Weather and Climate (1993) 13: 22-29

THE SOUTHERN OSCILLATION INDEX AND CLIMATIC PARAMETERS, AND THEIR RELATIONSHIP TO SNOW AND SKI CONDITIONS AT MT. RUAPEHU, NEW ZEALAND

Frances West and Terry Healy

Department of Earth Sciences, University of Waikato
Private Bag, Hamilton, New Zealand

ABSTRACT

The climatic record of the Chateau, Mt. Ruapehu, an isolated volcanic mountain located at 39°S in New Zealand's North Island, was investigated for influence from the Southern Oscillation (SO) in an attempt to ascertain whether any relationship between snow and ski conditions and the Southern Oscillation Index (SOI) could be detected. Climatological data for the period 1930-1980 were subjected to linear regression analysis, correlations and principal components analysis.

The analyses suggested that temperatures at the Chateau were positively correlated with the SOI for both annual ($R = 0.40$ to 0.57) as well as seasonal data, with R values typically ranging from 0.28 to 0.40 (autumn ($R = 0.28$ to 0.33), winter ($R = 0.39$), and spring ($R = 0.28$ to 0.40)) indicating that with an increase (decrease) in the SOI, air temperatures tend to increase (decrease). Precipitation shows a small but significant correlation with the SOI. The relationship is positive for total precipitation in winter ($R = 0.30$), and negative for the number of days with snow in autumn ($R = -0.27$), indicating that with an increase (decrease) in the SOI the total precipitation increases (decreases) in winter and the number of days with snow decreases (increases) in autumn. Wind variables showed no correlation to the SOI.

Principal components analysis of a data set of annual averages indicated that the SOI has a positive relationship with temperatures, a negative relationship with the number of days with snow, and no apparent relationship with wind.

In terms of ski field management, negative or zero annual SOI values have coincided with a 60% chance of "good" skiing conditions or an 80% chance of "good" to "fair" skiing conditions at Mt. Ruapehu. Positive SOIs have been associated with only a 32% chance of good skiing. Given future reliable predictions of the SOI, the likelihood of a good ski season can be predicted.

INTRODUCTION

It is believed by a number of investigators that New Zealand weather and climatic patterns may be strongly influenced by the El Niño Southern Oscillation (ENSO) phenomenon (Gordon, 1985; 1986; Vines and Tomlinson, 1985; Ward, 1985; Yarnal, 1985). When the SOI is in the so called "negative phase", southerly component winds are predominant in New Zealand (Gordon, 1986), while in the SOI "positive phase" the winds are predominantly north-east. Based on this premise, it seemed possible that the snow climatology for Mt. Ruapehu may also be related to the SOI. While these skifields are among New Zealand's most popular, they are sometimes marginal in terms of snow regularity. Accordingly, the aim of this paper is to investigate possible relationships between the SOI and climatic parameters at the Chateau, [illegible] to ascertain whether any such relation has potential application for ski field management.

Some investigators believe that in certain circumstances the SOI can be predicted up to three seasons in advance (Gordon, 1985; Graham and White, 1988; Chu and Katz, 1989; Enfield, 1989; Xu and von Storch, 1989). Accordingly if the climatic paramaters at the Chateau are statistically related to the SOI, this would raise the possibility for predicting snow and therefore ski conditions at Mt. Ruapehu, and clearly impact on aspects of skifield management.

In order to achieve the objectives of identifying possible relationships between snow and ski conditions, the mountain climate variables and the SOI, data analyses included:

(i) Description of the SOI for the period of investigation including:

(a) linear regression of the SOI with time; and

(b) plots of both the monthly and annual average SOI with time from 1939 to 1989;

(ii) Correlations between the SOI and monthly, seasonal and annual climatic data for the Chateau.

(iii) Principal components analysis with varimax rotation of the climatic data for the Chateau and the SOI to determine any interrelations in the data set, and possible links between the SOI and the climatic variables.

