Influence of Southern Oscillation on New Zealand Weather

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ABSTRACT

The Southern Oscillation is known to have a significant effect on New Zealand weather. In general, during the negative (El Niño) phase of the Oscillation, New Zealand experiences an increased frequency of cold southwesterly airstreams that result in more rain in the southwest of the country, and dry conditions in the north and east. During the positive (La Niña) phase, there is a tendency for increased cyclonic activity in the North Tasman and more slow-moving or blocking anticyclones to the southeast of New Zealand. This results in frequent warm moist northerly or northeasterly airstreams over the country, with warmer than normal temperatures nationwide and wetter conditions in parts of the North Island exposed to these prevailing winds.

The pressure anomalies in the New Zealand region associated with extremes of the Southern Oscillation Index show some seasonal variation. The anomalies are also not entirely linear with respect to the value of the SOI. This paper examines differences between El Niño and La Niña conditions as they affect New Zealand, and then discusses the predicted and observed anomalies in New Zealand weather associated with the 1988/89 La Niña episode.

1. Introduction

Interest in the Southern Oscillation and its regional effects has been high since the 1972–73 El Niño event that devastated the Peruvian anchovy fisheries, and particularly intense since the dramatic 1982–83 episode. Although the existence of the Southern Oscillation (SO) has been known for many years (Walker, 1923), it took some time for the link between the SO and periodic ocean warming off the Peruvian coast to be appreciated. However, the term ENSO, for El Niño–Southern Oscillation, quickly became accepted. More recently, the term La Niña has become popular for describing the opposite extreme to El Niño conditions.

There is a considerable recent literature on regional weather changes associated with fluctuations in the Southern Oscillation. In the Australasian region, for example, McBride and Nicholls (1983) have examined seasonal relationships between Australian rainfall and the Southern Oscillation Index (SOI). Some of the lag correlations they found are sufficiently promising that the Australian Bureau of Meteorology plans to start issuing regular seasonal outlooks to the public from mid-1989 (National Climate Centre, 1988). Gordon (1985, 1986) discussed how the seasonal patterns of rainfall and temperature over New Zealand are related to the SOI. These relationships, along with further work, enabled the New Zealand Meteorological Service to make statements about the long-range weather prospects during the 1986–87 El Niño and the more recent 1988–89 La Niña.

A good start has thus been made to documenting general SO–weather relationships. However, much more attention now needs to be paid to the differences from one ENSO event to another: the reasons for the different evolution of the anomaly patterns, and the regional implications. This paper is a contribution to this need, essentially from a New Zealand point of view. Our particular interest is to examine anomalies associated with La Niña and El Niño, and see whether the anomalies vary linearly with the SOI. Predicted and observed anomalies in New Zealand during the 1988/89 La Niña summer are used as an example.

2. Data

The Southern Oscillation Index data used here cover the period May 1851 to December 1988. Parker's (1983) monthly values from January 1935 to March 1983 were updated using the standard 6-hourly pressure readings (at 0000, 0600, 1200 and 1800 GMT) at Tahiti and Darwin. The base period 1941–80 was used to normalize the Tahiti–Darwin pressure difference to form the so-called "Troup" Index (McBride and Nicholls, 1983). The SOI time series was extended back to 1851 using the seasonal Index values published by Wright (1975). Regression equations were calculated for each month of the year (N.D. Gordon, pers. comm.) relating the monthly Tahiti–Darwin pressure difference to Wright's Index values of the surrounding three seasons. The period 1935–1974 was used to generate the regression equations, which were then applied to Wright's values to extend the SOI time series back to 1851.

Although the basic SOI time series consists of monthly values, running three-monthly means are used throughout the analyses of this paper.

The pressure anomaly calculations (Section 4) use monthly mean sea level pressures determined from daily grid-point values on a 5° by 10° latitude–longitude grid over the New Zealand–Australia region (Gordon, 1986). These data cover the period July 1957 to September 1988. In the verification of the 1988–89 anomalies, the pressure time series was updated to February 1989 using the daily ECMWF analyses over the Southern Hemisphere from 20°S to 90°S that are received operationally by the New Zealand Meteorological Service. In addition, time series of monthly temperature and rainfall at selected New Zealand stations were used.

3. Persistence

a. *SOI AUTOCORRELATION*

The SOI time series shows considerable persistence from month to month. Conventional wisdom has it that the autocorrelation is highest during May–July and there is a "break" in persistence about March–April. Hence, Gordon (1986) recommended that the 12-month period May–April, rather than the calendar year, be used when calculating annually averaged relationships with the SOI. The break in persistence occurs because there is a tendency for new ENSO events to become established in May–June and also for existing events to weaken during February–March (at least in so far as ENSO behaviour is represented by the SOI).

