Strong relationships for forecasting drought in eastern Australia. February 1997.

Author:
Cordery, I.

Publication details:
Report No. UNSW Water Research Laboratory Report No. 193

Publication Date:
1997

DOI:
https://doi.org/10.4225/53/57a4148690630

THE UNIVERSITY OF NEW SOUTH WALES
water research laboratory
Manly Vale N.S.W. Australia

STRONG RELATIONSHIPS FOR FORECASTING DROUGHT IN EASTERN AUSTRALIA

Research Report No. 193

February 1997

THE UNIVERSITY OF NEW SOUTH WALES
WATER RESEARCH LABORATORY

STRONG RELATIONSHIPS FOR FORECASTING DROUGHT IN EASTERN AUSTRALIA

by

Ian Cordery

Research Report No. 193

February 1997

BIBLIOGRAPHIC DATA SHEET

Report No. 193	Report Date: February 1997	ISBN: 8/85824/022/X

Title

STRONG RELATIONSHIPS FOR FORECASTING DROUGHT IN EASTERN AUSTRALIA

Author(s)

IAN CORDERY
School of Civil & Environmental Engineering, The University of New South Wales

Sponsoring Organisation

Supplementary Notes

The work reported was published under the direction of the Director of the Water Research Laboratory.

Abstract

Strong relationships have been developed between global and local phenomena in one season and precipitation in the next season. The relations explain more than 50% of the variance in the precipitation for areas up to 500,000 km^2 and more than 80% of the variance for smaller areas. The relations apply only to certain years which are indicated by the range in which a third variable falls. This form of forecasting based on partitioning of observed data has the potential to provide reliable three month ahead forecasts of precipitation for large regions.

Distribution Statement

For general distribution

Descriptors

Precipitation; Forecasting; Statistical analysis; Drought; Southern oscillation

Identifiers

Number of Pages: 17	Price: On Application.

https://doi.org/10.4225/53/57a4148690630

Strong relationships for forecasting drought in eastern Australia

Ian Cordery, School of Civil Engineering, The University of New South Wales

Abstract Strong relationships have been developed between global and local phenomena in one season and precipitation in the next season. The relations explain more than 50% of the variance in the precipitation for areas up to 500,000 km^2 and more than 80% of the variance for smaller areas. The relations apply only to certain years which are indicated by the range in which a third variable falls. This form of forecasting based on partitioning of observed data has the potential to provide reliable 3 month ahead forecasts of precipitation for large regions.

1. Introduction

Around the globe there are regions where precipitation is related to broadscale atmospheric phenomena such as El-Nino-southern oscillation, which is numerically defined by the southern oscillation index, SOI (1), sea surface temperatures (SST) and geopotential height (GpH). The demonstration of these relatively strong relationships for many regions (2) has aroused considerable interest and encouraged investigation of the possibilities of forecasting and perhaps alleviating some of the socially undesirable effects of sudden, unexpected occurrence of extremes such as droughts, floods and widespread fires. Investigation of relations between SOI and low rainfall in eastern Australia has been particularly encouraging, but unfortunately it has not led to relationships which have been sufficiently consistent to provide a sound basis for forecasting. (3, 4). In addition strong relationships between concurrent atmospheric or sea surface parameters and precipitation have little practical value. The need in terms of possibilities for forecasting is to have an easily measured phenomenon in one month, related to precipitation one, or preferably several months later. Though there has been considerable research along these lines (4, 5, 6, 7) there have been few instances of use of such relationships because either the relationships developed had not been strong enough or the delay between data collection and the forecast event has been too short to permit any action. Examples of forecast systems are the

Australian Bureau of Meteorology's "Seasonal Outlook" (8), which attempts to qualitatively indicate the precipitation to be expected during the following 3 months, and the estimation of snowpack water content from GpH in parts of western USA, indicating the volume of snow meltwater likely to be observed in subsequent months (9). A possible forecasting system has been presented (10) with lead times of up to 13 months but this approach has only been able to explain 50% of the variance in the target precipitation in one instance, with less than 35% of the variance being explained in most cases. Explaining only 35% of the variance in the target precipitation does not provide a basis for a credible forecasting service.

Since atmospheric and ocean surface phenomena have been shown to be quite strongly related to local precipitation, both concurrently and with a delay of several months, an investigation was undertaken to attempt to determine causes of changes in relationships in the hope of being able to develop relations that would allow consistent forecasting of precipitation in eastern Australia.

