Combined Southern Oscillation Index and Sea Surface Temperatures as Predictors of Seasonal Rainfall

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Abstract

Although the Southern Oscillation Index (SOI) has proved a useful predictor of seasonal rainfall in eastern and northern Australia, its value is limited by the fact that it is a global estimate. In commercial agriculture the SOI is inadequate in providing decision support for large investments in planting and fertilisation for crop production. In this paper it is shown that seasonal rainfall predictions for the inland subhumid - semiarid subtropics of eastern Australia are improved substantially by using ACE transformations and combining the SOI with Sea Surface Temperature (SST) data from selected ocean regions surrounding the Australian continent Regression analyses of four regions and four seasons have more than doubled mean R^2 values of seasonal predictions from 0.22 for the SOI alone to 0.54 with the SOI/SST combination. This suggests significant potential increases in skill in rainfall prediction in the regions studied. Further studies in other areas are also justified.

Introduction

ENSO (El Niño Southern Oscillation) has been identified as the driving force of the wide variations in flood and drought in part of the land areas adjacent to the Pacific Ocean. A comprehensive review of both the scientific linkages between weather and climate anomalies that occur globally and the ecological and societal impacts of these linkages have recently been summarised by Glantz et al. (1991).

A major impact of ENSO on eastern and northern Australia is highly variable rainfall and drought/flood alternation. Effects of this variability have been both low crop productivity and highly risk averse farmers, especially in the use of inputs such as nitrogen fertiliser.

Examples of the effect of rainfall variability on wheat yields in two El Niño events is shown in Table 1. Eastern Australia was most affected by these events but there were substantial differences between regions and years. In 1983 low rainfall reduced yields in Victoria to 18 percent of the average. Land degradation and dust storms had already begun when the event was terminated in April 1983. In comparison, in 1991, Victoria was hardly affected by the El Niño event with wheat yields only slightly below average.

In contrast, wheat yields in Queensland were reduced to 70 percent in 1982/83 and 44 percent in 1991/92 showing different effects in eastern Australia. The data in Table 1 also shows that the effect of El Niño on wheat yields in south Western Australia was negligible in both years.

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The Southern Oscillation Index (SOI) is the monthly, normalised mean sea level barometric pressure difference between Tahiti and Darwin. This is a useful predictor of seasonal rainfall in eastern and northern Australia and the potential of this index for long- range forecasts has been summarised by Nicholls and Katz (1991). But the usefulness of the SOI is limited by the fact that it is a global estimate. Also, with a large land area such as Australia, there are substantial differences in the reactions of different regions at different times as shown in Table 1.

Table 1. Wheat yield variability In two recent El Niño events.

Region	State	Mean Wheat Yields 1971-1991 t/ha	Wheat Yields as % of Mean	
			El Niño 1982/3	El Niño 1991/2*
Eastern Australia	Queensland	1.39	70	44
	New South Wales	1.45	32	54
	Victoria	1.68	18	94
Southern Australia	South Australia	1.25	39	123
South Western Australia	Western Australia	1.15	99	114

*Provisional values

In subhumid-semiarid areas where commercial agriculture is practised, the SOI is inadequate in providing decision-support involving large investments in crop production, especially in areas where soil available nitrogen levels are low and fertiliser is required. Hence there has been a search for additional variables which, when combined with the SOI, can improve seasonal rainfall predictions.

With drought conditions and very low SOI values (< -10) little can be done except to survive with as few losses as possible. The challenge lies in achieving higher crop yields in average and above average years. This is where useful seasonal rainfall predictions could be a key component in increasing crop yields.

Rainfall prediction based on the Southern Oscillation Index (SOI)

Significant advances have occurred in the 1980’s in understanding the role of the SOI (McBride and Nicholls 1983, Allan 1988). As early as 1929 a relationship between barometric pressure at Darwin in June to August and rainfall in wheat growing areas of Victoria in August to October was reported by Quayle (1929). This relationship was confirmed by Grant (1954) and Nicholls and Woodcock (1981) using later data. But little interest in, nor use of this relationship for predictive purposes was shown until recently.

