

# SOME ASSOCIATIONS IN AUSTRALIAN MONTHLY RAINFALLS

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**Abstract:** In further illustration of the merits of the association coefficient for extensive search and survey purposes, a broad study is made of the time and (for summer only) space associations between anomalies in monthly rainfall on the Australian mainland. There appears a marked persistence down the East Coast in spring and early summer, but little at other times and places and none in January to March: thus late summer rainfall is a random product of its individual months.

For summer monthly rainfalls the strongest regional bond is found in the North-Central and North-Eastern districts, and these rainfalls show slight but significant association with prior (October and November) Darwin pressure. Coastal districts on a spacing of about 1,000 miles exhibit little mutual association in the main summer months.

## 1. INTRODUCTION

A wet season would be described in simplest terms as one in which the total rainfall exceeds normal. But to those concerned with the structure of weather and climate, their causes and predictability, or otherwise with the best planning and use of a nation's water resources, the matter implies a probing into space and time scales. On the time scale such probing must first concern itself with the season's component months; artificial though this subdivision is for many scientific purposes, this is the form in which the data is readily available. Is, then, the variability of seasonal rainfall composed of a random combination of that of its individual months? If not, what associations do exist between the months? And over what typical areas, within the month or the season, do these variabilities show a conformity of behaviour? These questions admit of much further refinement, but even in this broad form they are important both in practice and in the orientation of research. Yet much of the classical statistical work, and even some of the more modern dynamical-climatological approach to seasonal anomalies, appears to have taken the answers for granted.

The data to be presented here represent an attempt to approach directly the first two questions and, in a quite preliminary way, the third, with main emphasis on the summer season. The results are given in the form of values of a particular coefficient of association which in an earlier paper (Priestley, 1962) has been termed the 'sympathy', and whose properties are described therein. Briefly, the sympathy  $s$  between series of values of two elements represents a measure of the frequency with which a high (low) value of one is found in conjunction with a high (low) value of the other. Subject to the errors of sampling,  $s$  is related to the correlation coefficient  $r$  by

$$r = \sin \frac{\pi s}{2} \quad \dots (1),$$

whilst at a true value of zero the variances of  $s$  and  $r$  are equal, being given by

$$\sigma_r^2 = \sigma_s^2 = \frac{1}{2n-1} \quad \dots (2),$$

for two series each composed of  $2n$  terms. Thus  $s$  is a less powerful statistic than  $r$ . But it has some advantages both in principle, in that it has no restrictions as to the frequency distribution of the parent populations, and in practice, in its simplicity of calculation. For

purposes of survey such as the present it achieves a wider compass for a given effort, whilst the use of  $r$  is held in reserve where a more detailed and precise treatment of special cases appears desirable.

Unless otherwise stated in what follows, the material used was drawn from two sources, which will be referred to by the initials below:-

WWR. World Weather Records (mainly monthly rainfalls) as published, from the beginning of the period when these were reasonably complete, up to the end of 1950. Because the rainfall of a single station may be only indifferently correlated with that of its region (Treloar, 1934) this was supplemented by

DA. District averages of monthly rainfall, as published by the Bureau of Meteorology (1938), and extended for the districts selected for study so as to provide a 48-year period ending March 1961.

The length of WWR record for which each of the two series concerned was complete varied from 64 to 110 years, and is quoted where relevant. The original intention was to utilise only the major portion of the record in the search and reserve a minor but substantial part for verification. But it was found that the overall pattern of results (on which, rather than individual values, the emphasis was placed) was generally clear enough to make this procedure unprofitable.

## 2. PERSISTENCE IN MONTHLY RAINFALLS

For each of the main Australian stations in WWR, the sympathy between the monthly rainfalls of each month and its successor have been calculated for the period of the record. These are given in Table 1. Where no value is recorded, at least one of the months experienced zero or very small monthly rainfall sufficiently often to make the technique meaningless. Values are underlined (doubly) where this or a higher absolute value would be obtained by sampling from independent populations less frequently than once in twenty (one hundred) times.