2. Inconsistencies in relations between precipitation and other phenomena

Gaffney (11) has shown that although there are strong relationships between SOI and precipitation in eastern Australia there are important deficiencies in the relations. For example in the 110 or so years for which concurrent precipitation and SOI observations are available there have been two important droughts during which the SOI remained close to its long term average and two occasions when very low SOI values occurred (usually suggesting drought conditions) concurrent with either average or above average precipitation . During the period there were 16 droughts and 16 occasions when the SOI was more than one standard deviation below its long term mean for several months in succession.

The general strength of SOI-precipitation relationships in many parts of the world suggests that these relations are not statistical artefacts but are reflections of the real influence of the Southern Oscillation phenomenon on changes in dominant wind directions over the equatorial Pacific Ocean, and the associated equatorial ocean currents and regions where ascending or descending air are dominant. However the anomalies in SOI-precipitation relations listed above suggest that precipitation over eastern Australia is not totally dominated by this global scale phenomenon. There would seem to be local scale phenomena which also exert considerable influence. There have been several allusions to this possibility and there have been demonstrations that other phenomena (eg latitude of W-E passage of anticyclones, SSTs of various ocean regions) are related to precipitation. Recently it has been shown that geopotential height is related to precipitation in various parts of the world (9, 12, 13, 14) and that for a large part of eastern Australia, using a seasonal time interval, relationships between GpH and precipitation are stronger than those between SOI and precipitation (15). Unfortunately GpH data have only been routinely collected over the last 50 years and so it is not possible to examine long term relations between GpH and precipitation.

In order to consider the possibility of assessing the influence of several phenomena on precipitation there is a need to develop a model of their interactions. At this stage practically nothing is known of the physics of the interaction between these phenomena except that they are observed to change in concert with each other and that they all tend to be correlated with each other. This means that a simple exploratory model such as multiple regression between precipitation and parameters such as SOI, SST and GpH cannot be of any usefulness in estimating precipitation from the others since, the simple linear correlation coefficients between SOI, SST and GpH, using a seasonal time interval, are of the order of 0.7, whereas valid use of multiple regression requires independence of the predictor variables.

2.1 Partitioning of data

Another means of examining the influence of two correlated variables on a third variable is to use one variable as a marker to partition the data. Where the three variables are in the form of concurrent time series, one variable could be used as a means of selecting the time intervals for which the relationship between the remaining two variables is to be examined. For example if both SOI and GpH influence precipitation it is possible that when SOI is low, which usually indicates below average rainfall in eastern Australia, there may be a strong relationship between GpH and precipitation. Hence a partitioning strategy, for say January, could be to select the years when the January SOI is in the lowest 25% of all January SOIs. For these years the January GpH–precipitation regression could be examined. This simple model includes the effects of both global (SOI) and local (GpH) influences on precipitation without compromising the requirements for valid use of regression as a prediction model.

2.2 Data available

Data available for this study comprised the monthly district precipitation for all thirty rainfall districts in New South Wales which has an area of 800,000 km^2. These data comprise a mean of the month's precipitation observed in each district. The number of stations used to obtain the monthly mean varies from district to district and from month to month. However, provided the number of stations used to estimate the mean value for each month is high, say greater than 10, the time series for each district should be relatively homogeneous. The data in this form were used because of their availability when the study began.

SOI data were provided from the Bureau of Meteorology archive. SOI is defined as the sea level pressure difference between Papeete (Tahiti) and Darwin (Australia) normalised for each month to have a mean of zero and standard deviation of 10. GpH data were available in the form of average monthly altitudes at which the particular pressure was observed. Data were initially obtained for four radiosonde observation locations, Nowra, Woomera, Darwin and Brisbane and for pressures of 1000, 900, 850, 800, 700 and 500 hPa. Later, GpH data were obtained for a wider range of radiosonde stations around Australia.

Seasonal analysis was used rather than monthly because it has been shown that the strength of association between precipitation and SOI varies with the data interval used, with the highest association being observed for a two month interval, closely followed by 3 months (4). Since 3 months is a season and 3 months would appear to be a worthwhile forecasting period, this interval was adopted for the analytical work.

3. Seasonal relationships between precipitation and GpH

Partitioning of seasonal data was accomplished by identifying the years in which the GpH was very high. Data were available for 1950 - 1987 and 1991 - 1993. GpH data for years 1988 - 1990 inclusive were not available in the Bureau of Meteorology archive. The data were supplied in monthly intervals and these were combined to provide seasonal data, autumn being March to May, winter June to August etc. When seasonal data were used they were assembled in a time series for each season, so that the autumn series comprised autumn 1950, autumn 1951 etc. To partition the data the years with the 10 highest GpH values for the particular season were selected. For these selected years precipitation for that season was in turn regressed against SOI and GpH for the same years. This provided regressions of concurrent autumn precipitation versus autumn SOI and of concurrent autumn precipitation versus autumn GpH for the 10 years with the highest autumn GpH. In summer neither variable was correlated with precipitation. In autumn and spring precipitation was correlated with GpH in the partitioned years with $r>0.6$ for small areas only. In winter the correlation between SOI and precipitation, for years with high GpH at Woomera, was very high, with $r>0.8$ for 60% of New South Wales, or 450,000 km^2 and $r>0.9$ for 15% or 100,000 km^2 as shown in Figure 1.