Fig. 1 shows the seasonal variation in autocorrelation of the 3-month running mean SOI at lags up to 12 months. The lag autocorrelations were calculated separately according to whether the starting 3-month mean SOI was positive (1a) or negative (1b). Gordon (1986) calculated lag correlations that included all starting SOI values irrespective of sign, and his Fig. 2 is very similar to our Fig. 1b. It appears then that the autocorrelation structure of "all SOI" is dominated by that for "negative SOI" (Fig. 1b). The pattern for a starting "positive SOI" is somewhat different, with slightly greater persistence for starting months January–March and reduced persistence for the remainder of the year. The "positive SOI" result is also much noisier, particularly in March–May, the southern autumn, although the sample size is similar for each month (at slightly over 40% of the total).

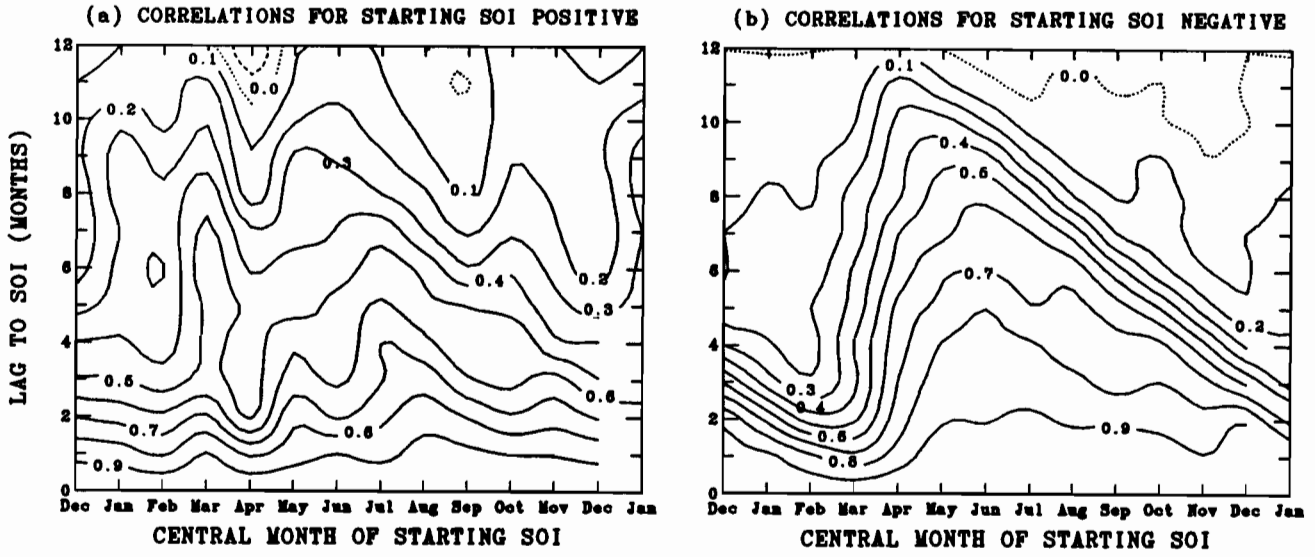

FIG. 1. SOI autocorrelation between the 3-month average centered on the given starting month and the 3-month average for 1–12 months later. Results cover the period May 1851 to December 1988 for 3-month average starting SOI positive (a), and for 3-month average starting SOI negative (b).

b. *LA NIÑA/EL NIÑO EVENTS*

In an attempt to identify further characteristics of La Niña and El Niño events, an objective definition of these events in terms of the SOI time series was applied. "Positive"/"negative" events (identified with La Niña/El Niño events, respectively) were defined to start when the 3-month running average SOI became at least S_0 above/below zero and remained that way for at least three consecutive months. The event continued until the 3-month running average SOI became smaller than S_1 above/below zero.

Various combinations of S_0 and S_1 were tried and the final values decided upon were $S_0 = 10$ and $S_1 = 5$ (in units of 0.1 standard deviation). The events identified by this choice agreed reasonably well with ENSO events identified by other authors (such as van Loon, 1984, and Rasmusson and Carpenter, 1982). Taking $S_1 = S_0$, for example, often resulted in breaking up what should have been single events into two or more parts.

Over the period of record, 11 positive (La Niña) events were identified, excluding the one apparently in progress in 1851 where the starting month could not be determined and the 1988–89 event that had not finished. The length varied from 10 to 23 months, with a mean of 14.0 months. Of the negative (El Niño) events, 29 were identified, of which 3 were of less than six-months duration (in 1857/58, 1957/58 and 1963/64). The length of the negative events varied from 3 to 47 months, with a mean of 13.7 months. Table 1 shows the distribution of the start and end months of the events selected. The reason for the seasonal break in persistence seen in Fig. 1 is quite obvious.

