A TEST OF THE REALITY OF RAINFALL SINGULARITIES [1]

Glenn W. Brier

U. S. Weather Bureau, Washington, D. C.

(Manuscript received 6 July 1960)

ABSTRACT

The tendency for the recurrence of weather events on or near the same calendar date has been the subject of controversy for many years. The statistical evidence has been far from conclusive, and no generally acceptable physical explanation of such phenomena, if real, is available. Dr. E. G. Bowen has advanced the meteoritic-dust hypothesis to explain singularities in the number of ice nuclei and in world rainfall amounts. This paper describes a statistical test comparing three independent series of daily rainfall: (1) world rainfall amounts determined from several hundred stations assembled by Bowen for the period 1880 to 1950; (2) average daily precipitation amounts during the period 1952 to 1957 for a network of approximately 150 stations distributed over the United States; and (3) average daily precipitation amounts for the same United States network during the year 1958. A non-parametric test, made possible through use of an electronic computer, shows a highly significant association among these series. These results lead to the conclusion that there has been a strong tendency for precipitation anomalies (both high and low) to occur on specific calendar dates.

1. Introduction

There are many references in the meteorological literature to weather events that appear to occur on or near fixed calendar dates. These events, known as "singularities," usually refer to anomalies in pressure or temperature over localized regions, although in 1952 Wahl [10] proposed broadening the singularity concept to include features of the general circulation. By using mean maps, he showed how the January thaw in New England was associated with certain changes in the circulation patterns over the United States. Bowen [2], on the basis of January rainfall records from a limited number of stations, concluded that in some localities there is a marked tendency for heavy falls of rain to occur on certain days rather than on others and for this pattern to be repeated year after year. He suggested the most likely cause of such an effect is extraterrestrial in origin and that the only phenomenon which meets the requirement of repeating year after year on the same dates is that of meteor showers. Thus, he was led to the hypothesis that the meteoritic dust accompanying the meteor showers provides rain-forming nuclei when it falls into cloud systems in the lower atmosphere. Furthermore, an examination of the dates of the known meteor showers suggested that the "peak" rainfall amounts occurred about 30 days after the earth enters a major meteor stream. Bowen's conclusions were criticized on both physical and statistical grounds by Hannan [6], Martyn [8], Swinbank[9], Whipple [11] and others, but he persisted in his efforts to collect precipitation statistics from more than 250 stations scattered over the world. Later, Bowen [3] published additional evidence, based mainly on the month of January, in support of the hypothesis. Bigg [1], after analyzing 18 yr of January cirrus-cloud observations for Australian stations, found that singularities in cirrus-cloud cover were statistically significant and occurred on the same calendar dates as the rainfall anomalies. He concluded that the rainfall anomalies found by Bowen on the same days as the cirrus maximal are related and also real. Additional evidence regarding the reality of singularities in January was presented by Kline and Brier [7] who found anomalous counts of freezing nuclei near the dates in January specified by Bowen. Their conclusions were based on an analysis of about 20 series of observations taken at various locations over the world during the period 1954 to 1958. The world-wide program for observing ice nuclei was initiated by Dr. Bowen, and special emphasis was placed on obtaining measurements during the month of January.

2. The material

All the discussion above has been concerned with the evidence for singularities based on observations of precipitation, cirrus-cloud cover or freezing-nuclei measurements made during the month of January. Although a few series of freezing-nuclei observations have been made during other parts of the year, the data are not sufficient for an adequate statistical test of singularities. Long records of daily rainfall are

[1] The research reported in this paper is a phase of an investigation sponsored jointly by the U. S. Weather Bureau and the National Science Foundation (Grant GL-29).