DATA SOURCE AND METHODS

The SOI data set comprised the monthly averages of the Tahiti-Darwin pressure difference, obtained from the New Zealand Meteorological Service.

The climatological enclosure at the Chateau, Mt. Ruapehu, is on the northern side of the mountain at an altitude of 1097 m, 39° 12'S 175° 30'E (New Zealand Meteorological Service, 1947). The climatic data consisted of meteorological records published since 1930 (New Zealand Meteorological Service, 1930, 1933, 1934, 1936-46, 1947-1986, 1986-1988).

In discussing the climatological enclosure at the Chateau, Salinger (1981), reported that the observation records are relatively free of many site inhomogeneities associated with urbanisation, relocation, or vegetation. The major disadvantage is a number of missing records for some months in 1930, 1932, 1935, 1937, 1973, 1974, 1975. Salinger (1981), however, did not mention changes in observation procedures. In particular, the recording time has changed with changes in New Zealand standard time. Variables affected by a change in the time of observation have been excluded from the analyses. Viz., dry and wet bulb temperatures, humidity, vapour pressure and amount of cloud. Wind data were believed to have been affected to a lesser extent, although were probably dependent on the observer. The variables analysed include all temperature data except wet and dry bulb temperatures, rainfall, wind direction and the number of days with snow.

RESULTS

Linear Regression and Time Series Plot of the SOI

In agreement with results found by Enfield (1988) linear regression of the annual SOI against time for the period 1930-1988 (Figure 1) shows no significant trend.

A time series plot of the monthly data of the SOI shows the irregular oscillating nature of the index (Figure 2). This timeplot has been described as having aperiodic fluctuations with swings from large negative departures to positive and back to negative again occurring every few years (Gordon, 1985; Graham and White, 1988).

Correlations between Averaged Seasonally Data and the SOI

All correlations between seasonal averages of SOI and climatic variables were less than 0.4 (Table 1). While some statistically significant correlations were found the relationships were too weak for practical significance. A summary of the results is as follows:

(i) In summer, no significant correlations are evident.

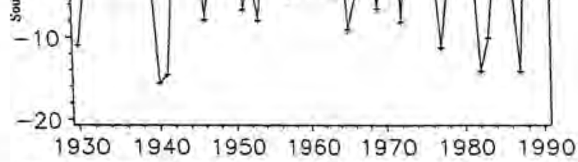

Figure 1. Time series plot and linear regression analysis of the yearly average of the Southern Oscillation Index (Tahiti-Darwin). Source: N.Z. Meteorological Service.

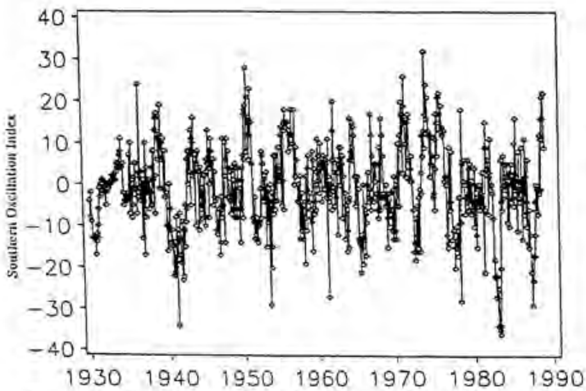

Figure 2. Time series plot of the monthly average of the Southern Oscillation Index (Tahiti-Darwin). Source: N.Z. Meteorological Service.

(ii) In autumn, the SOI and monthly average maximum, month's maximum and monthly mean temperatures are positively correlated, and the SOI and number of days with snow is negatively correlated.

(iii) In winter, the SOI is positively correlated with total precipitation and mean temperature.

(iv) In spring, the SOI is positively correlated with monthly average maximum, monthly average minimum, month's minimum and monthly mean grass minimum temperatures.

The relationship between precipitation, temperature and the SOI is a product of weather patterns, i.e. a positive SOI is reflective of weather from the northeast which would be warm and wet, rather than colder southwesterly winds associated with increased probability of snow and a negative SOI.