There is compelling evidence for the existence of some persistence, the count showing 60 positive, 34 negative, and 5 zero values; while the number of underlined values is 10, every one of which is positive, against a random expectation of 5 of mixed sign.

Whilst the stations are quite well distributed round the circumference of the continent (and have been tabulated accordingly) the fact that only two are inland sets a limitation to more detailed probing at this stage. But within this limitation it is possible to recognise one space-time block of figures where the sympathy behaves consistently: the data from the two inland stations do not encourage much hope that more such blocks would be evident if more inland stations were available.

The consistent block relates to the East Coast stations in late spring to early summer, with possible extension in space round to Darwin and in time, with weaker persistence, back into winter. The average value of the fifteen figures within the main block (Sept. - Jan.) is +0.18. Bearing in mind that the standard error is of the order indicated by Eq. (2) (note that this strictly applies only to random series with true  $s = 0$ ), it cannot be stated at this stage to what extent the individual variations within the main block can be regarded as real. For example, there is an indication, but at this stage no proof, that the persistence moves southward with the advance of season. But the existence of a significant tendency to persistence for this region and season as a whole is established beyond any reasonable doubt.

There might well be some bond between the component months of a season (particularly if the latter term may be extended to, say, a five month period) which does not necessarily involve marked sympathy or antipathy between named adjacent months. With this in mind, a number of tests have been made of the frequency of one, two, three, four, or five wet or dry months in various periods at various places. The general result was, however, that unless adjacent months were already displaying persistence, no further departures from random expectation were discovered.

Table 1. Sympathy between Rainfalls of Successive Months

Individual values for which  $P > 0.05$  underlined,  $P > 0.01$  doubly underlined.

Station	Years of Record	J-F	F-M	M-A	A-M	M-J	J-J	J-A	A-S	S-O	O-N	N-D	D-J
Onslow	64	- .09	+ .12	- .06	+ .06	+ .03	<u>+ .31</u>	- .16					
Perth	74	- .04	- .01	<u>+ .27</u>	- .05	<u>+ .24</u>	- .13	- .19	- .08	+ .08	- .16	- .03	- .19
Adelaide	110	- .07	- .02	+ .01	+ .03	+ .02	+ .05	+ .02	+ .13	- .05	+ .02	+ .13	- .11
Hobart	68	0	+ .06	- .06	0	- .12	- .06	+ .06	- .06	+ .18	+ .12	- .18	- .18
Sydney	110	+ .09	- .09	<u>+ .24</u>	<u>+ .31</u>	+ .02	+ .02	+ .05	+ .05	+ .09	<u>+ .24</u>	+ .05	<u>+ .27</u>
Brisbane	90	- .07	+ .11	+ .02	- .11	+ .02	+ .11	+ .16	+ .02	+ .20	+ .11	<u>+ .42</u>	+ .07
Cairns	68	- .04	+ .06	+ .12	+ .12	- .09	+ .18	0	+ .04	<u>+ .29</u>	+ .12	+ .18	+ .18
Darwin	70	- .03	+ .09	+ .14						+ .09	<u>+ .31</u>	+ .14	- .03
Alice Springs	76	0	- .05	0	+ .14					- .14	+ .05	+ .11	
Cloncurry	66	+ .21	- .15	+ .21						- .09	+ .09	+ .09	- .15



Despite the generally low values of persistence obtained, the survey may be said to have served its purpose in identifying the region and season wherein the longer-lasting effects may be studied with the greatest chance of success. One may expect that the incorporation of other elements (particularly sea surface temperature), the use of physical principles and a more flexible choice of periods than the fixed month offers, and a generally more selective approach, will result in levels of predictability surpassing those of Table 1.

