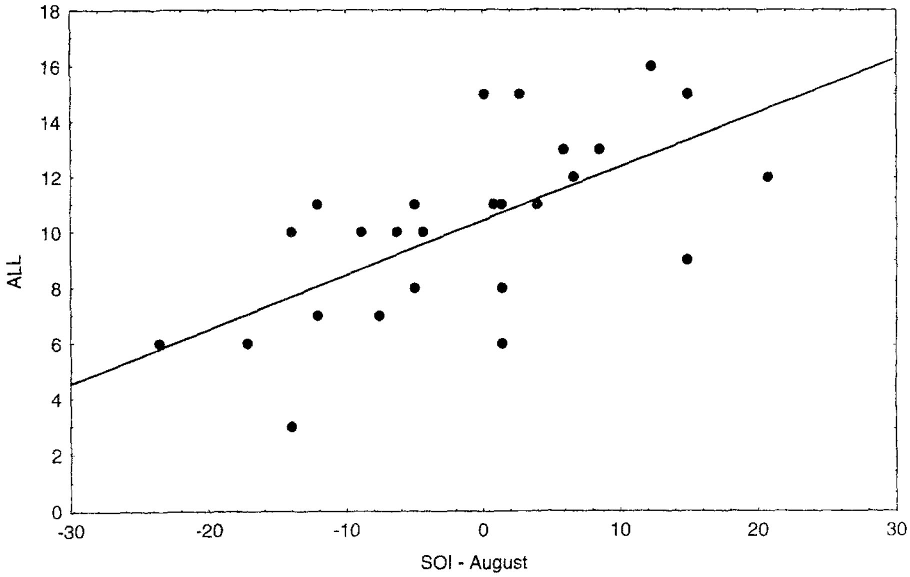

Fig. 4. Scatter diagram of the total number of tropical cyclones, versus the August SOI

Figure 4 is a scatter diagram of the total number of cyclones plotted against the August SOI. The correlation is 0.65 ($n = 27$, significant at 5%). Figure 5 shows a similar scatter diagram, but for the number of cyclones with minimum pressures less than or equal to 990 hPa (ie, combining the intense and moderate cyclones). The correlation in this case is 0.69. Linear lines of best fit are shown in the figures. The linear regression for the number of cyclones less than or equal to 990 hPa, is:

$$TC_{<=990} = 8.5 + 0.167SOI_{\text{August}}$$

where $TC_{<=990}$ is the number of tropical cyclones with minimum pressures less than or equal to 990 hPa, and SOI_{August} is the August value of the SOI. The corresponding equation for predicting all tropical cyclones is:

$$TC_{\text{all}} = 10.4 + 0.196SOI_{\text{August}}$$

where TC_{all} is the total number of tropical cyclones.

After the mid-1980s few systems were designated as tropical cyclones that did not reach a minimum pressure below 990 hPa. The first of the equations above, therefore, may be more

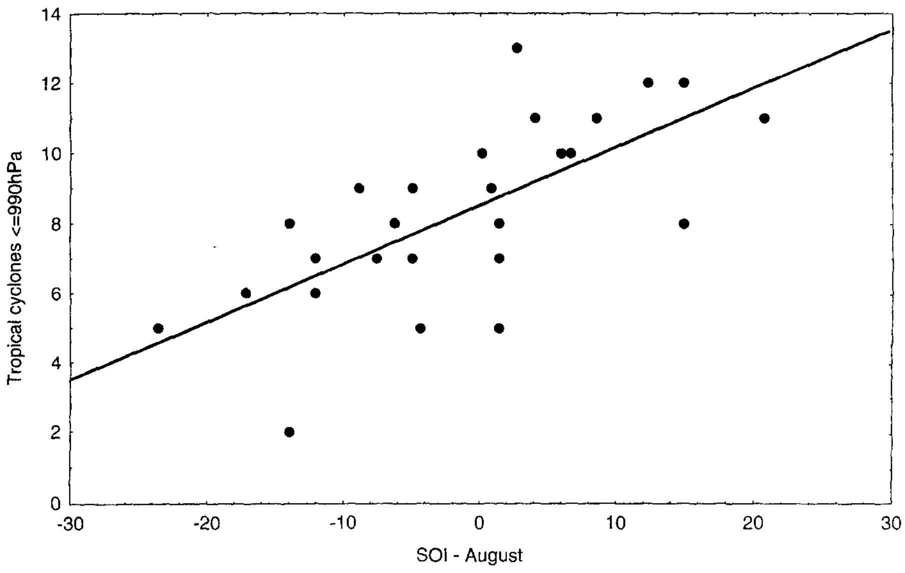

Fig. 5. Scatter diagram of the number of tropical cyclones with minimum pressures less than or equal to 990 hPa, versus the August SOI

appropriate for predicting Australian region tropical cyclone activity than the second, which would be compromised by the apparently artificial change in the number of weak systems noted earlier.

