THE RELATION BETWEEN RAINFALL AND METEOR SHOWERS

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ABSTRACT

Examination of rainfall figures for a large number of stations shows that there is a tendency for more rain to fall on certain calendar dates than on others. There is a close correspondence between the dates of the rainfall maxima in both the northern and southern hemispheres, and this is difficult to explain on a climatological basis. The effect might, however, be due to an extraterrestrial influence.

The rainfall peaks occur approximately 30 days after prominent meteor showers, and it is suggested that they are due to the nucleating effect of meteoritic dust falling into cloud systems in the lower atmosphere, the time difference being accounted for by the rate of fall of the material through the atmosphere.

The hypothesis is tested for a particular meteor stream, the Bielids, which is known to have a 6.5-year period. The rainfall 30 days after the meteor shower is found to have a similar period. Furthermore, the phase of the rainfall periodicity is almost identical with that of the meteor shower.

The data examined are confined to the month of January, and it is proposed to extend the investigation to other months in future papers.

1. Introduction

In studies of rain physics, it is a matter of common observation that clouds sometimes rain soon after they form, while on other occasions they build up to great heights in the atmosphere without doing so. This difference in behavior is known to be connected with the presence or absence of rain-forming nuclei in the atmosphere. In the particular case of supercooled clouds, the effective nuclei are the so-called freezing nuclei, which determine whether ice crystals will form.

In a study of the role played by these nuclei in the formation of rain, Smith and Heffernan (1954) have made measurements of the concentration of freezing nuclei in the free atmosphere by means of a cloud chamber carried in an aircraft. They found that the number of nuclei showed large fluctuations, and that the number which became active at a temperature of −15C, for example, might change by more than 1000 to 1 from one day to the next. It had always been thought that these nuclei were of terrestrial origin, but two observations made in the course of Smith and Heffernan's experiments give reason to doubt whether this assumption is entirely true:

1. The changes in freezing-nucleus concentration did not appear to bear a simple relation to air-mass movements. Observations made in approximately the same position and at the same height in an air mass on successive days sometimes gave entirely different values.
2. A measurement made in the terrestrial dust below a temperature inversion frequently gave a freezing-nucleus count which was lower than that in the clear air above.

These observations in themselves gave no indication of the origin of the freezing nuclei, but did suggest that they might be falling into the air mass from above. As rainfall is the quantity most likely to be influenced by variations in the freezing-nucleus concentration, an examination of rainfall records was then made, and some further interesting results emerged which will be discussed in detail in the present article.

2. Singularities in January rainfall

If the total daily rainfall of Sydney, Australia, is examined for the month of January for the period 1859 to 1952, it is found that there are marked variations from one day to the next. The rainfall curve is given in the left portion of fig. 1, which, like all curves discussed in this section, has been smoothed by taking three-day running means. There are three main peaks, on 13 January, 22 January, and 1 February, and it is natural to suppose that they are due to purely local rainfall fluctuations. If this were so, they would be smoothed out as records from adjacent stations were added. In the right portion of fig. 1 is given the total daily rainfall for 23 stations in New South Wales, for the period 1871 to 1946, the list of stations being given in the appendix. The stations are all more than 100 mi from Sydney and would therefore be expected to have quite different characteristics. It is seen that there are again three peaks on dates identical with those in Sydney. The magnitude of the fluctuations is almost unchanged, the greatest departures from the mean being approximately 35 per cent in each case. If the fluctuations were random and independent, they would have been reduced in the ratio $(23)^{\frac{1}{2}}:1$.

It can be concluded, therefore, that the fluctuations are not random and that, during this period, the rainfall of New South Wales was greater on certain days

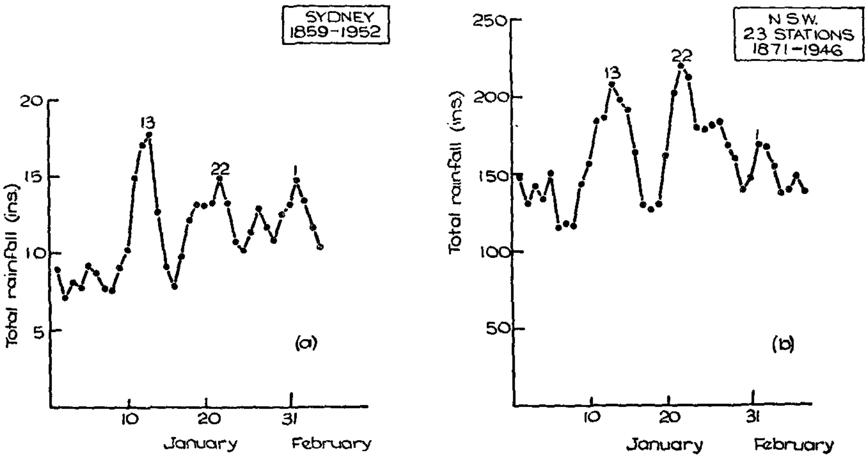

FIG. 1. Left: daily rainfall of Sydney for January and first few days of February for period 1859 to 1952. Right: daily rainfall totals of 23 stations in state of New South Wales for period 1871 to 1946.

in January than on others. Such fluctuations could, of course, still be explained by the selective passage of low-pressure systems over the area.