Another definite pointer obtained from the survey, albeit a negative one, is the total absence of any significant evidence of persistence through the mid-to-late summer season, January to March. In this season it appears that, throughout Australia, seasonal rainfall is no more than a random total of the component monthly rainfalls. This finding could with advantage be pursued into successively smaller time units until significant auto-correlation is identified, with considerable relevance as to the time scale in which physical and synoptic studies of late summer rainfall should most appropriately be conducted.

### 3. SPATIAL RAINFALL ASSOCIATIONS

For practice as well as for orientation of research, the question of the space scale is as relevant as that of the time scale. To provide a conspectus of space scale the summer season (November to February or March) was selected, and a limited number of districts chosen from the DA material as indicated in Figure 1. The choice of districts aimed at providing a broad coverage of the continent with emphasis on the coastal districts, and also on the northern part of the continent where the period under study includes the onset and main part of the wet season.

For the individual months November to February (excluding November for district 5 where the rainfall was too frequently negligible), the sympathy between each pair of the nine selected districts was evaluated for the 48 years of the DA record. The results are given in Table 2.

We may readily identify two important features of Table 2. District 48 is associated with each of the three coastal districts in the S. E. quadrant, and particularly strongly with 66, while the association with 48 also extends north-westward to reach 15 and 29, and possibly 14. An even stronger band of association encompasses the districts of the N. E. and North-Central quadrants, i. e. 14, 15, 29 and 31, reaching down as far as 48 as has been seen, but also possibly extending westward insofar as the association between 14 and 5 may also be real, though not of great magnitude. Clearly this second band represents the most extensive regional summer rainfall association of the continent.

The next question is whether significant associations exist between the peripheral districts. If 15, 29 and 48 are eliminated, there remains a more or less uniform distribution of districts around the coast. The indices of sympathy between these may be summarised by drawing up a table of frequencies and comparing with the distribution expected on the basis of complete randomness (Priestley, loc. cit.), and this is shown in Table 3.

Table 3. Frequency Distribution of Sympathy,  
Districts 15, 29 and 48 excluded.

s	$\leq - .25$	$- .17$	$- .08$	$0$	$+ .08$	$+ .17$	$\geq + .25$
Number of expected occurrences	5.8	9.3	15.1	17.7	15.1	9.3	5.8
Number of observed occurrences	3	6	16	$16\frac{1}{2}$	$18\frac{1}{2}$	11	7

