REMARKS ON THE PAPER BY T. R. VISVANATHAN ENTITLED "ON BOWEN'S HYPOTHESIS"*

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Visvanathan's paper (1965) has reopened the controversial question of rainfall calendaricities that has stimulated so much research and discussion since the paper by Bowen (1953). Visvanathan's suggestion that anomalous rainfall at Sydney results from the joint effects associated with the lunar month and the calendar date is an interesting one, and depends upon the conclusion that the correlations between the curves of his Figures 2(*b*), 2(*c*), and 2(*d*) are significant. Although these curves are based on data that have been smoothed, thus introducing serial correlation into them, an appropriate significance test can be made which does in fact show that the conclusions are valid. However, his findings led the writer to examine the Sydney data from another point of view, and this investigation led to results giving a different interpretation from that given by Visvanathan.

Evidence presented by Brier (1965) shows that the precipitation variations in the United States are related to the lunar tidal forces, which depend upon the synodic cycle, i.e. the time from one New Moon to the next. In addition, these forces depend upon the anomalistic cycle (from perigee to perigee) and upon the nodical cycle (the period between ascending nodal passages, i.e. crossing of the ecliptic from south to north). Visvanathan's analysis considers the lunar synodic cycle but, since the anomalistic and nodical cycles might show some influence, it seemed reasonable to determine whether or not the rainfall data were random in respect to these cycles. The data chosen were all cases of rainfall exceeding 1 in. at Sydney on January 12, 13, 14, 21, 22, and 23 during the period 1859–1952, the record available at the time this investigation began. The dates January 12–14 and January 21–23 were chosen because these periods show the largest and most pronounced peaks both in Bowen's curves and in the independent analysis of O'Mahony (1962). Furthermore, they are at least 7 days apart, helping to assure independence of the data in the statistical analysis. Further independence was assured by choosing only one day from each of the 3-day periods. The selection of rainfall exceeding 1 in. was based on several reasons. First, the heavy rainfalls contribute most to the variation in the daily averages, and secondly, the heavy rainfalls are of potential physical, meteorological, and economic importance. Another reason follows from the analysis by Brier (1965), which shows the advantage of using extreme values to detect the influence of periodic factors.

There were 22 cases of rainfall greater than 1 in., and the dates and amounts are shown in Table 1. The table also shows the rank (1–22), as well as the values of the synodic, anomalistic, and nodical cycles expressed in terms of 100 decimal classes. The data in this table were plotted on polar diagrams to test whether there was any tendency for the points to distribute in a non-random fashion; the highest values should be of particular interest. Using a test for the consistency of phase on a polar

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diagram, the synodic cycle (Fig. 1) showed a distribution which departed from chance with the highest significance ($p < 0 \cdot 01$). For example, considering the 12 highest rainfalls, all of which were greater than $1\frac{1}{2}$ in., the probability is 0·01 that the largest "gap" on the circle will be equal to or greater than 171°. The observed gap as shown is over 180°, and in fact the first 16 highest-ranking rainfalls are distributed on the syzygy half of the circle. In addition, although this analysis was not concerned with rainfall during the other days of the month, it is interesting to note that the greatest extreme

TABLE 1

DATES OF RAINFALL EXCEEDING 1 IN. AT SYDNEY BETWEEN JANUARY 12–14 AND JANUARY 21–23 DURING THE PERIOD 1859–1952

Rank	Rainfall (in.)	Date	Decimal Class		
			Synodic	Nodical	Anomalistic
1	7·08	Jan. 13, 1911	0·45	0·13	0·08
2	6·53	12, 1918	0·98	0·04	0·83
3	3·75	22, 1863	0·11	0·24	0·19
4	3·72	23, 1933	0·91	0·81	0·08
5	3·06	22, 1901	0·07	0·24	0·86
6	2·80	13, 1872	0·11	0·70	0·16
7	2·51	12, 1873	0·46	0·11	0·40
8	2·13	23, 1895	0·93	0·78	0·40
9	1·94	21, 1887	0·92	0·34	0·29
10	1·70	12, 1883	0·12	0·30	0·92
11	1·67	12, 1892	0·44	0·11	0·23
12	1·56	12, 1885	0·88	0·17	0·46
13	1·56	21, 1879	0·97	0·96	0·24
14	1·34	21, 1924	0·48	0·89	0·67
15	1·31	21, 1951	0·45	0·31	0·58
16	1·29	12, 1910	0·04	0·66	0·78
17	1·15	21, 1922	0·79	0·09	0·21
18	1·15	22, 1927	0·64	0·21	0·49
19	1·09	14, 1920	0·80	0·97	0·42
20	1·05	23, 1893	0·19	0·94	0·89
21	1·02	13, 1922	0·50	0·77	0·89
22	1·02	14, 1948	0·10	0·77	0·55