A relationship between the "intensity" of an event and its duration was also sought. Defining the starting intensity I_n of an event as the mean of the unsmoothed SOI values over the first n months, I_n was correlated against duration. While nothing useful was found for negative events, quite large correlations were found for positive events, which maximised at $n = 5$ ($r = +0.90$). Fig. 2 shows a scatter plot of La Niña starting intensity (average SOI over first 5 months) against duration.

TABLE 1. Start and end months of the 11 La Niña and 29 El Niño events identified in the period 1851–1988.

	J	F	M	A	M	J	J	A	S	O	N	D
Start month:												
La Niña	1	0	1	2	2	1	1	0	0	1	1	1
El Niño	1	3	3	7	2	1	3	3	1	2	1	3
End month:												
La Niña	1	2	1	2	0	0	0	0	2	1	1	1
El Niño	2	5	10	2	3	0	0	0	1	2	4	0

The 1988–89 La Niña event began strongly (I_5 = 16.8), and on the basis of Fig. 2 would be estimated to last for about 19–20 months from the start of August 1988; i.e., to about February–March 1990 before the 3-month running average SOI fell below +5. This prediction may not be too successful, as according to the latest observations (March 1989 Climate Diagnostics Bulletin) the current "cold episode conditions continued to show signs of weakening". Various U.S. modellers (e.g., Cane and Barnett, as reported in The New York Times, 1989) also seem to agree that the current La Niña event should be over by mid-1989.

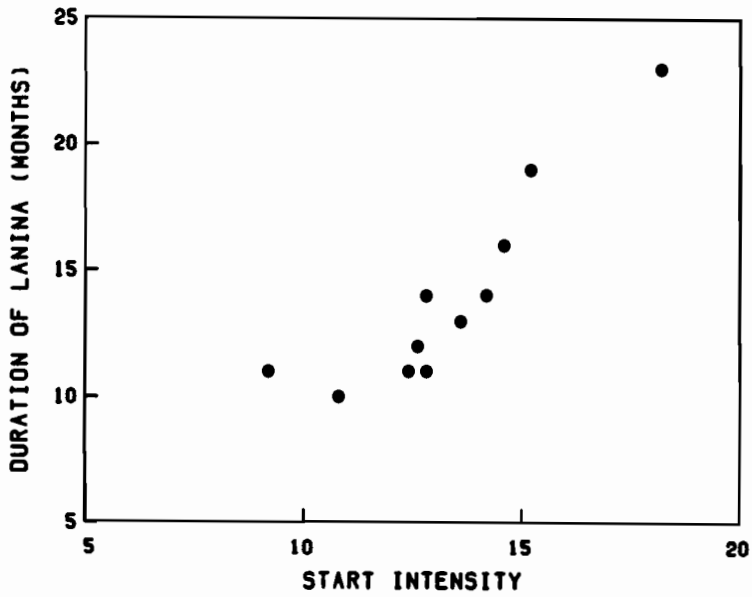

FIG. 2. Scatter plot of La Niña starting intensity (5-month average SOI, in units of 0.1 standard deviation) against calculated duration in months.

4. Pressure Anomaly Composites

a. *METHOD*

Gordon (1985,1986) calculated seasonal correlation maps of mean sea level pressure against SOI for an area covering Australia and New Zealand . Both positive and negative Index events were

included in the correlations. Overall, he found that positive SOI was associated with anomalous northeasterly flow over New Zealand (and, conversely, anomalous southwesterly flow during negative SOI periods). There was some seasonal variation in this pattern, with the flow anomalies displaying a more east/west direction in summer and more north/south in winter (for positive/negative SOI respectively).

In this section we will analyse the pressure variations not by a correlation pattern but by compositing seasonal pressure anomalies, weighted by the 3-month mean SOI for that season. Thus, if the array Y_i is the seasonal msl pressure anomaly over the Australia–New Zealand area, and x_i the seasonal SOI, we have:

$$Y_i = R\,x_i + C + E_i$$

where R is a "response" matrix, C a constant matrix, and E_i a random field for season i. Assuming that E_i has zero mean and is uncorrelated with the Index (i.e., $\bar{E}_i = 0$ and $\overline{x_i E_i} = 0$), we find:

$$R = \left(\frac{\overline{x_i Y_i} - \overline{x_i}\,\overline{Y_i}}{\overline{x_i^2} - \overline{x_i}^2} \right)$$

and $C = \bar{Y}_i - R\,\overline{x_i}$.

