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Preliminary Experimental Evaluation of Snomax™ Snow Inducer, Pseudomonas syringae, as an Artificial Ice Nucleus for Weather Modification

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Abstract: Snomax™ Snow Inducer, Pseudomonas syringae, has undergone preliminary laboratory and atmospheric studies in order to assess its usefulness as an artificial ice nucleus. Initial laboratory results show that Snomax is a very efficient condensation and freezing nucleus, exhibiting activities of 10^{12} to 10^{13} nuclei per gram at temperatures colder than -4°C and showing significant activity (approximately 10^{10} per gram) at temperatures as warm as -2.5°C. A preliminary aerial trial has demonstrated that Snomax powder can be easily dispersed to initiate nucleation in natural supercooled clouds.

1. INTRODUCTION

Very much has been learned in the past 15 years regarding the ability of certain strains of naturally occurring bacteria to efficiently nucleate the formation of ice at slight supercoolings. Ice nucleation active (INA) bacteria have been implicated in frost damage to plants (Lindow et al., 1978), their role as sources of atmospheric ice nuclei has been suggested (Vali et al., 1976: Maki et al., 1978), they are being utilized to improve the efficiency of snowmaking operations at ski areas, and their utility for controlled use in cloud seeding has been suggested and investigated (Maki and Willoughby, 1978; Levin et al., 1987). While the atmospheric implications of naturally occurring concentrations of INA bacteria has been judged to be minimal (Levin and Yankofsky, 1988), the basic understanding of the nucleation properties of these bacteria is not complete and is important, particularly for potential weather modification applications. One particularly efficient organism, Pseudomonas syringae (Snomax Snow Inducer) is now commercially available for snowmaking and is being evaluated for its nucleation modes, activity, and rates in conditions that simulate a natural cloud environment. We present the results of the preliminary investigation here.

2. SNOMAX AS AN ICE NUCLEATING AEROSOL

Snomax Snow Inducer is a natural source of ice-nucleating proteins that induces the formation of ice crystals. Water molecules apparently attach to the bacterial proteins in an arrangement that mimics the structure of an ice crystal, thereby decreasing the amount of supercooling that might normally be required during the nucleation process. The efficiency of Snomax in causing nucleation by the immersion-freezing of solutions at low levels of supercooling is well defined and is the foundation for its use in snowmaking operations.

Until recently, the ability of Snomax to cause nucleation in a supercooled cloud environment was unknown. Preliminary tests of Snomax in a supercooled cloud were performed at Atmospherics Incorporated (AI) in Fresno, California. Through the use of a small freezer chest, dry powdered Snomax aerosols were qualitatively tested for nucleation ability over the temperature range of 0 to-20°C. Snomax was found to be an effective ice nucleus in supercooled clouds at temperatures between 0°C and -5°C. Formvar coated microscope slides were used to encapsulate and replicate the artificially generated ice crystals. Photos 1A through 1D are increasing magnifications of a transmission electron micrograph of an ice crystal captured after Snomax aerosol introduction into a -20°C supercooled cloud. These photos clearly show a single Pseudomonas syringae bacterium in the center of the crystal. It is evident that the Snomax bacterial particle was indeed the nucleation site for the formation of this ice crystal.

3. SNOMAX ICE NUCLEATION STUDIES

Laboratory experiments were performed in the Colorado State University (CSU) isothermal and dynamic cloud chambers (see Garvey, 1975; DeMott et al., 1983; and DeMott, 1988 for chamber descriptions). The isothermal chamber was used to quantitatively survey the fractions of bacterial particles acting to form ice crystals when dispersed into a continuously replenished, water saturated cloud at temperatures from -4 to -12°C. Computations of ice crystals formed per gram of Snomax powder dispersed permitted a standard comparison to other artifical ice nucleating aerosols that have been tested in the same chamber. Procedures outlined by DeMott et al. (1983) were used to assess the basic nucleation mode based on the kinetics of ice crystal formation. The dynamic cloud chamber was used to test the cloud condensation nucleus (CCN) activity of the bacterium by simulating adiabatic expansion-cooling of an air parcel. Continued expansion-cooling of the cloud thus formed permitted the first simulation of the continuous condensation and