Correlation between Yearly Averaged Data and the SOI

Correlations between yearly averages of meteorological variables and the SOI (Table 2) yielded much stronger correlations than correlations with monthly data. However,

TABLE 1: STATISTICALLY SIGNIFICANT (95% LEVEL) CORRELATION COEFFICIENTS FOR SEASONAL AVERAGES OF CLIMATIC PARAMETERS VERSUS THE SOI. FIGURES IN BRACKETS INDICATE PERCENTAGE VARIANCE EXPLAINED BY THE SOI.

Variable	summer	autumn	winter	spring
mean temperature		0.28 (7.6%)	0.39 (15.5%)	
Average maximum temperature		0.33 (10.8%)		0.39 (15.2%)
Average minimum temperature				0.40 (16.3%)
Maximum temperature		0.29 (8.5%)		
Minimum temperature				0.28 (8.0%)
Mean grass minimum temperature				0.34 (11.4%)
Total rain			0.30 (8.9%)	
Number of days snow		-0.27 (7.5%)		

TABLE 2: STATISTICALLY SIGNIFICANT (95% LEVEL) CORRELATION COEFFICIENTS OF ANNUAL AVERAGES OF METEOROLOGICAL DATA VERSUS THE SOI.

Variable	R	Variance Explained
Yearly average of the monthly mean temperature	0.57	32.7%
Yearly average of the daily maximum temperature	0.51	26.3%
Yearly average of the daily minimum temperature	0.52	27.1%
Yearly average of the monthly minimum temperature	0.40	16.3

only temperature variables showed significant correlations. The standard year of January to December was used.

Table 2 demonstrates moderate levels of correlation of climatic parameters with the SOI, particularly between the average maximum temperature, average minimum temperature, monthly minimum temperature, mean temperature and the SOI. Of these, the yearly mean temperature showed the strongest correlation with the SOI, with a coefficient R = 0.57 (99% significant) implying that 32.7% of the variation in the mean temperature is explained by the SOI. The analysis shows a positive correlation between the SOI and temperatures consistent with a tendency for lower temperatures in an El Niño event (strongly negative SOI) and higher temperatures in a La Niña event (positive SOI).

Correlations between Yearly Wind Data and the SOI

Correlations between the SOI and yearly averages of the wind data indicate that the SOI had no statistical association with the local wind direction at the Chateau. This is surprising as one would expect an association between the direction of the regional wind pattern and the SO. However, lack of statistical correlation is believed to be a function of the recording station site being subject to localised topographic wind funnelling.

TABLE 3: PRINCIPAL COMPONENTS ANALYSIS OF 21 CLIMATIC VARIABLES FROM THE CHATEAU STATION, MOUNT RUAPEHU, USING VARIMAX ROTATION. LOADINGS LESS THAN 0.5 EXCLUDED.

FACTOR	1	2	3	4	5	6	7
Mean temperature	0.96						
Average maximum temperature	0.90						
Average minimum temperature	0.88						
Maximum temperature	0.74			0.54			
Minimum temperature	0.67			-0.62			
Mean daily range temperature			-0.69	0.52			
Extreme range temperature				0.98			
Mean grass minimum temperature						0.83	
Lowest grass minimum tempearture						0.86	
Total precipitation			0.86				
Days with rain			0.78				
Days with snow	-0.66						
Northerly wind direction		0.86					
North-easterly wind direction							0.75
Easterly wind direction		0.80					
South-easterly wind direction					0.79		
Southerly wind direction					0.82		
South-westerly wind direction							0.76
Westerly wind direction		0.54			0.50		
North-westerly wind direction		0.69					
Southern Oscillation Index	0.50						
% Total Variance	**26.2**	**15.3**	**14.3**	**12.8**	**11.6**	**11.5**	**8.2**

Principle Components Analysis of Climatic Data from the Chateau and the SOI

Principal components analysis was performed on the SOI and yearly averages of climatic variables for the Chateau. The analysis was limited in that the count of snow days stopped in 1971. To overcome this limitation two analyses were performed, firstly on all variables, and secondly on the data set between 1930 and 1970. The second analysis excluded wind variables.

