COUNTS OF ATMOSPHERIC FREEZING NUCLEI AT CARNARVON, WESTERN AUSTRALIA, JANUARY 1956

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[*Manuscript received June 29, 1956*]

Summary

A new instrument for measuring freezing nucleus concentration is described, and an account given of a series of measurements made at Carnarvon in Western Australia during January 1956. The measurements were made on the ground in marine air with a long travel over the Indian Ocean and are thought to be free from contamination by terrestrial dust and smoke from industrial sources.

The measurements showed distinct maxima on dates which are identical or nearly identical with those expected from Bowen's meteor theory.

I. Introduction

Freezing nucleus measurements were made at ground level in Carnarvon, Western Australia, over the same period as those in South Africa described in the preceding paper. This particular site was chosen because the weather at this time of year was known to be remarkably uniform, being practically cloudless and with persistent on-shore winds. This ensured that the air sampled would be as free as possible from contamination by smoke or terrestrial dust.

II. Method of Measurement

The observations were made by a new technique in which ice crystals formed in a cold chamber of simple design were allowed to fall into a slightly supercooled solution of cane sugar and water, where they grew large enough to be counted easily. This avoided the difficulty of making a visual estimate of the concentration of ice crystals in a beam of light as used in the South African and other experiments.

A sketch of the apparatus used in the present measurements is given in Figure 1. It consisted of a hollow cylinder surrounded by two jackets containing ethylene glycol and water mixtures. The outer of these was cooled with dry ice, and the temperature of the mixture in the inner jacket—which could be stirred vigorously to ensure uniform temperature distribution—represented the minimum temperature of the inner cylinder and hence of the cloud which it contained. The cloud chamber was kept in an insulated box until a measurement was to be made. A fresh sample of air was obtained merely by lifting it from this box, and a cloud was formed when it was placed in the position shown in the sketch, on a tank bearing a dish of supercooled sugar solution. Ice crystals generated in the cloud then fell into the solution at the base of the chamber, and after a fixed period of 2 min could easily be counted.

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Some precautions were essential. Perhaps the most important was the removal of frost from all surfaces in contact with the cloud. This was ensured by careful and frequent wiping with glycerol. Spontaneous nucleation in the sugar solution, which could occur if the cold sugar solution absorbed water from the air, or if the temperature fell too low, was avoided by frequent replacement of the sugar on humid days, and by ensuring good thermal regulation. Accurate counting was limited to a maximum of about 100 crystals with the usual method of operation, though it could be extended by slowing down the rate of crystal growth.

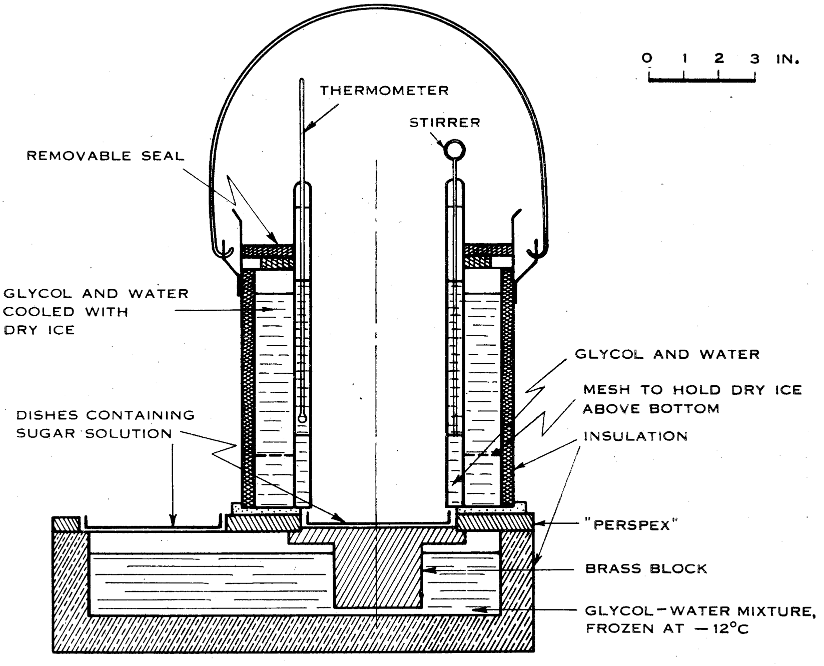

Fig. 1.—Cold chamber and cooling box.

