Relationship between the Southern Oscillation and rainfall in Vanuatu

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Abstract

Changes in Walker Cell circulation and associated Southern Oscillation are a manifestation of atmospheric variability that is known to influence spatial and temporal rainfall patterns in the Pacific. This research examines relationships between the Southern Oscillation Index (SOI) as a surrogate for atmospheric circulation and rainfall in the Vanuatu region of the tropical South Pacific. Seasonal and annual rainfall data for the northern, central and southern regions of Vanuatu are analyzed alongside SOI data for the periods from 1971 to 2009. As the occurrence of tropical cyclones brings intense and often localized rainfall in certain years, rainfall data associated by these events are removed from the dataset so as to maintain focus on mean synoptic regional-scale circulation. We found that La Niña conditions coincide with high rainfall on average and El Niño with drier conditions. The results of statistical analysis show that the strength of relationships between SOI and rainfall depends on the time periods used and on the particular geographic region of Vanuatu. The closest relationship occurs with three month lag in the southern region, increasing to a six month lag in the north. The results indicate that dry season rainfall can be predicted with modest credibility for the central and southern regions several months ahead. However, predictability is much better for wet season rainfall in the northern region.

1. Introduction

The availability of fresh water from rainfall is a high priority issue for some island nations of the tropical Pacific where water shortage is a serious problem. A better understanding of rainfall variability is important for future water resource management. Changes in atmospheric circulation associated with El Niño and the Southern Oscillation (ENSO) are a manifestation of atmospheric variability that are known to influence spatialand temporal rainfall patterns in the Pacific (Suppiah, 2004; Ropelewski and Halpert, 1989; Philander, 1990; Halbert and Ropelewski, 1989). ENSO is a coupled oscillation of the zonal Walker circulation across the tropical Pacific and the mixed layer of the Equatorial Pacific Ocean, that is closely linked to the South Pacific Convergence Zone (SPCZ). The Southern Oscillation Index (SOI), which is a measure of monthly atmospheric pressure differences between Tahiti in the east and Darwin in the west Pacific, can be used as a measure of the state and strength of ENSO (Kidson, 1975; Barnett, 1985; Ropelewski and Jones, 1987; Allan et al, 1991). El Niño conditions are usually marked by several months of strongly negative SOI values, while La Niña conditions coincide with several months of strongly positive SOI values.

Climate conditions associated with ENSO can have a strong influence on Vanuatu rainfall. For example, the pronounced El Niño events of 1982/83 and 1997/98 resulted in significant and widespread freshwater shortage (Vanuatu Meteorological Services, 2007). Likewise, the La Niña event of 1999/2000 caused extensive flooding, including the overflow and disappearance of Lake Siwi on Tanna Island in 2000. Dry and wet periods are also linked to other aspects of regional climate of Vanuatu, such as the SPCZ, particularly its position and movement and its strength and persistence (Trenberth, 1976; Basher and Zheng, 1998; Salinger et al., 2001; Folland et al., 2002; Widlansky et al., 2011). The focus here, however, is on advancing an understanding of the extent to which rainfall variability is linked to ENSO. In this context, the aim is to examine temporal and spatial relationships between rainfall and the SOI, given that the latter may be used as a surrogate for atmospheric circulation in the Vanuatu region of the tropical South Pacific. Improved understanding of this might assist in the prediction and management of fresh water resources of Vanuatu.

2. **Method**

The 82 islands that comprise the tropical Pacific nation of Vanuatu are spread over a large area with about a 1,300 km north-to-south distance between the outermost islands. To cater for spatial differences in rainfall that may exist the Vanuatu region is divided into three sub-regions, namely, north, central and south, the climate of which are represented by the climate stations at Sola, Lamap and Anelgauhat, respectively (Figure 1). These climate stations provide high quality rainfall data and are broadly representative of the three climatic sub-regions of Vanuatu. Monthly rainfall time-series from each of these stations for the 39-year period from 1971 to 2009 are used. Rainfall statistics including time series graphs of rainfall in Vanuatu can be found on the Vanuatu Meteorological Services (VMS) official website (VMS, 2012).