If the pressure field (Y_i) and SOI (x_i) time series were both normalised over the same base period as the composites are calculated for, then C would be zero. The pattern shown by the response matrix R is of course very similar to that of the correlation matrix. Thus, when displaying the pressure anomaly patterns associated with "all SOI", it is equivalent to show either the correlation field (as in Gordon, 1986) or the predicted $\hat{Y}$ (evaluated for some nominal Index value $x_i = 1$, say). Since our interest here is in the pressure pattern for subsets of the SOI data (in particular, positive and negative periods), it is more convenient to display the results in terms of the predictand $\hat{Y}$.

The significance of the resulting composite field was assessed by a Monte Carlo randomisation procedure. For the same season (e.g., summer) and period (1957-88) as the field in question, 1000 *sets* of composited response fields were calculated for randomly generated SOI series (with the same mean and standard as observed). The mean random response $\bar{\bar{R}}$ is essentially zero, but the standard deviation $S_{\bar{\bar{R}}}$ of the random response allows us to calculate the significance of the initial composite. We thus normalise the composite by evaluating:

$$R_N = 100 \left(\frac{R - \bar{\bar{R}}}{1.64\, S_{\bar{\bar{R}}}} \right)$$

Values of $|R_N|$ greater than 100 denote regions where the pressure response is significantly different from random at the 90% level (2-sided test).

b. *RESULTS*

Weighted composites of seasonal pressure anomaly fields were calculated for each season for three cases: using the whole sample regardless of the sign of the SOI ("all"), compositing only those seasons when the SOI was positive ("+"), and compositing only those seasons when the SOI was negative ("-"). The linearity of the pressure response with respect to the sign of the SOI could thus be assessed. Calculations showed that the linearity was good through December–May (Southern Hemisphere summer and autumn), but relatively poor in the June–November (winter and spring) period. Hence, using the seasonal correlation patterns of Gordon (1985,1986) to predict flow

