RAPID ICE NUCLEATION BY ACETONE-SILVER IODIDE GENERATOR AEROSOLS

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ABSTRACT. A field test conducted on 10 January 1987 confirmed a postulate that rapid ice nucleation occurs on wet silver iodide aerosols at temperatures below -6 C. The postulate was developed from laboratory tests and is consistent with results from winter orographic cloud seeding programs which have used ground generators sited at mountain tops and along ridges, where they are located within supercooled water clouds during their operation.

1. INTRODUCTION

Winter orographic storm seeding strategies, involving release of hydrophobic silver iodide (AgI) aerosols from ground-based acetone combustion generators, generally assume that the nucleant aerosol is dispersed and that ice nucleation occurs by contact of aerosol particles with supercooled cloud droplets (contact nucleation mechanism) at temperatures of -6 C and lower.

Therefore, ground generators in winter orographic cloud seeding programs are frequently sited at some distance from the target area to allow for transport and dispersion of the AgI aerosol particles. If the generators are located at lower elevations and warmer temperatures, contact nucleation is probably the dominant nucleation mechanism of the AgI aerosols reaching the cloud.

Ground generators are occasionally located at higher elevations and lower temperatures in winter orographic cloud seeding programs. In the Lake Almanor, CA program of the Pacific Gas and Electric Company, the generators are located on ridges immediately upwind of the target area (Stone and Warburton, 1985). Analytical studies of silver (Ag) and indium (In) tracer content in snow from the target area have found that the majority of snow samples from the target area contained Ag and In, despite their proximity to the generators (Stone and Warburton, 1985). If contact nucleation were operating, one would expect the sampling sites in close proximity to the generator either to have no silver or to have silver in a 1:1 ratio with indium, indicating scavenging, because of the slow rate at which contact nucleation proceeds. Thus, modeling studies (Chai, 1987) are unable to account for the 15:1 ratio of Ag to In in the snow close to the generators if it is assumed that AgI functions by contact nucleation. These studies have conclusively demonstrated that there was a much more efficient incorporation of silver into snowfall than possible by contact nucleation. Thus, in the cloud seeding program, the mode of function of AgI aerosol was not by contact nucleation, but rather by some other, more efficient mechanism.

Similarly, in the Bridger Range, Montana, program (Super and Heimbach, 1983), the ground generators were located along a mountain ridge where the ambient temperatures during storms were generally below -6 C. The generators were often in cloud. Aggregated ice crystals in high concentrations were observed at the first ridge top, approximately 2 km from the generators (A. Super, personal communication). The aggregation may have been promoted by high ice crystal concentrations close to the generators. The results from this program also indicate that a fast ice nucleation mechanism, other than contact nucleation, was occurring.

Laboratory studies using the isothermal cloud chamber at Colorado State University have demonstrated that AgI aerosols from field scale generators function exclusively by the contact nucleation mechanism when they are diluted with dry air and injected into the cloud chamber operating at water saturation, and with a liquid water cloud, down to and including -16 C (DeMott et al., 1983).

Laboratory studies (Rilling et al., 1984; Finnegan et al., 1984; Blumenstein et al., 1987) have also demonstrated that the injection of wet AgI-containing aerosols (after dilution with saturated room-temperature air) into the Colorado State University isothermal cloud chamber resulted in very rapid formation of ice crystals at temperatures between -6 and -20 C. Unlike chamber runs when contact nucleation acted, which typically took

30 - 40 minutes to generate the ice, the "wet" aerosols functioned within the first two minutes (including time to fall to the microscope slides). In addition to the rapid rate, the yields of "wet" aerosols at -10 C are a factor of 5 higher than in dry aerosol injection experiments.

It is not generally appreciated that an acetone solution burning AgI generator using an auxiliary propane flame cogenerates copious quantities of water vapor. On complete combustion, acetone and propane yield 0.93 and 1.64 grams of water, respectively, per gram of material burned. Thus, AgI aerosols produced in the field may function by mechanisms other than contact nucleation, due to the presence of the accompanying water vapor when the aerosols are generated into the atmosphere at temperatures below -6 C, the nominal activity threshold temperature for AgI aerosols.

Considering the preceding laboratory and field evidence, it was postulated that acetone burning AgI aerosol generators that use auxiliary propane flames produce ice nucleus aerosols that exhibit rapid and highly efficient nucleating characteristics in cloud or near water saturation conditions and at temperatures of -6 C or lower. This paper describes the field experiment conducted to test the postulate.

2. EXPERIMENTAL

An experiment was conducted between 0500 and 0615 local time on 10 January 1987 at Stead, a rural suburb north of Reno, Nevada. The objective was to determine whether ice crystals would form close to two acetone solution combustion ground generators of AgI aerosols operating below -6 C in a supercooled fog.