was on January 31, 1938, the day of a New Moon. The two next highest values, both over 4 in., had an average position near point 11 on Figure 1, between 2 and 3 days before syzygy.* The nodical cycle (Fig. 2) showed the next greatest departure, also highly significant, while a less pronounced but still highly significant departure from chance was found for the anomalistic cycle (Fig. 3). In each figure, the phase and amplitude rainfall amount are plotted as well as the rank for the amounts exceeding $1\frac{1}{2}$ in. Upon reference first to Figure 1, it is seen that there are only four cases falling in the left half of the circle, and these are the smaller rainfalls. Obviously, there is a preference in respect to a New or Full Moon, or a few days before. Figure 2 shows a preference in respect to the time of the cycle when the Moon is going from south to

* Data for more recent years are given by O'Mahony (1962). The date of highest rainfall is January 23, 1955, synodic decimal 0·98 or one half-day before New Moon.

north. The 5 highest rainfalls are distributed in this half of the circle, and only 5 of the 22 cases are in the opposite half. In Figure 3, it is seen that ranks numbered 1–6

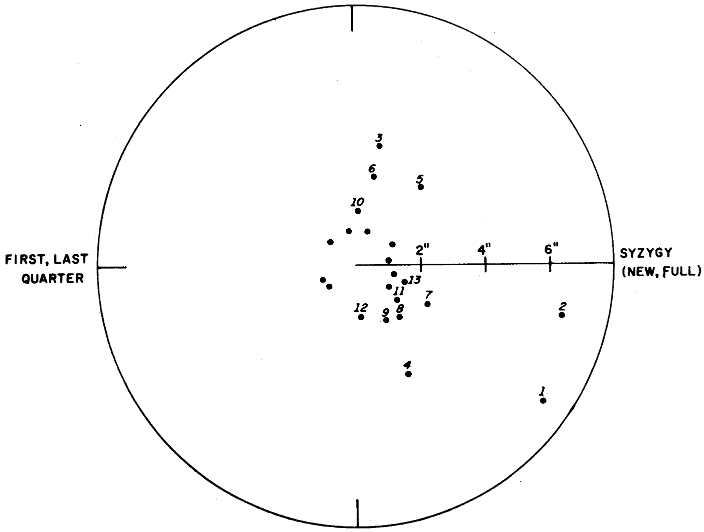

Fig. 1.—Excessive rainfalls at Sydney plotted on a polar diagram to show amplitude and phase with respect to the lunar synodic cycle. Numbers plotted next to the points are the ranks for the rainfalls exceeding $1\frac{1}{2}$ in.

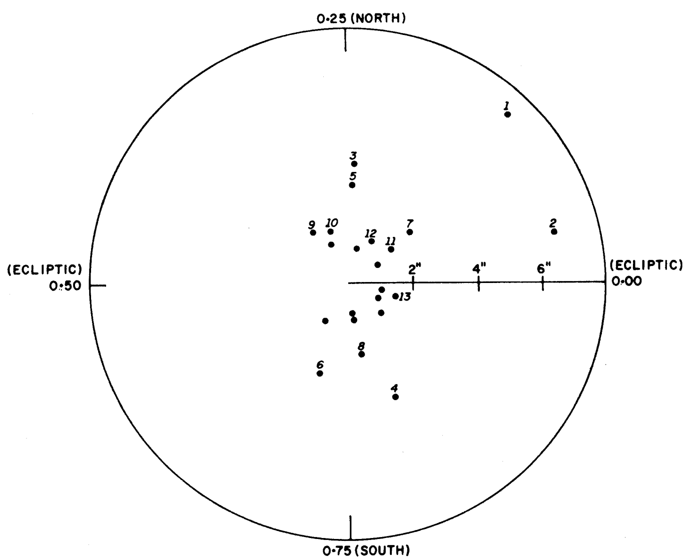

Fig. 2.—Excessive rainfalls at Sydney plotted on a polar diagram to show amplitude and phase with respect to the nodical cycle. Numbers plotted next to the points are the ranks for the rainfalls exceeding $1\frac{1}{2}$ in.

fall nearer perigee than apogee. This is expected since the tidal forces are greatest near perigee.

