Ice Nucleus Measurements in Hawaii

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ABSTRACT

A 10-day experiment is described in which simultaneous measurements of ice nucleus concentrations have been made in upslope and downslope wind regimes on the island of Hawaii, near sea level at Hilo airport, at Mauna Loa Observatory (MLO) (elevation 3.4 km), and midway at Kulani (elevation 1.5 km). The main results show: (1) at MLO the downslope flows contain the highest concentrations of ice nuclei, (2) the same downslope flows contain the lowest concentrations of large terrestrial particles, (3) the greatest care must be exercised in using the expansion cold chamber technique to collect data on ice nuclei in the humidity extremes at Hilo and MLO, and (4) no evidence was found in favor of a local terrestrial origin of the ice nuclei, and it is suggested that earlier measurements by Kline and Price and Pales were influenced by instrumental errors.

1. Introduction

The origin of the ice nuclei active at temperatures warmer than −20C is a problem of considerable meteorological importance, for these are the particles most likely to influence rain formation in supercooled clouds. A review of evidence concerning their origin has been given by Mossop (1963), and the most likely possibilities appear to be dusts blown by the wind from the dry earth or particles reaching the atmosphere from space.

Apparently crucial experiments were performed on the island of Hawaii by Kline (1963) and by Price and Pales (1964). A unique situation exists on this island in that experiments may be performed at two relatively close sites, one at Hilo near sea level in air containing a wide variety of terrestrial particles, and the other at Mauna Loa Observatory at an altitude of 3.4 km in air which is usually above the tradewind inversion and (particularly at night) unusually free from aerosols of any kind.

They found that the concentrations of ice nuclei measured at sea level were comparable with those obtained on the North American mainland, while those obtained at the Mauna Loa Observatory (MLO) were at least an order of magnitude less. They then made the reasonable deduction that the ice nuclei originated at the Earth's surface.

However, measurements made by Bigg (1964) at the same places using another technique failed to find such a difference, and he suggested that the effect observed by Kline may have been instrumental in nature.

There is the possibility that, since Bigg's experiment covered only a limited period, conditions may not have been typical. Because of the importance of the problem, it was therefore decided to conduct a more comprehensive set of experiments.

2. Measurements made using millipore filters

In order to avoid possible differences in operation of cold chambers under the conditions of low pressure, temperature and humidity usually found at MLO and under the conditions of excessive humidity and warm temperatures found at Hilo, the millipore technique was used to measure the ice nucleus concentrations. In this method, described by Bigg, Mossop, Meade and Thorndike (1963), particles suspended in the air are captured on a cellulose ester membrane filter, where they are subsequently detected in a processing laboratory by cooling the filter, providing water vapor, and growing the ice crystals to a large visible size by pouring over the filter a supercooled solution of sodium silicate.

One known defect of the millipore method is that the apparent concentrations measured tend to decrease with the volume sampled, possibly because of interactions between hygroscopic particles and ice nuclei. It is therefore necessary to expose several filters simultaneously at varying flow rates in order to arrive at a proper comparison between concentrations at different sites. The concentrations measured at small sampling volumes are less influenced by differences in the condensation nucleus populations, but are subject to statistical fluctuations. It appears desirable then to calculate the curve of apparent concentration as a function of volume sampled, extrapolated to a sampling volume of 100 liters or less.

Filters were exposed at three sites over a 10-day period from 28 August to 6 September 1964. Vacuum pumps drawing air through six 1.2 μ size filters, at flow rates ranging from 12.5 l hr^{-1} to 400 l hr^{-1}, were installed at the Weather Bureau instrument shelter at Hilo Air-

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port, at the Mauna Loa Observatory (elevation 3.4 km), and at Kulani prison (elevation 1.5 km) halfway between the two (Fig. 1).

At Hilo and MLO a set of six millipore filters was changed twice daily; once on the first hour after the upslope wind regime had been established; and second, on the first hour after the downslope wind had been established. The wind regime was considered to be established after it had persisted for more than 15 minutes.

In the event of morning upslope winds being unusually delayed, the filters were changed at 1200 hours; and in the event of the afternoon downslope wind being late, the filters were changed at 2000 hours. Records were kept at Hilo and at MLO of the times of onset of upslope wind, onset of downslope wind, and change of the millipore filters.

As no wind information was readily available, the filters at Kulani prison were changed three times daily, at 0900 hours, 1500 hours, and at 2100 hours.