A physical justification for this form of partitioned relationship also needs to be found. Nazemosadat and Cordery (15) have provided a tentative explanation for high GpH over inland Australia being associated with wetter than average conditions over south eastern Australia. The combination of low SOI, which is associated with descending air over the western Pacific, with high GpH which is also associated with below average precipitation, presumably reinforce each other in winter.

In this season anticyclones cross Australia from west to east at 25° – 30°S latitude. To the south of these anticyclones the air motion over most of the southern part of the continent is westerly with cool, moist, cloudy southern maritime airmasses from the Indian and Southern Oceans. These airmasses are usually dominant at latitudes greater than 30°S (central and southern NSW) . Orographic and frontal lifting of these airmasses produce much of the winter rainfall in NSW, particularly on the western slopes of the Great Dividing Range. In winter Woomera (31°S) is located close to the average path of the anticyclones where air is generally descending. However, below average GpH at Woomera is an indication that Southern Ocean depressions with their ascending air intrude further to the north and influence a large part of NSW. Precipitation occurs from this cool ascending air, especially on the western side of the Great Dividing Range. The north of the state lies in the track of the anticyclones, so that when the GpH is lower the precipitation in this region increases but when GpH is above average the dominant air movement is downward and the region is dry. Nazemosadat and Cordery (14) observed that in winter the GpH at Woomera reflects the latitudinal position of the anticyclones and is more strongly related to precipitation than is SOI.

4. Lag relationships

While strong relationships between concurrent SOI, GpH and precipitation are of great interest they have no practical value for the possible forecasting of precipitation. To be useful for forecasting, the precipitation in one season needs to be related to other parameters in an earlier season. However, lag relations, between, say, SOI in one season and precipitation in the next season are generally not strong enough to have any potential for forecasting. To examine the possibility of using a partition model for forecasting, the years with the 10 highest spring GpH values were identified. For these years, spring SOI was regressed against summer precipitation. As shown in Figure 2 for this relationship, the correlation coefficient exceeded 0.7 for an area of about 70,000 km^2 and for 300,000 km^2 it exceeded 0.6. When, for the 10 years of highest spring GpH the spring GpH values were regressed against summer precipitation the area with $r \geq 0.7$ increased to 250,000 km^2 and $r \geq 0.6$ included 450,000 km^2 or more than half the state, as shown in Figure 3. However for these two different models, with summer precipitation related to spring SOI or GpH the regions in which the strong relationships occurred were quite different, as can be seen from comparison of Figures 2 and 3. The reasons for the differences are not obvious, particularly since strong relationships are not limited to one side of the Great Dividing range, nor do they correspond to any defined climatic zone.

Using Woomera 800 hPa GpH for spring as the partitioning variable, relations with correlation coefficient r greater than 0.7 (explaining 50% of the variance in the precipitation) were found between spring SOI and summer precipitation for an area of 70,000 km^2 and between spring GpH itself (the partitioning variable) and summer precipitation for 250,000 km^2. The two regions with high correlation did not overlap. Later, GpH data for other stations were used and it was found that stronger relations covering larger areas were obtainable. For example when the partitioning variable was the 700 hPa height at Perth, 2000 km to the west of the region for which precipitation data were available, values of $r>0.7$ were obtained for 400,000 km^2 when the independent variable was spring SOI, as shown in Figure 4. However there was weaker correlation between Perth GpH in spring and summer precipitation for these partitioned years, compared with the degree of association shown in Figure 3.

Further examination of lag relations using data partitioned in the same manner as above enabled development of strong relations for all seasons. For example for spring and autumn precipitation, partitioned relations were developed with Woomera GpH and SOI in the previous season with correlation coefficients greater than 0.7 for 200,000 km^2 for spring precipitation and 250,00 km^2 for autumn precipitation. Between autumn GpH or SOI and winter precipitation strong relations were found for more limited areas. When data were partitioned on autumn SOI, relations for winter precipitation with correlation coefficients exceeding 0.7 were found for 200,000 km^2 with autumn GpH at Alice Springs.

