A RELATION BETWEEN SNOW COVER, CIRRUS CLOUD, AND FREEZING NUCLEI IN THE ATMOSPHERE

By E. G. Bowen*

[*Manuscript received August 2, 1956*]

Summary

It is reasonable to suppose that observations like that of cirrus cloud in the upper air and heavy falls of snow in relatively warm latitudes correspond to the presence of a large number of freezing nuclei in the atmosphere. A 300-year record of snow covering the ground at Tokyo and a 10-year record of cirrus cloud in Western Australia are examined and compared with one year's measurement of freezing nucleus concentration. The curves show a high degree of correlation, and all three tend to maximize on certain calendar dates.

These dates are nearly identical with those on which singularities occur in world rainfall. It has previously been suggested that this phenomenon is due to the nucleating effect of dust from meteor showers.

The record of snow cover at Tokyo for the three days December 29, 30, and 31 is examined separately and found to show a distinct recurrence tendency, which, over the 300 years of record, is identical in period and phase with that of the Bielid meteor shower.

I. Introduction

In a recent publication, Arakawa (1956) described how the first time that snow completely covered the ground in Tokyo was for many years an occasion for seasonal greetings and the payment of feudal dues, and that the date has therefore been recorded over a long period of time. The record is an interesting one for two reasons. It covers a period of more than 300 years, which is considerably longer than the majority of meteorological records. Secondly, among the many meteorological requirements which must be satisfied for snow to cover the ground at Tokyo, it is probably essential that a large number of freezing nuclei should exist in the atmosphere.

Interest in the role played by freezing nuclei in the atmosphere has lain dormant for many years but was revived by the work of Schaefer (1946) and Cwilong (1947), and more recently by the work of Ôkita (1952) and Isono (1955) on the chemical composition of some of the particles responsible. Interest has again been aroused by the suggestion that particles of meteoritic dust might act as freezing nuclei when they fall into the lower atmosphere and in this way have an influence on the weather at the Earth's surface (Bowen 1956*a*). This proposal has proved unacceptable to the majority of meteorologists and a number of papers have appeared in the literature arguing that it is incorrect. (See, for example, Martyn (1954), Neumann (1954), Swinbank (1954), Oliver and Oliver (1955), and Bhalotra (1956).) The difficulty which many meteor-

* Division of Radiophysics, C.S.I.R.O., University Grounds, Chippendale, N.S.W.

