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# A NOTE ON FREEZING NUCLEI ANOMALIES

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## ABSTRACT

Daily freezing nuclei observations taken in the Washington, D. C., area during the first 3 months of 1958 showed large fluctuations in time relative to probable observational uncertainties. Anomalous values were detected around the January dates predicted by the meteoritic dust hypothesis. However, subsequent "peaks" do not appear to be associable with any known major meteor streams. A composite analysis of the dates of dominant peaks in similar observations at a number of other locations since 1954 tends to confirm the existence of singularities in January which are statistically highly significant.

## 1. INTRODUCTION

Information regarding the sources, physical properties, and natural variability of freezing nuclei in the atmosphere is relatively meager. Most current observational techniques are tedious and subject to uncertainties and differences in interpretation. Few systematic or routine observations over extended periods have been attempted in the United States. The most extensive series is that summarized by Schaefer [20].

The intriguing hypothesis that significant anomalies in the freezing nuclei content of the lower atmosphere during January may be attributable to dust from meteor streams intercepted by the earth's atmosphere some 30 days earlier has been advanced by Bowen [4]. Direct physical confirmation is lacking, and both favorable and inconclusive evidence have appeared in the literature. It is generally felt that serious meteorological as well as astronomical difficulties exist and remain to be resolved.

The purpose of this note is to present a preliminary summary of the results of a series of nuclei observations taken during January, February, and March 1958, near Washington, D. C. (about 8 miles west of the metropolitan area). Also, the question is considered whether these observations and similar ones made elsewhere over the past few years during the month of January lend any support to the hypothesis that there is some common factor producing worldwide variations in freezing nuclei.

## 2. OBSERVATIONAL PROCEDURES

This program was undertaken by the Weather Bureau in cooperation with the Radiophysics Division of the Australian Commonwealth Scientific and Industrial Research Organization, which kindly provided observational equipment of the type described by Warner [24]. Practical considerations required using the 10-liter cold box as a "mixing chamber" rather than as an expansion chamber as originally intended. The procedure adopted was essentially that described by Schaefer [20]. In addition, efforts were made to prevent frost formation by coating all interior surfaces with glycerin. This precaution was found to be of crucial importance, since the occurrence of frost was observed to produce highly erratic readings, sometimes increasing the number of observed ice crystals by 1 or 2 orders of magnitude over a 2-minute observational period. The refrigeration system was thermostatically regulated to maintain a wall temperature of about −21° C. In practice, however, the wall temperature fluctuated between −19° and −23° C., due to the cycling of the compressor. Since there were measurement uncertainties including sampling volume, moisture control, temperature variations, time-dependency of nucleation effects, and other observational factors, it was felt essential to introduce some degree of replication in the observational program. The usual procedure was to observe a series of six samples at each observational period which,

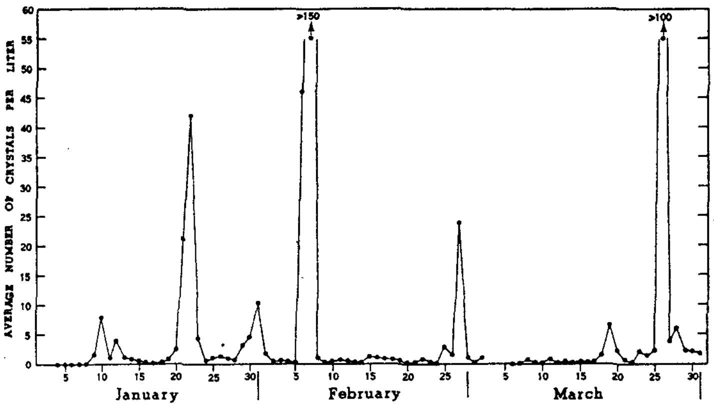


FIGURE 1.—Daily observations of ice nuclei at a mean temperature of −21° C., Washington, D. C., January 4–March 31, 1958.

during the first 2 months, was both morning and evening. The March program was confined mainly to evening observations. Ordinarily one series of six samples was examined. On a number of occasions, however, several additional series were obtained during periods of interest in order to evaluate the consistency of the observations. Data for March 3 and 4 are missing due to equipment malfunction.