4. Effect of the SOI on the Trend in Cyclone Numbers

As noted above, the SOI has exhibited a weak downward trend in recent decades, mainly due to the tendency for negative values throughout the 1990s (Trenberth and Hoar, 1996). Here we examine whether the downward trend in the numbers of cyclones in the Australian region simply reflects the trend in the SOI.

The effect of the SOI on the trend in tropical cyclone numbers can be assessed through linear regression. Figure 6 shows the total number of tropical cyclones, along with the number of cyclones "predicted" by linear regression from the August SOI, using the above equation. The linear trend of both time-series with year is also included in Fig. 6. Both time series exhibit a downward trend. The trend in the observed numbers is similar to that "predicted" by the

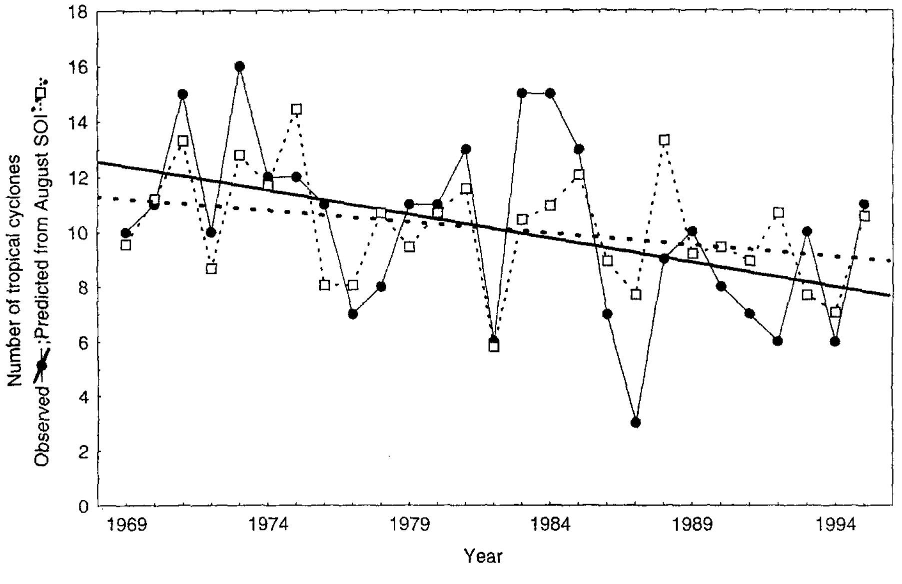

Fig. 6. Time series of the total number of tropical cyclones (full line with full circles identifying each year's data), and the number of cyclones "predicted" with the linear regression against August SOI (broken line and open squares). Heavy full and broken lines illustrate the linear trend in each time series

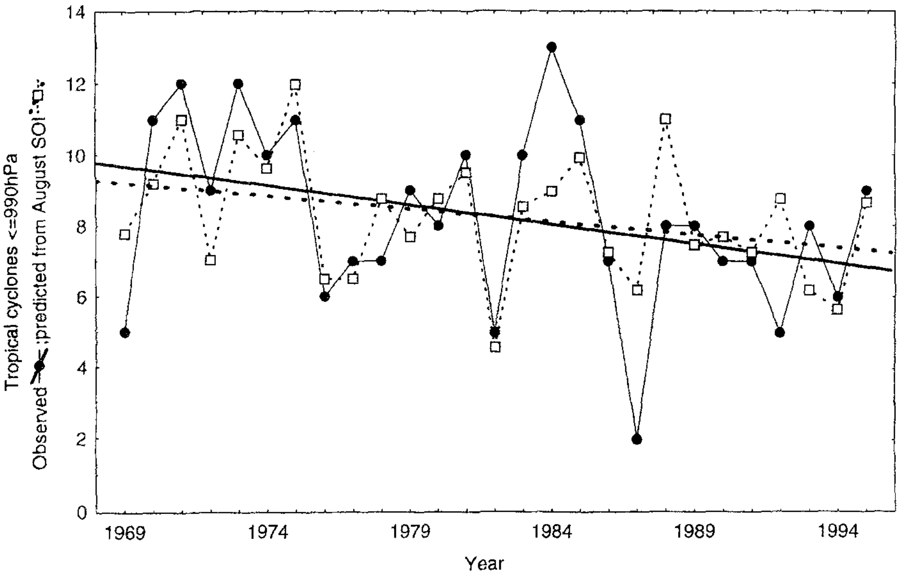

Fig. 7. Time series of the number of tropical cyclones with minimum pressures less than or equal to 990 hPa (full line with full circles identifying each year's data), and the number of cyclones "predicted" with the linear regression against August SOI (broken line and open squares). Heavy full and broken lines illustrate the linear trend in each time series

August SOI suggesting that the SOI trend is the "cause" of much of the trend in cyclone numbers.