At the conclusion of the experiment, all of the filters were returned to the Radiophysics Laboratory of the Commonwealth Scientific and Industrial Research Organization, Sydney, for systematic processing.

3. Results of the millipore filter measurements

Because the crystal count on any one filter is subject to large variations, it is necessary for the purpose of the experiment to consider average counts over the entire period.

Fig. 2 summarizes the results for all filters exposed between 1500 hours on 27 August 1964 and 2000 hours

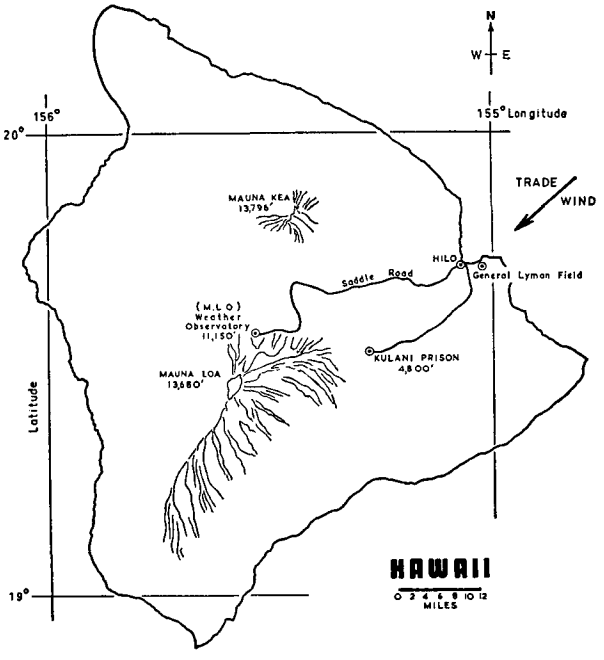

FIG. 1. Sampling sites on the Island of Hawaii.

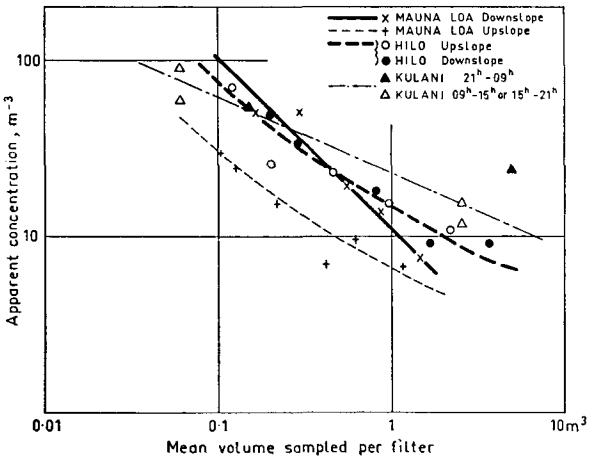

FIG. 2. A plot of average ice forming nuclei processed at −15C against volume sampled at all sites, using the millipore technique.

on 6 September 1964. The important point to note is the comparison between the conditions of downslope flow at MLO (shown as a full curve) and upslope flow at MLO or any conditions at the other sites, for sampling volumes of 100 liters or less. The differences from Kline's experiment are obvious; the downslope flows at MLO contain the highest concentrations of ice nuclei, while the upslope flows contain the least. The conclusion of Kline, and Price and Pales that a local terrestrial origin of the ice nuclei is indicated is therefore not supported.

The data also suggest that there are important variations in the millipore "covering-up" effect at the different sites. For instance, at Kulani, which is commonly in the cloud layer, the relatively high counts at high sampled volumes suggest that the hygroscopic nuclei probably responsible for the "covering-up" have been mainly incorporated in the cloud droplets and lost.

4. Results of large particle study

The concentrations of large (greater than 4 μ diameter) particles were estimated by scanning 9 mm^2 of each of the highest flow rate filters exposed at Hilo and MLO with an optical microscope. The mean concentration of large particles thus estimated is shown in the table below and compared with the estimated ice nucleus concentration, normalized to a 100 liter volume.

	Large particles	Ice nuclei
Hilo upslope	3100 m^{-3}	90 m^{-3}
Hilo downslope	2600	90
MLO upslope	500	30
MLO downslope	70	110

If the ice nuclei were of recent terrestrial origin, a positive correlation would be expected, instead of the negative correlation observed.