## 3. ANALYSIS OF WASHINGTON, D. C., DATA

The results of observations near Washington, D. C., are summarized in graphical form in figure 1. The plotted values are the arithmetic averages of all individual samples taken each day, omitting, however, the relatively few observations when frost was detected inside the cold box. Since no absolute measuring technique exists in this field, a quantitative interpretation of the observed numbers of nuclei seems impracticable at this stage. However, the relative variations obtained appear to be of interest since they exhibit a reasonable degree of internal consistency.

One or more series of observations during a particular observation period will be defined as a "set" in the following discussion of the statistical analysis of the data. During the 87-day period from January 4 through March 31, a total of 146 sets was obtained, 93 in the evening and 52 in the morning. In all, a total of 1,074 individual samples was observed. The values ranged between 0 and more than 400 per liter. Since these numbers were far from normally distributed the Freeman-Tukey [12] transformation

$$T=\sqrt{x}+\sqrt{x+1}$$

was made on the data where $x$ was the observed nuclei count. The statistical analysis was then performed on the variable $T$.

An analysis of variance indicated that, for the data as a whole, there was no consistent difference between the morning and the evening observations. The variation between series within a set was usually quite small but was statistically significant due to the contribution of a few periods such as January 29–30, February 6–7, and February 27 when the counts were fairly high. When average counts are high or increasing rapidly, this behavior might be expected from statistical sampling considerations. Physically, it probably indicates that the air is not completely mixed by turbulent diffusion and that the distribution of nuclei in the free air is not uniform. In addition, it appears that these variations are due to sampling different parcels of air and not a result of appreciable errors in counting.

The variation of mean nuclei counts between sets of observations was very large and statistically highly significant. Table 1 shows the analysis of variance of the 1,074 samples. The variance between sets is 20 times the "experimental error," based on the variability between samples within the sets. To be significant at the 1 percent level a variance ratio F of only 1.43 would be required as compared with the observed F=20.1. Clearly, these variations of nuclei counts with time represent some real physical phenomenon, regardless of the explanation.

Efforts to relate these freezing nuclei anomalies to synoptic weather features or local sources of contamination have so far proved inconclusive. All of the "peaks" occurred during high humidity conditions and situations in which the air flow was such as to indicate at least a limited marine trajectory during the preceding 24-hour period. Nevertheless, low values also occurred during similar situations, and the interpretation of the results is complicated by uncertainties regarding "washout" mechanisms due to precipitation, and possibly other factors such as strength and duration of air movement over the ocean and resulting salt particles produced from the ocean surface. In this connection evidence has been reported by Birstein and Anderson [3] that sea salt may act as a freezing nucleus at a threshold temperature of about −15° C. There were no instances of anomalous freezing nuclei concentrations active in the observed temperature range in airmasses with a definite continental trajectory. Considered alone, these results therefore cannot be dissociated from terrestrial influences.

The January anomalies in the Washington, D. C., data appear to be of interest in that they occurred on or near the dates predicted by the meteoritic dust hypothesis, that is, around January 12, 22, and 31 (or February 1). On the other hand, the subsequent "peaks" during February and March, two of which were quite pronounced, do not appear to be associable with any well-recognized meteor streams reported in the literature. It should be pointed out, however, that this period is not devoid of meteoritic activity, and that improved observational techniques in this field may eventually reveal the presence of meteor showers.

TABLE 1.—*Analysis of variance of nuclei counts (transformed data)*

| Source of variance | Degrees freedom | Mean square | F |
|---|---|---|---|
| Between sets | 144 | 6,703 | 20.1 |
| Within sets, "error" | 929 | 334 | |
| Total | 1,073 | | |

## 4. STATISTICAL ANALYSIS OF SUPPLEMENTARY DATA

In view of the difficulties of interpreting the variations in a single series of nuclei observations, and the implications if corresponding anomalies occur elsewhere at widely scattered locations, it is appropriate to examine all available data bearing on the point. In following up his meteoritic dust hypothesis, Bowen has encouraged a number of groups to obtain ice nuclei measurements during the month of January and the first few days of February since 1954. Comparatively few observations exist for other months.

A number of pertinent observations have been made, some by aircraft and some at the surface. Table 2 presents a summary of January observations known to the authors at this date which were available in conveniently usable form. The dates shown as dominant peaks in the table represent the day of the month in which the nuclei counts were highest. In cases where the original data were reported in terms of the threshold temperature at which nuclei were detected, the day on which the warmest temperature was observed was selected. In all cases, however, the peaks listed as dominant were very pronounced with the actual values departing by several standard deviations above the background "noise" level for the month. The other peaks listed were less pronounced, on the average, than the dominant peaks and were determined by selecting those dates on which the values were higher than the adjacent days and above the monthly average. Although in a few cases the selection of these minor peaks might be questioned, it seemed desirable to include them in the list for the information of the reader rather than to take the chance of introducing a bias by arbitrarily omitting them.