It is pertinent to inquire whether this tendency to persist over an area also persists in time. In Sydney, the day for which the rainfall total is greatest over the whole period of record is 12 January. (The magnitude of this peak is reduced and shifted to 13 January when running means are taken as in fig. 1.) If the rainfall records are now divided into periods from 1860 to 1879, 1860 to 1899, 1860 to 1919, *etc.*, containing successively 20, 40, 60, 80 and 93 years of records, it will be seen from table 1 that:

1. The mean daily rainfall for January is substantially the same for each of the periods.
2. The standard deviation of the daily mean (σ) decreases with increasing amounts of data.
3. The mean rainfall of 12 January is consistently two to three times the mean for the month.
4. Finally, the ratio x/σ, where x is the departure of the 12 January rainfall from the mean for the month, increases with increasing number of years to a value of 3.6 at 60 years. It then remains at a value greater than three as the number of years continues to increase.

A departure of three times the standard deviation is highly significant at the 1 per cent level for a function with a normal distribution. However, as the distribution of rainfall is non-normal and there is also a tendency for it to be serially correlated, the significance of the above departure is somewhat lower. But there can be no doubt that the mean rainfall of 12 January at Sydney is consistently more than double the mean for the whole month, and that its departure from the mean, compared with the standard deviation, tends to increase with increasing length of the record.

It appears, therefore, that in the rainfall of New South Wales during January, there are departures from the mean which persist both over the area and over the period of record.

It is of interest now to examine the rainfall of other regions to see if similar fluctuations occur. As a small number of stations may not be representative of any given region, it is preferable to use a large sample for an analysis of this kind. It is also desirable to use the daily rainfall figures, but these unfortunately are difficult to obtain; they are seldom published and often exist only in manuscript form in the weather services. The present treatment, which has only been made possible through the ready cooperation of the directors of the weather services in many parts of the world, is therefore based on such data as already existed or could readily be made available. They include daily figures for a limited number of stations, the daily mean rainfall where this has already been computed, records of the date and amount of the greatest falls of the month, and, in the case of the British records, the days on which more than 2½ in of rain were recorded anywhere in the United Kingdom.

We shall be particularly concerned with the occurrence of peaks in the records and, as indicated in an earlier paper (Bowen, 1953), these are usually due to a tendency for heavy falls to occur on a given day and not to a greater frequency of rain. For the present

TABLE 1. January rainfall of Sydney.

Period:	1860–1879	1860–1899	1860–1919	1860–1939	1860–1952
Number of years:	20	40	60	80	93
Mean daily rainfall (in):	.111	.115	.113	.115	.117
Standard deviation (σ):	.068	.054	.066	.051	.041
Mean rainfall of 12 January (in):	.222	.256	.354	.277	.254
x/σ	1.6	2.6	3.65	3.2	3.3

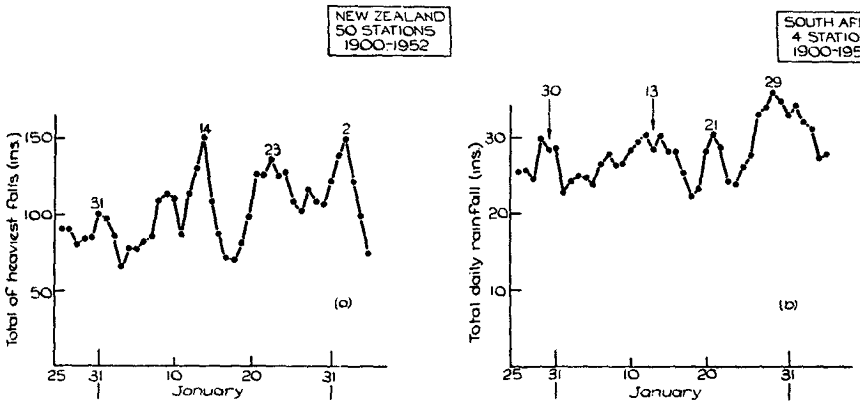

FIG. 2. Left: total of heaviest falls of month for 50 stations in New Zealand, 1900 to 1952. Right: total daily rainfall of four stations in South Africa and Rhodesia, 1900 to 1953.

purpose, therefore, either the daily rainfall or the heaviest falls of the month contains the necessary information.

In the records for the regions which will now be discussed, a rainfall maximum tends to appear at the beginning of January. The curves have, therefore, been extended to include the last few days of December.

Southern-hemisphere records.—In the left portion of fig. 2 is given the total of the heaviest falls of the month for 50 stations[1] in New Zealand from 1900 to 1952, chosen by officers of that weather service to give a representative cover of the whole country. The list of stations is given in the appendix, together with the period for which the records exist. The curve shows many similarities to that of New South Wales. There are peaks on 31 December, 14 January, 23 January, and 2 February, the last three each being displaced one day from those in fig. 1.