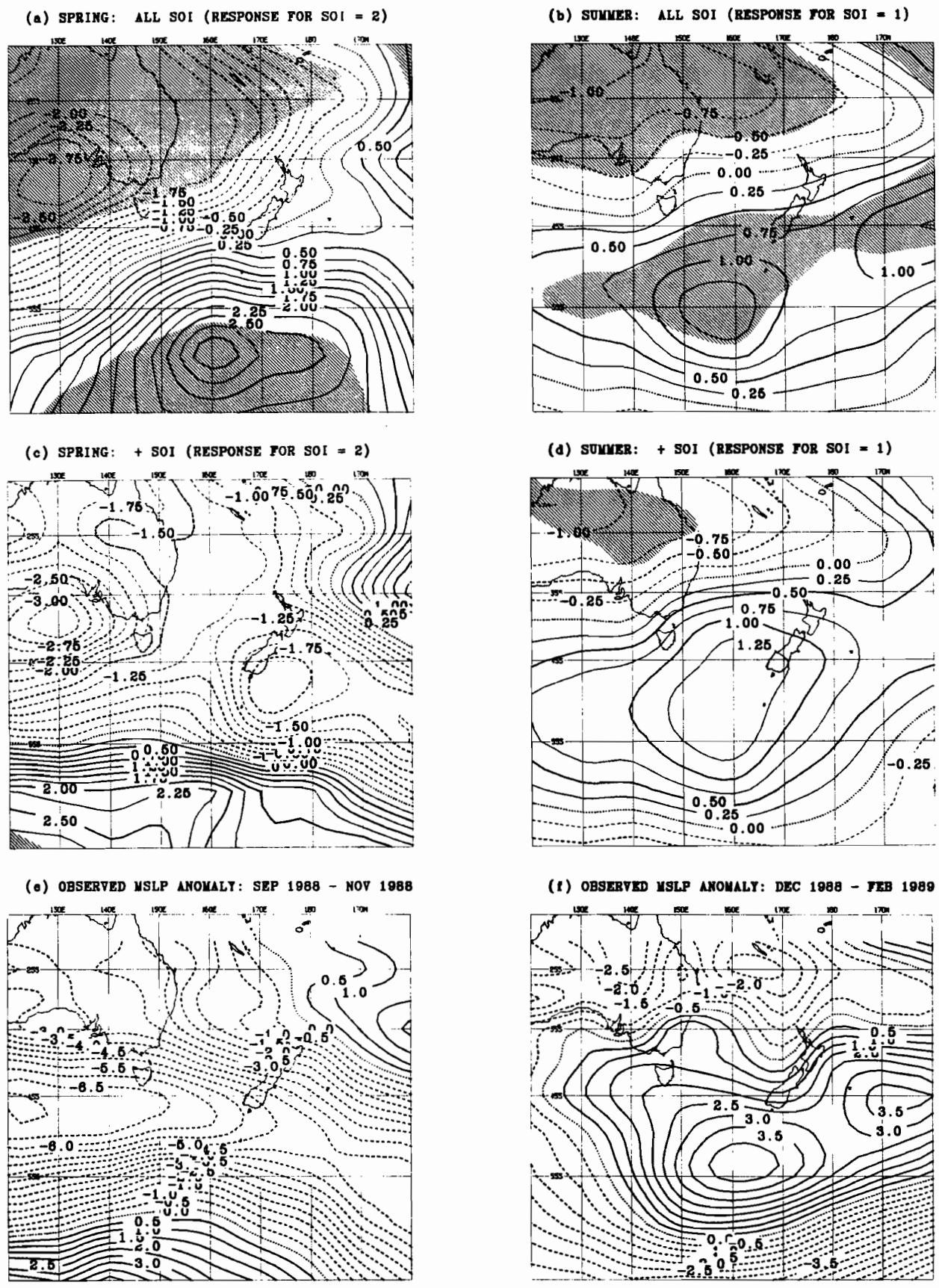

FIG. 3. Seasonal pressure anomaly patterns. Predicted anomaly, based on sample of "all" seasons, for a spring SOI of 20 (3a) and a summer SOI of 10 (3b). Predicted anomaly, based on sample of "+" SOI seasons, for a spring SOI of 2.0 (3c) and a summer SOI of 1.0 (3d). Observed anomaly for spring 1988 (3e), and for summer 1988/89 (3f). Shading indicates the composite response is significantly different from random at 90% level.

anomalies during both La Niña and El Niño periods could be expected to be reasonably successful in summer and autumn, but less so in winter and spring. Further discussion here is restricted to the spring (September–November) and summer (December–February) seasons.

Fig. 3 shows examples of calculated and observed seasonal pressure anomalies (in millibars) for the spring (Fig. 3a, c, e) and summer (Fig. 3b, d, f) seasons. The periods used to calculate the composites did not include the verification period September 1988–February 1989. The observed anomalies (Fig. 3e, f) cover a period of the current La Niña event. The 3-month running average SOI (Fig. 4) reached a maximum of 2.0 for the September–November (spring) 1988 period and decreased to an average of 1.1 over December–February (summer) 1988/89. (Note the change in contour interval from 0.25 mb in the composites to 0.50 mb in the observed fields.)

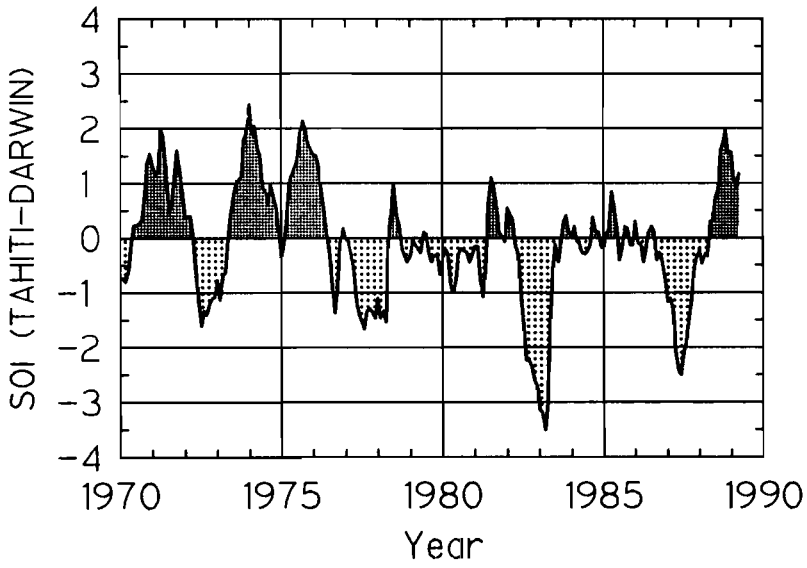

FIG. 4. Three-month running average SOI from January 1970 to April 1989 (in standard deviation units).

New Zealand was affected by stronger than normal westerlies throughout the 1988 winter and much of spring. This caused high rainfalls and some severe flooding on the west coast of the South Island, while drought conditions developed on the eastern side of the South Island mountain range. A sudden breakdown of the strong westerly flow occurred in early November, and a succession of persistent slow-moving anticyclones crossed the South Island during the summer, which served to further aggravate the drought there. Fig. 3e, f show the seasonal pressure anomaly patterns over this spring and summer period.

The predicted spring pressure anomaly, evaluated for the observed SOI of 2.0, is shown in Fig. 3a, c. It is clear that developing the composite using all spring seasons (Fig. 3a), and therefore the standard correlation approach too, completely fails to capture the stronger westerlies that affected New Zealand during the 1988 spring. The composite developed from only those spring seasons where the SOI was positive (Fig. 3c) is much more successful. Since Fig. 3c uses only about half the data set of Fig. 3a, the significance levels are lower, as indicated by the shading changes. The predicted summer pressure anomaly associated with Southern Oscillation changes is shown in Fig. 3b, d, evaluated for an SOI of 1.0, close to that observed. As mentioned above, the relationship between the flow anomaly over New Zealand and the SOI is more linear in summer than spring, so Fig. 3b, d are quite similar. The main difference is that in Fig. 3d the anticyclone is stronger and extends over more of the country.