The consistency of rainfall datasets can be affected by non-meteorological changes such as shifting observation stations, replacement of measuring devices, changes of vegetation, construction in the vicinity of a station, gradual changes in the environment or urbanization, and changes in the time of observation. None of the three climate stations were moved during the study period 1971-2009.

To check for other possible effects on homogeneity of the rainfall record, the Mass Curve method (Searcy and Hardison, 1960; Wigbout, 1973) was used to plot cumulative rainfall values against time to assess the consistency of data and to identify changes in trends indicated by the changes in slope. The results showed that there is consistency in the rainfall records. Of the three climate stations, Anelgauhat has no missing data, Lamap has only one missing value (for June 2008) while Sola has missing data on certain days during nine months in 2001. For stations with some months of missing data, two cumulative curves were plotted, firstly with missing month values, then followed by missing monthly values filled in by inserting the long term (30 years average, from 1971-2000) monthly values that are used by the Vanuatu Meteorological Services (VMS). Inserting the long-term monthly rainfall for missing values is not usually advisable in a region significantly affected by ENSO. It is better to have long-term averages for La Niña, El Niño and ENSO-neutral periods. In the present circumstances however, there are only a very few short periods missing.

Tropical cyclones are common features of the wet months (November-April) in the tropical Pacific. These severe storms often produce extreme rainfall that can overwhelm the influence of mean regional air circulation patterns on rainfall (Suppiah, 2004). Because of this, rainfall associated with tropical cyclone events was removed from the dataset, in several steps. The first involved using synoptic charts and tropical cyclone data supplied by the VMS

Table 1. Pearson correlation coefficients (R) and R^2 values for relationships between mean annual rainfall anomaly and SOI for the Northern, Central and Southern regions of Vanuatu (N = 39) showing significance levels.

+ significant at the 0.01 level

*significant at the 0.05 level

Region	**R**	$\mathbf{R^2}$
Northern	0.36^*	0.13
Central	0.52^+	0.27
Southern	0.68^+	0.47

to determine days during which a tropical cyclone was in the immediate vicinity of Sola, Lamap and Anelgauhat stations. Second, daily rainfall totals for each station for this period were assembled and subtracted from monthly accumulations.

Linear regression and correlation is used as an exploratory statistical tool to analyze relationships between the SOI and monthly and annual rainfall anomalies in each region, where the monthly rainfall anomaly is the actual monthly rainfall minus the mean monthly rainfall for the 30 year record 1980-2009. Annual rainfall anomalies are calculated as actual annual rainfall minus mean annual rainfall for the whole time series.

Lag and lead relationships between SOI and rainfall are identified using the following procedure. First, rainfall indices for north, central and south Vanuatu are calculated for the study period using Wright's (1984) procedure. The technique involves transforming data for the three regions by taking the cube root of monthly rainfall values. Next, the monthly means for the study period are found for each region. Finally, for each individual month during the period 1971 to 2009, the cube root of rainfall is expressed as a percentage of the corresponding mean to form an index. The method used to identify optimum lag and lead periods between SOI and rainfall is that described by Thompson (1987) in which cross correlations between three-month running means of SOI and rainfall indices are produced for time lags of up to 12 months. The results are then plotted to locate the optimum lag or lead interval.

An alternative approach is used to evaluate the strength of relationships for predictions of regional rainfall for the dry season (May-October) months and wet season (November-April) months. Here SOI is correlated with monthly rainfall anomaly data (not transformed) for the two seasons for each region. In the case of the dry season, SOI was lagged by one month (April), two months (March-April), three months (February-April), four months (January-April), five months (December-April) and six months (November-April). In the case of the wet season, SOI was lagged by one month (October), two months (September-October), three months (August-October), four months (July-October), five months (June-October) and six months (May-October). By "lagged" we mean successively extending the pre-wet/dry season SOI by one month at a time in order to assess how the length of the SOI averaging period affects its usefulness as a predictor of wet/dry season rainfall.