Unauthenticated | Downloaded 12/10/24 06:09 PM UTC

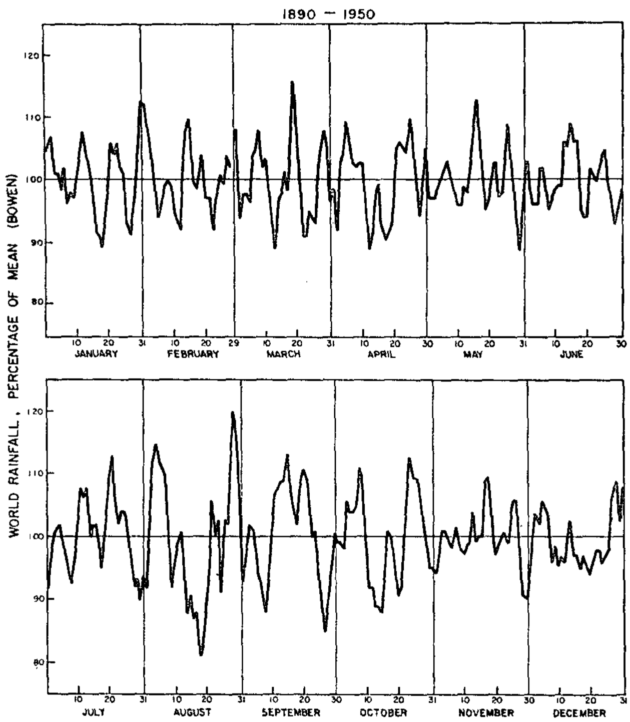

FIG. 1. World rainfall averages for each day of the year for the period 1880–1950 based on 300 stations.

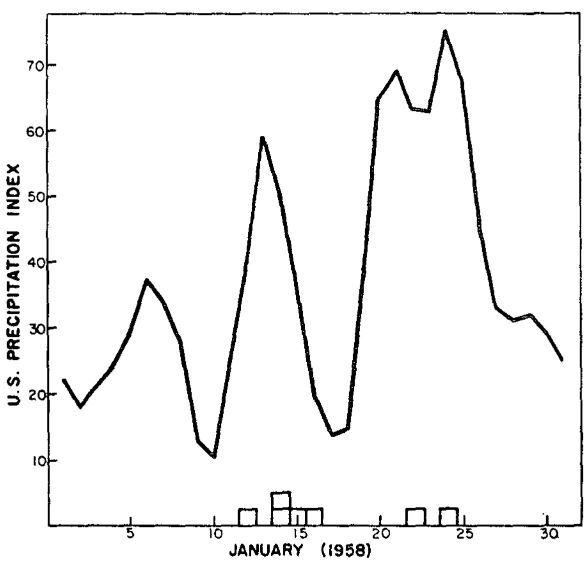

FIG. 2. Daily precipitation index for United States for January 1958.

available, of course, for many stations. Bowen [4; 5] has made an analysis of precipitation data for approximately 300 stations distributed over the world for the months of August, September, October, November and December. Summaries of the remaining months of the year (February, March and April), although unpublished, have been prepared by Bowen and kindly furnished to the author. The plot showing his data is given in fig. 1. The values shown are three-day moving averages and are based on 300 stations with records extending from approximately 1880 to 1960. Note that there are rather pronounced high points or "peaks" with values as great as 20 per cent above the normal as well as sharp troughs with values nearly 20 per cent below the normal. These peaks and troughs are either the result of statistical fluctuations or they are real, representing some underlying physical process. If they are real, then it would be expected that similar but independent data for periods subsequent to 1950 should confirm the variations providing the effect is strong enough to show above the "noise" level. Daily precipitation averages for a world-wide network are not readily available since 1950, but, fortunately, daily averages are easily obtained for a network of stations in the United States. During the investigation of the freezing nuclei observations in 1958, it was found that a good measure of the total precipitation falling over the United States each day could be obtained from the data plotted on the Daily Weather Map published by the United States Weather Bureau. A chart showing the three-day running totals of these daily amounts for the month of January 1958 is given in fig. 2. Note that the variation between peaks and troughs is as great as a factor of 7. The boxes shown at the bottom of the graph indicate the days of highest freezing-nuclei counts observed at 7 locations over the world in January 1958 as summarized by Kline and Brier [7].

Data similar to those shown in fig. 2 were obtained for the remainder of 1958. Since this could be done so easily, it was decided to prepare daily averages for the 6-yr period 1952 to 1957 inclusive, since this would be independent of the 1958 results as well as independent of the period used by Bowen in preparing fig. 1. These three separate series of daily precipitation amounts were then identified and defined as follows:

Series 1 — United States precipitation, 1952–57;
Series 2 — United States precipitation, 1958;
Series 3 — World rainfall (Bowen), 1880–1950.

Each of these series has 365 values, one for each day of the year with leap day omitted since it did not occur in 1958 and occurred only twice between 1 January 1952 and 31 December 1957.