5. 1988/89 Summer

The observed temperature and rainfall anomalies in New Zealand during the 1988/89 summer (December 1988–February 1989) are shown in Fig. 5a, b. The maps are based on daily temperature and rainfall observations from 46 stations evenly distributed around the country. Fig. 5c indicates the locations of places mentioned in the text. Temperatures were above normal over the whole country, with the largest anomalies occurring in the South Island and the southwestern half of the North Island. Rainfall was below normal in almost all eastern districts from Dunedin to East Cape.

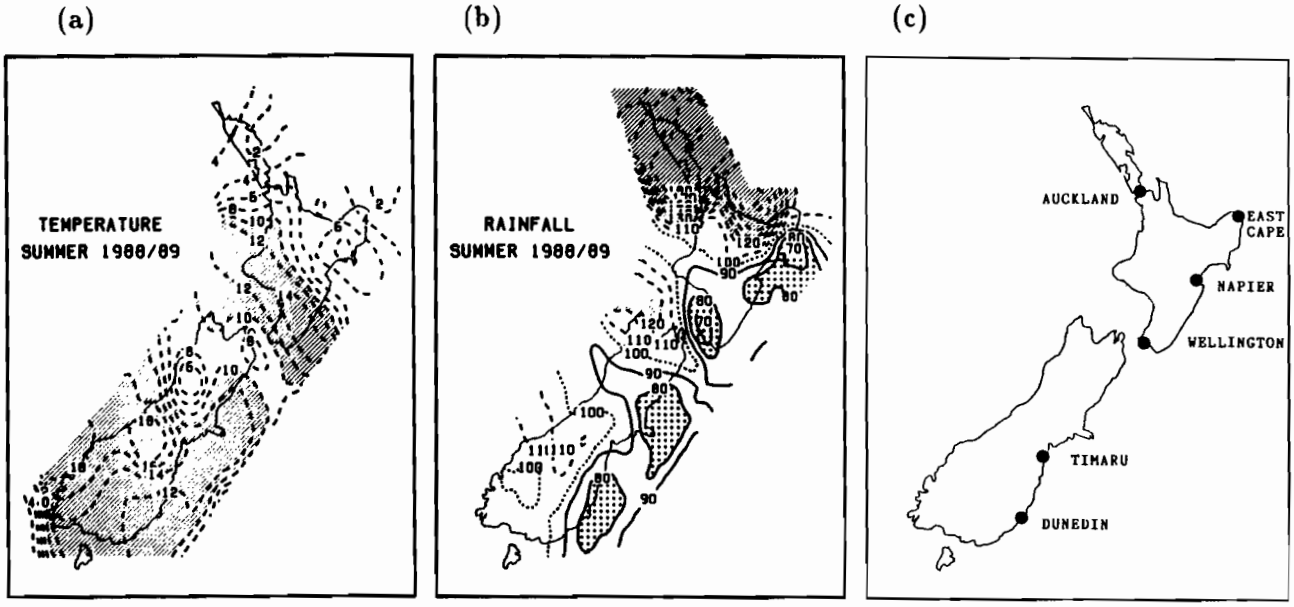

FIG. 5. Observed temperature anomalies (a, in 0.1°C) and rainfall (b, as % normal) over New Zealand during the 1988/89 summer season. Temperature anomalies greater than 1.0°C are shaded. Rainfall greater than 120% normal shaded and less than 80% stippled. (c) Map of New Zealand, showing some places mentioned in text.