Figure 1a. (3,000X) 20 um

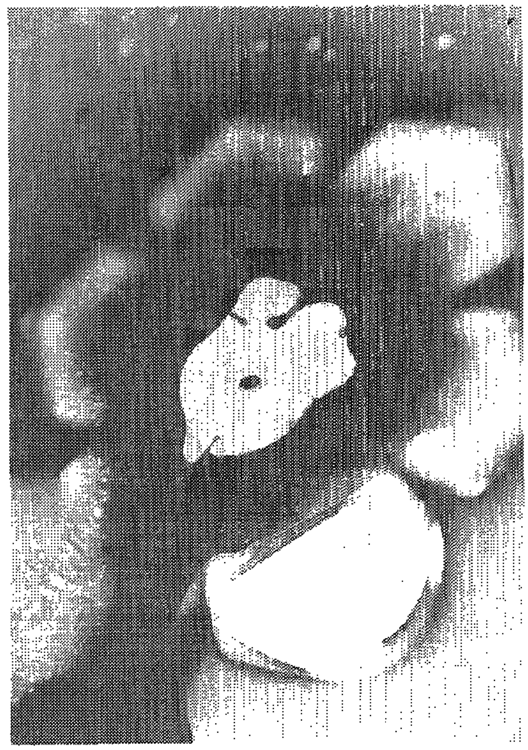

Figure 1b. (4,200X) 15 um

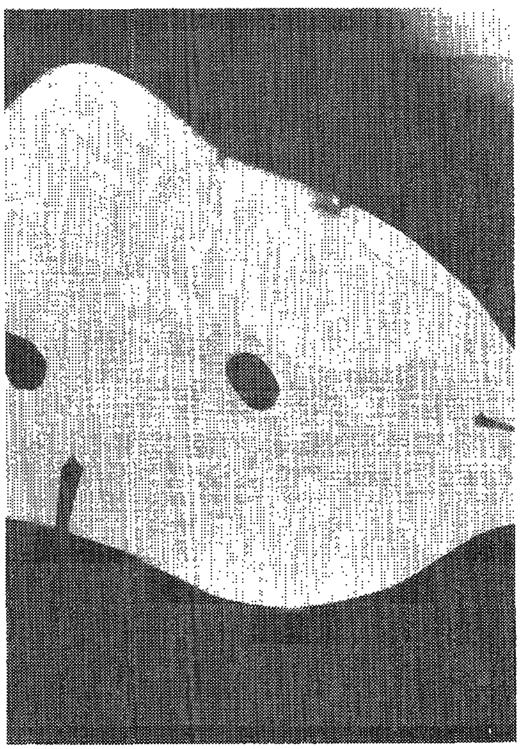

Figure 1c. (15,360X) 5 um

Figure 1d. (30,000X) 2 um

Figure 1a - 1d. Increasing magnifications of a transmission electron micrograph of an ice crystal captured after Snomax aerosol introduction into a -20°C supercooled cloud.

freezing activity of a known INA bacterium. The influences of the presence of other CCN particles and of warm versus supercooled cloud base temperature on these basic nucleation processes were also examined. These studies add to the understanding of nucleation by INA bacteria and are relevant to the potential use of such materials for weather modification. Brief summaries of the isothermal and dynamic chamber results are given in this paper. A complete treatise of the laboratory experimental procedures and results is being written for future publication. We also present the results of preliminary seeding tests with Snomax in real clouds in this section.

3.1 Isothermal Chamber Results

Snomax aerosols were found to be highly efficient and fast-functioning ice nucleating aerosols, apparently nucleating ice by a condensation-freezing mechanism and at rates comparable to those of dry ice under similar conditions (90% of ice crystals formed in 3 to 5 minutes). Rates of ice crystal formation showed no significant dependence on liquid water content between 0.5 and 1.5 g/m^3. Figure 2 shows the average (6 tests at each temperature) active number of Snomax particles per gram dispersed as compared to dry ice and two highly efficient AgI-type ice nucleating aerosols produced by solution combustion and a pyrotechnic formulation, respectively. The Snomax aerosols were assessed under similar environmental conditions and in the same chamber as the dry ice and AgI aerosols. Snomax yield in the isothermal cloud chamber was found to decrease by less than one order of magnitude between -12°C (5.5×10^{12} g^{-1}) and -4°C (1.3×10^{12} g^{-1}). This contrasts with three to five orders of magnitude losses of effectivity for AgI-type aerosols over the same temperature range. The potential advantages of Snomax versus AgI aerosols are evident at temperatures warmer than about -5 to -7°C where AgI aerosols are very inefficient. Rapid nucleation rates compared to most AgI-type aerosols may also be advantageous. Snomax yields are within a factor of 2 of yields from dry ice seeding over the temperature range tested.