The foregoing suggests that the necessary conditions for extreme rainfall are related to the tidal influences as they are reflected in the synodic cycle of 29·53 days, the anomalistic cycle of 27·55 days, and the nodical cycle of 27·21 days. Once a particular combination of these cycles occurs, it is a relatively long time before these conditions, or conditions close to these, recur. One such period is about 27 months, and another one is 18 years and 11 days, the well-known Saros period. It is enlightening to inquire whether a given set of "favourable tidal conditions" (FTC) will be distributed uniformly with respect to some other time scale, say the calendar year. In

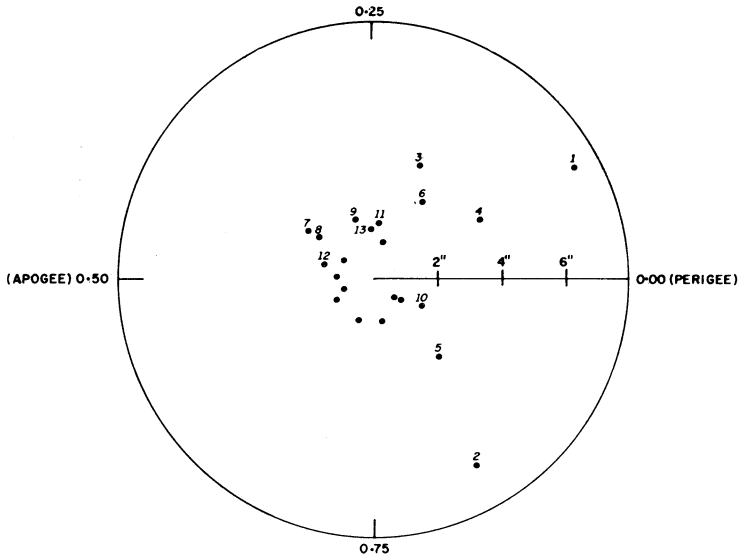

Fig. 3.—Excessive rainfalls at Sydney plotted on a polar diagram to show amplitude and phase with respect to the anomalistic cycle. Numbers plotted next to the points are the ranks for the rainfalls exceeding $1\frac{1}{2}$ in.

particular, it might be asked whether, during a period of 50 or 100 years, the events FTC have occurred equally frequently on each calendar date of January. To determine this the period 1900–49 was selected, and a tally was made on the January calendar whenever the following three conditions were met:

(i) phase 0·35–0·45, 0·85–0·95;

(ii) anomalistic decimal 0·90–0·10;

(iii) nodical decimal 0·40–0·60, 0·90–0·10.

The results showed that eight cases fell between January 1–5, nine cases between January 11–14, five cases between January 20–22, and eight cases between January 30–February 3. There were no cases between these groups. The mean dates are January 3, 12, 21, and February 1. *These are the singularity dates* given by the various articles of Bowen, and shown in his world rainfall curve as published by Brier (1961).

The relation between the events of FTC and calendar date is illustrated in another way by Figure 4. On this chart the synodic decimal is plotted as a function of the anomalistic and nodical decimals for each January 13 from 1900 to 1949. A number with a line under it means the particular day was five classes or less from a New (0·00) or Full (0·50) Moon, and it is noticed that no underlined number occurs between anomalistic decimal classes 0·10 and 0·65. It is obvious that the numbers plotted in this figure are not uniformly or randomly distributed, but fall in a systematic pattern determined by the astronomical factors involved. Similar results would be obtained if other conditions were specified.

To complete this phase of the study, the remaining months of the year were examined in the same way. The results are shown in Table 2. The mean date, shown in italics in each group, was selected as a key day for use in a superposed epoch analysis,

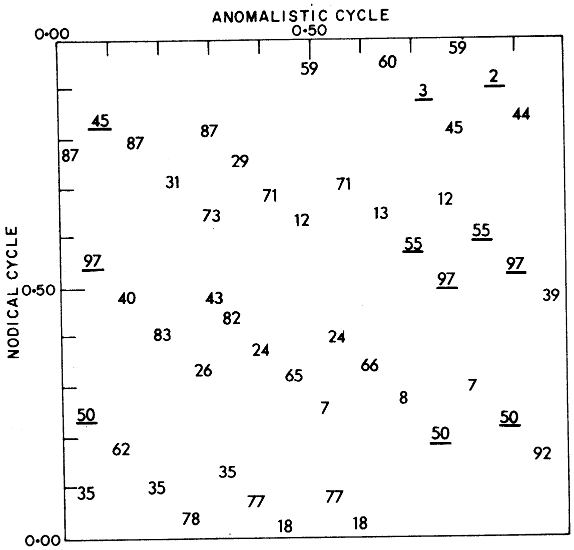

Fig. 4.—Relationship between the synodic, anomalistic, and nodical cycles for January 13 for the period 1900–49. The numbers plotted are the synodic decimals, and underlined numbers represent cases where the synodic decimal is within 5 classes of a New or Full Moon.

using the world rainfall data summarized by Bowen. Averages were obtained for the key dates and 5 days on each side, the results being shown in Figure 5. The amplitude for January is larger than for the remainder of the year, but this may be due in part to the smaller size of the sample. Furthermore, the Earth is at perihelion during January, and an amplification of any tidal effects would be expected at this time. This may be the reason that the January data gave the greatest evidence of departure from randomness in the analysis reported by O'Mahony (1962).