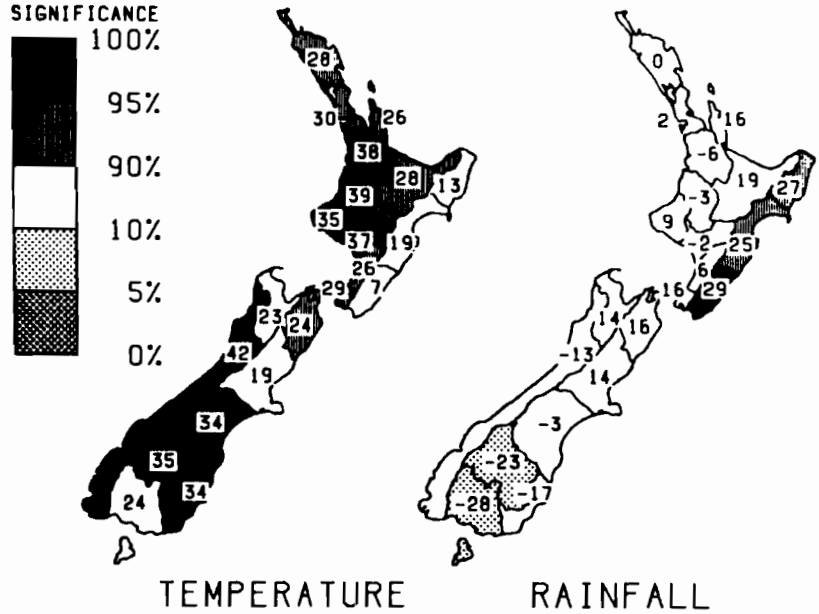

FIG. 6. Correlations ($x100$) between summer temperature and rainfall anomalies and the summer SOI, for various subregions of New Zealand. Significance levels indicated by shading (from Gordon, 1985).

Over the summer the drought that had previously affected only southeastern South Island areas extended up into eastern districts of the North Island as well. On the other hand, much above normal rainfall was experienced in the northern part of the North Island. Many places from Auckland northward received almost twice their normal summer rainfall. January was a particularly wet month, with rainfall in these northern areas being three to five times normal.

The pattern of temperature and rainfall anomalies over the country can be compared to the correlation patterns found by Gordon (1985), based on 30–34 years of data (Fig. 6). The main discrepancies with the observed patterns over the 1988/89 summer occur in the north and east of the North Island. In the north there was more rainfall, greater cloudiness and smaller (but still positive) temperatures anomalies than might have been anticipated. In the east of the North Island, rainfall was below normal (presumably as a result of the more intense anticyclonic anomaly over the country with a ridge extending up the east coast, Fig. 3f), and not above normal as Fig. 6 would indicate for significantly positive SOI.

6. Analogue Prediction

A comparison of Fig. 5 and Fig. 6 shows some features of (particularly) the rainfall distribution over New Zealand where the correlation pattern does not agree too well with that observed during the La Niña summer of 1988/89. Thus, we attempt again to separate the effects of La Niña and El Niño in the rainfall pattern as was done with the pressure anomaly. In this case. however, a somewhat different approach was taken: namely, the selection of analogues. (This analysis was actually done prior to the 1988/89 summer season, and was part of the background information used by the New Zealand Meteorological Service in issuing a long-range weather outlook for the summer on 19 October 1988.)

Analogues of 1988 were selected subjectively from examination of the 3-month running average SOI series. We selected La Niña start years (years zero, in the terminology of Rasmusson and Carpenter, 1982) to be those where the SOI rose from essentially zero at the beginning of the year to a positive value of at least one standard deviation above zero in the middle part of the year. Analogue years after 1900 were 1909, 1916, 1938, 1950, 1955, 1964, 1970, 1973, and 1975. Earlier events were not relevant since, in general, the station data sets do not extend back beyond the early years of the century. The only difference between this set of years and those chosen more objectively in Section 3b was the inclusion of 1964 which did not appear in the earlier set. The temperature and rainfall distribution during the winter and spring of year zero and during the following summer were then examined. Only the results for summer rainfall will be discussed here.

Monthly rainfall over the summer season at a number of representative long-record stations was allocated to categories of "dry", "near normal" and "wet", where for the examples shown here we take "near normal" to mean 81–119% of the normal monthly rainfall. Doing this for all years in the period of record, we could calculate an *a priori* probability that a summer month would be "dry" or "wet". The actual number of "dry" and "wet" summer months for the La Niña analogue seasons were counted, and the binomial test applied to assess the significance of the result. Fig. 7 shows the result in histogram form for the stations of Auckland and Timaru.

The changed temperature and rainfall category distribution in La Niña analogue years generally supported the correlation maps shown in Fig. 6, although there were some differences. Fig. 7a gives a stronger indication than Fig. 6 of Auckland being wet during a La Niña summer, although the results do not quite come up to the 90% significance level. (For example, the *a priori* probability of

a "dry" summer month in Auckland is $p = 0.460$, but during past analogue La Niña summers only 9 of 27 months have been "dry", which has a probability of 0.13 of occurring by the binomial test.) The analogue approach also predicted the east coast of the North Island (Napier, not shown) should not be as dry in La Niña summers as "all" summers, a result that supports Fig. 6 but conflicts with the observations (Fig. 5b).