3. Results

To gauge long-period associations, annual data are examined. Pearson correlation coefficients (R) and R^2 values for the relationships between annual SOI and annual rainfall anomalies for the three regions are presented in Table1. The results show the relationship is strongest for the Southern region where SOI account for 47% of the variation in annual rainfall, statistically significant at 99% percent level. The relationship is weakest in the Northern region (Table 1).

The strength of relationships for monthly data is not as good, as would be expected. Correlations between Rainfall Index values and various lag and lead times expressed as months that SOI leads or lags rainfall for each of the three regions are shown in Figures 2, 3 and 4. In each figure a circle indicates the point (month) of highest correlation. For the Northern region, the SOI lead time is approximately 6 months, which compares with

4 and 3 months for the Central and Southern regions, respectively. Correlation coefficients range between 0.4 and 0.5, suggesting that SOI accounts for between 16 and 25 percent of the variation in monthly rainfall throughout Vanuatu.

Next, the reliability of using SOI to predict rainfall in the following wet season and dry season is assessed. Figure 5 shows the differences in the reliability in predicting dry season rainfall for the three regions using SOI in the preceding wet season months. The results are best for the Southern region for dry season rainfall, with R coefficients approaching 0.6. R values are slightly lower in the Central region (~0.4), with little or no reliability in the prediction of dry season rainfall in the Northern region. In contrast, the results are generally better for the Northern region in that wet season rainfall can be reliably predicted (Figure 6). R values for the Northern region is in the vicinity of 0.5, while they are closer to 0.4 for both the Central and Southern region.

4. Discussion

The SPCZ tends to move north-eastwards during the Southern Hemisphere winter and El Niño and move south-westwards during the Southern Hemisphere summer and La Niña (Takahashi and Battisti, 2007; Scott, 2011). Changes in position have a profound influence on climate. During the southern summer the SPCZ can produce heavy rainfall in the Vanuatu region. Since the usual position of the SPCZ is at the northern end of the arc of the Vanuatu islands, this may explain why the SOI-rainfall correlation positive for Vanuatu (Trenberth 1976; Vincent, 1994; Folland et al., 2002; Widlansky et al., 2011). The relationship between SOI and rainfall in Vanuatu using yearly data is best for the Southern region of Vanuatu, but weakens as one moves north (Table 1). When time lags are taken into account, the results show that the strength of the relationship between 3-monthly SOI and rainfall in Vanuatu increases with increasing lead time for the 3-month SOI as a predictor □ at least for up to 3-6 months lead (Figures 2 to 4). As with the annual data, it is evident that the strength of the relationship increases towards the south.

The findings of this study are comparable with those of Salinger et al. (1995) and Hales et al. (1999). Salinger et al. (1995) use the period 1953-1990 and SOI Region 4 (subtropical region) that comprise New Caledonia, Vanuatu (Central and Southern region), most of Fiji, Tonga, Raoul Island to northeast of New Zealand. Hales et al (1999) use data from 22 Pacific islands for an undefined time period. In both cases the strength of correlations is higher than that found in the current study.

This contrasts with the results reported by Gilbert and Brindle (2009) who found no clear correlation between monthly rainfall and monthly SOI. However, it is worth noting that the Gilbert and Brindle analysis is based on only 11 years of data taken from climate stations at different locations to those used in the current study; namely, mean monthly rainfall for period from 1995 to 2005 for the climate stations of Pekoa on Santo island in the Northern region, Bauefield on Efate island in the Central region, and Whitegrass on Tanna island, in the Southern region.

Figure 1: Map of Vanuatu region showing locations of climate stations used in the study and the three sub-regions they represent.