3. Method of analysis

The purpose of the statistical analysis was to test the correlations between the three series. It was desired to perform a test that was independent of any assumptions regarding the normality or the auto-correlations of the precipitation series. It is known, for example, that the precipitation measured over a large area in one day is correlated with the

Unauthenticated | Downloaded 12/10/24 06:09 PM UTC

TABLE 1. Classification of peak days (1), trough days (−1) and other days (0) in series 1, 2 and 3.

Month	Jan.			Feb.			Mar.			Apr.		
Series	1	2	3	1	2	3	1	2	3	1	2	3
Day 1	−1	0	0	1	−1	1	0	0	1	0	0	−1
2	−1	0	0	1	−1	0	0	−1	1	0	0	−1
3	0	0	0	1	−1	0	0	−1	0	1	0	−1
4	0	0	0	0	0	0	0	−1	0	1	1	1
5	−1	0	0	0	0	0	−1	0	0	1	1	1
6	−1	0	0	0	0	0	−1	1	0	0	1	1
7	−1	0	0	0	0	0	−1	1	1	0	0	0
8	0	0	0	−1	0	0	−1	1	1	0	0	0
9	0	−1	0	−1	0	0	−1	0	1	0	0	0
10	0	−1	0	−1	0	0	0	−1	0	0	0	0
11	−1	−1	1	0	0	−1	0	−1	0	1	−1	−1
12	−1	1	1	−1	0	−1	0	−1	−1	1	−1	−1
13	−1	1	1	−1	1	−1	0	0	−1	1	−1	−1
14	0	1	0	−1	1	1	0	0	−1	0	0	0
15	1	0	0	0	1	1	0	0	0	0	0	0
16	1	−1	0	0	0	1	0	0	0	0	−1	−1
17	1	−1	−1	0	0	0	0	0	0	−1	−1	−1
18	0	−1	−1	0	0	0	0	0	1	−1	−1	−1
19	0	0	−1	0	0	0	0	0	1	−1	0	0
20	0	1	0	0	0	0	1	0	1	0	0	0
21	1	1	0	0	0	−1	1	0	0	0	0	0
22	1	1	0	0	0	−1	1	0	−1	0	0	0
23	1	1	0	0	0	−1	1	1	−1	0	0	0
24	0	1	0	0	0	0	1	1	−1	0	−1	0
25	0	1	0	0	1	0	0	1	0	0	−1	1
26	0	0	−1	0	1	0	−1	−1	0	0	−1	1
27	0	0	−1	0	1	0	−1	−1	0	0	1	1
28	0	0	−1	0	0	1	−1	−1	0	0	1	0
29	0	0	0				0	0	0	0	1	0
30	0	0	1				0	0	0	0	0	0
31	0	0	1				0	0	0			

Month	May			June			July			Aug.		
Series	1	2	3	1	2	3	1	2	3	1	2	3
Day 1	0	0	0	0	0	0	0	0	0	0	0	0
2	0	1	0	0	0	0	0	1	0	1	0	0
3	0	1	0	0	0	0	0	1	0	1	0	1
4	−1	1	0	0	−1	0	0	1	0	1	−1	1
5	−1	0	0	0	−1	0	0	0	0	0	−1	1
6	−1	0	0	0	−1	0	0	1	0	0	−1	0
7	0	0	0	0	0	0	0	1	0	0	0	0
8	0	0	0	0	0	0	0	1	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0	0	0	−1
14	0	0	0	0	0	1	0	0	0	0	0	−1
15	0	0	1	0	0	1	0	0	0	0	0	−1
16	0	−1	1	0	0	1	0	0	0	0	0	−1
17	0	−1	1	0	0	0	0	0	0	0	0	−1
18	1	−1	0	0	0	0	0	0	0	0	0	−1
19	1	−1	0	0	0	0	0	0	0	0	0	−1
20	1	−1	0	0	1	0	0	0	1	0	0	0
21	0	−1	0	0	1	0	0	0	1	0	0	0
22	0	0	0	0	1	0	0	0	1	0	0	0
23	0	0	0	0	0	0	0	0	0	0	1	0
24	0	0	0	0	1	0	0	0	0	−1	1	−1
25	1	0	1	0	1	0	−1	0	0	−1	1	−1
26	1	0	1	1	1	0	−1	0	0	−1	0	−1
27	1	−1	1	1	−1	0	−1	0	0	0	−1	0
28	0	−1	−1	1	−1	0	0	0	0	0	−1	1
29	0	−1	−1	0	−1	0	0	0	−1	1	−1	1
30	0	0	−1	0	0	0	0	0	−1	1	0	1
31	0	0	0				0	0	−1	1	−1	0