It is apparent from the above reported results that there are large regions where precipitation is strongly related to SOI or GpH in the previous season for those years when GpH is high. An example of this is shown in Figure 5 where correlation coefficients for relations between the autumn 700 hPa GpH at Alice Springs and winter precipitation are shown, for the years of lowest autumn SOI. Whilst there was very little correlation between Woomera GpH in autumn and winter precipitation, and the general correlations shown in Figure 5 cannot be considered very strong, there is clearly a degree of association over a large area of the north of NSW west of the Great Dividing Range. It would appear that if other combinations of data were examined (eg partition using SOI, or GpH for different pressure levels or for different locations) relations would probably be found which would allow one season ahead forecasting of precipitation from regressions with correlation coefficients exceeding 0.7 (explaining >50% of the variance) and possibly exceeding 0.8 for all locations. An example is shown in Figure 6, where autumn precipitation for more than half of NSW (>450,000 km^2) is associated with GpH (700 hPa) in summer at Woomera with correlation coefficient >0.7 for those years when the highest values of summer GpH occur at Perth. Here the association between summer parameters and autumn precipitation is stronger than that mentioned earlier, but does not include the whole of the area of strong association for the former case, which was between Woomera summer GpH and autumn precipitation for years of low summer SOI. However to find these many relationships that will allow forecasting for any location and any season would require a systematic search over a huge data base and will require considerable time.

4.1 Limitations of partitioning data for forecasting

A disadvantage of this approach is that although strong reliable relationships may be developed, in forecasting mode they may not point to all drought situations, since it is possible that a drought may by chance occur in a year when the GpH used to partition the data, or trigger the use of a regression, may be just outside the range which indicates a drought is likely to occur. There is a need to reverse the relationship defining process, to include in a relationship all low precipitation occurrences in the target season. To this end the partitioning process could be reversed with low precipitation in one district being used to select the years of interest. This is a kind of hindcasting. When this form of partitioning was undertaken significant correlations were found between precipitation in selected districts and either SOI or GpH in the previous season. However a model such as this is not ideal for forecasting for two reasons. Firstly the defined lag relationship between, say, SOI in one season and precipitation in the next season includes a range of SOI values, not just the lowest values. Therefore there is no clear means to initiate or trigger the use of the established lag relationship. The second deficiency of this approach is that it was shown earlier that neither SOI nor GpH alone are very strongly related to precipitation. Rather the very strong relationships ($r \geq 0.8$) are those that feature both general global factors, such as SOI, and local regional parameters such as GpH.

5. Causes of predictive relations

Nazemosadat and Cordery (15) have given suggestions for GpH over central Australia being related to precipitation in eastern Australia. However those suggestions only apply to concurrent observations. It is not as yet apparent why a combination of global and more local atmospheric features in one season would influence precipitation in the next season, that is three months later. There is a degree of autocorrelation between monthly values of SOI but when the time interval is increased to three months the autocorrelation is small. Both seasonal GpH and precipitation appear to be totally independent, therefore autocorrelation of the variables cannot be the cause of the observed relations. Alternatively the relations cannot be statistical accidents because they are too consistent, occur for all four seasons and in one season or another provide strong correlations with precipitation in all parts of the land area studied.

Low precipitation can be forecast 3 months ahead using a model which takes as input both global and local climatic data. The model needs local data from different locations in order to provide forecasts for each particular target location. It would seem likely that it will be possible to forecast low precipitation for any location in New South Wales and any season once the location of GpH that has the greatest influence on that precipitation has been found. However it is also imperative that the physical basis for success of this type of model be found, both to avoid unexpected forecasting inaccuracies and to provide a more sound basis for the models, which should lead to even more reliable forecasting.

6. Conclusion

For many years significant relations have been known to exist between precipitation and global variables such as SOI and SSTs. Though these relations have been statistically significant they have not been strong enough to provide consistently reliable estimates since the proportion of the variance they have been able to explain in the target precipitation has generally been less than 40%. In addition the strong relations have been between concurrent variables, and lag relations, in which precipitation is related to observations of other variables in previous months, have generally been weak. It has been shown here that precipitation is strongly related to combinations of observations of SOI and GpH one season earlier, and that these relations are strong enough to explain more than 50% of the variance in the precipitation over large areas of eastern Australia. Not only have relations been developed which can provide a three months forecast of precipitation, but they have been developed for all four seasons.

7. References

[1] Pittock, A.B. 1973. Global meridional interaction in the stratosphere and troposphere. *Q J Roy. Met. Soc.*, 99:424-437.

[2] Ropelewski, C.F. and Halpert, M.S. 1996. Quantifying southern oscillation - precipitation relationships. *Jour. of Climate*, 9:1043-1059.

[3] Nicholls, N. 1984. The stability of empirical long-range forecast techniques: a case study. *Jour. Climate Appl. Meteorol.*, 23:143-147.

[4] Opoku-Ankomah, Y. and Cordery, I. 1993. Temporal variation of relations between New South Wales rainfall and the southern oscillation. *Int. Jour. Climatology*, 13:51-64.