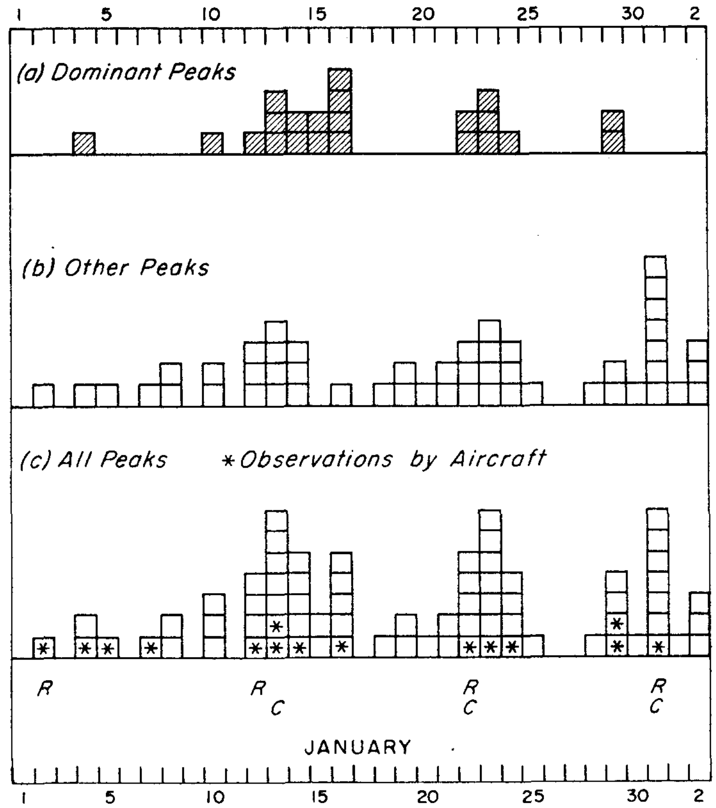


Figure 2.—Dates of high ice nuclei counts, January 1954–1958 and dates of rainfall singularities (R) reported by Bowen [7] and cirrus cloud singularities (C) reported by Bigg [2].

Table 2.—*Dates of high freezing nuclei counts, January 1954–58*

| Year | Location | Reference | Day of month: Dominant peak | Day of month: Other peaks | Remarks |
|---|---|---|---|---|---|
| 1954 | Sydney, Australia | 21 | 22 | 4, 12, 14, 31 | Aircraft. |
| 1955 | Sydney, Australia | 21 | 23 | 13, 29 | Aircraft. |
| | Tucson, Ariz | 21, 16 | 16 | 7, 24 | Aircraft—7 and 24 somewhat questionable. |
| | Panama | 11, 6 | 13 | 18, 31 | |
| | Haleakala, T. H | 5, 6 | 29 | 10, 23 | |
| 1956 | Sydney, Australia | 5 | -------- | -------- | No peaks. |
| | Pretoria, South Africa | 17 | 29 | 2, 13 | Aircraft. |
| | Southern England | 19 | 4 | -------- | Aircraft—sampling did not include all days. |
| | Western Australia | 1 | 23 | 13, 21, Feb. 1 | |
| | Palo Alto, Calif | 8 | 13 | 21 | |
| 1957 | Swakopmund, South West Africa. | 10 | 10 | 12, 24 | |
| | West Palm Beach, Fla | 15 | 16 | 13 | |
| | Palo Alta, Calif | 15 | 16 | 23, 31 | |
| | Australia | 6 | 15 | 22, 25, Feb. 2 | Data used were mean daily values from 6 stations. |
| | Frankfurt/Main, Germany. | 14 | 23 | 8, 14, 30 | |
| 1958 | San Juan, P. R | | 24 | 14, 19 | |
| | Washington, D. C | | 22 | 10, 12, 31 | |
| | West Palm Beach, Fla. | | -------- | 28, Feb. 2 | Blowing dust at critical dates. |
| | Mauna Loa Obser., T. H. | | -------- | 12, 24, 29 | Equipment difficulties—missing data during month. |
| | Palo Alto, Calif | 9 | 14 | 8, 19, 24 | Sampling did not include all days. |
| | Kleiner Feldberg, Germany. | 13 | 16 | 23, 29 | |
| | Pretoria, South Africa | 18 | 14 | 23, 31 | |
| | Swakopmund, South West Africa. | 18 | 12 | 16, Feb. 2 | |
| | Australia | 6 | 15 | 5, 22, 31 | Data used were mean daily values from 6 stations. |