To quantify the relationship between the SOI and seasonal rainfall an analysis has been carried out over the period 1951-1990. The land area chosen for detailed, rainfall study was the inland subhumid semiarid subtropics of eastern Australia, extending from latitude 22.5°S to latitude 32.5°S. This area receives both summer and winter rainfall. Cyclones can affect the amount of rainfall in this region although the impact is higher in the north than the south. The sub-regions were defined using numerical taxonomy.

Cluster analysis of rainfall from 52 stations with long-term records resulted in the definition of four sub-regions with similar climate (Figure 1). There were 12-14 stations in each sub-region and seasonal groupings were Summer (December to February); Autumn (March to May); Winter (June to August) and Spring (September to November). The dependent variable (rainfall) was normalised and values expressed as standard deviations above or below the 40 year mean. The independent variable was the value of the SOI for the three months prior to the seasonal rainfall.

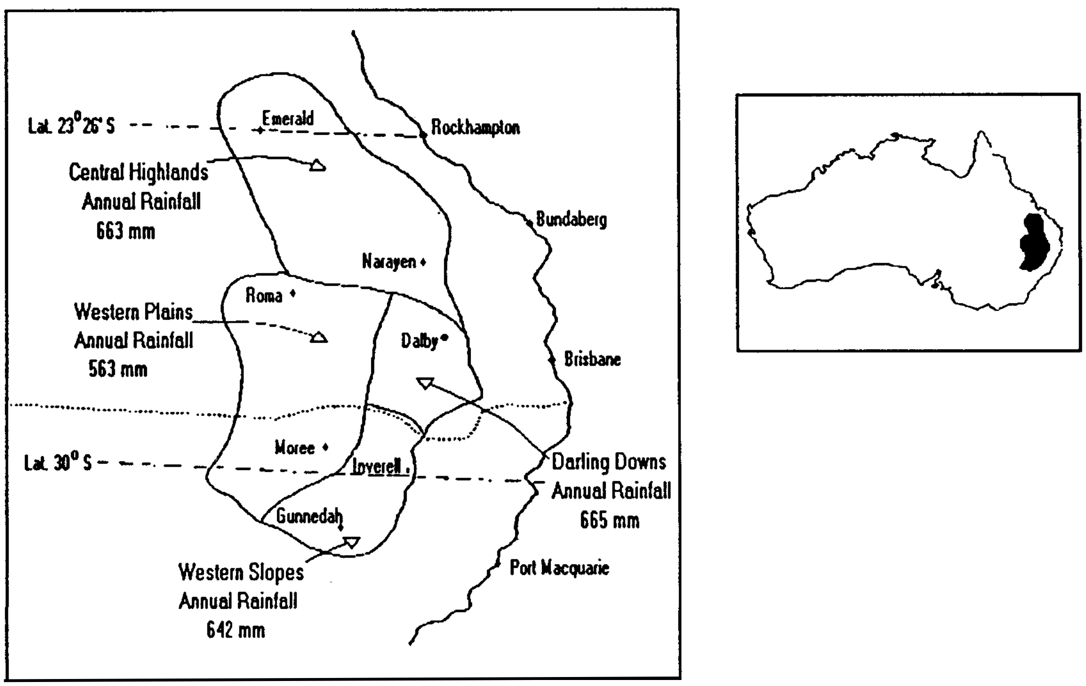

Figure 1. Location of four land regions in eastern Australia selected for detailed rainfall analysis.

The analysis was carried out using the ACE (Alternating Conditional Expectations) algorithm (Breiman and Friedman 1985). The proportion of variance of seasonal rainfall explained by the SOI compared with actual values for each region and season are shown in Table 2. One value of rainfall in autumn 1983 was deleted from the analysis because both it and the prior summer SOI were extreme outliers. Values of R^2 ranged from 0.112 to 0.305 with an overall low proportion of the variance of seasonal rainfall explained by the SOI.

Globally there is increasing interest in prior Sea Surface Temperature (SST) and subsequent rainfall in specified localities. Some of the earliest work was carried out in relation to north east Brazil (Hastenrath 1984). There has also been continuing interest in the prolonged low rainfall period in the Sahel region over the last 20 years. A recent paper by Folland et al. (1991) has found relationships between a southern/northern hemisphere SST ratio and rainfall in this region.

Table 2. Proportion of variance of seasonal rainfall affected by prior values of the SOI over the period 1915-1990 for four sub-regions.