In the right portion of fig. 2 is given a curve of daily rainfall for four stations in South Africa and Rhodesia, for the period 1900 to 1953. This again shows similar features, with a peak on 30 December, a broad maximum centered on 13 January, and other peaks on 21 and 29 January. Although there are small displacements in the maxima in one region as compared with another, the general characteristics are remarkably similar. It begins to appear that there may be an influence affecting South Africa, Australia and New

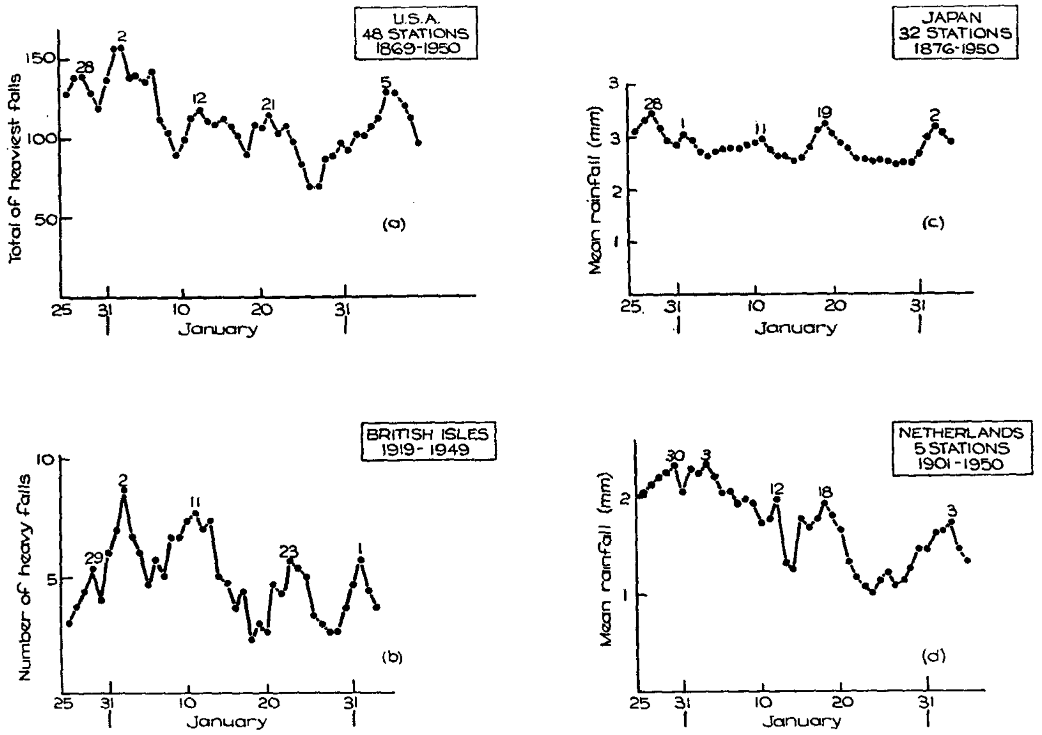

FIG. 3. Upper left: total of heaviest falls of month for 48 stations in United States, 1869 to 1950. Lower left: number of falls exceeding 2½ in in 24 hr anywhere in Great Britain for period 1919 to 1949. Upper right: mean daily rainfall for 32 stations in Japan, 1876 to 1950. Lower right: mean daily rainfall for five stations in Netherlands, 1901 to 1950.

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[1] *Editor's Note.* One datum per station-month is selected. These are grouped by date. The totals of these groups are used to form the displayed three-day running means.

Zealand which tends to give increased rainfall at nearly identical times.

Rainfall of northern-hemisphere regions.—Fig. 3 gives rainfall curves for four widely separated regions in the northern hemisphere, namely the United States, Great Britain, Japan and the Netherlands.

The curves are, respectively:

(*a*) The total of the heaviest fall of the month for 48 stations[1] in the United States from 1869 to 1950. They were chosen one per state, by officers of the U. S. Weather Bureau, to be representative of the whole country.

(*b*) The number of occasions on which more than 2½ in of rain was recorded in 24 hr anywhere in the British Isles from 1919 to 1949. This criterion was chosen as it was the one given in the *Records of the British Rainfall Organization*. Although the number of events is comparatively small, these data relate to some thousands of rain gauges.[2]

(*c*) The mean daily rainfall for 32 stations in Japan for the period 1876 to 1950.

(*d*) The mean daily rainfall for five stations in the Netherlands for the period 1901 to 1950.

In all cases, the curves are three-day running means and the list of stations used in compiling them is given in the appendix. It will be seen that, in spite of the wide variety of climatic conditions involved, there is again a correspondence in the rainfall curves of these regions in the northern hemisphere. The number of peaks is similar in each case, and the dates on which they occur are closely grouped. Furthermore, the dates in both hemispheres are closely related.