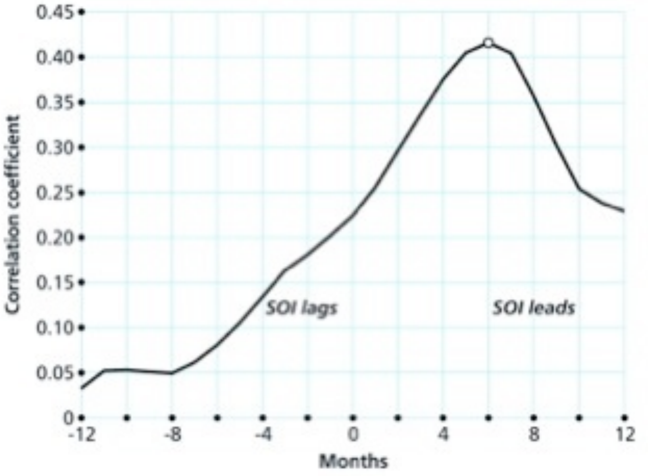

Figure 2. Three month running mean lag correlations between SOI and Rainfall Index values for the Northern region of Vanuatu. The peak correlation coefficient of 0.42 occurs at approximately six months (marked with circle).

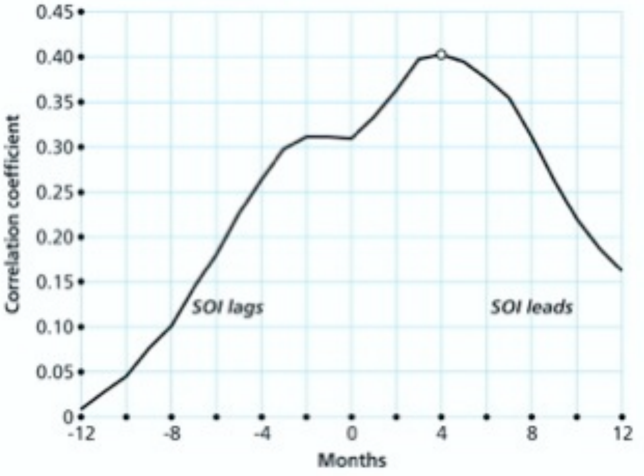

Figure 3. Three month running mean lag correlations between SOI and Rainfall Index values for the Central region of Vanuatu. The peak correlation coefficient of 0.40 occurs at approximately four months (marked with circle).

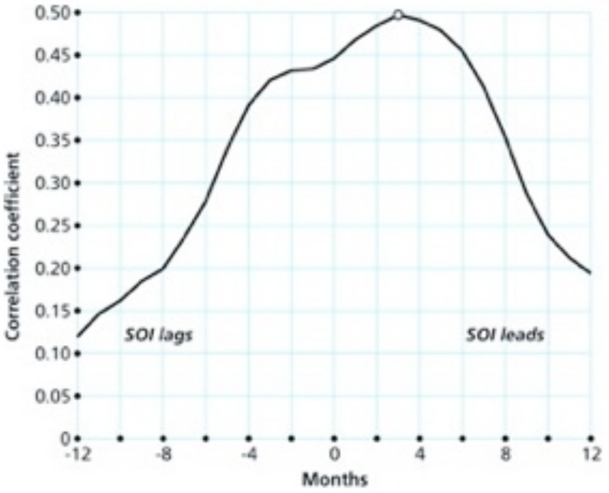

Figure 4. Three month running mean lag correlations between SOI and Rainfall Index values for the Southern region of Vanuatu. The peak correlation coefficient of 0.50 occurs at approximately three months (marked with circle).

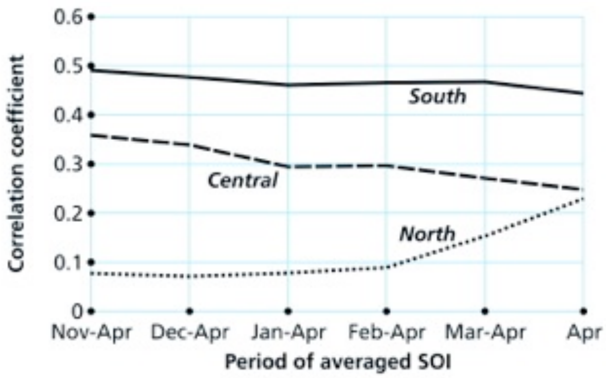

Figure 5. Correlation coefficients between dry season rainfall anomaly and preceding SOI as a function of SOI averaging period, indicating differences in reliability in predicting dry season rainfall in the Northern, Central and Southern regions of Vanuatu. The curves show the usefulness of the length of the SOI averaging period as predictor of dry season rainfall.