[5] Nicholls, N. 1984. Toward the prediction of major Australian droughts. *Aust. Met. Mag.*, 33:161-166.

[6] Cordery, I., Yao, S.L. and Opoku-Ankomah, Y. 1993. Forecasting drought - is it possible? *Hydrology & Water Res. Symp., Inst. Engrs. Aust., Nat. Conf. Publ.*, 93/14:387-391.

[7] Opoku-Ankomah, Y. and Cordery, I. 1994. Atlantic sea surface temperatures and rainfall variability in Ghana. *Jour. Climate*, 7:551-558.

[8] Australian Bureau of Meteorology. *Seasonal outlook*. Various dates.

[9] McCabe, G.J. and Legates, D.R. 1995. Relationships between 700 hPa height anomalies and 1 April snowpack accumulations in western USA. *Int. Jour. Climatology*, 15:517-530.

[10] He, Y.X. and Barnston, A.G. 1996. Long-lead forecasts of seasonal precipitation in the tropical Pacific islands using CCA. *Jour. of Climate*, 9:2020-2035.

[11] Gaffney, D.O. 1991. Australian droughts in relation to the southern oscillation index during the period 1882-1991. Unpublished.

[12] Drosdowsky, W. 1993. An analysis of Australian seasonal rainfall anomalies: 1950-1987. II Temporal variability and teleconnection patterns. *Int. Jour. Climatology*, 13:111-149.

[13] Kozuchowski, K. and Wibig, J. 1992. Connections between air temperature and precipitation and the geopotential height of the 500 hPa level in a meridional cross-section in Europe. *Int. Jour. Climatology*, 12:343-352.

[14] McCabe, G.J. 1996. Effects of winter atmospheric circulation on temporal and spatial variability in annual streamflow in the western United States. *Hydrological Sci. Jour.*, 41:873-887.

[15] Nazemosadat, M.J. and Cordery, I. 1997. The influence of geopotential heights on New South Wales rainfall. *Meteorology and Atmos. Physics*, Accepted for publication.