Analysis of all variables yielded seven factors (Table 3). Factor 1, explaining 26.0% of the variance, indicates a pattern in the data in which positive SOI is associated with high temperature values and a low number of recorded snow days. Conversely, a high number of days with snow is associated with low temperatuers and negative SOI values, as was evidenced in the correlations of autumn averages. Thus SOI values are associated with recorded days of snow.

The second principal components analysis of the data set between 1930 and 1970, in which wind variables were excluded, yielded four factors (Table 4). Factor 1, accounting for 41.8% of the variance is almost identical to factor 1 in Table 3, again linking SOI and temperature inversly with recorded days of snow. Notably the number of snow days is independent of the total precipitation and days with rain.

DISCUSSION

The SOI between 1930 and 1988

The apparent return interval of major SOI fluctuations varies between about 2 and 10 years, with an average of 3 to 4 years (Ward, 1985). Chu and Katz (1989) likewise found that the SOI has a period of approximately four years. Cane and Zebiak (1985) also reported that ENSO peaks occur at semi-regular intervals, typically 3 to 4 years, the peaks tending to be locked in an annual cycle with events peaking at the end of the calender year.

Regression analyses of the SOI indicated no detectable change between 1930 and 1988 (West, 1990), suggesting that the SOI has not been influenced by global warming to date, which is in agreement with Enfield (1988).

The Relationship between Temperature and the SOI

Correlations with the SOI are stronger for temperature than for precipitation. Both the

TABLE 4: PRINCIPAL COMPONENTS ANALYSIS OF THE DATA SET EXCLUDING THE WIND VARIABLES USING VARIMAX ROTATION. LOADINGS LESS THAN 0.48 EXCLUDED.

FACTOR	1	2	3	4
Mean temperature	0.97			
Average maximum temperature	0.95			
Average minimum temperature	0.86			
Maximum temperature	0.72		0.48	
Minimum temperature	0.72		-0.61	
Mean daily temperature range		-0.73	0.57	
Extreme temperature range			0.97	
Mean grass minimum temperature				0.92
Lowest grass minimum temperature			0.91	
Total precipitation		0.85		
Days with rain		0.85		
Days with snow	-0.66			
SOI	0.61			
% Total Variance	41.8	22.2	19.0	17.0

seasonal and yearly averaged temperatures were positively correlated with the SOI. Thus positive values of the SOI (La Niña) are associated with higher average temperatures while negative values of SOI (El Niño) are associated with lower temperatures. Correlations with seasonal data showed definite but small correlations whereas annual data showed substantial correlations. These results are in agreement with Gordon (1985, 1986) who ascertained that the SOI was significantly positively correlated to New Zealand temperatures, in all seasons with autumn showing the weakest correlations. However, we found weakest correlations for SOI and summer temperatures for the Chateau data, whereas Gordon overall found weaker correlation for winter data.

The Relationship between Precipitation and the SOI

The SOI is positively correlated with total precipitation and negatively correlated with the recorded number of days with snow. Statistically significant correlations occurred between precipitation and SOI in winter and inversely between recorded snow days and SOI in autumn. Correlations were definite but small. They suggest both more rainfall and less snowfall when the SOI is positive (La Niña) and more snow and less rainfall when the SOI is negative (El Niño conditions). However, the principal components analyses indicate that the number of days with snow is independent of total precipitation and days with rain.

The Relationship between the Number of Days with Snow and the SOI

Of central interest to this paper is the relationship between the SOI and the number of days with snow at Mt. Ruapehu. As records of the number of days with snow ceased to be published in 1971, only 41 years were available for analysis. However, relationships established for the period containing snow data (1930 to 1971) appear to be applicable to the present situation.