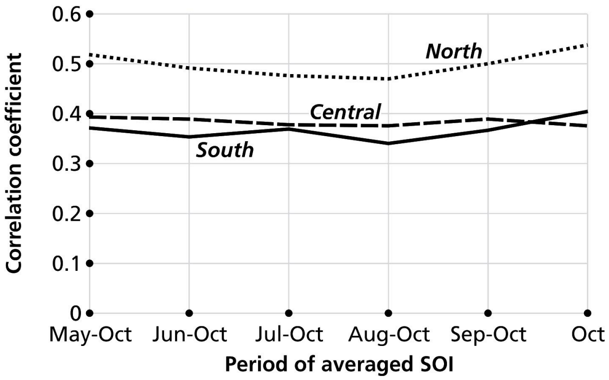

Figure 6. Correlation coefficient between wet season rainfall anomaly and preceding SOI as a function of SOI averaging period, indicating differences in reliability in predicting wet season rainfall in the Northern, Central and Southern regions of Vanuatu. The curves show the usefulness of the length of the SOI averaging period as predictor of wet season rainfall.

The results of the current research for cross-correlation analysis for lags of up to 12 months are consistent with those of Thompson (1987) who found similar lag periods and correlations between SOI and rainfall in Northern and Southern Tuvalu. However, correlation coefficients had signs opposite to those found in the current study; that is, positive SOI values were associated with a decrease in rainfall in Tuvalu but increase rainfall in Vanuatu. The longer SOI lead months for the northern region might indicate that other regional tropical South Pacific circulation indicators such as sea surface temperature might be more closely associated with rainfall in this region than the SOI. On the other hand, one might expect the south-westward movement of the SPCZ in a La Niña to take time to evolve, thus the more southern islands of Vanuatu have more lead time once an ENSO event starts than the northern islands very close to the SPCZ's climatological position.

The results for dry season rainfall anomaly and the wet season lagged months SOI for the Southern and Central regions are consistent with the findings of McBride and Nicholls (1983) in a study of eastern Australia. McBride and Nicholls (1983) found R values between 0.2 and 0.4, with the best results for three months lag time.

5. Conclusion

There are positive relationships between monthly SOI and monthly rainfall anomalies, with the strongest in the Southern region of Vanuatu once time lag effects are taken into account. By and large, La Niña conditions coincide with high rainfall on average and El Niño with drier conditions. The results show the time factor to be an important consideration in that rainfall lags behind influences of atmospheric circulation (as conveyed by the SOI) by several months. As far as seasonal rainfall predictability is concerned, wet season rainfall accumulations are reasonably closely linked to SOI in all three regions, while dry-season rainfall accumulations can only by foreseen with any degree of reliability in the Southern and to a lesser extent the Central region.

The results of the seasonal data analysis indicate the strongest relationships with SOI are in the Southern region in the case of dry season (Figure 5) and in the Northern region in the case of the wet season (Figure 6). This latter is in contrast to the correlation during the dry season in the Northern region when the relationship is weak at best. Apart from this, the results have some predictive value, in that appropriate water management action plans can be put in place several months ahead of the dry season in the south (several months ahead) and central region (six to three months ahead).

This study only considers SOI, the atmospheric component of the ENSO. Further research might consider links between SSTs and rainfall in Vanuatu and the role of the SPCZ in particular. There is also potential for future research to explore relationships between Vanuatu's rainfall and other indices such as Wright SOI, Darwin pressure and Tahiti pressure or develop another index (for example between Port Vila and Rarotonga) and find its relationships with the Vanuatu's rainfall.

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