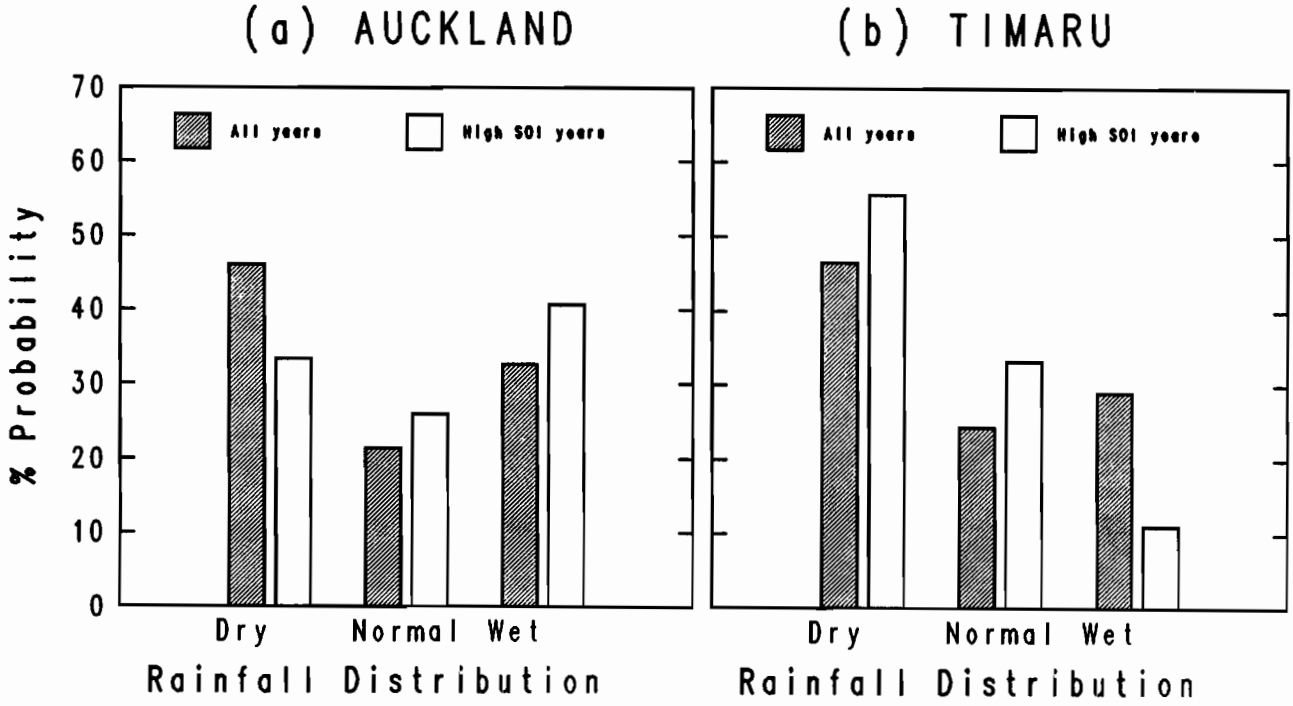

FIG. 7. Probability of Auckland (a) and Timaru (b) rainfall falling into one of three categories, comparing all years of record with La Niña analogue years.

7. Conclusions

Although New Zealand is not near the centres of action of the Southern Oscillation, it is nevertheless affected by this phenomenon. Significant anomalies in the seasonal pressure distribution around New Zealand do occur, and these result in temperature and rainfall anomalies over the country. The general pattern of the anomalies and their seasonal variation have been documented previously in terms of correlation maps. This procedure implicitly assumes a linearity of the response to the forcing.

We have shown that this assumption of linearity is not always valid. In particular, over the period September–November 1988 when the SOI reached a positive extreme, it seems necessary to take account of *nonlinearity* in the response in order to explain the observed pressure distribution. The summer case is not as obvious although, even here when the SOI value was less extreme, there was some improvement in the predicted anomalies using only that part of the historical record when the SOI was positive.

Acknowledgments

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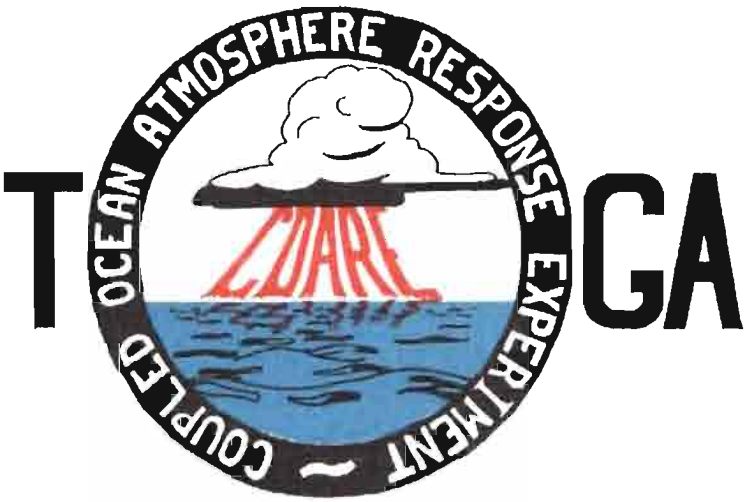

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