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Forecasting the occurrence of low precipitation three to twelve months ahead

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Abstract To be accepted and acted upon, forecasts of drought need to be seen to be reliable. A simple partitioning model is presented here in which occurrence of one variable (say geopotential height) within a specified range of values points to the existence of a strong relationship between another variable (say Southern Oscillation Index) in the same season and precipitation one to four seasons later. Partition relations are demonstrated to explain more than 65% of the variance in the precipitation in the next season for areas of up to 500 000 km^2 in Australia, and 50% of the variance in the precipitation four seasons (one year) ahead for similar sized areas.

INTRODUCTION

There is a desire among water, agricultural and national economic managers for forewarning of drought. However to develop acceptance of issued forecasts the potential users must observe that the forecasts have the possibility of providing them with some realizable benefit. In 1997 news media coverage of the developing El Niño and drought occurrences continued with such intensity that some agriculturalists in northeastern Australia held back from their normal activities. There was little or no meteorological service or consultant advice that drought was likely. In subsequent months the rainfall and available water resources were below average but the timing of the rainfall was such that yields of rainfed field crops were quite close to average. Farmers who had been persuaded that they would suffer drought effects and had not planted their normal crop were upset that they had foregone a potentially profitable growing opportunity. This experience reinforces the previously enumerated fact that meteorological, hydrological and agricultural droughts do not always occur concurrently (Cordery & Curtis, 1985; Heathcote, 1969) and that news media are not reliable sources for advice on strategic decision making. However the unfortunate consequence of this experience is that, although persuading potential users that forecasting systems are reliable has always been a difficult and lengthy process (usually until potential users have observed reliability of the forecasts), in eastern Australia marketing of a drought forecasting service will now be even more difficult.

To gain credibility issued forecasts must be experienced to be correct most of the time. With few exceptions (notably Hastenrath & Greischar, 1993) most advocated forecasting systems have not been able to explain more than about 40% of the variance in the precipitation for the target period. At best only two of every five issued forecasts can be expected to be correct. An alternative scheme which is capable of explaining more than 65% of the variance for areas of up to 500 000 km^2 one season ahead and 50% of the variance for similar areas up to four seasons (one year) ahead will be outlined here. This is a very large improvement in performance. This forecasting model is based entirely on statistical relationships developed from observed data. There is also a need to investigate the possible physical mechanisms, which could underlie such relationships.

RELATIONS BETWEEN LOCAL PRECIPITATION AND GLOBAL CLIMATE PHENOMENA

For the last 20 years there has been considerable interest in investigating "teleconnections" between local phenomena such as precipitation and temperatures and global scale properties of entities such as the Southern Oscillation, sea surface temperatures (SST), the North Atlantic Oscillation (NAO) and the altitude of various geopotential surfaces (GpH). The most widely used of these phenomena in relationships with precipitation have been the Southern Oscillation Index (SOI) and SSTs. While it has been possible to relate precipitation to SOI and SSTs, in general the relations have not been very strong. Experience in Australia was similar to that in other places in that relations with precipitation were stronger than could occur by chance but were not strong enough to provide a basis for forecasting precipitation, except for one or two restricted locations. This suggests that precipitation is governed by more than one factor, and perhaps there is a large, truly random component, but that El Niño or SSTs have considerable influence. Since it is known that at least SOI, SSTs and GpHs are related to precipitation in various places, and in eastern Australia it has been shown they are about equally strongly related to precipitation (Nazemosadat & Cordery, 1997; Opoku-Ankomah & Cordery, 1993), it may be possible to combine the information from two or three of these to obtain improved estimates of precipitation. However, since all three of these phenomena are correlated with each other, there is a need to be careful not to develop a statistically invalid relationship such as a multiple regression using, say, SOI and GpH as independent variables when in fact they are far from independent. A possible means of avoiding this statistical invalidity is to use one of the variables as a trigger, or partitioning indicator, to point to the seasons in which that variable is indicating precipitation may be in a particular range. A relationship then needs to be developed between that other variable and the precipitation in the indicated seasons. For example it is known that drought in many parts of Australia tends to be associated with the highest observed values of GpH. To attempt to estimate summer precipitation from spring, i.e. to forecast three months or one season ahead, the years with highest spring GpH values could be selected. For these years the spring SOI could then be related to summer precipitation. When this was done it was found that strong relations were obtained over a wide area of eastern and northern Australia as indicated in Fig. 1. Similar relationships were obtained for other seasons and for target seasons further into the future, although, as the forecast period increased, the size of the region with strong relationships and the strength of the relations diminished as can be seen in a comparison of Figs 1–3 for summer precipitation.