5. Results of cold chamber measurements

Since the millipore method failed to show the ice nuclei concentration difference measured by Kline, and Price and Pales at the same two sites, the most probable explanation of the discrepancy is that their experimental technique may have caused the difference. Therefore, the difficulties involved in the use of expansion cold chambers of the type described by Warner (1957) at the two sites were investigated.

It was found that for ambient relative humidities less than about 35 per cent which are common at MLO, a cold chamber whose walls were coated with pure glycerine to prevent frost formation failed to form a persistent water cloud, and as a result, underestimated the ice nucleus concentration. It was necessary to substitute a 50 per cent aqueous solution of glycerine for coating the walls. If this was not done, counts at MLO would generally be lower than those at Hilo, particularly at low relative humidities.

Extreme care was found to be necessary to keep the specific gravity of the sugar solution used within the very narrow range of tolerances specified by Warburton and Heffernan (1964). At MLO, in low humidities, the solution lost moisture rapidly and would fail to nucleate after it had been used for two or three measurements, while at Hilo it gained moisture so rapidly that spurious nucleation was found. Unless new solutions are used for each observation, the counts at Hilo generally exceed those at MLO for this reason also.

Finally, it was found that frost formation in the cold inlet pipe of the pressurizing pump was a severe problem with the high humidities at Hilo. Since it was often necessary, because of leakage, to increase the chamber pressure by pumping before expansion, frost splinters from the inlet pipe lead to serious overcounts. This was overcome by using a glycerine-coated plug of polyester foam in the inlet hole.

It is not possible, in retrospect, to be certain which, if any, of these experimental errors was involved in the earlier experiments. However, since all work in the direction of increasing the counts at Hilo over those at MLO, and no such excess is observed when these precautions are taken, it is a reasonable inference that at least one of them was responsible for the earlier results.

Some measurements were then made at both sites with adequate regard to these precautions and are shown in Fig. 3 in comparison with those made earlier by Bigg. No substantial differences from his conclusions are indicated.

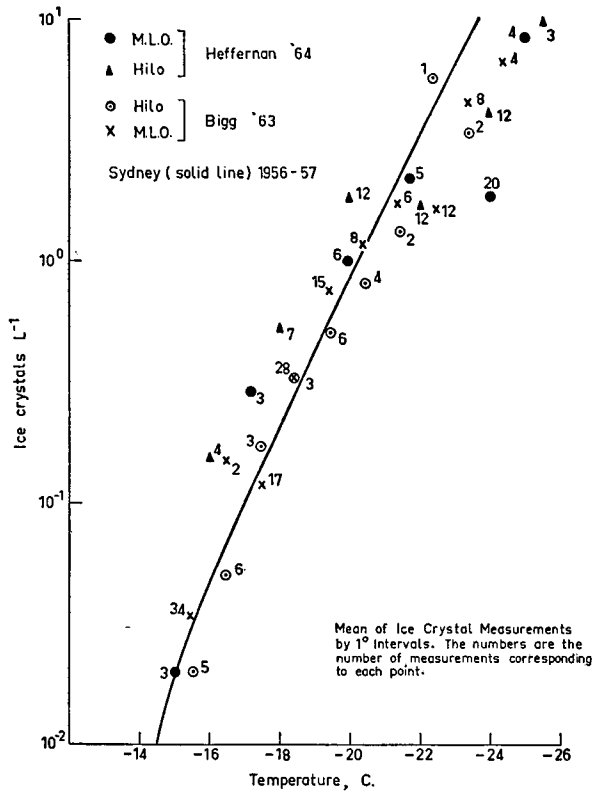

FIG. 3. A summary of ice forming nuclei measurements using expansion boxes.

6. Conclusions

We conclude that measurements made in Hawaii provide no evidence in favor of a local terrestrial origin of the ice nuclei, and suggest that earlier measurements by Kline and Price and Pales were influenced by procedural errors.

Because it is consistently above the tradewind inversion, which is a substantial barrier to the upward transport of particles, MLO is probably one of the best sites in the world free from terrestrial pollution for ice nucleus studies. However, our work has indicated that it is very necessary to pay close attention to the limitations of the techniques used.

It would be a great pity if our work should not be followed up by a more extensive investigation of the sort described by Kline and Price and Pales, for we still have remarkably little knowledge of the origin and life history of ice nuclei and the cause of "ice nucleus storms."

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