Owing to the mixed nature of the data used in compiling the curves, it is difficult to devise a quantitative test of the significance of the correspondence between them. As a simple test, the curves of figs. 1 (right), 2 and 3 have been combined by summing the respective departures from the mean, giving the curve of fig. 4. This may be regarded as a mean curve for January for some 250 stations in the regions which have been discussed. It shows all the characteristics of the individual curves, having a double-humped maximum with peaks on 29 December and 2 January, and other maxima on 12 January, 22 January, and 1 February.

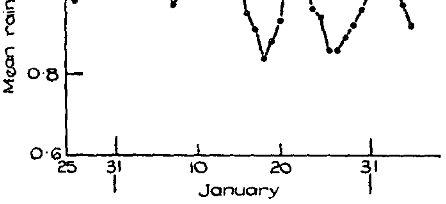

FIG. 4. Mean curve for January obtained by summing means of figs. 1 (right), 2 and 3.

It appears, therefore, that at least over these regions of the world, the rainfall tends to be greater on certain calendar dates as compared with others. The appearance of the effect on a hemisphere-wide basis, and in particular the correspondence between the northern and southern hemispheres, is extremely difficult to explain on climatological grounds. The only remaining explanation seems to lie in an influence which can operate simultaneously in all parts of the globe, that is, one of extraterrestrial origin.

3. Possible relation to meteor showers

In addition to being an extraterrestrial influence, the effect must also be one which operates on particular calendar dates. There is only one known to the writer which meets these requirements, namely meteor showers. The Earth in its orbit is known to pass through streams of dust particles which exist in vast elliptical orbits about the sun. The larger particles burn up on entering the earth's atmosphere and become visible as meteors. The smaller particles fall slowly through the atmosphere as dust. There is only one important meteor shower in the month of January, namely the Quadrantids, which occurs on the 3rd. A little earlier in time are three other showers, the Ursids on 22 December, the Geminids on 13 December, and the Bielids which are quoted as exextending from 15 November to 2 December (Porter, 1952; Lovell and Clegg, 1952). The first three showers are prominent ones and of relatively short duration. The Bielids, however, differ in several respects. They are associated with Biela's comet, which appeared in the early part of the 19th century, and in 1846 was observed to split into two parts. As a result, it gave rise to two meteor streams which are referred to as the Bielids I and II, respectively. The Bielids II make their appearance on a fixed date (2 December), but the Bielids I retrogress in time by one day in every five or six years. They appeared on 27 November in 1885, but by 1940 had shifted to 15 November (Lovell and Prentice, 1948).

It will be seen that the dates of the meteor streams fall almost exactly a month before the rainfall peaks in fig. 4. The differences in time between the meteor showers and the rainfall peaks are given in table 2, the mean time difference being a little over 30 days.

TABLE 2. Time difference between meteor showers and rainfall peaks.

Meteor shower	Date	Date of rainfall peak	Time difference (days)
Bielids I	November 27→15	December 29	—
Bielids II	December 2	January 2	31
Geminids	December 13	January 12	30
Ursids	December 22	January 22	31
Quadrantids	January 3	February 1	29

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[2] This curve is similar to fig. 2 in the previous paper (Bowen, 1953). But an error of three was made in the ordinates in that paper, owing to inadvertent use of three-day running totals instead of three-day running means.

The hypothesis has therefore been advanced that the effect is due to the nucleating action of dust from meteor showers falling into the cloud systems in the lower atmosphere, the time difference being accounted for by the rate of fall of the material through the atmosphere.

4. The periodicity associated with the Bielids

Of the meteor streams listed in table 2, the Geminids, Ursids and Quadrantids do not show conspicuous variations in intensity from one year to the next. Neither is there any readily detectable periodic behavior in the rainfall about 12 January, 22 January, and 1 February. However, the Bielids differ in having made exceptionally strong appearances at 6- to 7-yr intervals. This arises from the facts that the meteor particles are concentrated in one part of the orbit, and the orbital period is approximately 6.5 yr. It appears that the earth passed through this region several times in the latter part of the 19th century, and meteor showers were recorded in 1867, 1872, 1879, 1885, 1892 and 1899, *i.e.*, at intervals of 5, 7, 6, 7 and 7 yr, respectively. The appearances of 1872, 1885 and 1892 were exceptionally brilliant ones; but that of 1899 was much reduced in intensity, and since that date the appearances have not been strong.

If the present hypothesis is correct, the rainfall during the latter part of December and the first few days of January is connected with the Bielids and should show a similar periodic behavior. In fig. 5 is given the United States rainfall totalled for the three days near the center of this period, namely 29, 30 and 31 December, for each successive year from 1871 to 1950. It is apparent that there is a tendency for the rainfall to be greater than average at approximately 6-yr intervals, particularly during the last 50 yr.