Observations were made at a series of fixed temperatures and a plot of ice crystal concentration against temperature obtained. Typical measurements showed that the number of ice crystals usually increased logarithmically with decreasing temperature. Concentrations less than 1/l were estimated by performing the experiment many times at approximately constant temperature and finding an average. The temperature for a concentration of 0·1/l was deduced by this means, usually with the help of some extrapolation. The high probability of obtaining a count other than the true mean when the numbers were small was reduced by taking many observations and, except when the number of crystals did not increase logarithmically with decreasing temperature, the error from this source was probably less than ± 2, ± 1, ± 1 °C for 0·1/l, 1/l, and 10/l respectively. On the remaining occasions it may have been twice as great.

III. Results

The temperatures at which the concentrations of ice crystals reached on the average 0·1/l, 1/l, and 10/l are plotted in Figure 2. This figure differs from Figure 1 of the preceding paper in giving integrated rather than instantaneous

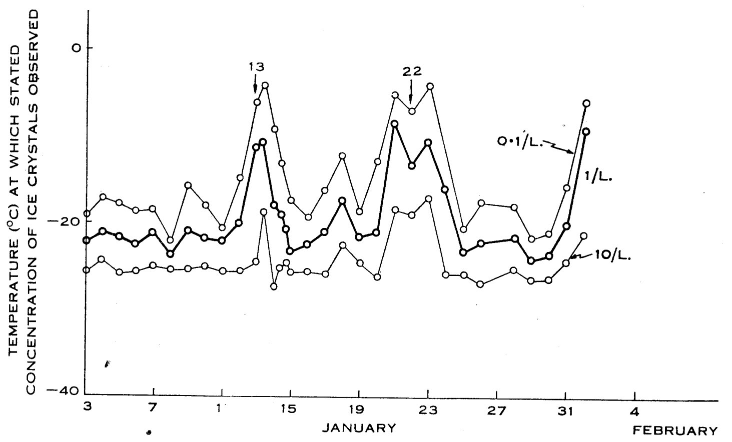

Fig. 2.—The temperatures for 0·1, 1, 10 crystals/l during January at Carnarvon, Western Australia.

concentrations. A second difference is that a concentration of 10/l is shown instead of 1000/l, as counts above 100 were not usually made. Omission of the 0·1/l readings for January 14 (third experiment) and January 24 were made

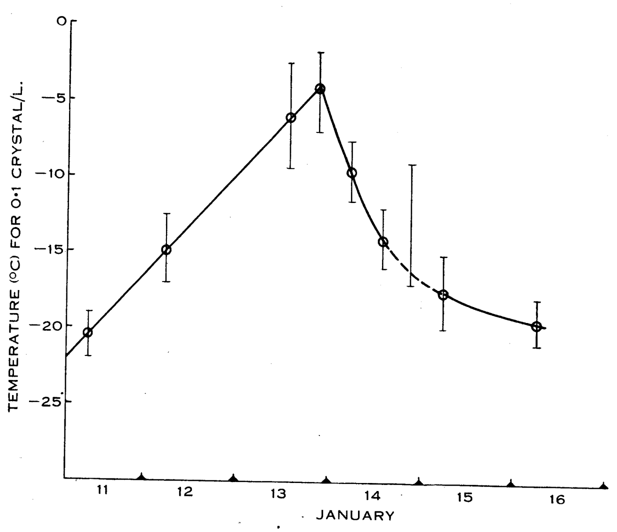

Fig. 3.—The temperatures for 0·1 crystal/l, January 11–16.

necessary by unusually wide scatter in the readings, while there was no dry ice on January 2 and 27.

The fluctuations in freezing nucleus concentration shown in Figure 2 are quite spectacular. Their relatively regular progress is illustrated in Figure 3 by the example of the period January 11–16, for which some additional experiments were performed. The probable limits of error estimated from the scatter in readings are shown.

