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Recent apparent changes in relationships between the El Niño - southern oscillation and Australian rainfall and temperature

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Abstract. High quality historical temperature and rainfall data sets have been used to produce time series of annual rainfall and temperature, averaged over Australia. The relationships between these series, and with the Southern Oscillation Index, have been examined. A change in the relationships between the variables appeared in the early 1970s. Since then, for any value of the SOI or rainfall, maximum temperature has tended to be higher than previously. Likewise, rainfall, for any value of the SOI, has tended to be greater than would have been expected for such an SOI value in previous years. Artificial changes, such as changes in instrumentation, seem unlikely to account for these observed changes in relationships. Model experiments have duplicated some of the changes in the relationships. Increased Indian Ocean temperatures may be the causal factor underlying these changes.

Introduction

For some years there has been concern that an enhanced greenhouse effect, or other anthropogenic influences on climate, may affect the behaviour of the El Niño - Southern Oscillation (e.g., Nicholls, 1993; Meehl and Washington, 1996; Trenberth and Hoar, 1996). The El Niño - Southern Oscillation has a substantial impact on Australian climate (e.g., Allan, 1991). A change in El Niño - Southern Oscillation behaviour may, therefore, influence Australian climate variations. Likewise, a change in the background (mean) climate, even without a change in the El Niño - Southern Oscillation, may also lead to changes in the relationships between El Niño - Southern Oscillation and Australian climate variations. Such a change might invalidate current methods designed for the prediction of these climate variations. Here we use new high-quality historical rainfall (Lavery et al., 1997) and temperature (Torok and Nicholls, 1996) time series for Australia to document apparent recent changes in the relationships between rainfall and temperature, and with the El Niño - Southern Oscillation. The possibility that these decadal-scale variations in the relationships are artificial, resulting from instrumental or observational changes, is discussed.

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Results

Spatial averages of annual rainfall, and minimum and maximum temperature, for Australia as a whole, were calculated using Theissen polygon coefficients (Louie, 1977). All three variables have increased during the 20th century (Lavery et al., 1997; Torok and Nicholls, 1996). Minimum temperatures are not correlated with rainfall or the SOI. Rainfall and maximum temperature are significantly correlated with each other and with the SOI. The relationship between maximum temperature and rainfall is evident in the time series of these variables in Figure 1 (note that maximum temperatures have been multiplied by -1 in this figure, to assist in the display of the strong negative relationship). The tendency for low temperatures in years of high rainfall is clear. The figure also suggests a change in the relationship from the early 1970s. Before about 1973 the two time series are well separated; from 1973 onwards they are almost coincident. This apparent change in the relationship is also suggested by calculations of the linear correlation coefficient between the two variables. Using data up to and including 1972, the correlation is -0.72. The inclusion of 1973 causes the magnitude of the correlation to drop to -.61 and it remains about -0.6 with the addition of later data. It thus appears that a quite abrupt change in the relationship occurred about 1973. Note that including the post-1972 data, but excluding 1973, also leads to relatively weak correlations, indicating that it is not just the one year (1973) which produces this apparent relationship change.

Regressions between the SOI, rainfall, and maximum temperature are provided in Table 1, for two periods: 1910-1972 and 1973-1992, i.e., before and after the apparent change in the relationships evident in Figure 1 and in the correlations. Figure 2 shows the negative relationship between maximum temperatures and rainfall. The correlation between the variables is clearer if the data are separated into two periods, before and after the early 1970s. In the later period maximum temperatures were higher, for any value of rainfall, than was the case prior to that date.

Figure 3 shows the relationship of rainfall with the SOI. Rainfall is higher than normal when the SOI is positive. Again, the relationship between the two is clearer if the data are stratified into two periods. After the early 1970s, rainfall tends to be greater for any specific value of the SOI than was the case in the earlier data.