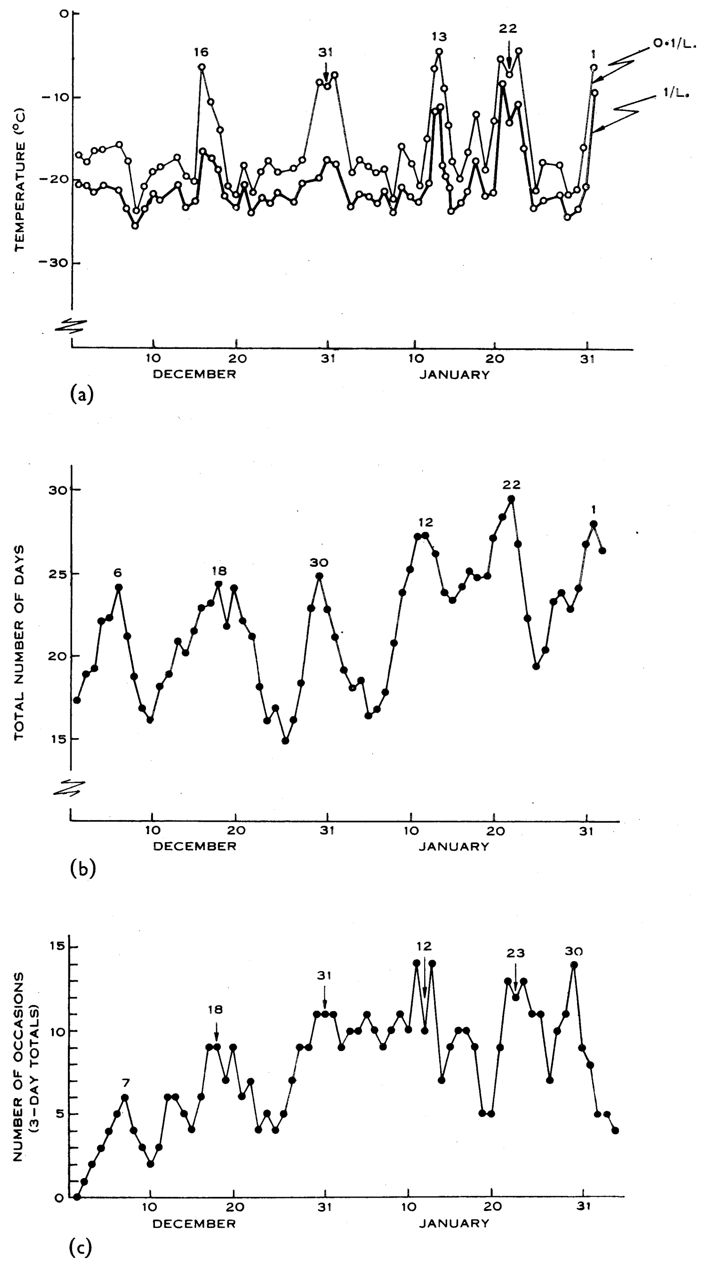

Fig. 1 (*a*).—Concentration of freezing nuclei measured on the ground in Western Australia, December 1955 and January 1956.

Fig. 1 (*b*).—Occurrence of cirrus cloud at six stations in Western Australia over a 10-year period.

Fig. 1 (*c*).—Date on which snow first covered the ground at Tokyo, from 1632 to 1955.

ologists find in accepting the hypothesis is no doubt partly due to a lack of appreciation of the part played by freezing nuclei in atmospheric processes, and partly to the absence of a long series of freezing nucleus measurements upon which a judgment might be based.

If the meteoritic dust hypothesis is correct, it would be expected that:

(*a*) high freezing nucleus counts would tend to occur almost simultaneously in different parts of the world,

(*b*) they would repeat on approximately the same calendar dates each year.

Measurements of freezing nucleus concentration made in several parts of the world in January 1954, 1955, and 1956 tend to confirm these expectations (Bowen 1956*b*), but a longer series of observations is probably required before this is generally accepted.

One purpose of the present paper is to point out that certain of the more conventional meteorological observations may serve as indicators of the presence of large numbers of freezing nuclei in the atmosphere. Among these are records such as that of snow cover in Tokyo, which has already been referred to, and the occurrence of cirrus cloud in the atmosphere.

II. Cirrus Cloud in Western Australia

The existence of cirrus clouds indicates that, among other things, there must at the time of observation be a considerable number of freezing nuclei in the upper air. In Figure 1 (*a*) is a curve of freezing nucleus concentration measured by Bigg (1956) in a cold chamber on the ground at Carnarvon in Western Australia during the months of December 1955 and January 1956. It shows the temperature at which 1 and 0·1 freezing nucleus per litre respectively were observed in that locality. In Figure 1 (*b*) is a curve of the total number of days on which cirrus cloud was observed at six stations distributed over the western half of Australia during a 10-year period. It is obvious by inspection that there is a high degree of correlation between them, and Bigg has shown this to be so quantitatively. This suggests that cirrus cloud is a good indicator of a high freezing nucleus content in the atmosphere, and that over a 10-year period the count has tended to be high on certain calendar dates.

In the more densely populated areas of the world, low cloud frequently interferes with the observation of cirrus cloud. It is unlikely, therefore, that long unbroken records of this kind will be found except in arid regions like Arizona, the Sahara, and the western part of Australia.

III. First Snow Cover in Tokyo

As already mentioned, the record of snow cover at Tokyo might also indicate days on which there was a high freezing nucleus concentration in that part of the world. This particular record refers to a different hemisphere from that in which the measurements just discussed were made, to a different season of the year, and to an entirely different climatological situation. According to accepted meteorological concepts, therefore, it would not be expected that these results would bear any relation to those in Western Australia. On the other hand, if meteoritic dust were involved, one might expect a relationship between them.

In Figure 1 (*c*) are the 3-day totals of the date of the first appearance of snow cover at Tokyo for the period 1632 to 1955, taken from Tables 1 and 2 of Arakawa's paper. As there is only one observation per season, as compared with one per day in Figure 1 (*b*), the statistical fluctuations are considerable, but in Figure 1 (*c*) there is a distinct preference for certain dates and the major peaks appear to correspond closely with those in the previous two curves. Cross correlation of curves (*b*) and (*c*) gives a correlation coefficient of 0·33, which is significant at the 99 per cent. level. This suggests, with a high degree of probability, that the association between the curves is a real one and that there is some physical phenomenon which is common to both. The relation which each curve bears to Figure 1 (*a*) indicates that this common factor may be the concentration of freezing nuclei in the atmosphere.

