NOTES AND CORRESPONDENCE

A Note on "Stationary" Cloud Seeding Effects

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Since Schaefer's (1946) pioneering work in cloud modification, the dissipation of supercooled stratus clouds and fog by seeding with dry ice has been demonstrated by numerous investigators. The customary technique employed has involved the free fall of dry ice pellets from aircraft, small rockets and free balloons down through the cloud layers of interest. Eadie and Mee (1962) have shown in the laboratory that the contact time between supercooled cloud air and dry ice particles falling at terminal velocity is not sufficiently long for effective nucleation at temperatures between approximately −5C and 0C. This note presents a "stationary" seeding technique which appears capable of overcoming that deficiency and which does not require extensive or elaborate equipment. Photographs of selected crystal growth patterns accompanying seeding experiments in Greenland and at Yellowstone National Park are shown.

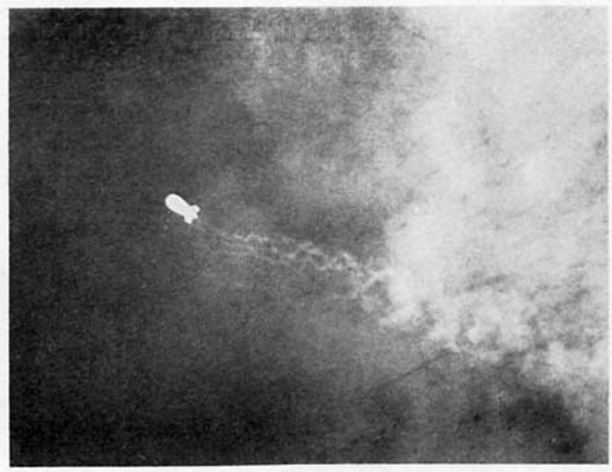

FIG. 1.

The seeding technique consists of the suspension of dry ice packages in low stratus clouds or fog by means of a tethered blimp, a technique which showed promise during a brief seeding experiment in the Pacific Northwest (Wells, MacCready *et al.*, 1957). This method was employed (Jiusto and Rogers, 1961) during a series of whiteout[1] modification experiments on the Greenland Ice Cap. As shown in Fig. 1, droplet nucleation occurred as the cloud moved through the array of dry ice packages attached to the tethering line. In the two experiments eight to ten open-mesh baskets, each containing one pound of dry ice, were hung at 25-ft intervals along the blimp[2] tether. Since the dry ice is not dispersed but is held aloft within the cloud, relatively small quantities are required for long periods of seeding; the sublimation time of a one pound payload was approximately one hour. The optimum vertical spacing of dry ice as a function of cloud parameters and wind conditions has yet to be determined.

Prevailing weather conditions during the experiments are summarized in Table 1. In both cases, snowfall

[1] An optical phenomenon, commonly caused by the blending of unbroken snow cover and overcast clouds or fogs, which results in a degradation of visibility and orientation.

[2] 1200-cu-ft Blimp, Type S-1000, Sefang Co.

TABLE 1. Weather conditions during seeding experiments.

Experiment	Clouds	Cloud base	Estimated cloud thickness	Cloud temp.	Ground wind speed	Predominant ice crystal type after seeding
1.	Stratus overcast	180 m	60–100 m	− 4.5C	2 mph	Ice needles (1 mm)
2.	Stratus overcast	330 m	100 m	−10C	1 mph or less	Dendrites (1–3 mm)

Fig. 2a.

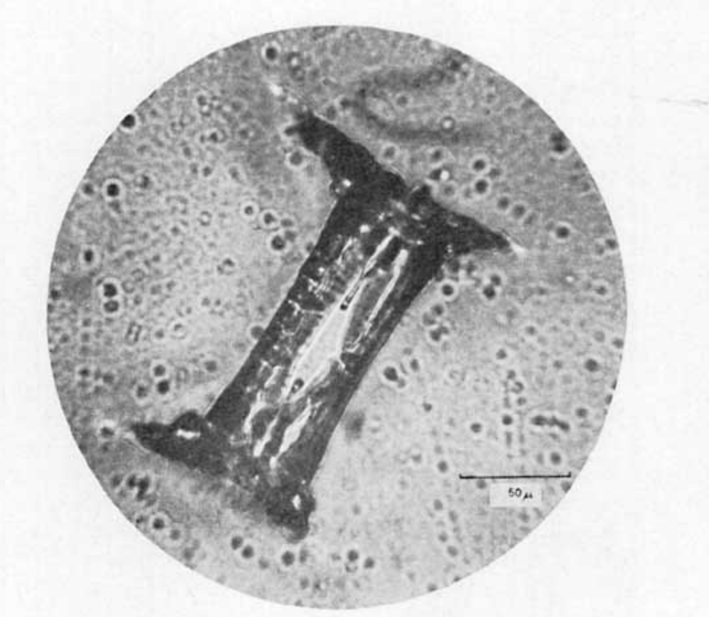

Fig. 2b.

commenced in a narrow band directly downwind of the seeding site approximately 30 minutes after seeding. Clear lanes up to 0.5 mile wide resulted.

Thus, with a modest quantity of dry ice and simple equipment, significant dissipation of supercooled, stratus clouds was achieved. The blimp-seeding technique appears well suited to air terminal use during periods when low supercooled clouds or fog impede traffic.