Month	Sept.			Oct.			Nov.			Dec.		
Series	1	2	3	1	2	3	1	2	3	1	2	3
Day 1	0	−1	0	0	0	0	0	0	0	0	0	−1
2	−1	−1	0	0	0	0	0	0	0	0	0	0
3	−1	0	0	0	0	0	0	0	0	0	0	0
4	−1	0	0	0	−1	0	0	0	0	1	0	0
5	0	0	0	1	−1	0	0	0	0	1	0	0
6	0	0	0	1	−1	0	0	0	0	1	0	0
7	−1	0	−1	1	0	1	0	0	0	0	0	0
8	−1	0	−1	0	0	1	0	0	0	0	0	0
9	−1	0	−1	−1	0	1	0	0	0	1	0	0
10	0	0	0	−1	0	0	−1	0	0	1	0	0
11	0	0	0	−1	0	0	−1	0	0	1	0	0
12	0	0	0	−1	−1	0	−1	0	0	0	0	0
13	0	0	0	−1	−1	0	1	0	0	0	0	0
14	0	0	1	1	−1	−1	1	0	0	0	0	0
15	0	1	1	1	0	−1	1	1	0	−1	0	0
16	0	1	1	1	0	−1	0	1	0	−1	−1	0
17	0	1	0	0	0	0	0	1	1	−1	−1	0
18	1	0	0	−1	0	0	1	0	1	0	−1	0
19	1	1	1	−1	0	−1	1	0	1	0	0	0
20	1	1	1	−1	0	−1	1	0	0	0	0	0
21	0	1	1	0	0	−1	0	−1	0	0	0	0
22	1	0	0	0	0	0	0	−1	0	0	0	0
23	1	0	0	0	0	1	0	−1	0	0	0	0
24	1	0	0	0	0	1	0	0	0	0	0	0
25	0	0	0	0	0	1	0	0	0	0	0	0
26	0	0	−1	0	0	0	−1	1	0	0	0	0
27	0	0	−1	0	0	0	−1	1	0	0	1	0
28	0	0	−1	0	0	0	−1	1	0	0	1	1
29	0	0	0	0	0	0	0	0	−1	0	1	1
30	0	0	0	0	0	0	0	0	−1	0	0	1
31				0	0	0				−1	0	0

Unauthenticated | Downloaded 12/10/24 06:09 PM UTC

amount measured the following day. Furthermore, the use of a three-day moving average introduces a further auto-correlation in each of the precipitation series. This may be good or bad, depending upon the purpose of the smoothing or filtering accomplished by the moving average. In any case, the effect of such smoothing is to inflate the *absolute* value of the correlation between the two series and thus invalidate the standard significance test of the correlation coefficient. Although approximate methods have been developed to allow for the effect of auto-correlation in testing the relationship between time series, here it was felt desirable to avoid the use of such tests whose validity might be questioned because of the assumptions that must be made regarding each of the time series. Therefore, a test was devised based on the known principle that symmetrical filters (such as moving averages) produce no phase changes or phase correlations between time series which are random with respect to each other. This was accomplished as follows.

From the rainfall data shown in fig. 1, the dates of the twenty highest peaks and the twenty lowest troughs were selected. The dates of these twenty highest peaks and twenty lowest troughs were designated as peak days and trough days, respectively. A peak was defined as a day with rainfall higher than the adjacent days, and a trough was defined as a day with lower rainfall than the adjacent days. Thus, for example, 12 January is defined as a peak day in Series 3 (shown in fig. 1) because (a) the rainfall is higher than 11 and 13 January and (b) the rainfall on 12 January ranks as one of the twenty highest such peaks during the entire year. On the other hand, January 2 is not classified as a peak day since it does not meet requirement (b) above although the rainfall is higher than on 1 or 3 January. These twenty peak days, as well as the preceding and following days were assigned a code number 1. A trough day and the adjacent days were assigned the value −1 and all other days were classified as 0. The same procedure was followed for each of the other two series, the results of classifying the 365 days in each series being shown in table 1.