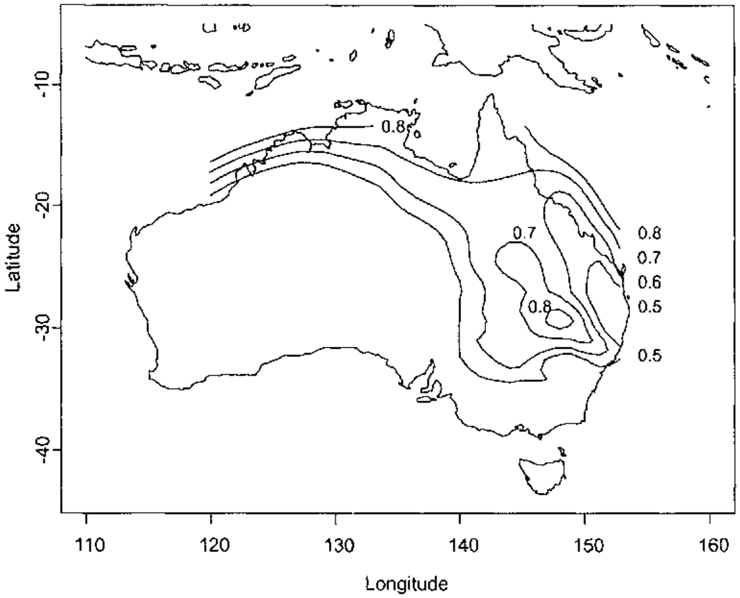

Fig. 1 Isopleths of correlation coefficient between spring SOI and summer precipitation for the 10 years with highest spring GpH (700 hPa at Perth). Period of record 1950–1987, 1991–1993.

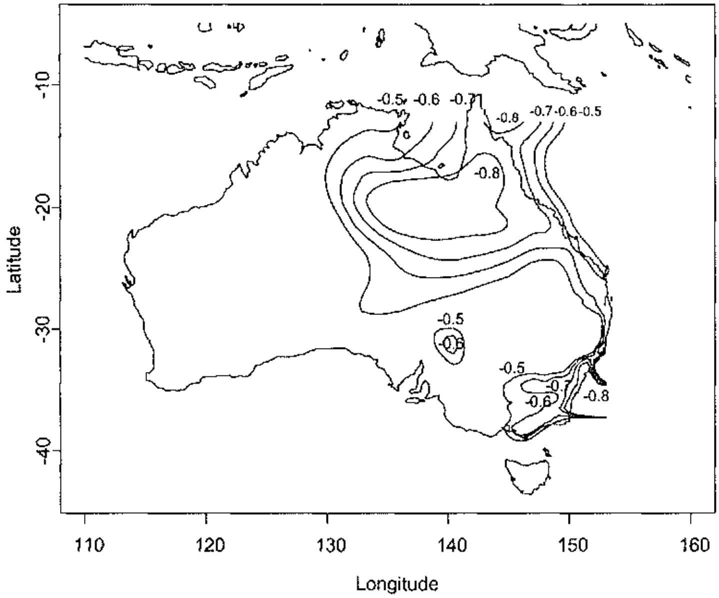

Fig. 2 Isopleths of correlation coefficient between winter GpH (700 hPa at Woomera) and summer precipitation for the 10 years with highest winter GpH at Woomera. Period of record 1950–1987, 1991–1993.

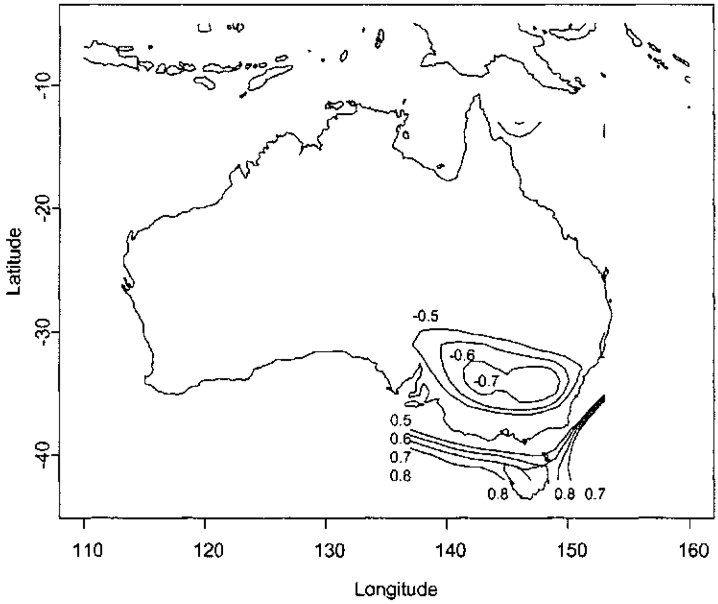

Fig. 3 Isopleths of correlation coefficient between summer SOI and summer (12 months later) precipitation for the 10 years with highest summer GpH (700 hPa at Melbourne). Period of record 1950–1993.