It is also apparent from Figure 1 that both cirrus cloud in Western Australia and snow cover in Japan tend to maximize on certain calendar dates during December and January; and that these dates are almost identical in the two regions, which are in different hemispheres, in entirely different geographical situations, and subject to entirely different climatic regimes. It is difficult to explain this behaviour except through the agency of an extraterrestrial phenomenon such as meteoritic dust. Finally, the fact that the curves in Figure 1 refer to 1, 10, and 323 years of observation respectively suggests that the effect has been present for several centuries.

IV. Relation to Rainfall Singularities

In the first column of Table 1 are the dates in Figure 1 (*b*) on which cirrus cloud is a maximum. In the second column are the dates on which the major peaks in the Tokyo snowfall record of Figure 1 (*c*) are centred. There are

Table 1

PEAK DATES IN CIRRUS CLOUD, SNOW COVER, AND WORLD RAINFALL

Date of Maximum in Cirrus Cloud in Western Australia	Date of Maximum in Snow Cover at Tokyo	Date of Maximum in World Rainfall
December 6	December 7	December 5
18	18	14
30	31	December 29 }
		January 1 }
January 12	January 12	January 12
22	23	22
February 1	January 30	February 1

smaller peaks on December 13 and January 5 and 16 which may or may not have any significance and have been neglected. It has already been pointed out (Bowen 1956*b*) that during these same months there are singularities in world rainfall on the dates given in the third column of Table 1. It will be observed that they are nearly identical in all three cases. If the three phenomena were random and independent of each other, the probability of an association as close as this occurring by chance may be calculated to be less than one in a million.

It has also been shown (Bowen 1956*b*) that the peaks in world rainfall occur approximately 30 days after prominent meteor streams. It is not proposed to pursue this relationship in the present paper, but to point out a special property of one of these meteor streams, namely the Bielids, and the precipitation thought to be associated with it.

V. Periodicity Associated with the Bielid Meteor Stream

The Bielid meteor stream is outstanding among those in the latter part of the year for its very pronounced periodic behaviour. It is associated with Biela's comet which is known to have a 6·6-year period of rotation around the Sun and the meteors have made many strong appearances at 6- or 7-year intervals. A list of the years in which either the comet or the meteor stream has been seen is given in the first column of Table 2 (Porter 1952). Where there are closely spaced appearances, as in 1845, 1846, and 1847, the mean is taken.

Table 2

BIELA'S COMET AND METEORS, AND SNOW COVER AT TOKYO

Date of Appearance of Biela's Comet and Meteors	Snow Covering the Ground at Tokyo on December 29, 30, and 31
	1672
	1731
1741	1742
	1756
1772	
	1778
	1785
	1792
1798	1798
1805	
$\left.\begin{matrix}1830\\1832\end{matrix}\right\}$ 1831	
1838	
$\left.\begin{matrix}1845\\1846\\1847\end{matrix}\right\}$ 1846	
1852	
	1859
1867	
1872	
1885	1884
1899	
	1905

There are many gaps in the sequence, which may have been due to failure of the meteors to appear, to unsuitable observing conditions, or to other reasons. Nevertheless a distinct recurrence tendency at 6- to 7-year intervals is apparent.

There does not appear to be a generally recognized method of serially correlating such data and the following procedure has therefore been adopted. The years given in the first column of Table 2 are marked on two horizontal time scales and successively displaced 0, 1, 2, 3, 4, . . ., etc. years in the usual