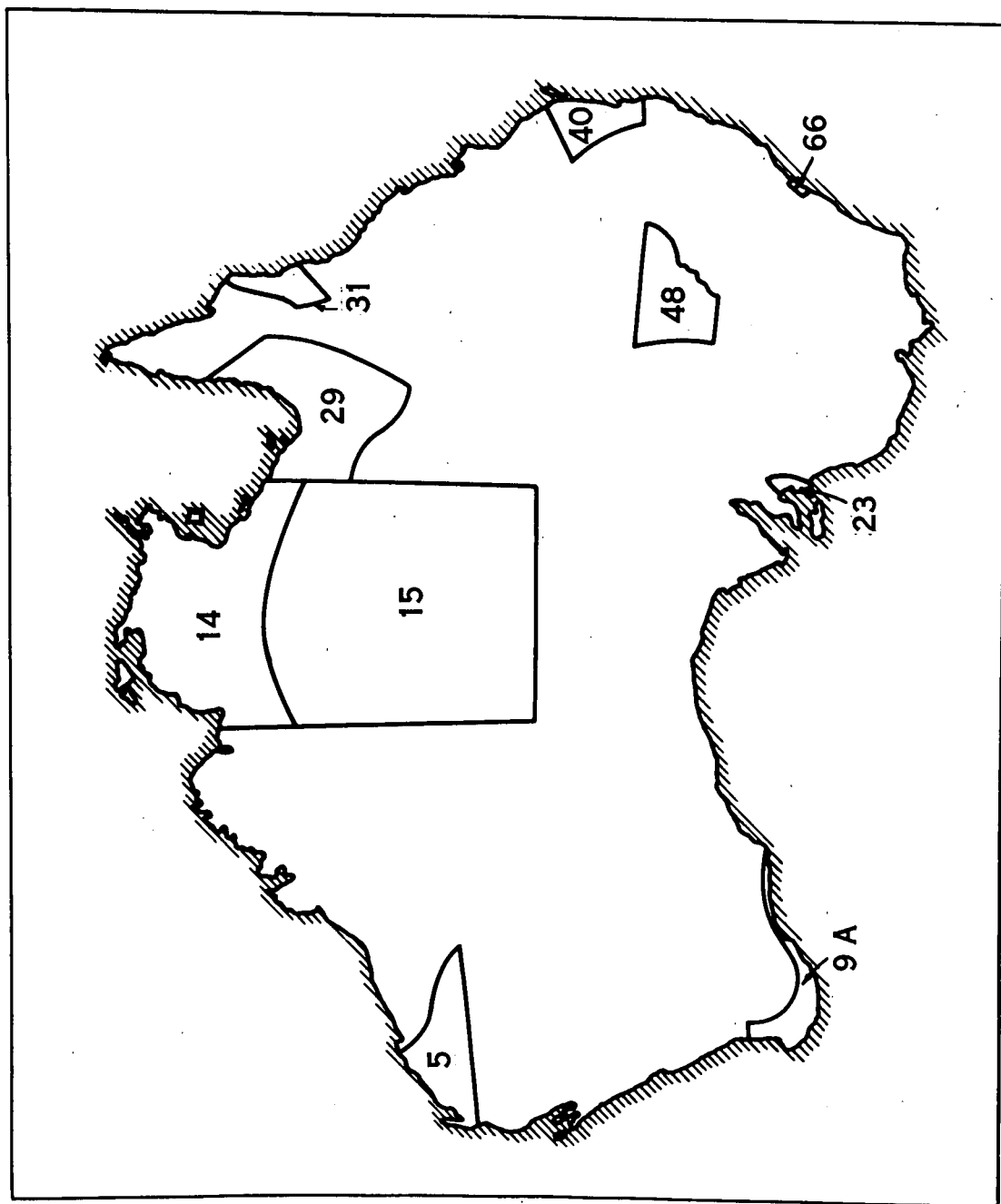


Fig. 1 Delineation of rainfall districts.

Whilst the observed magnitudes are not discordant with those of a random distribution, there is still in evidence a distinct bias towards positive values. In seeking to analyse this further, one may note firstly that the consistency of sign and the magnitudes of the association between districts 40 and 66, reinforced by one's general meteorological judgement leave little doubt of the reality of this particular association. The remainder may be broken down into months, according to sign, as follows:-

November	9 positive	1 negative	4 zero
December	9 "	9 "	2 "
January	6 "	8 "	6 "
February	9 "	7 "	4 "

One is led to conclude that the remaining positive bias derives wholly from November and that for the other months this scale of spacing between peripheral districts results in sets of monthly rainfalls which are, to a first approximation, mutually independent.

With this conclusion in particular however, and also elsewhere throughout the paper, we are to be reminded that we are dealing with departures from climatic normals (strictly, medians): the normals of the districts are not to be thought of as independent but as connected by the relationships established by studies of climatic zoning by Griffith Taylor, Gentilli, Köppen, and others.

As a variant of the above tests, though only for the 24 year period 1913-36, some of the districts were chosen as foci, and, for each in turn, their sympathy determined with every other district in the continent. These values were inserted on monthly maps and isopleths of sympathy drawn, the area lying within the +0.33 isopleth being measured as representing the area of high correlation (i. e.  $r \geq 0.5$  in Eq. (1)) so providing a direct measure of spatial scale. The areas are shown in Table 4. It is when districts 14 and 15 are foci that the largest areas of conformal behaviour are obtained. Note that the area of the continent is 2950 in the units of Table 4, so that the highest figure represents about 70 per cent of the continent (District 15 for November). The number of years is, of course, rather small to be sure of the full representativeness of the figures: however, the difference between November and the main summer months is again in evidence.