Geopotential height is observed at a limited number of locations. In Australia only a few stations have records from 1955 or earlier. Monthly values from four stations only (Perth, Alice Springs, Woomera and Melbourne) were used and it was found that 700 hPa altitudes were most strongly correlated with precipitation. However when data from these four stations and SOI values were interchanged, either as partitioning variable or as independent variable to estimate precipitation, the strength of the relationships changed considerably, meaning there is a need to examine all possible combinations of variables in order to find the strongest (and therefore potentially most reliable) relationships for forecasting precipitation at any particular location. Among the four sets of GpH observations and the SOI values, there was no discernible pattern to indicate which combination may give the best relationship for a particular precipitation district. It is therefore possible that improved relationships may be obtainable if GpH values for other stations which have shorter periods of record were used, but at this stage these possible relationships have not been considered. It is also possible that a trigger variable in one season may suggest that a forecast variable in the next season may be strongly related to precipitation in a later season. An example is shown in Fig. 4, where for the years of maximum winter GpH at Woomera, the following spring SOI is strongly related to the subsequent summer precipitation for large areas of eastern Australia.

FORECASTING LOW PRECIPITATION

To demonstrate the way in which a forecasting system such as that proposed here could be used in practice, an independent data set for the years 1988–1990 and 1994–1996, which were not used in developing the forecasting system, was utilized.

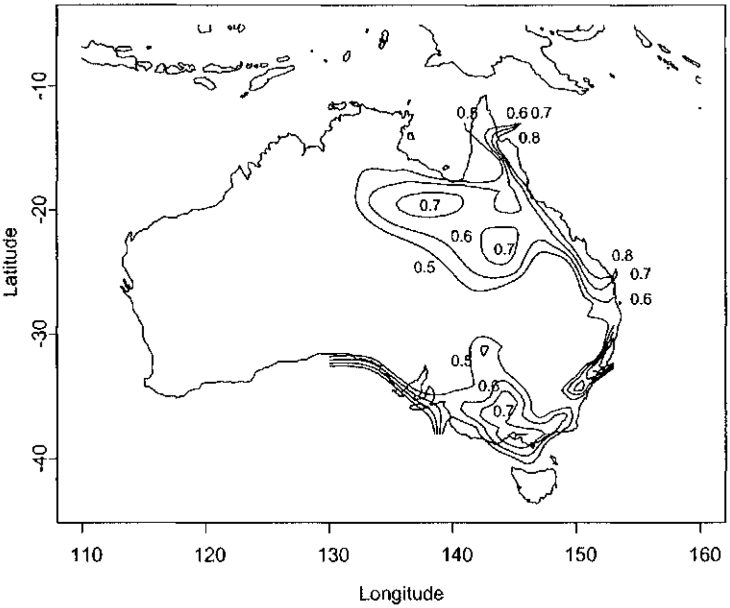

Fig. 4 Isopleths of correlation coefficient between spring SOI and summer precipitation for the 10 years with the highest winter GpH (700 hPa at Woomera). Period of record 1950–1987, 1991–1993.

From the period 1954–1987 and 1991–1993, the years with the 10 lowest autumn SOI values were selected, (approximately 25% of the 37 years), and for these years regressions were developed between the average autumn 700 hPa height at Alice Springs and winter precipitation for each of the 107 rainfall districts in Australia. For demonstration purposes districts 55 and 64, which are in the centre of eastern Australia will be used as examples. For these two districts the linear correlation coefficients between the autumn GpH and winter rainfall for the years selected by the partitioning were respectively 0.74 and 0.78. After development of the results discussed above, data became available for the missed years 1988–1990 and for 1994–1996, and an attempt was made to use the model in forecasting mode with this independent data set. Table 1 shows the observed winter rainfalls and the estimated (forecast) values. In the columns of forecast values the words "not low" occur where the autumn SOI value was not in the lowest 25% of observed values, to which the partitioned relationship applied, and therefore no value could be estimated except to forecast that the value should be above the lowest 25% of all observed winter rains.