An inverse relationship between the SOI and number of days with snow is seen in the correlations between the SOI and autumn averages of climatic data. In autumn, low temperatures and increased snow are associated with negative SOI. Of the remaining seasons, temperatures and the SOI have a positive correlation in spring. This relationship would relate to snow since temperature determines whether precipitation falls as snow or rain.

The principal components analysis involving all variables also indicates a negative relationship between the SOI values and number of days with snow. These results are similar to that found by Thompson et al. (1984), Budin (1985), Ward (1985) and Cerveny et al. (1987). Ward (1985) reported that following the extremely low SOI in 1982/3 a strong cold southerly flow developed over New Zealand resulting in generally low temperatures and widespread snowfall. Cerveny et al. (1987) correlated a ten year satellite recorod of South American snow cover with the SOI, from which it was demonstrated that 40% of the variation in snow cover in June and July was explained by the SOI. In preliminary investigations into the relationship between SOI and snow accumulation on the Quelccaya ice cap Thompson et al. (1984) found a negative relationship in the nineteen years of accumulation prior to 1984. Investigation of Australian snow depth with the SOI by Budin (1985) demonstrated that a large snow depth accumulated in the year preceding an El Niño event but that a small depth accumulated in the year of the actual El Niño event.

In order to determine whether ski season quality at Whakapapa is related to the SOI, a count of ski conditions for the years 1930 to 1986, as classified by Napper (1986), has been related to annual SOI as either negative, approximately zero, or positive. From the data (Table 6) it is evident that when the annual average SOI is zero or negative there is:

(i) a 60% probability of "good" skiing conditions; and
(ii) an 80% probability of "fair" to "good" skiing conditions.

This suggests that if the SOI can be predicted in advance, there is a reasonable chance of predicting the following ski season quality, thus allowing ski field operators on Mt. Ruapehu to plan both their operations and investment strategies.

As a test of the above hypothesis, the recent winter of 1991 experienced 'very abundant' snow conditions — "the best for 10 years" — while that of 1992 could be considered 'superabundant' on Mt. Ruapehu. Notably both were years of strongly to moderately average nega-

TABLE 5: FREQUENCY OF SKIING CONDITIONS WHEN THE ANNUAL SOI IS NEGATIVE, ZERO OR POSITIVE. THE SKIING CONDITIONS ARE AS RATED BY NAPPER (1986).

Snow Conditions	Yearly Averaged SOI: Negative	Zero	Negative and zero	Positive
Good	17 (57%)	3	20 (60%)	7 (32%)
Fair	7 (23%)	0	7 (20%)	7 (32%)
Poor	6 (20%)	1	7 (20%)	8 (36%)

tive SOI (annual average of -0.76 for 1991 and -1.1 for the 10 months to October of 1992) and El Niño conditions over New Zealand. Perhaps of strong significance, the autumn monthly SOIs in both 1991 and 1992 were highly negative with some monthly averages exceeding -2.0 in each year.

Also of importance to the snow conditions are the local temperatures. Annual average temperature at the Chateau showed a moderate correlation with the SOI, indicating that negative SOI is associated with cooler temperatures, and a positive SOI with warmer temperatures. With a cooler temperature overall the fallen snow will also provide a good base for further snow falls, thus improving the chance of good skiing conditions.

CONCLUSIONS

(i) The SOI is positively correlated to temperatures and negatively correlated to recorded days with snow at the Chateau, Mt. Ruapehu, indicating that when the SOI is strongly negative, temperatures tend to be low and days with recorded snowfall high.

(ii) The principal components analysis suggests that days with snowfall are independent of total precipitation and days with rain.

(iii) The analyses show that when the SOI is negative or zero there is a 60% chance of "good" skiing conditions and an 80% chance of "good" to "fair" skiing conditions.

(iv) With these relationships it appears that snow conditions at the Whakapapa skifield, Mt. Ruapehu, could be predicted with a reasonable probability given a prior estimate of the SOI value.