An examination of the tidal cycles and of the ephemeris reveals that the dates shown in Table 2 are "slipping" at the rate of about 9 days every 102 years. These are completely predictable, of course, and for the half-century 1950–99 the dates will average about $4\frac{1}{2}$ days later than those shown in Table 2. However, it would take 400 or 500 years, or more, for things to average out in such a way that every calendar date would have a reasonable chance of being represented by all significant combinations of the three tidal cycles.

TABLE 2

RANGES OF DATES UPON WHICH CERTAIN "FAVOURABLE TIDAL CONDITIONS" OCCURRED DURING THE PERIOD 1900–49

Jan.	:	1–*3*–5 [8],* 11–*12*–14 [9], 20–*21*–22 [5], 30–*1*–3 [8]
Feb.	:	9–*11*–12 [6], 18–*20*–22 [8], 28–*1*–4 [11]
Mar.	:	10–*11*–12 [6], 19–*20*–21 [8], 28–*30*–1 [5]
Apr.	:	8–*9*–11 [2], 17–*18*–19 [4], 28–*29*–30 [3]
May	:	6–*8*–10 [6], *16*–17 [2], 27–*28*–29 [5]
June	:	4–*5*–7 [3], 14–*15*–16 [3], 23–*25*–27 [4]
July	:	4–*5*–6 [3], 13–*14*–16 [4], 22–*24*–26 [6]
Aug.	:	*1*–2 [2], 11–*12*–14 [4], 19–*21*–23 [4], 30–*31*–1 [3]
Sept.	:	7–*9*–12 [5], *19* [2], *29* [2]
Oct.	:	4–*8*–11 [7], *17*–18 [2], 27–*28*–29 [4]
Nov.	:	4–*6*–8 [5], 15–*16*–17 [3], 23–*25*–27 [6]
Dec.	:	3–*4*–5 [4], *13*–14 [2], 21–*23*–26 [5]

* The mean date is given in italics, and the number of events is shown in brackets after the dates.

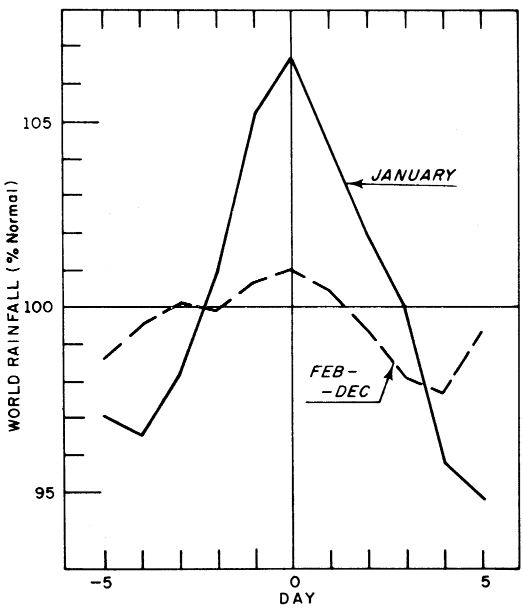

Fig. 5.—Results of superposed epoch analysis, showing average rainfall for 5 days before and after key dates shown in Table 2. Rainfall data used were worldwide averages prepared by Bowen and published by Brier (1961).

Conclusions

It now seems possible to conclude the following, from the analysis of Visvanathan and the results presented here.

(1) There is a highly significant lunar component in the Sydney records of excessive rainfall for days in January over the past 100 years.

(2) When a period as short as 50 or 100 years is considered, particular conditions that are determined by the three lunar tidal cycles do not occur uniformly throughout the year, but tend to occur in groups that are about 10 days apart.

These extreme rainfall data show beyond any reasonable doubt that Bowen (1953) was essentially correct in concluding that the January rainfall data for Sydney showed significant departures from randomness. Some independent supporting evidence was provided by the analysis of O'Mahony (1962) of the heavy rainfalls for Rockhampton, Qld., but some other stations failed to show significant departures from randomness. Some of Bowen's critics have claimed that the departures from expectation were most likely spurious and due to the influence of a relatively few large rainfalls. Actually, these extreme rainfall occurrences demonstrate that significant departures from randomness do exist, but that these anomalies are closely associated with the lunar calendar, rather than with the calendar date. However, in fairness to the pioneering work of these earlier investigators, it should be emphasized that there was at that time no reason to suspect any lunar influence on precipitation or that the solilunar tidal cycles might have any appreciable aliasing effect with calendar date. These effects must be considered in testing for any possible calendaricities, and although the foregoing points do not rule out the possible influence of meteoritic dust on rainfall, they do mean that such an hypothesis is not necessary to explain any apparent tendency for particular meteorological events to occur on some calendar dates more than on others.

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