A measure of association between the three series was then determined by counting the number of times the following combination of events happened:

(a) occurrence in each of the three series of class (1) on the same day — for example, 4 April;
(b) three occurrences of class (−1) on the same day — for example, 18 April;
(c) three occurrences of class (0) on the same day — for example, 3 January;
(d) two occurrences of class (1) with a class (0) on the same day — for example, 21 January; and
(e) two occurrences of class (−1) with a class (0) on the same day — for example, February 12.

TABLE 2. Example showing method of displacement of series 2 and series 3 relative to series 1.

Series 1	27	28	29	30	July 1	2	3	4	Lag 0
Series 2	26	27	28	29	30	July 1	2	3	+1
Series 3	29	30	July 1	2	3	4	5	6	−2

TABLE 3. Number of hits according to various combinations of displacements lags for series 2 and 3. Add 100 to each value in the table.

	Series 2										
Series 3	−5	−4	−3	−2	−1	0	1	2	3	4	5
5	57	58	73	74	65	49	55	54	51	51	66
4	67	68	75	69	59	52	53	56	58	61	73
3	69	72	74	62	60	60	63	64	68	66	68
2	70	71	60	55	60	70*	75*	75*	73	66	62
1	76	64	57	59	66*	(75)	(82)	86*	72	58	55
0	66	54	51	62*	(71)	*78*	(87)	79*	65	51	58
−1	58	49	59	70*	(78)	(78)	74*	69	59	55	60
−2	44	54	65	72*	75*	69*	65	56	58	57	65
−3	55	68	72	73	68	64	57	53	57	61	69
−4	64	68	69	65	63	55	53	54	62	64	67
−5	67	60	56	61	59	53	53	58	64	61	69

By counting all cases of a, b, c, d and e as hits, a score of 178 is obtained from the data shown in table 1. The relative frequency of 1, 0 and −1 in the three series is such that the expected score would be 155 hits if the three series were independent. The question of whether the observed score of 178 is significant can be examined by considering the sets of scores that can be generated by displacing the series relative to one another, as illustrated by table 2. In this example, series 2 has been displaced one day toward the right (called +1 lag) and series 3 has been displaced two days toward the left (−2 lag). Series 2 was extended in length 31 days on each end by adding the months of December 1957 and January 1959, thus making it possible to displace series 2 up to as many as 31 lags, plus and minus. By considering series 3 as circular, it could be displaced up to 91 lags, plus and minus, without repeating any combination. This means that series 2 has 63 possible positions and that series 3 has 183 possible positions. The product of $63 \times 183 = 11{,}529$ possible scores that could be computed. In this study, scores were computed for displacements up to 20 lags, plus and minus, for series 2 and series 3, giving a total sample of $41^2 = 1681$ cases. The numerical work was performed with the Bendix G-15D electronic computer, which stored the basic data of table 1 and computed the number of hits for each combination of displacements that was programmed into the computer.

4. Results and conclusions

Although a total of 1681 scores was computed, the ones of greatest interest are those resulting when series 2 and 3 are near their initial positions. The

Unauthenticated | Downloaded 12/10/24 06:09 PM UTC

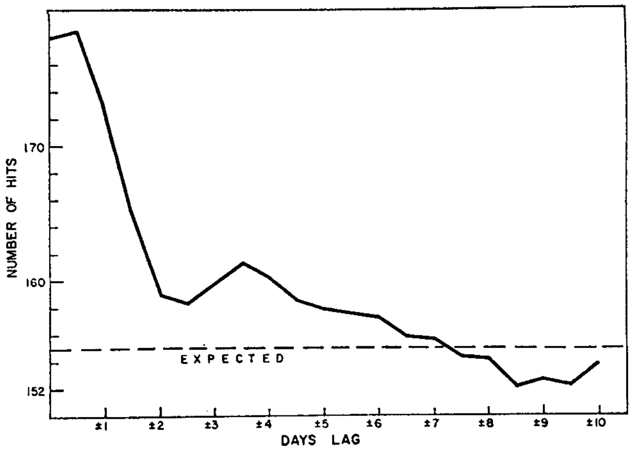

FIG. 3. Average number of hits according to mean displacement of precipitation series from central day.