In considering this illustration, it should be observed that a whole year, with all its variations in weather, elapses between each point on the curve. According to accepted meteorological concepts, therefore, the points should be distributed at random and should not be serially correlated. If, however, the present hypothesis is correct, they should be serially correlated and show a 6- to 7-yr recurrence tendency. The serial correlation coefficients have been computed in the usual way from the data of fig. 5, giving the values shown in table 3. For displacements of 6, 12, 18, 24 and 30 yr, the coefficients are all positive; and for displacements of 3, 9, 15, 21 yr, *etc.*, they are all negative, indicating a distinct 6-yr period. The correlation coefficients for displacements of 6 and 30 yr are 0.35 and 0.36, respectively, which, on the basis of 80-yr data, are significant at the 1 per cent level. There can be no doubt, therefore, that the data show a 6-yr recurrence tendency and support the hypothesis that the rainfall about this period is connected with the Bielid meteor stream.

TABLE 3. Serial correlation coefficients for rainfall of 29, 30 and 31 December in the United States.

Displacement (years)	3	6	9	12	15	18	21	24	27	30
Correlation coefficients	−.23	.35	−.18	.14	−.23	.06	−.1	.16	−.07	.36

A similar analysis has been carried out for the same three days for the 50 stations in New Zealand for the period 1900 to 1952, the curve of rainfall being given in the top portion of fig. 6. The periodic behavior is not as well marked as in the United States, and there is disagreement between the two curves in the period 1900 to 1910. After 1910, however, there are prominent peaks which occur either in the same year as those in the United States or one year removed. The serial correlation coefficients have been calculated as before, and the maximum values appear at displacements of 5, 12, 19 and 24 years, as given in table 4. The coefficients for 3, 9, 15 and 21 years are all negative. Although less significant than in the United States, this analysis shows that the same 6-yr recurrence tendency exists.

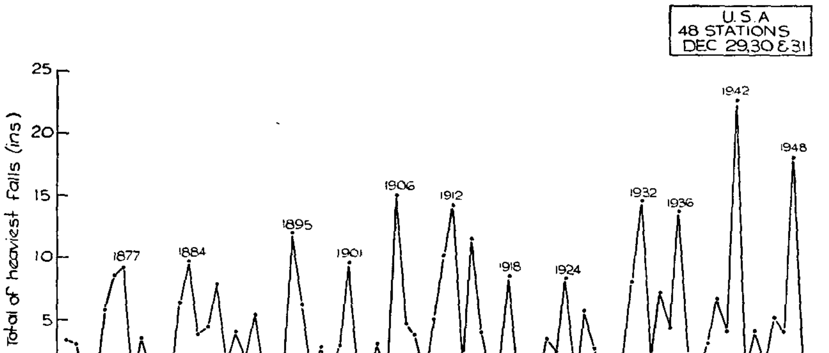

FIG. 5. Heaviest falls of month, totalled for three days (29, 30 and 31 December) for 48 stations in United States for each year from 1871 to 1950.

Table 4. Serial correlation coefficients for rainfall of 29, 30 and 31 December in New Zealand.

Displacement (years)	3	5	9	12	15	19	21	24
Correlation coefficients	−.24	.09	−.10	.16	−.15	.38	−.10	.15

Table 5. Serial correlation coefficients for rainfall of 29, 30 and 31 December in state of New South Wales.

Displacement (years)	3	6	9	12	15	18	21	23
Correlation coefficients	−.1	.12	−.1	.07	−.09	.07	−.07	.17

Finally, in the bottom portion of fig. 6 are given similar figures for 80 stations in the state of New South Wales, the only other bulk rainfall records of this kind available to the writer. There are no peaks which appear to be significant in the first 10 yr. But subsequently there are peaks in 1914 and 1926 which correspond to minor peaks in the record for the United States, one in 1919 which is one year removed, and then a series of maxima in 1930, 1936, 1942 and 1948, which agree closely with those in the United States. The serial correlation coefficients are all low, as given in table 5, but this appears to be due to the existence of the exceptionally large peak in 1948. However, the same 6-yr recurrence tendency is again evident.

If the phase of the periodicity is now determined by the method of superposed epochs — the phase being defined as the year nearest to 1900 at which a maximum appeared — it is found to be 1900 for the United States and New South Wales, and 1899 for New Zealand. This should be compared with the maximum of the meteor shower which occurred in the year 1899. Apart from any other consideration, the fact that there is a similarity in the periodicity and phase of the rainfall about this period in both the northern and southern hemispheres is itself evidence of an extraterrestrial influence.

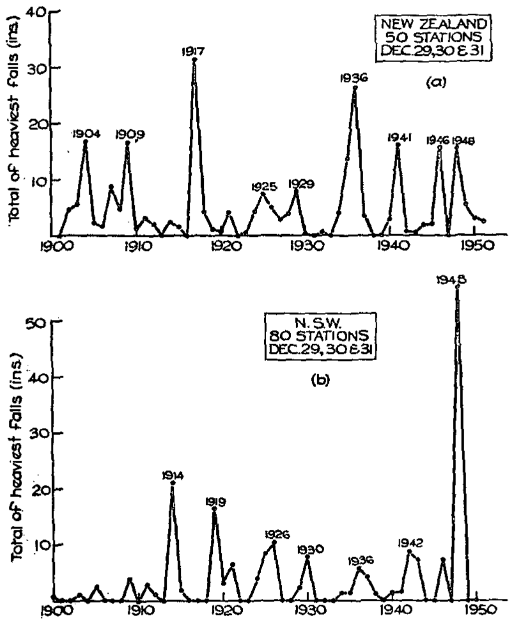

Fig. 6. Top: heaviest falls of month for 29, 30 and 31 December for 50 stations in New Zealand from 1900 to 1952. Bottom: heaviest falls of month for 29, 30 and 31 December for 80 stations in New South Wales from 1900 to 1950.