IV. Discussion of the Results

(a) *Meteorological Conditions*

The observation, that a concentration of ice crystals as great as 1/l active at −10 °C can occur, is of considerable meteorological significance. It is thought that concentrations of this order of magnitude are sufficient to produce continuous rain from suitable clouds, so that unless such nuclei are purely local their influence on the weather must be great under favourable conditions. It is important therefore to determine whether the nuclei could be of local origin.

On the coastline one might expect the direction of the surface wind to make a marked difference in the numbers of nuclei of terrestrial origin. Days on which the wind was off-shore when the measurements were made were January 11, 18, 19, 28, and 29. Of these days three had below average counts, one average, and one high, showing that there was no consistent effect.

If sea-salt nuclei were also freezing nuclei, a high on-shore wind should lead to high counts. That this was not the primary cause of fluctuations in the freezing nucleus counts is shown by the example of January 13 and 16. On each of these days at the time of the experiment there was a 20–30 knot wind from the sea, yet the temperatures for 0·1/l were −6 and −19 °C respectively.

The properties of the cloud produced in the apparatus could have a possible influence on ice crystal formation. The dew-point, which is a reasonable criterion of the available water vapour, had only a very small range about a mean of 22 °C with the exception of January 11 and 18, when it was low. The count was slightly below average on the 11th and above average on the 18th, which again suggests no significant effect. Upper winds at Carnarvon were variable during January. Frequently a region of off-shore winds occurred between the surface and high altitude on-shore winds. No clear relation to freezing nucleus counts could be found in the characteristics of these winds.

On a wider scale, the pressure distributions did not suggest any cause for the large fluctuations in freezing nucleus counts. Certainly, there was a slightly deeper depression (996 mb) than usual within 500 miles on January 13 when the count was high, but the same was true on January 17 when the count was low. The pressure at Carnarvon itself showed how little the area was influenced by the passage of weather systems to the south, varying only between 1001 and 1010 mb.

The meteorological conditions thus provided no basis for assuming that the nuclei were of local origin.

(b) *Relation to the South African Results*

The average temperature for 1 crystal/l was −22 °C, ignoring peaks, or −19 °C including them. This was considerably warmer than the South African figure of about −33 °C. The different sites, the fact that the measurements were made on the ground rather than in the air, and the slightly different quantities measured could have contributed to this discrepancy. It was possible, however, that much of it was due to inherent differences in the methods of observation.

Of the two significant peaks in the South African results at 20,000 ft, that of January 13 coincided exactly with a West Australian measurement, while that of January 29 was 3 days ahead of the nearest corresponding peak. The degree of coincidence is insufficient to draw any acceptable conclusions.

However, the dates on which the count of airborne particles at 20,000 ft reached a maximum near Pretoria coincided exactly with the dates on which the freezing nucleus concentrations reached a maximum at Carnarvon. If, for some reason, ice formed on these particles but did not produce scintillating crystals, they would be overlooked in a cold box relying on visual detection in a light beam, but not by one using a supercooled sugar solution as a detector. There would then be the very important result that changes in freezing nucleus content in South Africa and Western Australia were simultaneous. There is no evidence for or against the supposition that non-scintillating ice particles may exist, but the possibility is clearly in need of examination.

(c) *Relation to Bowen's Meteoritic Dust Theory*

The dates of maximum freezing nucleus counts in January were almost exactly those specified by Bowen's meteoritic dust theory. The probability that this was a coincidence is clearly small in view of the close agreement, the freezing nucleus concentrations having reached maxima close to all the specified dates in January. Carnarvon may have been a more suitable locality for the experiments than others used, or alternatively the equipment used may have been better.

V. Conclusion

The freezing nucleus peaks of January 13 and 21–23 and February 1 appear to have been quite uninfluenced by local weather conditions. Strong support is lent to Bowen's meteoritic dust theory by the appearance of nuclei exactly on or within a day of the dates which it specifies.

The meteorological significance of the abrupt appearance of relatively high concentrations of nuclei active at -10 °C on certain dates, emphasizes the need, pointed out in the preceding paper, for further surveys of this kind.

VI. Acknowledgments

I should like to thank the meteorological staff at Carnarvon for making available local weather data.