result for lags up to plus and minus 5 are shown in table 3. The score of 178 hits for the initial position of the 3 series, matched up according to date, is shown underlined in the center of the table. Out of the 1681 scores computed, there were 21 additional cases where the number of hits was 178 or greater. This makes the score of 178 significant at the $\frac{22}{1681} = 0.0131$ probability level. The highest score found was 187, shown in table 3 in a position indicated by a displacement of series 2 one day to the right. No other score as high as or higher than 187 was found among the 1681 scores computed, and a careful inspection of the data indicated that it was quite unlikely that any score that high would be found if all possible 11,529 scores were computed. However, if the high score of 187 had appeared in any one of 5 other positions, it would have been considered just as significant. These 6 equivalent positions are shown in table 3 by the use of parenthesis ( ) around the numbers. And, of course, if the high score of 187 had occurred in the center position of table 3, it would have been considered even more significant. Therefore, the statistical significance of the location of the highest score is $P = \frac{7}{1681} = 0.0042$, and the probability is quite likely as low as $P = \frac{7}{11{,}529} = 0.00061$. There can be little doubt but that the three series of daily precipitation are correlated. However, the question remains as to how sharply phased this relationship is in terms of the calendar date. This can be determined by computing the average score when the series are displaced from each other by 0 day, 1 day, 2 days, 3 days, etc. As mentioned before, the score for 0 displacement is 178, the central value in table 3. The average score for a total displacement of 1 day is determined from the six values in parenthesis in table 3. The average score for a total displacement of 2 days is found from the scores marked with an asterisk* in table 3. Average scores were computed for displacements up to 20 days. The results are shown in fig. 3, where the abscissa is expressed in terms of $\frac{1}{2}$ the total displacement in days. For example, if series 2 is displaced 2 days to the right and series 3 is displaced 2 days to the left, the total or maximum displacement between any 2 series is 4 days, but the deviation from the mid-point is only 2 days. In any case, it is quite obvious from fig. 3 that the correlation falls off quite rapidly as the series are displaced relative to each other. This means that the correlation found between the series cannot be explained on the basis of some obscure climatological tendency for an unspecified meteorological event to occur within a period of a week or two in a particular season. Some mechanism that provides a sharper timing impulse is necessary, and it appears desirable to make a more direct test of the meteor-dust hypothesis as one of the possible mechanisms.

Acknowledgments. The writer is indebted to Thomas H. Carpenter for programming and operating the Bendix G-15D and to Mrs. Annie M. Johnson, Mrs. Ernestine G. Scott and Mrs. Helen M. Wilson for clerical and statistical assistance.

REFERENCES

1. Bigg, E. K., 1957: January anomalies in cirriform cloud coverage over Australia. *J. Meteor.*, **14**, 524–526.
2. Bowen, E. G., 1953: The influence of meteoritic dust on rainfall. *Austral. J. Phys.*, **6**, 490–497.
3. ——, 1956: The relation between rainfall and meteor showers. *J. Meteor.*, **13**, 142–151.
4. ——, 1956: A relation between meteor showers and the rainfall of November and December. *Tellus*, **8**, 394–402.
5. ——, 1957: Relation between meteor showers and the rainfall of August, September and October. *Austral. J. Phys.*, **10**, 402–417.
6. Hannan, E. J., 1955: A test for singularities in Sydney Rainfall. *Austral. J. Phys.*, **8**, 289–297.
7. Kline, D. B., and G. W. Brier, 1958: A note on freezing nuclei anomalies. *Mon. Wea. Rev.*, **86**, 329–333.
8. Martyn, H. F., 1954: Comments on a paper by E. G. Bowen entitled The influence of meteoritic dust on rainfall. *Austral. J. Phys.*, **7**, 358–364.
9. Swinbank, W. C., 1954: Comments on a paper by Bowen entitled The influence of meteoritic dust on rainfall. *Austral. J. Phys.*, **7**, 354–358.
10. Wahl, E., 1952: The January thaw in New England. *Bull. Amer. meteor. Soc.*, **33**, 380–386.
11. Whipple, F. L., and G. S. Hawkins, 1956: On meteors and rainfall. *J. Meteor.*, **13**, 236–240.

Unauthenticated | Downloaded 12/10/24 06:09 PM UTC