Figure 2 gives a graphical presentation of these data. Figure 2a shows how the dominant peaks were distributed during the first 33 days of the year. The 22 dominant peaks are distributed among 11 dates and 5 groups or clusters. It would be possible for the 22 peaks to be distributed among as many as 22 dates instead of 11, and it would be possible for the 11 dates observed to be separated into as many as 11 groups instead of the 5 clusters observed. If these 22 peaks are not related to any common physical phenomenon, one would expect them to be distributed randomly throughout the period more or less uniformly. On the other hand, an alternative hypothesis is suggested by the singularity concept to the effect that the 22 peaks should tend to cluster around a relatively few dates or periods during the month. A relatively simple statistical test can then be made by asking whether the dates of the 22 peaks observed show a significant departure from a random selection of dates, each date between January 1 and February 2 being equally likely. This question can be answered making use of the work of Stevens [22] and Swed and Eisenhart [23]. This is equivalent to determining the probability that in 22 trials, 11 or fewer numbers will be selected and grouped in 5 or fewer clusters if chosen at random from the numbers 1 to 33, when each number has a constant probability of 1/33 of being selected on each trial. For these data the results turn out to be P=0.00075. If one ignores the tendency of the 11 days to cluster in groups, the probability is P=0.0012, and if the more general Smirnoff-Kolmogoroff test for departure from a rectangular distribution is used, then $P<0.01$. Clearly, there is strong evidence here of an association between measurements taken in different years and locations. Additional evidence is provided by the distribution of dates for the other peaks shown in figure 2b. On the basis of the random hypothesis, the data in figure 2a and figure 2b should show a slight negative correlation, since the selection of a date as a dominant peak precludes the selection of that or a nearby date as a minor peak. As a matter of fact, however, the distribution of the other peaks tends to show the same sort of departure from chance that is indicated by the dominant peaks. No formal significance test was made on these data (fig. 2b) because of complicated problems in mathematical statistics which would arise. Figure 2c shows the combined data for all peaks with the additional information regarding whether or not the observation was made by aircraft. The aircraft observations do not differ significantly from the remainder, but the data are too few to detect small effects even though they might exist.

At the bottom of figure 2 are shown the dates, **R**, of worldwide rainfall singularity reported by Bowen [7]. The letter C indicates the dates of cirrus cloud singularities reported by Bigg [2]. They are presented here as a matter of interest and information without comment or interpretation since they are discussed in the referenced papers.

## 5. CONCLUDING REMARKS

Although there is considerable uncertainty at this stage regarding the physical and quantitative significance of available data, there seems little doubt that the variability of freezing nuclei is a real phenomenon. Taking the data at face value, there is good statistical evidence to support the hypothesis that there is a temporal association in anomalous counts at widely separated locations over the earth during the month of January. Whether or not these singularities are attributable to meteoritic debris is a question that cannot be resolved at this time. Close inspection of available data indicates that many of the anomalies appear to be relatively sudden and shortlived. It is difficult to reconcile this with existing meteorological concepts of dispersal and diffusion mechanisms in the atmosphere. It therefore seems reasonable to consider other possible mechanisms that could contribute to these variations. One might speculate on the possible effect of solar variations. Although the association may be entirely coincidental, it is of interest to note that the major peaks of February 7 and March 26 in the Washington, D. C., data corresponded with the occurrence of unusual bursts of solar radio noise in the 10,000-mc. band. In any case, the empirical evidence now accumulated suggests that efforts are warranted in obtaining further observations on the variations and physical nature of freezing nuclei and their meteorological (and geophysical) significance.