The existence of a periodicity in the rainfall of the last few days of December is consistent with the present hypothesis but is clearly in need of more thorough analysis than is possible with the data at present available. The date and amount of the greatest rainfall of a given month are not the most appropriate quantities to use for an investigation of periodic effects, and it would be preferable to use the daily figures. It is proposed to make a more detailed analysis when the latter become available. There are indications that the 6-yr period is detectable for a few days on either side of the dates used above and, given the daily figures, it would be instructive to determine the spread more precisely.

The fact that the Bielids have not given prominent displays of visible meteors since 1899, but the influence on rainfall seems to have continued during the subsequent 50 yr, suggests that the particles responsible for the phenomenon are the smaller meteoritic particles, that is, the ones which are too small to give visible tracks when they enter the earth's atmosphere. As a result of the Poynting-Robertson effect, they would be expected to be slightly displaced with respect to the visible meteor particles, and it is possible that the earth would continue to pass through the dust for some time after it had passed away from the region which contained the larger particles. This might also account for the slight phase displacement between the visible meteors and the rainfall maximum.

5. The physical mechanism

In the light of these results, it is not difficult to formulate a hypothesis to explain the physical connection between meteors and rainfall in general terms. It must be admitted, however, that there are deficiencies in the details of the suggested mechanism.

It is known that meteor particles exist in elliptical orbits around the sun, and that the Earth in its own orbit passes through many of these streams of dust on certain fixed dates. The particles consist of a wide range of sizes, and the large ones burn up on entering the Earth's atmosphere, giving visible meteors. The smaller particles do not have enough kinetic energy to be consumed, however, and fall to the ground as dust together with the debris which results from the destruction of the larger particles (Whipple, 1950). Little is known about the characteristics of this dust, but it accumulates around the 80- to 90-km level; and it was shown in the previous paper (Bowen,

1953) to be intimately connected with the appearance of noctilucent clouds at that height. The present hypothesis is that the dust then falls through the atmosphere and finally enters the cloud systems of the lower atmosphere. If at this time the atmosphere were relatively free of rain-forming nuclei, the dust might act as a nucleating agent which stimulates the clouds to produce rain.

There are two quite serious weaknesses in this hypothesis. The first relates to the total mass of meteoritic material falling on the earth. The highest figure which can be allowed on astronomical grounds is some 10^4 tons/day, which at most would give 1 particle of the required size per cubic meter. This, at first sight, would not appear to be sufficient to influence rainfall. However, meteor showers are almost certainly responsible for the formation of noctilucent clouds at the 90-km level. Since these are visible by eye from a distance of several hundreds of kilometers, they must consist of many particles per cubic centimeter; that is, either the number of effective meteor particles is much greater than has previously been supposed, or a multiplication process takes place in the atmosphere analogous to but not necessarily similar to that in a Wilson cloud chamber, where a single high-speed particle produces a large number of water droplets or ice crystals.

Alternatively, although the number of particles falling into the lower atmosphere may be as low as 1 per cubic meter, it is conceivable that multiplication could take place soon after they entered a supercooled cloud system. Immediately as ice crystals formed, they might for example increase rapidly in number by the splintering process described by Brewer and Palmer (1949).

A second feature which is difficult to accept is the sharpness of the rainfall peaks and the apparent consistency in the time of fall of the dust as between one meteor stream and the next. Owing to the distribution of particle sizes, it would be expected that the effect would be spread over a long period of time. However, to have a relatively sharp effect on rainfall on a given date, it is not necessary that there should be a small distribution of particle sizes — only a sharp, advancing front. This is provided by the mechanism proposed by Whipple (1950).

There appears to be very little information in the literature on the fall of meteoritic dust through the atmosphere, but Link (1953) has given a fall time of 30 days for particles in the size range from 4 to 10μ. In addition, Svestka (1951) has estimated the time of fall from a study of the moon's brightness at times of total eclipse. He considered that this was influenced by the amount of dust in the lower atmosphere of the earth, and he showed that the greatest departures from the mean brightness occur 30 to 40 days after some of the major meteor streams. He concluded that this was due to a concentration of meteoritic dust in the lowest 10 km of the atmosphere at that time. This conclusion, derived from entirely different reasoning, agrees in a remarkable way with that arrived at from a study of rainfall data.