Table 4. Areas (thousand square miles) over which  $s$  exceeds +0.33

	Nov.	Dec.	Jan.	Feb.
With district 9A	160	110	450	320
" " 14	1540	750	900	1600
" " 15	2110	1100	1050	1640
" " 23	1420	330	120	1050
" " 40	1670	160	320	135
" " 48	1740	720	690	1380

To support the foregoing study an analysis was also made of sympathy between records from four stations, each the principal town of the four selected northern districts, i. e. Darwin post office (district 14), Alice Springs (15), Cloncurry (29), and Cairns (31). The analysis was extended to include March and also the December to February totals, so that some comparison could be made between the strengths of monthly and seasonal associations on this scale. The data was taken from WWR and extended to 1959 by courtesy of the Bureau of Meteorology, omitting 1940 to 1947 when some records were lost or uncertain. Beginning in 1882, this provides 70 years for paired sympathies excluding those involving Cloncurry, which date from 1884 and comprise 68 years. These are set out in Table 5. The so-called mutual associations in the lower part of the Table represent counts of the years (out of 68) in which the rainfalls at all four stations, or at any selected three, were all high or all low (all above or all below the median): in judging the significance of these, note that the random expectancy is a count of 17 for three and  $8\frac{1}{2}$  for four stations.

Table 5. Inter-Station Associations in Rainfall

	Nov.	Dec.	Jan.	Feb.	March	Dec-Feb.
<u>Paired Sympathies</u>						
Darwin - Alice Springs	+ .17	+ .14	+ .23	+ .37	+ .09	0
Alice Springs - Cloncurry	+ .24	+ .29	+ .18	+ .18	+ .18	+ .06
Darwin - Cloncurry	0	+ .47	+ .06	+ .12	+ .29	+ .29
Darwin - Cairns	+ .20	+ .49	+ .03	+ .14	+ .26	+ .03
Alice Springs - Cairns	+ .18	+ .14	- .09	+ .09	+ .20	- .09
Cloncurry - Cairns	+ .06	+ .35	0	+ .09	+ .35	+ .29
<u>Mutual Associations (68 years)</u>						
Years with all high or all low	18	24	11	20	20	14
Ditto excluding Cairns	25	31	25	29	26	24
" " Darwin	25	29	19	24	29	21
" " Alice Springs	21	39	18	23	33	27
" " Cloncurry	26	29	20	29	27	17

Beyond confirming the regional association for individual stations, naturally at a lower absolute level as compared with Table 2 because of the intrusion of purely local variability, some further pointers of interest emerge from Table 5. Overall the regional association reaches its peak in December, drops sharply in January, and improves successively in February and March. The slump is largely, though perhaps not wholly, attributable to Cairns, due presumably to the influence of tropical cyclones from the Pacific. Secondly, the associations between December to February totals are generally not as high as the average of the component months, suggesting that the regional bond is stronger on the monthly than on the three-monthly time scale. Further subdivisions of the time scale might yield a point (longer than a day according to one's present intuition) at which the association reached a maximum, and at which the term "regional association" would be more appropriate than at any other.

#### 4. REGIONAL ASSOCIATION WITH PRIOR DARWIN PRESSURE

It has been shown above that the rainfalls of individual summer months for the Darwin - Alice Springs - Cloncurry - Cairns region are (except for Cairns in January) in quite strong mutual association. It has also been shown, here and in the previous (1962) study, that there is little significant month-to-month persistence at these stations in summer, but that Darwin summer rainfall at least is significantly associated (in the negative sense) with the prior Darwin pressure of October and November.