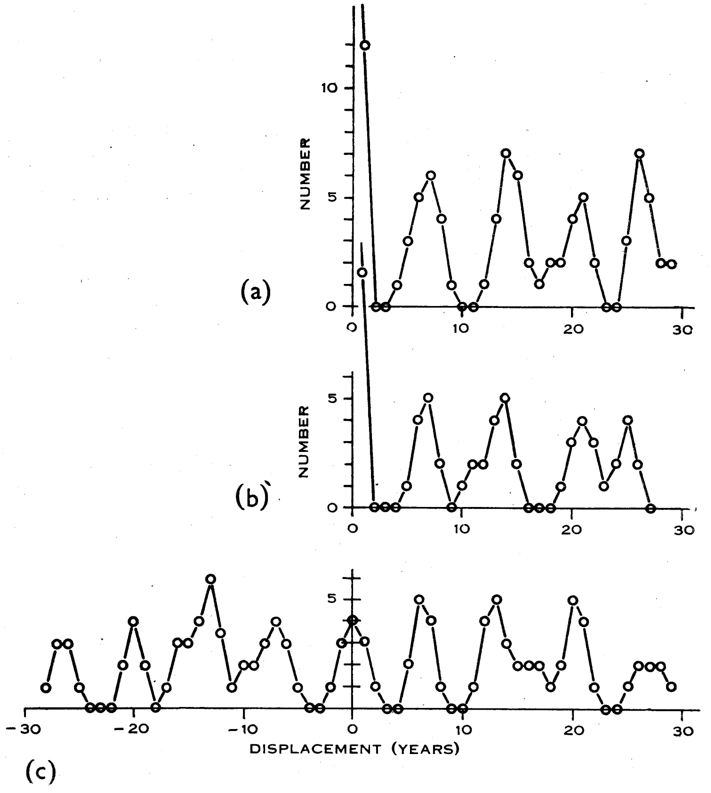

Fig. 2 (*a*).—Serial correlation of the years on which Biela's comet or associated meteors appeared.

Fig. 2 (*b*).—Serial correlation of years on which snow first covered the ground at Tokyo on any of the three days December 29, 30, and 31.

Fig. 2 (*c*).—Cross correlation of snow cover at Tokyo on December 29, 30, and 31, and Biela's comet and meteors.

way. The coincidence of two events is arbitrarily given a score of 2, and events separated by one year a score of 1. All other separations score zero. Proceeding in this way gives the correlogram of Figure 2 (*a*) which shows a very definite recurrence tendency in the data, with a period between 6 and 7 years.

It has been shown (Bowen 1956*a*) that there is a similar recurrence tendency in the rainfall of several parts of the world during the three days December 29, 30, and 31, which are approximately 30 days after this meteor shower. An investigation will now be made of the snow cover data for Tokyo to see if the same phenomenon exists.

In the second column of Table 2 are the years on which the first snow cover occurred at Tokyo during the same three days, December 29, 30, and 31. Again there are breaks in the sequence, due to the many conditions of temperature, synoptic situation, etc., all of which have to be satisfied before a heavy fall of snow is recorded. If, now, the dates are serially correlated in the same way as the comet and meteor data, the correlogram of Figure 2 (*b*) is obtained, which again shows a distinct recurrence tendency with a period between 6 and 7 years.

Finally, if the years of snow cover and those on which meteors appeared are cross-correlated, the correlogram given in Figure 2 (*c*) is obtained. It shows the same periodic behaviour with a significance at least as great as that in Figure 2 (*a*) and its symmetry about zero displacement indicates that the phase of the two occurrences is identical.

VI. Conclusions

It appears therefore that:

(i) Records of cirrus cloud and the date on which snow first covers the ground in Tokyo are good indicators of the existence of high freezing nucleus counts in the atmosphere.

(ii) During December and January there is a close relationship between cirrus cloud in Western Australia, snow cover in Japan, and world rainfall, which is difficult to explain except on the basis of an extraterrestrial influence acting on all three quantities.

(iii) The incidence of snow cover at Tokyo on December 29, 30, and 31 shows, over a period of 300 years, a recurrence tendency which is identical in period and phase with that of the Bielid meteor stream.

VII. References

Arakawa, H. (1956).—*Quart. J.R. Met. Soc.* **82**: 222–6.
Bhalotra, Y. P. R. (1956).—*Weather* **11**: 48–51.
Bigg, E. K. (1956).—New evidence of a meteoritic influence on rainfall. *Tellus* (in press).
Bowen, E. G. (1956*a*).—*J. Met.* **13**: 142–51.
Bowen, E. G. (1956*b*).—*Nature* **177**: 1121–3.
Cwilong, B. M. (1947).—*Proc. Roy. Soc.* A **190**: 137–43.
Isono, K. (1955).—*J. Met.* **12**: 456–62.
Martyn, D. F. (1954).—*Aust. J. Phys.* **7**: 358–64.
Neumann, J. (1954).—*Aust. J. Phys.* **7**: 522–6.
Ôkita, T. (1952).—*Sci. Rep. Tôhoku Univ. Ser. 5, Geophysics* **4** (2): 78–82.
Oliver, M. B., and Oliver, V. J. (1955).—*Bull. Amer. Met. Soc.* **36**: 147–51.
Porter, J. G. (1952).—"Comets and Meteor Streams." (Chapman and Hall: London.)
Schaefer, V. J. (1946).—*Science* **104**: 457–9.
Swinbank, W. C. (1954).—*Aust. J. Phys.* **7**: 354–8.