Figure 4 shows the relationship between maximum temperatures and the SOI. Maximum temperatures tend to be lower

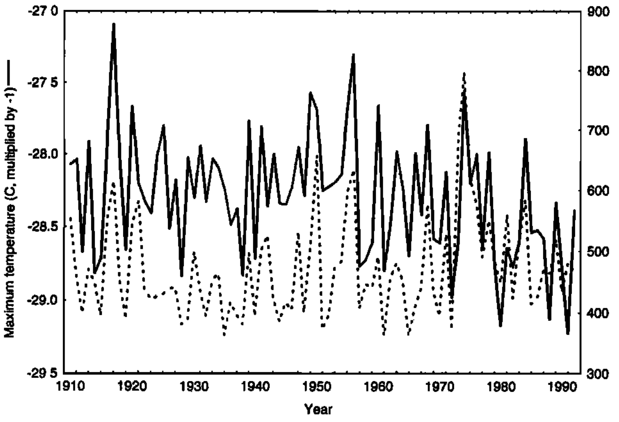

Figure 1. Time series of All-Australian maximum temperature (solid line) and rainfall (broken line). Note that the temperatures have been multiplied by -1 to provide a clearer display of the relationship with rainfall.

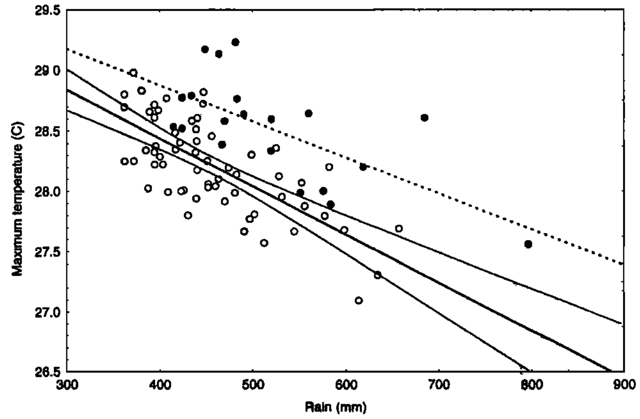

Figure 2. Scatter diagram of All-Australian maximum temperature versus rainfall. Data from 1910-1992. Years after 1972 are indicated by full circles. The thick continuous line is the linear regression calculated from the 1910-72 data. The thin continuous lines indicate the 95% confidence band for this regression. The thick broken line is the regression line calculated from the 1973-92 data.

when the SOI is positive (presumably reflecting the fact that rainfall is high in such situations). Figure 4 suggests that maximum temperatures tend to be higher for any value of the SOI after the early 1970s than prior to this date.

Figures 2-4 include the regression lines calculated from the 1910-72 data and from the 1973-92 data. The 95% confidence bands for the population regression lines of the 1910-1972 data are also shown. In each case, the regression lines for the 1973-92 data lie well outside the confidence bands for the earlier period. The regression lines based on the post-1972 data are significantly different to those calculated from the earlier data.

The geographical variations in the change in relationships between the variables were also examined. The change in the relationship between maximum temperature and rainfall was most apparent in the northwest of the continent, and not evident in the northeast. The change in the relationship between rainfall and the SOI was most evident in the southeast.

Discussion

These results indicate that since the early 1970s, the relationships between Australian rainfall, maximum temperature, and the SOI have been rather different to those present earlier this century. The possibility that this change is an artefact, perhaps representing a bias introduced when metric meteorological units were introduced in Australia during the early 1970s, was considered. Lavery et al. (1992) and Nicholls and Kariko (1993) examined the possibility that rainfall observations might have been affected by the change in units and measuring equipment. They concluded that any substantial artificial change in rainfall totals was unlikely. Torok and Nicholls (1996) found no evidence that the change to metric temperature measurements in 1972 led to biases in the temperature time series. Comparisons of thermometers used before and after metrication revealed no obvious biases which could explain the apparent changes in relationships. The available evidence suggests that the apparent changes in behaviour evident in Figures 1-4 since the early 1970s probably cannot be explained by changes in observing practices or instrumentation, despite the proximity of these apparent changes to the time of introduction of metric units.