The most obvious implication is that the rainfalls of the other three stations should be tested against the same Darwin pressures, and the results of doing so are given in Table 6. As in Table 5, 70 years of data (68 years at Cloncurry) have been included. Three values are shown in brackets because they represent simultaneous rather than lag associations.

The magnitudes in general are rather slight, but except for Alice Springs there is a marked predominance of negative values and the overall significance is unquestioned. An interesting point here is that, in contrast to Table 5, the seasonal totals tend to be more strongly associated than the individual monthly values. Here then, alone of the results reported in the paper, do the attributes of an essentially seasonal or longer-term phenomenon appear to be in evidence.

#### 5. CONCLUDING REMARKS

As indicated at the end of Section 2, the present type of enquiry must be regarded essentially as a search, and its results as providing mainly an identification and starting point for studies of a more detailed and critical nature in which more flexible methods of synoptic

Table 6. Summer Rainfalls Associated with Prior Darwin Pressures

	Rainfall Period					
	Nov.	Dec.	Jan.	Feb.	Mar.	Dec-Feb.
Darwin Oct. pressure with rainfall at Alice Springs	- .09	+ .26	+ .06	- .09	- .14	+ .15
" " " " Cloncurry	- .04	- .01	- .13	+ .01	- .25	- .13
" " " " Cairns	- .32	- .21	- .09	- .03	- .09	- .20
Darwin Nov. pressure with rainfall at Alice Springs	(- .26)	0	- .03	- .23	- .17	- .12
" " " " Cloncurry	(- .15)	- .09	- .06	0	- .18	- .17
" " " " Cairns	(- .29)	- .24	- .09	+ .15	- .21	- .17

classification and meteorological, etc. judgement are fully brought to bear.

Lag associations such as those of Tables 1 and 6 represent a measure of predictability, and it is a reasonable expectation that this will be improved by the type of more detailed study suggested above. Even as they stand, however, results falling in the magnitude range of 0.15 to 0.2 for  $s$  may be of immediate value if used correctly. Since the time of Sir Gilbert Walker, it appears to have been widely held that the criterion of usefulness lies at about a magnitude of 0.4 for  $r$  (0.26 for  $s$ ). This is based on the consideration that a significant part of the variance must be accounted for. However, in the present state of knowledge one can aspire at best to predict monthly rainfalls in terms of broad classifications (though perhaps in more than two classes), and the appropriate coefficient of association then becomes more relevant than one of correlation. And there are many fields of activity, notably in primary industry, where advance decisions have to be made in the light of expectations for the coming season; "black or white" predictions based on even a small advantage of probability, or shade of odds in betting parlance, must be better than no information at all provided the odds are stated.

#### REFERENCES

- |                       |      |   |
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PAPERS PRESENTED AT SYMPOSIUM ON MONSOON METEOROLOGY,  
TENTH PACIFIC SCIENCE CONGRESS, HONOLULU, SEPTEMBER, 1961

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At this Symposium, Mr. W. J. Gibbs, the Convenor, on behalf of the Bureau of Meteorology advised that it would publish any Symposium papers not published elsewhere.

Three such papers are included in this issue of the Australian Meteorological Magazine; they are:

1. Some Characteristics of the Average Monsoon Rainfall along the Coasts of India and Burma  
by Gangopadhyaya, M. , Sreenivasan, P. S. and Venkataraman, R.
2. Contingency Technique Applied to Medium Range Forecasting of Rainfall during the Monsoon Season in India  
by Jagannathan, P. and Ramamurthi, K. M.
3. Formation and Structure of Indian Summer Monsoon Depressions  
by Koteswaram, P. and Bhaskara Rao, N. S.

The September 1963 issue of the Magazine will contain two more papers:

4. Thermal Effects of the Tibetan Plateau during the Asian Monsoon Season  
by Rangarajan, S.
5. The Structure of the Asian Summer Monsoon  
by Koteswaram, P. and Bhaskara Rao, N. S.