## ACKNOWLEDGMENTS

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# CORRESPONDENCE

## Comments on "Some Interesting Aspects of a Subtropical Depression, May 18–28, 1958"


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October 1, 1958

In a recent article Clark and French [1] referred to forecast rules used at the District Forecast Office at Washington to forecast the movement of both tropical and extratropical cyclones. They briefly explained these rules as follows (see second column, p. 191, of their article): "When 12-hour pressure *rises* are in the path of a storm the Low will tend to turn to the left. Alternatively, when 12-hour pressure *falls* are in the path, the Low will tend

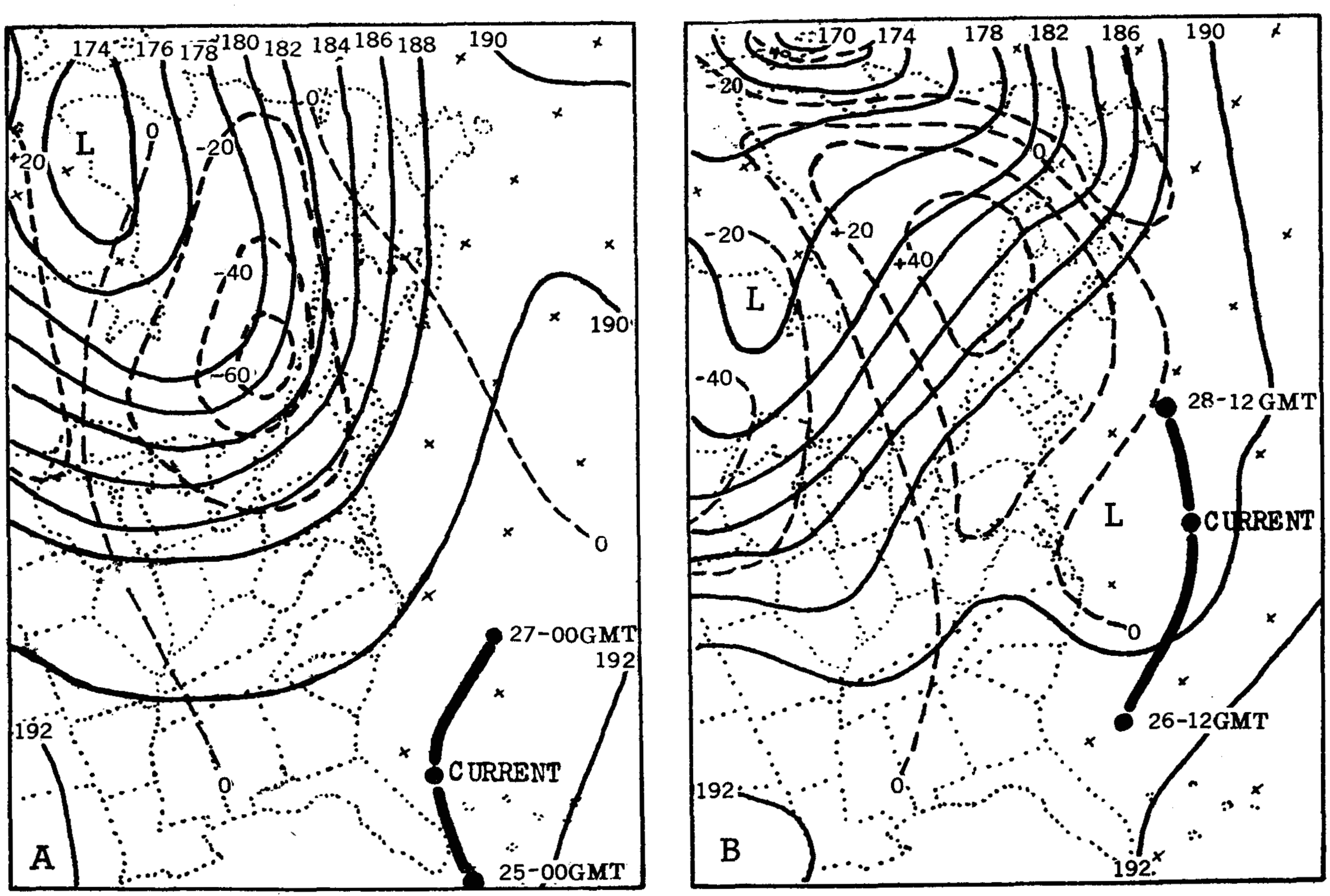


Figure 1.—500-mb. contours (solid) in hundreds of feet, and their 24-hour height changes (dashed) in tens of feet for (A) 0000 GMT, May 26, and (B) 0000 GMT May 27, 1958. Track of the subtropical depression is shown on each chart for the 24 hours before and after map time.