Though the results shown in Table 1 do not appear very impressive at first glance, they are quite consistent with the correlation coefficient values. In the four years 1988–1990 and 1996 the forecasts are completely correct in that all the observed values were in the vicinity of, or above the median values. In 1995 the forecasts were approximately correct in that they were for values within the range of the lowest 25% of observations and the observed values were in this (drought) range. For 1994 the forecasts were incorrect. So the forecasts were correct for five years out of six.

Table 1 Precipitation forecasts of winter rain for years for which data was not used in model development.

Winter of year	District 55 Forecast winter rain (mm)*	District 55 Observed winter rain (mm)	District 64 Forecast winter rain (mm)*	District 64 Observed winter rain (mm)
1988	Not low	369	Not low	324
1989	Not low	531	Not low	450
1990	Not low	602	Not low	422
1994	550	183	504	135
1995	288	216	297	144
1996	Not low	522	Not low	648
Median winter rainfall (mm)		387		378
Lowest 25th percentile winter rainfall (mm)		282		290

* Forecast prepared at end of autumn.

TESTING OF THE FORECAST MODEL

In order to develop real confidence in the reliability and useability of the relationships developed here the physical basis needs to be determined. At this time the relationships are purely empirical observations. While a physical basis for concurrent relationships has been suggested (Nazemosadat & Cordery, 1997), no defensible physical explanation has yet been developed for the lag relationships, which are the basis of the proposed forecasting model.

In the absence of a physical basis for the forecasting models, there is a need to demonstrate that the relationships are not accidental occurrences or artefacts of the simple mathematical formulation. One test that was used was to substitute a random process for the simple partitioning device of selecting the data pairs as those with either minimum SOI or maximum GpH at the time of forecast formulation. For example, instead of selecting data for the years when autumn GpH was in the highest quartile of autumn GpH values, a random selection of years was made. For these years the autumn SOI and winter precipitation were correlated for all 107 precipitation districts. Several hundred runs were undertaken for each forecast period and season with a different, randomly selected set of 10 years of data values being used in each case. For a few target periods strong correlations resulted for a surprisingly large number of precipitation districts as shown in columns 4 and 5 of Table 2. A contribution to the large mean number of districts with strong correlations was the fact that rainfalls tend to be strongly correlated within regions. This can be seen by the size of the standard deviations of numbers of districts for which correlations were significant. In most cases the standard deviation is about equal to the mean.

By comparison the proposed partition model in most cases produced strong correlations (including lag relations) in far more districts than result from the random selection process. As can be seen in column 3 of Table 2, in most cases the number of districts with significant relationships from the proposed model is more than two standard deviations greater than the number of districts for which significant correlations result from the random selection process. This suggests there is less than 3% chance the large numbers of districts with strong relationships from the proposed partition model

Table 2 Number of Australian rainfall districts for which significant correlations occur between rainfall and SOI or GpH for the forecasting period shown. Total number of districts = 107.

Lag between forecast formulation and target season	Target season	No of districts with $\|r\| > 0.6$ (significant at 95% level):		
		Partition model selection of data	Random selection of data Mean of 500 runs	St. dev. of random runs
Concurrent data (zero lag)	Spring	67	27	17
	Summer	50	4	3
	Autumn	47	12	11
	Winter	50	15	13
3 months (one season)	Spring	58	18	15
	Summer	34	5	6
	Autumn	47	16	12
	Winter	20	4	4
6 months (2 seasons)	Spring	23	8	9
	Summer	31	4	5
	Autumn	34	13	9
	Winter	36	6	7
12 months (4 seasons)	Spring	28	8	10
	Summer	26	16	11
	Autumn	18	7	5
	Winter	13	11	10

could have occurred by chance. This small experiment demonstrates that it is unlikely that the results obtained are a statistical artefact. Rather it reinforces the need to understand the processes which might be responsible for such a set of results.

It can also be seen from Table 2 that the number of districts for which significant relationships are produced by the proposed model decreases as the lag or forecast period increases, but that even with one year ahead forecasts, strong relationships were obtained for far more districts than could have occurred by chance.

CONCLUSION

It has been demonstrated that it is possible to forecast low precipitation 3–12 months in advance, with a better than even chance of being correct, for large parts of Australia. The regions for which forecasts are possible vary with the choice of input variables, but, with the selection of appropriate values of Southern Oscillation Index and geopotential height, it is possible to provide forecasts of low precipitation for most parts of the 8×10^6 km^2 landmass of Australia.

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