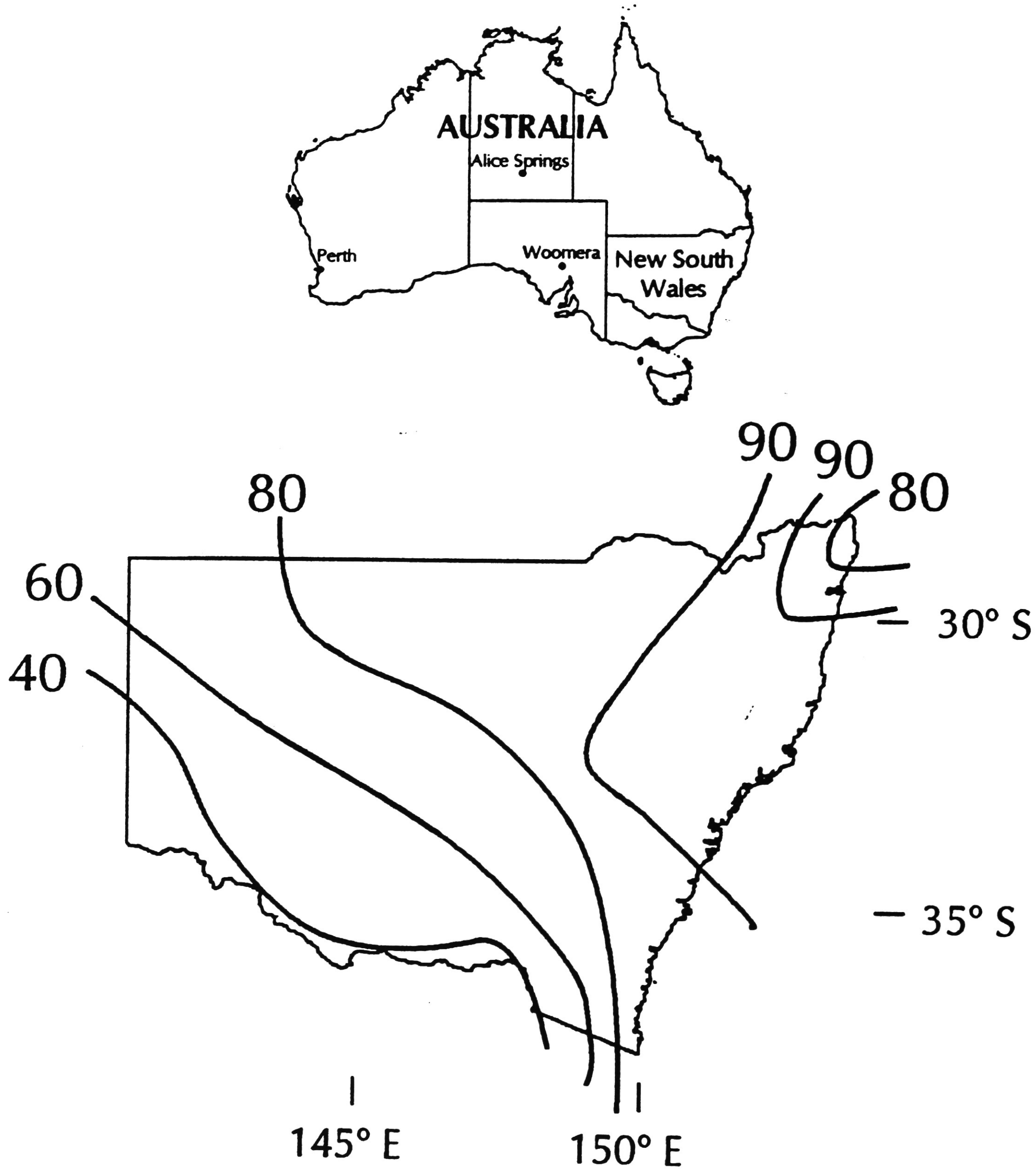

Figure 1 New South Wales. Isopleths of correlation coefficient (as percentage) between winter SOI and winter precipitation for the 10 years with highest winter GpH (800 hPa at Woomera). Period of record 1950-1993.

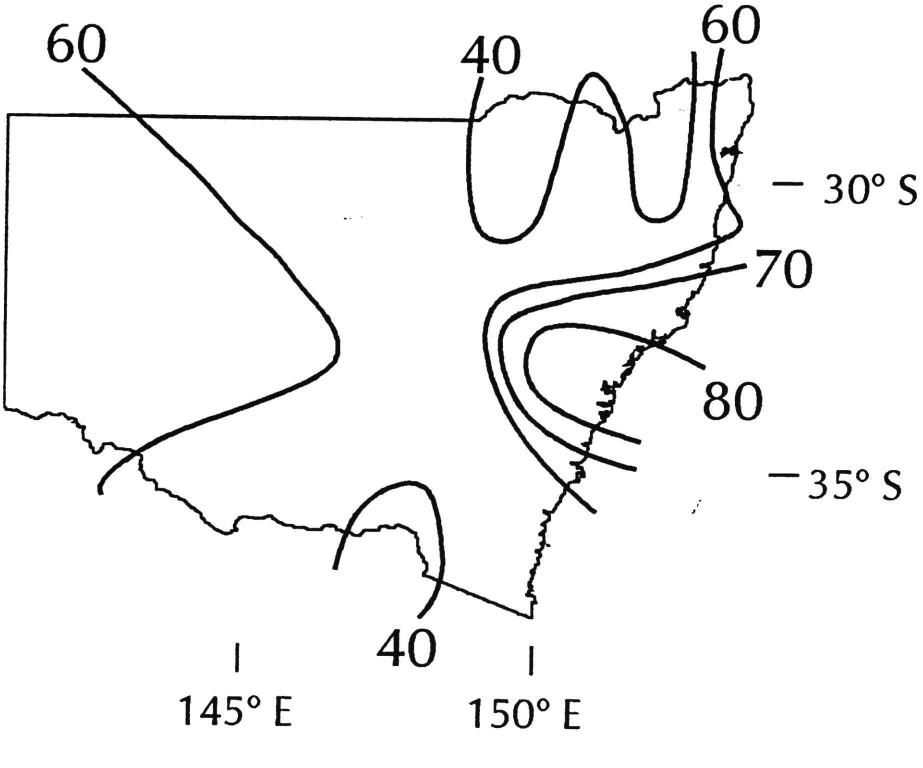

Figure 2 New South Wales. Isopleths of correlation coefficient (as percentage) between spring SOI and summer precipitation for the 10 years with highest spring GpH (800 hPa at Woomera). Period of record 1950-1993.