The ice needles resulting from the first seeding, where cloud temperature measured −4.5C, are consistent with Nakaya's (1951) ice crystal experiments in the laboratory. However, in the second case dendrites were not expected with a cloud temperature of −10C since they ordinarily require formation temperatures of −14C to −17C. Photomicrographs of representative dendrites, one of which is shown in Fig. 2a, have been provided by Dr. Motoi Kumai of the U. S. Army Cold Regions Research and Engineering Laboratory. As noted by Kumai (1962), the extremities of the dendrites consisted of thick hexagonal plates—a crystalline form which is customary at a temperature of −10C. It can also be seen that the initial ice embryo produced was of plate form and that two transitions subsequently occurred, first to dendrite, and then again to plate form. Such a progression is compatible with a steady warming trend from the low temperature marking the onset of droplet nucleation.

Thus, crystal structure appears to reflect the low-temperature, high-supersaturation influence of the dry ice during the early stages of crystal growth. It is believed that the initial plates and dendritic growth modes were initiated while the ice embryo was relatively close to the dry ice. As the crystal moved downstream and approached an ambient cloud temperature of −10C, plate growth commenced on the dendrite extremities. Calculations of the growth rate of ice crystals suggest that dendritic growth continued well after the crystal was exposed to warmer environmental temperatures. Barring the possibility of natural thermal variations of a few degrees within the thin cloud, no explanation can presently be given. Under the semi-artificial growth conditions imposed, the molecular arrangement of deposited water molecules consistent with a given temperature appears to establish a crystal growth pattern that substantially lags temperature changes.

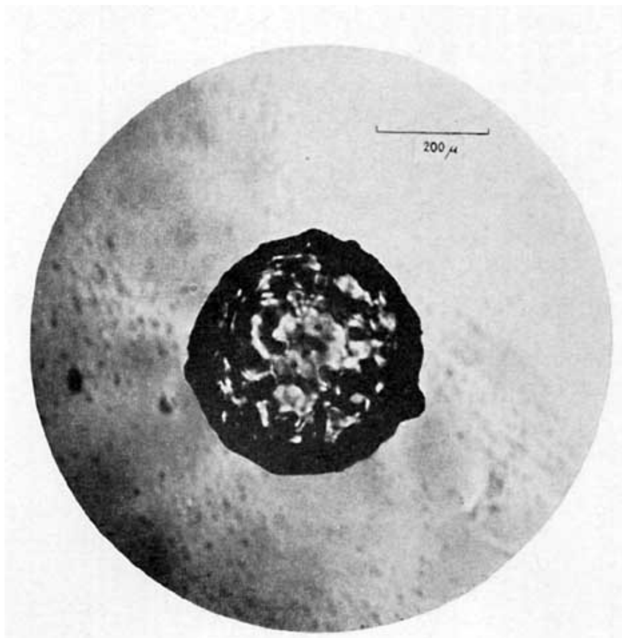

Fig. 2c.

Some less common snow crystals were also observed during wintertime seeding experiments at Yellowstone National Park, the site of the second Yellowstone Field Research Seminar of the Atmospheric Sciences Research Center of the State University of New York. By virtue of the continual transport of water vapor from hot geysers and springs into cold ambient air, a readily accessible source of low-level condensate, often supercooled, is available for experimentation.

Seeding consisted of manually exposing dry ice to slowly drifting supercooled clouds (fog), a procedure analogous to the "stationary" blimp-seeding technique. Fig. 2b typifies the capped columns that resulted from one seeding where air temperature four feet above the ground was −7C. Capping of the columns presumably occurred as the newly formed crystals were convected to higher, colder altitudes.

Fig. 2c represents a krylon replica of a spherical ice pellet, a crystal type occasionally observed subsequent to seeding with dry ice at Yellowstone. The frozen spheres appear to have resulted when relatively large geyser droplets, supercooled during the early portion of their trajectory, were intercepted and nucleated during descent by small ice embryos. Insufficient time was available for the ice sphere to develop crystalline facets. This indicated sequence of events tends to support the concept of influencing certain freezing rain situations.[3] By seeding with dry ice and creating large concentrations of ice embryos within cold layers of ice-saturated air below the rain generation level, it may be possible to convert supercooled hydrometeors to the ice phase prior to their reaching the ground.

[3] Pilie, Roland J., 1956: Final Report—Project FREEZE. No. VC-952-P-1. 25 June 1956, (published by and available without charge from Cornell Aeronautical Laboratory, Buffalo 21, N. Y.).

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Comments on "Condensed Water in the Free Atmosphere in Air Colder than −40C"

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In a recent issue of the *Journal of Applied Meteorology*, Schaefer (1962) prefaces his interesting report of cloud observations in Yellowstone National Park with brief remarks concerning an "interesting dilemma" in which various reports, including those of icing on aircraft at very cold air temperatures, pose questions as to the reality of a critical temperature for homogeneous nucleation near −40C. Particular reference is made to "subjective observations" from aircraft reported in a paper (Simpson, 1962) given at the AMS 201st National Meeting in Norman, Oklahoma.

First, I should like to agree with Schaefer that the dilemma to which he refers needs to be illuminated and resolved as objectively and as soon as possible.

Secondly, it is appropriate to point out that the observations to which my paper referred, while subject to interpretation, can hardly be dismissed summarily as "subjective." The observational evidence is recorded by time lapse photography with kodachrome film, and there are numerous incidents in which ice accumulations were photographed at temperatures colder than −40C.

This photographic evidence is supported by graphic