However, the possibility that the apparent change may be artificial means that other data need to be examined for evidence of atmospheric changes in the early 1970s. Evidence of a change in atmospheric circulation in the Australian region is found in Figure 11 of Allan and Haylock (1993) which shows low pass filtered June-August mean sea level pressure anomalies in the region. Pressures were substantially higher over Australia after about 1970, relative to the period 1911-1970. Pressures at higher latitudes at Australian longitudes

Table 1. Regressions and correlations (r) between All-Australia mean annual rainfall (RAIN), mean annual maximum temperature (MAXT), and the Southern Oscillation Index (SOI)

1910-1972		1973-1992		1910-1992
Regression	r	Regression	r	r
RAIN = 455 + 6.0 SOI	0.55	RAIN = 532 + 8.0 SOI	0.61	0.50
MAXT = 30.0 - 0.004 RAIN	-.72	MAXT = 30.1 - 0.003 RAIN	-.66	-.52
MAXT = 28.2 - 0.03 SOI	-.49	MAXT = 28.5 - 0.02 SOI	-.36	-.46

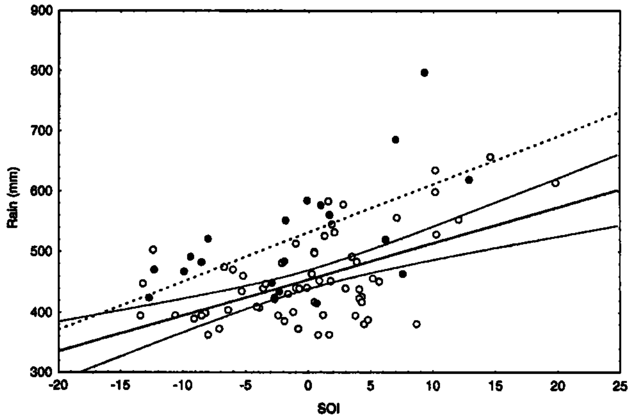

Figure 3. As in Figure 2, but for All-Australian rainfall versus the SOI.

were relatively low after 1970. These apparent changes in circulation, occurring at about the same time as the apparent change in relationships in Figures 1-4, lend some credibility to the reality of the changes.

There is also evidence of a large-scale change in temperatures around the Australian region, early in the 1970s. Figure 5 shows the spatial distribution, and their time series, for the first two principal components of global sea surface. The first component reflects the El Niño, and its time series indicates an apparent change in behaviour in the mid-1970s (cf., Trenberth and Hoar, 1996). Of more interest here is the behaviour of the second principal component (Figure 5, second panel). The time-series of this component shows a marked jump, corresponding to an increase in temperature in the west Pacific and most of the Indian Ocean in the early 1970s. Indian Ocean sea surface temperatures are related to variations in Australian rainfall, separate to the influence of the El Niño - Southern Oscillation on Australia (Nicholls, 1989). Warmer temperatures in the north Indian Ocean tend to be associated with wetter conditions, especially over southern Australia. So, the abrupt change in this pattern of sea surface temperatures could have resulted in a change in the relationships between the El Niño - Southern Oscillation and Australian climate, at around this time.

To investigate the possible effect of changes in the global sea surface temperature, since the early 1970s, on the

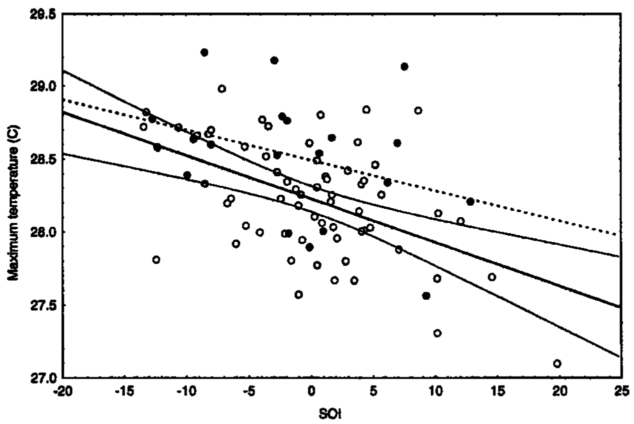

Figure 4. As in Figure 2 but for All-Australian maximum temperature versus the SOI.