Rainfall Sub-region	Summer Dec-Feb	Autumn Mar-May	Winter Jun-Aug	Spring Sep-Nov
Central Highlands	0.270	0.250	0-.291	0.225
Darling Downs	0.270	0.298	0.214	0.201
Western Slopes	0.258	0.243	0.120	0.194
Western Plains	0.305	0.112	0.160	0.170

Rainfall prediction based on the SOI combined with selected Sea Surface Temperature areas.

In earlier work we used air temperature data from islands adjacent to Australia as indicators of changes in SST. Examples of these off-shore islands in the Pacific included Thursday, Willis, Norfolk, Lord Howe and Matsuyker Islands. However there were very few opportunities of this nature available in the southern part of the continent and in the Indian Ocean. The only exception, other than Islands very close to the coast such as Rottnest, was Cocos Island.

Our recent research has focussed on the combination of the SOI and Sea Surface Temperature (SST) in selected areas surrounding the Australian continent as predictors of seasonal rainfall. This has involved using historical COADS data (Comprehensive Ocean-Atmosphere data set, mainly provided by ships) and near real time SST data from the Geostationary Meteorological Satellite (GSM-4) which is recorded on a daily basis. There have been some limitations of available data due to tendency of ships to follow regular shipping lanes. There is little detailed SST data below latitude 45°S compared with equivalent latitudes in the northern hemisphere. Other areas also have sparse ship data, such as the Gulf of Carpentaria and the northern part of the Great Australian Bight.

The ocean areas chosen for more detailed studies are shown in Figure 2. Using CODADS data over the period 1951-1990 eight areas were selected comprising 32(10° x10° latitude - longitude boxes). These were combined into larger areas ranging from 2 to 6 (10° x 10° latitude - longitude boxes extending from the equator to 50°S latitude from 100°E to 170°E longitude.

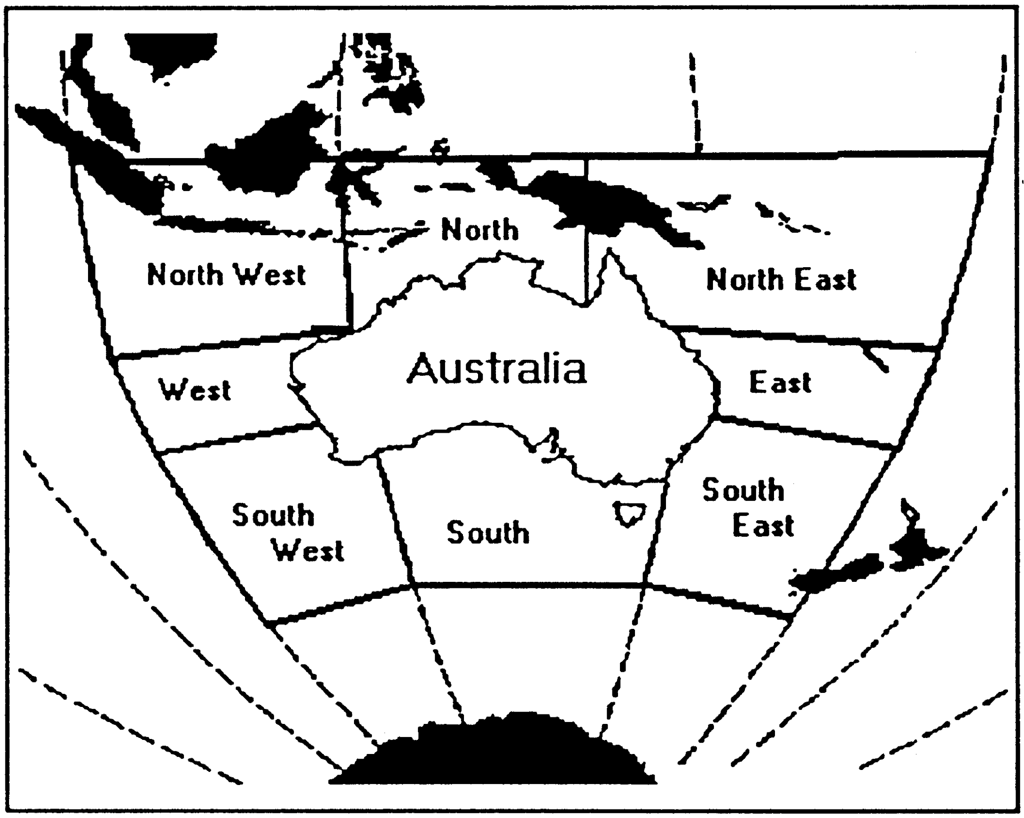

Figure 2. Location of sea surface temperature regions in the analysis of seasonal rainfall.