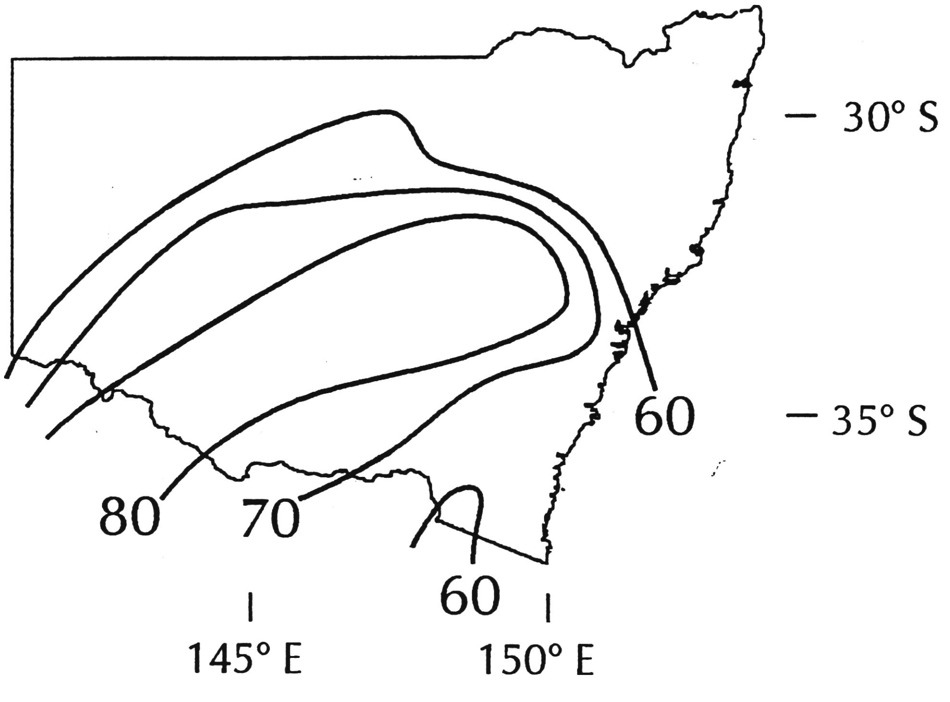

Figure 3 New South Wales. Isopleths of correlation coefficient (as percentage) between spring GpH (800 hPa at Woomera) and summer precipitation for the 10 years with highest spring GpH. Period of record 1950-1993.

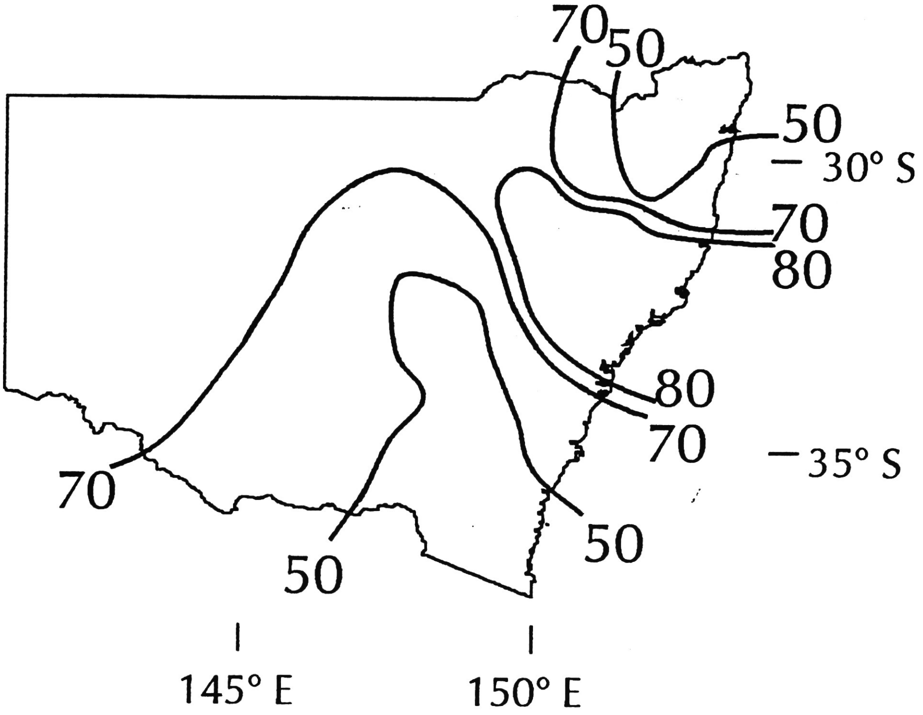

Figure 4 New South Wales. Isopleths of correlation coefficient (as percentage) between spring SOI and summer precipitation for the 10 years with highest spring GpH (700 hPa at Perth). Period of record 1951-1987, 1991-1993.