6. Discussion

If the ideas expressed in this article are found to be correct, they will have a number of important implications from a meteorological point of view. It is too early to deal with these in a comprehensive way, but it may be useful to consider them briefly.

Forecasting.—If the meteor hypothesis is confirmed, it would find application in short-term forecasting if used in conjunction with a good knowledge of the synoptic situation. It might be considered that the conditions necessary for meteoritic dust to influence rainfall are:

1. A comparative absence of other rain-forming nuclei in the atmosphere.
2. A synoptic situation conducive to the growth of large cloud systems.

If these conditions were met, meteoritic dust falling into the system might then produce exceptionally heavy falls of rain. An alternative approach would be to consider the synoptic situation as defining the extent to which clouds might build up, and the amount of meteoritic dust or the freezing-nucleus concentration in the atmosphere as having a bearing on whether rain falls.

Influence on the general circulation.—It is a fundamental concept in meteorology that the way in which a pressure pattern develops will determine the amount and distribution of the rain which subsequently falls. If the ideas described above are found to be correct, this view might have to be modified in one important respect. It is well known that the release of precipitation leads to the release of a great amount of latent heat into the atmosphere, and it has been calculated that 1 in of rain over a given area is equivalent to about 3 days' solar radiation. The sudden release of this amount of energy could have an important bearing on the subsequent development of a given synoptic situation and, if this were to occur simultaneously at a number of points over the globe, it is possible that the whole circulation pattern would be affected. Brier (1954) has already pointed out that the meridional index at 50°N shows variations which are closely related to those in the rainfall. He poses the fundamental question whether the changes in index cause the rainfall variations or are a consequence of them. This is certain to be a matter of great controversy which could hardly be settled on the information at present available.

Singularities.—A great deal of work has been done in the past on singularities in temperature and pressure, without the emergence of a sound physical explanation. It is interesting to observe that at least one of these singularities, namely the temperature singularity of 22–23 January (Wahl, 1953), which is known to occur over a great part of North America and Europe, coincides with one of the rainfall singularities discussed in the present article. It is conceivable, therefore, that rainfall singularities are the fundamental ones and that the consequent release of latent heat into the atmosphere might produce the temperature and pressure singularities which have been observed.

Long-term climatic change.—The problem of long-term climatic change over the Earth is an outstanding geophysical question which has been the subject of much speculation in the past. Attempts have been made to relate changes of climate to changes in the solar constant. This, however, is comparatively invariant and most unlikely to alter over short periods of time. The climate of the Earth, on the other hand, is known to have changed rapidly on the scale of geological time. Hoyle (1954) has pointed out that the present results may provide an explanation of the phenomenon. If meteor showers have a direct effect on world rainfall, an increase or decrease in the amount of dust in the solar system could easily explain the changes which have occurred. They would not necessarily be of a cyclic character. They could happen more or less at random with the appearance or disappearance of cometary material in the solar system or, alternatively, with the passage of the solar system through a dust cloud in space. Such events might have a profound effect on the precipitation pattern over the Earth and consequently on the whole thermo-dynamic equilibrium of the atmosphere.

Conclusion.—The results discussed in this article are limited in two distinct ways. First, the areas of the globe which have been examined are those for which the rainfall records are most readily available. The connection with meteor showers appears to exist in all of them, but it does not follow that this will be true over the whole world. For example, regions in which there is an adequate supply of nuclei from terrestrial sources might not show the phenomenon; in a similar way, areas subject to a large proportion of non-freezing rain may not show it. Secondly, the data discussed have been almost entirely confined to the month of January. Examination of other months is required before the present hypothesis can be substantiated, and it is proposed to do this in future papers.

Acknowledgments.—The writer would like to acknowledge the great help in analyzing the records which has been given by Mrs. Owen and Mrs. Beazley, and the cooperation of the directors of the many weather services who have so willingly made records available for this study.

APPENDIX

List of stations and dates used in compiling figs. 1 (right), 2 and 3.

Fig. 1 (right), *New South Wales*

Inverell	1875–1946
Uralla	1885–1946
Bundarra	1884–1946
Bingara	1879–1946
Avondale	1904–1941
Ashford	1901–1946
Guy Fawkes	1888–1946
Guyra	1886–1946
Tenterden	1882–1946
Gravesend	1887–1946
Pallamallawa	1901–1946
Tenterfield	1871–1946
Warialda	1884–1946
Tingha	1910–1946
Bendemeer	1879–1946
Bonshaw	1891–1946
Dalmorton	1901–1946
Deepwater	1901–1946
Emmaville	1885–1946
Drake	1901–1946
Glen Innes	1882–1946
Jeogla	1907–1946
Walcha	1880–1946