ACKNOWLEDGEMENTS

The authors are grateful to Dr W. Bolstad (Department of Mathematics, University of Waikato) who assisted with the statistical analyses, Dr W. de Lange and Dr W.E. Bardsley (Department of Earth Sciences, University of Waikato) for reviewing the paper, Dr H.A.I. Madgwick for his assistance and comments, and Ms Heather Windsor who assisted with the manuscript preparation.

REFERENCES

Budin, G.R. 1985. Interannual variability of Australian snowfall. *Australian Meteorological Magazine*, 33(3):145-159.

Cane, M.A. and Zebiak, S.E. 1985. Theory for El Niño and the Southern Oscillation. *Science*, 228(4703):1085-1087.

Cerveny, R.S., Skeeter, B.R. and Dewey, K.F. 1987. A preliminary investigation of a relationship between South American snow cover and the Southern Oscillation. *Monthly Weather Review*, 115(2):620-623.

Chu, P-S. and Katz, R.W. 1989. Spectrum of univariate time series models with application to the Southern Oscillation. *Proceedings of the Fourth International Meeting on Statistical Climatology*, March 1989. Rotorua, New Zealand, pp. 110-114.

Enfield, D.B. 1988. Is El Niño becoming more common. *Oceanography*, 1(2):23-27.

Enfield, D.B. 1989. El Niño past and present. *Review of Geophysics*, 27(1):159-187.

Gordon, N.D. 1985. The Southern Oscillation: A New Zealand perspective. *Journal of the Royal Society of New Zealand*, 15(2):137-155.

Gordon, N.D. 1986. The Southern Oscillation and New Zealand weather. *Monthly Weather Review*, 114(2):371-387.

Graham, N.E. and White, W.B. 1988. The El Niño cycle: A natural oscillator of the Pacific Ocean — Atmospheric system. *Science*, 240:1293-1302.

Napper, J. 1986. Tongariro National Park Snow Level Study. Report for Department of Conservation. 15pp.

New Zealand Meteorological Service, 1930, 1933, 1934, 1936. *Supplement to the New Zealand Gazette*.

New Zealand Meteorological Service, 1936-1946. Meteorological Observations for 1936-1946. *New Zealand Meteorological Service Publication*.

New Zealand Meteorological Service, 1947-1986. *new Zealand Meteorological Service Miscellaneous Publication,* **109**.

New Zealand Meteorological Service, 1987-1988. Monthly Climate Table. *New Zealand Meteorological Service Publication.*

Salinger, M.J. 1981. *New Zealand Climate: The Instrumental Record.* Unpublished Ph.D. Thesis, Victoria University, Wellington, New Zealand.

Thomspon. L.G., Mosely-Thompson, E. and Arnao, B.M. 1984. El Niño Southern Oscillation events recorded in the stratigraphy of the tropical Quelccaya Ice Cap, Peru. *Science,* **226**(4670):50-53.

Vines, R.G. and Tomlinson, A.I. 1985. The Southern Oscillation and rainfall patterns in the Southern Hemisphere. *South African Journal of Science,* **61**(3):151-156.

Ward, G.F.A. 1985. The Southern Oscillation and its effects on New Zealand weather. *New Zealand Agricultural Science,* **19**(1):34-38.

West, F.M. 1990. *The climate, snowline and glaciers of Mt. Ruapehu: Influences of global warming and the southern oscillation.* M.Sc. thesis, Department of Earth Sciences, University of Waikato. 113pp.

Xu, J-2., and von Storch, H. 1989. Prediction of extremes of the Southern Oscillation with POP analysis. Pages 102-109 In *Proceedings of the Fourth International Meeting on Statistical Climatology,* March 1989. Rotorua, New Zealand.

Yarnal, B. 1985. Extratropical teleconnections with El Niño/Southern Oscillation (ENSO) Events. *Progress in Physical Geography* **9**(3):315-352.