Figure 7 repeats this analysis, but this time for the number of cyclones with pressures less than or equal to 990 hPa. In this case the trend "predicted" from the August SOI is even closer to that observed. The closeness of the trends in this figure, compared to the situation in Fig. 6, probably results from the compromising of the total number of cyclones by the apparently artificial decline in the number of weak systems in the mid-1980s. Most of the trend in the number of cyclones with pressures less than or equal to 990 hPa is attributable to the downward trend in the SOI.

Another approach to estimate the effect of a trend in the SOI on the trend in cyclone numbers is first to detrend the cyclone number series and the SOI series. Then the linear regression between the detrended series can be calculated and used, with the actual trend in the SOI, to estimate the trend in the cyclone numbers that could be expected from the observed trend in the SOI. This was done for the total cyclone numbers and the numbers of cyclones with minimum pressures less than or equal to 990 hPa. This analysis confirmed the results from the analysis presented in Figs. 6 and 7.

The above analysis on detrended series was also applied to the number of intense cyclones. The correlation between the detrended August SOI and the detrended number of intense cyclones was 0.39 (cf. 0.30 for the undetrended series). Thus the detrending, by removing the confounding effect of the weak trend in cyclone numbers and the trend in the SOI, revealed a statistically-significant correlation with August SOI, although this correlation was still weak relative to the correlations with the total number of cyclones and the number of cyclones less than or equal to 990 hPa.

The linear regression of the detrended number of intense cyclones on the detrended August SOI was:

$$\delta \mathrm{TC}_{\mathrm{intense}} = 0.126 + 0.138\delta \mathrm{SOI}_{\mathrm{August}}$$

Where $\delta \mathrm{TC}_{\mathrm{intense}}$ is the change from year to year of the number of intense tropical cyclones and $\delta \mathrm{SOI}_{\mathrm{August}}$ is the change in August SOI from one year to the next. The trend in the August SOI from 1969 to 1995 was −11.3. This trend can be used with the above equation to estimate the effect of this SOI trend on the number of intense tropical cyclones. The downward trend in the SOI should have led to a reduction of about 0.76 in the number of intense tropical cyclones, over this period. In fact, the number of intense cyclones increased, despite this tendency to a reduction due to the downward SOI trend. It would appear, therefore, that in the absence of the downward trend in the SOI that the increase in the number of intense cyclones may have been larger than that observed.

5. Concluding Remarks

A strong downward trend in tropical cyclone numbers in the Australian region over the past few decades is partly attributable to an improved discrimination between tropical cyclones and other systems. This improved understanding appears to have led to a sudden drop in the number of named, weak tropical cyclones in the mid-1980s. If the effect of this improved discrimination is avoided, by ignoring the weak cyclones, then the trend is more gradual across the period of record. This more gradual trend largely reflects the downward trend in the SOI.

These results indicate the care needed in the analysis of "derived" variables such as tropical cyclone numbers, especially if trends in the variables are to be examined. If only total cyclone numbers are examined, one might conclude that the Australian region cyclone numbers have exhibited a significant trend similar to that in the Atlantic (Landsea et al., 1996). The difference between the two basins, however, is that in the Atlantic it is the intense cyclones which have exhibited a downward trend in numbers. In the Australian region, the intense cyclones have shown a weak upward trend. This trend does not appear to be attributable to the improved discrimination between tropical cyclones and other systems, nor to trends in the SOI. In fact, the observed increase in intense cyclones may have been larger, but for the downward trend in the SOI.

The analysis has demonstrated that the SOI, although a good predictor of the number of tropical cyclones in the Australian area, confirming many earlier studies, is not a good predictor of the intensity of cyclones. Only the number of moderate cyclones were significantly correlated with prior values of the SOI (although the number of intense cyclones were correlated significantly, but still relatively weakly, with the SOI if the effect of trends in the variables were removed). The weaker correlations with the more intense cyclones suggests that the El Niño-Southern Oscillation plays a major role in dictating the broad scale environmental conditions that may help or hinder tropical cyclone genesis throughout the season, but once a cyclone has formed other factors not strongly related to the El Niño-Southern Oscillation influence whether it will develop into an intense system, or remain relatively weak.

Acknowledgments

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