Fig. 2 (left), *New Zealand*

North Island

Mangonui	1902–1952
Kaitaia	1900–1952
Rangiahua	1902–1950
Auckland	1900–1952
Kawhia	1906–1952
Turua	1902–1952
Hamilton	1900–1952
Rotorua	1900–1952
Waiotapu	1902–1952
Taupo	1902–1952
Tolaga Bay	1900–1952
Gisborne	1900–1952
New Plymouth	1900–1952
Ohawe	1900–1952
Patea	1907–1952
Hunterville	1900–1950
Tutira	1900–1952
Hedgeley (Eskdale)	1900–1952
Pukehou	1900–1952
Waimarama	1900–1952
Mount Vernon	1900–1952
Gwavas	1900–1952
Fielding	1900–1952
Otaki	1900–1952
Eketahuna	1900–1952
Takapau	1904–1952
Woodbank	1903–1952
Summit	1900–1952
Featherston	1900–1952

Karori Reservoir	1900–1952
Wellington	1900–1952
Waitatapia	1900–1952

South Island

Nelson	1900–1951
Reefton	1905–1952
Greymouth	1900–1952
Otira	1907–1952
Hokitika	1900–1952
Ross	1910–1952
Farewell Spit	1900–1952
Cape Campbell	1900–1952
Christchurch	1900–1952
Lincoln	1900–1952
Benmore	1907–1952
Timaru	1900–1952
Queenstown	1900–1952
Clyde	1900–1952
Roxburgh	1900–1952
Oamaru	1900–1952
Dunedin	1900–1952
Tapanui	1900–1952

Fig. 2 (right), *South Africa and Rhodesia*

Capetown	1906–1953
Pretoria	1906–1950
Durban	1900–1950
Salisbury	1898–1946

Fig. 3 (upper left), *United States of America*

Concord, New Hampshire	1903–1950
Boston, Massachusetts	1871–1950
Duluth, Minnesota	1871–1950
Key West, Florida	1871–1950
Savannah, Georgia	1871–1950
Little Rock, Arkansas	1880–1950
New Haven, Connecticut	1873–1950
Nashville, Tennessee	1871–1950
Madison, Wisconsin	1869–1950
Oklahoma City, Oklahoma	1891–1950
Helena, Montana	1881–1950
Chicago, Illinois	1871–1950
Huron, South Dakota	1882–1950
St. Louis, Missouri	1871–1950
North Platte, Nebraska	1875–1950
Dodge City, Kansas	1875–1950
Spokane, Washington	1882–1950
Baltimore, Maryland	1871–1950
Denver, Colorado	1872–1950
Cheyenne, Wyoming	1871–1950
Bismarck, North Dakota	1894–1950
San Francisco, California	1905–1950
Indianapolis, Indiana	1872–1950
Philadelphia, Pennsylvania	1871–1950
Portland, Oregon	1872–1950
New York, New York	1871–1950
Salt Lake City, Utah	1875–1950
Washington, D. C.	1871–1950
Charleston, South Carolina	1871–1950
Burlington, Vermont	1893–1950
Atlantic City, New Jersey	1874–1950
Vicksburg, Mississippi	1880–1950
Block Island, Rhode Island	1881–1950
Detroit, Michigan	1871–1950
Davenport, Iowa	1872–1950
Richmond, Virginia	1898–1950
Albuquerque, New Mexico	1892–1950
Winnemucca, Nevada	1878–1950
Louisville, Kentucky	1872–1950
Boise, Idaho	1899–1950
Galveston, Texas	1872–1950
Hatteras, North Carolina	1887–1950
Portland, Maine	1872–1950
New Orleans, Louisiana	1871–1950
Yuma, Arizona	1876–1950
Cleveland, Ohio	1871–1950
Parkersburg, W. Virginia	1889–1950
Mobile, Alabama	1871–1950

Fig. 3 (lower left), *Great Britain*

The records for Great Britain were obtained from *British Rainfall*, published each year by H. M. Stationery Office. They were taken from the section entitled "Heavy falls on rainfall days," heavy falls being defined as (a) those of $2\frac{1}{2}$ in or more in the rainfall day, or (b) those which exceed 7.5 per cent of the total rainfall for the year.

Fig. 3 (upper right), *Japan*

Kagoshima	1884–1950
Izuhara	1896–1950
Fukuoka	1890–1950
Oita	1887–1950
Kochi	1886–1950
Okayama	1891–1950
Hamada	1893–1950
Sakai	1886–1945
Osaka	1883–1950
Tsu	1909–1950
Takayama	1900–1950
Tokyo	1876–1950
Choshi	1887–1950
Mito	1897–1950
Maebashi	1897–1950
Kofu	1896–1950
Tsuruga	1898–1950
Kanazawa	1886–1950
Miigata	1886–1950
Fukushima	1890–1950
Ishinomaki	1888–1947
Miyako	1884–1950
Akita	1886–1950
Aomori	1886–1950
Hakodate	1896–1947
Suttsu	1891–1950
Sapporo	1889–1950
Asahikawa	1889–1950
Obihiro	1894–1950
Kushiro	1911–1950
Abashiri	1891–1950
Nemuro	1899–1950

Fig. 3 (lower right), *Netherlands*

Den Helder	1902–1950
Groningen	1901–1950
Vlissingen	1901–1950
Maastricht	1902–1950
Hoofddorp	1903–1950

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