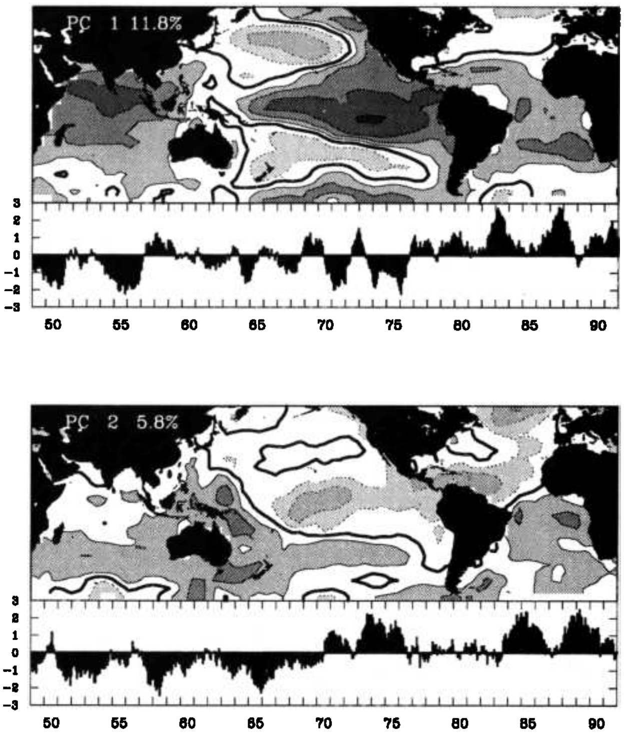

Figure 5. Spatial patterns and time series of the first two principal components of monthly sea surface temperature anomalies. Broken lines indicate negative weightings. The last two digits of the year are indicated on the horizontal axes for the time series.

relationship between Australian rainfall and the SOI, we have analysed results from an ensemble of five global simulations of the period December 1949 - November 1991, with the Australian Bureau of Meteorology Research Centre (BMRC) Climate Model. The only external forcing was the boundary forcing due to the observed sea surface temperature and sea-ice. The model has a reasonable climatology, with the simulated global circulation, their seasonality and variance, in good agreement with the observations, and reproduces the observed relationship between rainfall, the SOI, and global sea surface temperatures (Frederiksen et al., 1995a, b). The relationship between simulated rainfall and the SOI, and the shift in the regression line after 1972, is similar to that observed. The incremental shift in the intercept is, however, only about 30% of the observed. As in the observations, the change in the relationship in the model is most pronounced in the southeast.

These results suggest that the changed relationship between Australian rainfall and the SOI may be explained by the changes in the spatial distribution of the global sea surface temperature anomalies since the early 1970s. Frederiksen and Balgovind (1994) have demonstrated, in a series of climate model simulations, that warm sea surface temperature anomalies to the north/northwest of Australia generally result in increased rainfall in the south/southeast of the continent. Thus, the positive anomalies seen in the second principal component since the early 1970s (Figure 5) would be expected to modify the relationship between Australian rainfall and the SOI, especially in the south/southeast, in a way consistent with the results presented here.

Concluding remarks

The change in the Australian climate relationships appears to have two aspects. The first is an increase in maximum temperatures, relative to rainfall. So, since the early 1970s, Australia's maximum temperatures have tended to be higher, relative to rainfall, than was the case in earlier years. This, if real, might be attributed to a changing climate where temperature increases but rainfall does not alter significantly. The second change is that rainfall now appears to be higher, relative to the SOI, than was the case previously. This may reflect differential warming of the Indian Ocean, relative to the Pacific Ocean, with a consequent effect on Australia's rainfall separate to the influence of the El Niño - Southern Oscillation.

Seasonal climate prediction for Australia is based largely on lagged statistical relationships between the SOI and rainfall. Since the simultaneous relationship between these variables has changed, it seems likely that the lagged relationships used in prediction would also have changed. Climate impacts studies often attempt to determine the effect of a single climate variable (e.g., rainfall) on the impact variable. Such efforts may be confounded by changes in the relationship between rainfall and temperature.

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