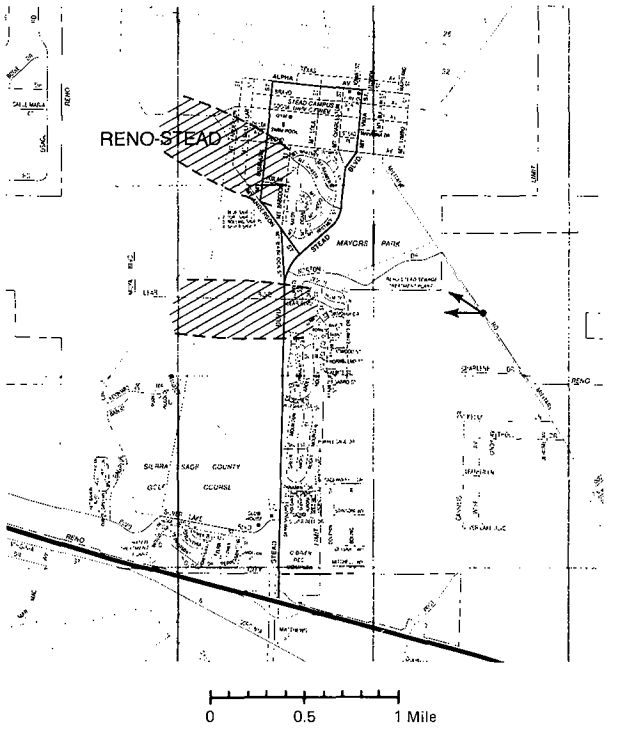
The Desert Research Institute (DRI) and the Bureau of Reclamation each operated ground generators during the experiment. The former burned an AgI - NH_4I - acetone - water solution (2% AgI and 0.26% H_2O by weight) in a propane flame (708 liters of propane per hour) to produce 7.3 g AgI per hour. By calculation, it produced 0.63 g H_2O and 0.002 g AgI per second. The latter generator burned an AgI - NH_4I - NH_4CLO_4 - acetone - water solution (3% AgI and 2% water by weight) in a propane flame (approximately 1127 liters propane per hour) to produce 30 g AgI per hour. By calculation, this generator produced a total of 1.25 g H_2O and 0.0083 g AgI per second. A cloud physics van was provided by the Bureau of Reclamation for measurement of wind, temperature, and humidity. It also contained a Particle Measuring System 2D-C ice crystal probe.

During the experiment, a supercooled fog deck covered the area, but did not extend down to ground level. The base was visually estimated to be 50 to 100 feet (15 to 30 m) aloft. The depth of the supercooled fog was unknown. The experiment was conducted in clear air. Initially, the temperature was -8 C, but it fell to -9 C by 0525. Data acquisition was terminated at that point due to mechanical problems. The relative humidity was initially 50%, rising to 60% by 0525. The air was thus about 60% saturated with respect to ice, initially. During the experiment, the winds were light, about 3 m/s, initially from the southwest and changing to easterly by 0530.

Observations of both generators disclosed that visible water vapor (steam) plumes could be seen at the exits, extending a few meters upward. Very small ice crystals in high concentrations were visible in flashlight beams within 30 m downwind of the generators (about 10 s transport time). The ice plumes were tracked, with sporadic success, to 50 - 100 m during the first half hour. Frequent minor wind shifts and the low relative humidity with respect to ice may have impaired efforts to track the plumes. At 0530, the wind shifted and steadied. The temperature continued to decrease, and probably yielded higher relative humidity. The fog never did descend to ground level, however, and generator emissions continued into subsaturated air. After 0530, the plume could be traced 350 m downwind. The plume tracking was limited by a traversing creek. Even at the most distant observation, the ice crystal concentration remained high. Lacking ice replication techniques, we were unable to determine whether ice crystal growth or aggregation had occurred within that distance. The plume widths were estimated to be about 40 m at the most distant observation. The observers concurred that ice crystal concentrations in the Bureau of Reclamation generator plume were higher than those in the DRI generator plume. This may have resulted from the greater emission rates of AgI and H_2O of the Bureau of Reclamation generator.

On conclusion of the experiment, snow powder was observed on the roads approximately 2 km from the generator site in the two major directions downwind of the generators, but in no other directions. An independent observation by another DRI employee indicated that the snowfall signatures extended for several kilometers in the directions of the prevailing winds (Figure 1). The snow may have been produced by the top of the plume lofting into the supercooled fog. The dimensions of the snow swaths, and the extension for several kilometers in the direction of the prevailing winds, all point to the ground based generators as the sources of aerosol particles serving as ice nuclei responsible for the snow.

FIGURE 1



Map of Reno-Stead area of Nevada, showing ground-based generator site (location with two arrows denoting directions of prevailing wind) and areas where snow was observed on the ground after the experiment.

3. DISCUSSION AND CONCLUSIONS

Considering the atmospheric conditions prevailing during these experiments, we conclude that the ice crystals observed resulted from extremely rapid nucleation of aerosols from the generators. We believe the rapid nucleation rate was the result of generator-produced water vapor, and that the mechanism of nucleation was forced condensation-freezing.

There are several important implications of these results. Acetone solution combustion generators operating at temperatures below -6 C under ambient conditions of ice saturation or higher are now believed to rapidly produce high concentrations of small ice crystals, rather than produce AgI aerosols which slowly function by contact nucleation as they diffuse. The results obtained in the Lake Almanor, CA and Bridger Range, MT programs suggest that the fast nucleation process was operative in each program. Thus, seeding strategies in winter orographic cloud programs may be able to take the present observations into consideration to help explain previous results and to plan for future programs.

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