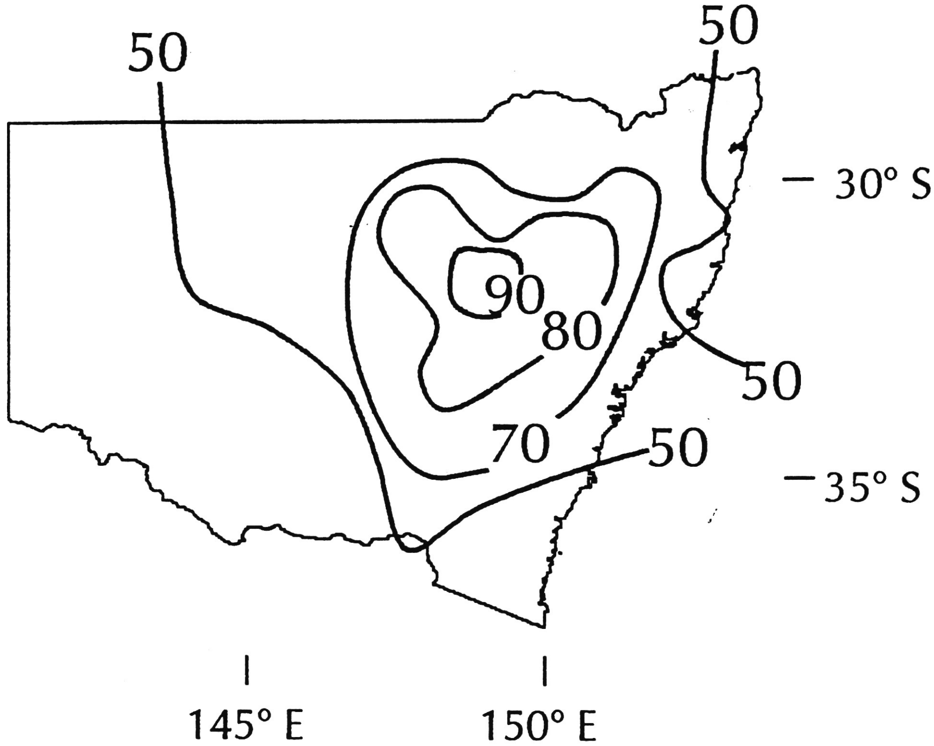

Figure 5 New South Wales. Isopleths of correlation coefficient (as percentage) between autumn GpH (700 hPa at Alice Springs) and winter precipitation for the 10 years with lowest autumn SOI. Period of record 1954-1987, 1991-1993.

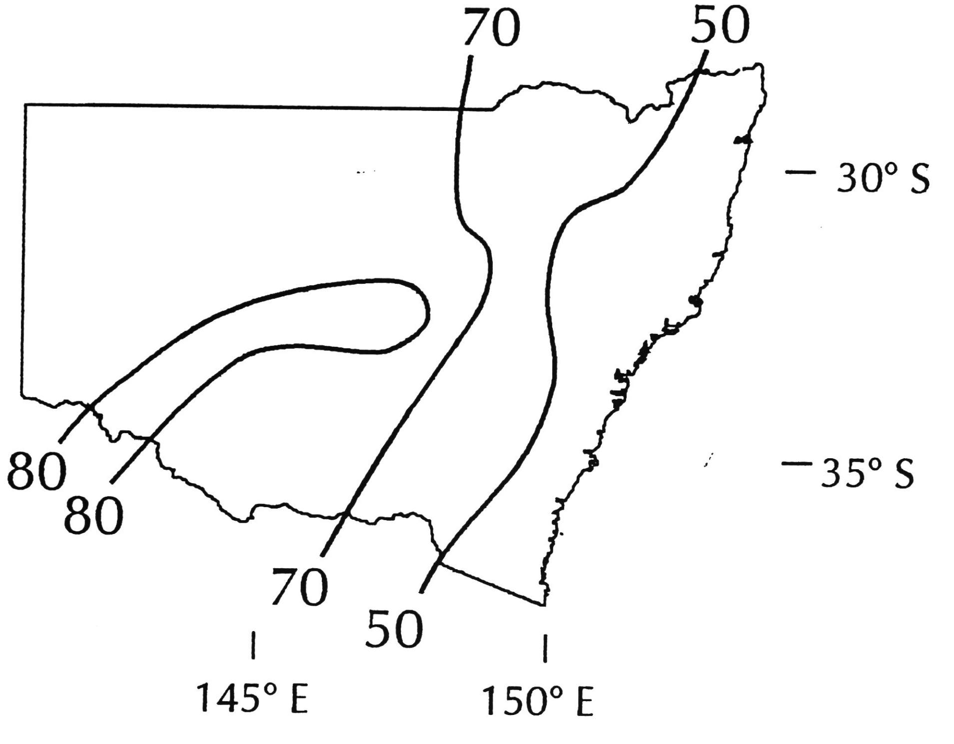

Figure 6 New South Wales. Isopleths of correlation coefficient (as percentage) between summer GpH (800 hPa at Woomera) and autumn precipitation for the 10 years with highest summer GpH (700 hPa at Perth). Period of record 1951-1987, 1991-1993.