The ACE analysis was carried out as for the SOI and seasonal rainfall as previously described except that the SST of specific regions adjacent to the Australian coast were also included as dependent variables. In addition to the eight ocean areas shown in Figure 2a further 16 ocean areas were included in the analyses with eight analyses comprising two combined ocean areas, e.g. North/north-east and North-east/east, etc. and a further eight analyses comprising three combined ocean areas, e.g. North/North-east/East, and Northeast/East/South-east, etc. This gave 24 distinct ocean areas which were used in the analysis.

The ocean regions with the highest proportion of variance of seasonal rainfall described by the analyses were selected. The R^2 values for these analyses are shown in Table 3. The ocean regions which were most predictive, as measured by the highest variance explained out of 24 regions, are shown in Table 4.

Table 3. Proportion of variance of seasonal rainfall accounted for by prior values of the SOI and SST of ocean regions over the period 1951-1990 for four regions.

Rainfall Sub-region	Summer Dec-Feb	Autumn Mar-May	Winter Jun-Aug	Spring Sep-Nov
Central Highlands	0.593	0.560	0.495	0.538
Darling Downs	0.594	0.463	0.545	0.613
Western Slopes	0.591	0.466	0.620	0.537
Western Plains	0.563	0.521	0.460	0.427

Table 4. Combinations of contiguous SST regions giving the best predictive estimates of seasonal rainfall.

Rainfall Sub-region	Summer Dec-Feb	Autumn Mar-May	Winter Jun-Aug	Spring Sep-Nov
Central Highlands	S-SW-W	N-NE-E	NE-E-SE	S-SW-W
Darling Downs	E	SE	N-NE-E	W
Western Slopes	SW-W	NE	N-NE-E	E-SE-S
Western Plains	E	N	NE-E-SE	SW

The R^2 values using the SOI/SST region were substantially higher than for the SOI alone. The most predictive ocean regions were the East and North-east. The effect was most marked for predictions of summer and autumn rainfall. The East ocean region comprised only two 10°x10° latitude, longitude boxes and the latitude of this region was from 20° to 30°S which was very similar to the latitude of the land area chosen for study. The North-east region was most prominent in predicting autumn and winter rainfall.

The third most important ocean regions occurred in the West and South-west of the continent. Their effects were marked in predicting spring rainfall and to a lesser extent in predicting summer rainfall. All of the other ocean regions were selected at least three times except for the North-west ocean region.

The inclusion of selected SST regions in addition to the SOI more than doubled the proportion of variance accounted for by seasonal rainfall with overall R^2 values increasing from 0.226 to 0.536. Whilst some improvement could be expected from the additional variable we found a consistent improvement in the analysis with no overlap of the two residual distributions.

Climate prediction using ACE

One of the features of ACE is that rainfall predictions can be made once the framework has been established. However the availability of SST on a daily basis prior to the seasonal rainfall period to be predicted is a combination of ship SST data undergoing collation and the daily data from the GMS-4 satellite. This enables predictions to be made within the first 15 days of the 90 day seasonal forecast.

The concept of skill in predicting weather is an important one in meteorology. Although research on long term seasonal rainfall predictions has been carried out intermittently for over a century (Das 1986, Russell 1990) it is only in the last decade or so that the possibility of increasing skills in this area has been generally accepted. The advantage, reported in this paper, of the SOI and SST for seasonal predictions is that both are relatively slow moving systems and represent atmosphere and ocean influences. Also, the combination of the COADS long-term SST data base and the availability of mean real-time satellite SST data enables us to explore more fully the potential for developing greater skills in predicting seasonal rainfall.

The study reported here has focussed on a relatively limited area in the subtropics. There is certainly scope for applying the methodology more widely in the Australian region and possibly to other regions, especially where both the SOI and SST influences are prominent.

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