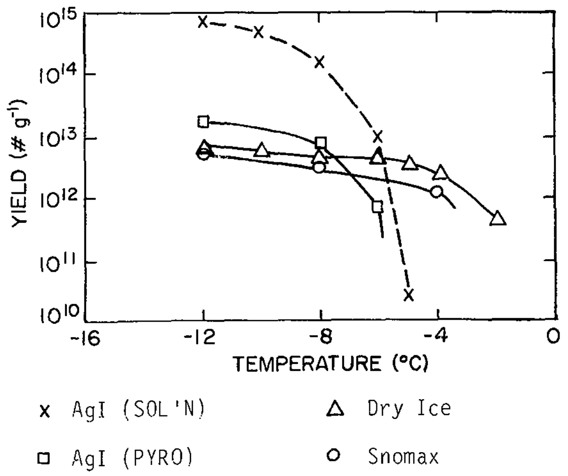

Figure 2. Comparison of the ice crystal yield versus temperature for Snomax, dry ice, and two of the more efficient AgI-type ice nucleating aerosols from solution combustion and pyrotechnic formulation.

3.2 Dynamic Chamber Results

Snomax yields as a function of temperature during continuous expansion cooling of clouds in the dynamic chamber were in close agreement with results from the static isothermal cloud chamber. These unique experiments also demonstrated the particularly narrow temperature ranges for the activation of large fractions of the bacteria. Initial ice formation started at temperatures as warm as -2.5°C. Figures 3a, 3b, and 3c are examples from one experiment that show the ice crystal flux (aerosol fraction nucleated s^{-1}), cumulative yield, and cloud droplet concentration respectively, as a function of temperature during expansion cooling. Snomax aerosols were used as CCN for cloud formation in this example. The cooling rate was approximately 1°C min^{-1} after cloud formation. The observed tendency for nucleation activity to be centered in specific temperature ranges was a consistent feature in these experiments. This has been noted for other bacterial nuclei in the past (Levin and Yankofsky, 1988), but never verified for freely suspended bacterial aerosols acting first as condensation and then as freezing nuclei.

Direct injection of Snomax aerosols into cooling cloud parcels in the dynamic cloud chamber has lead to apparent enhancements of ice crystals formed compared to particles injected. This phenomenon is under investigation.

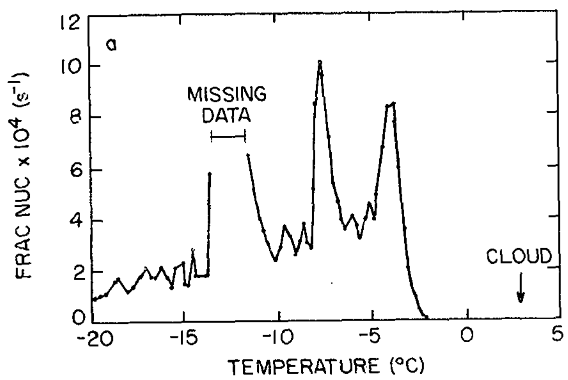

Figure 3a.

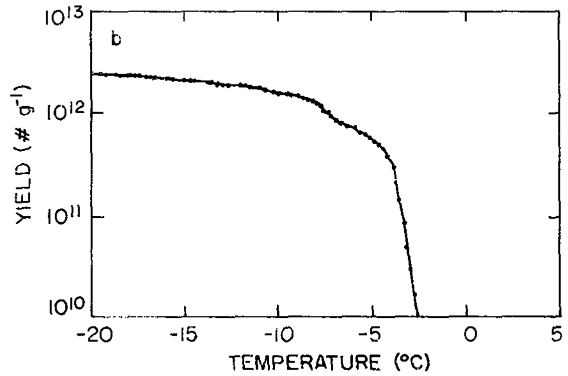

Figure 3b.

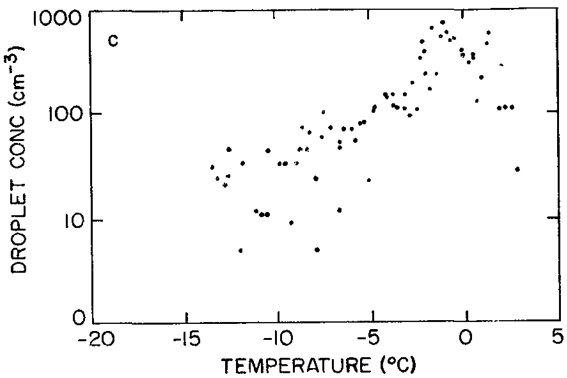

Figure 3c.

Figure 3. a) Ice crystal flux (aerosol fraction nucleated s^{-1}), b) cumulative yield, and c) cloud droplet concentration plotted as a function of temperature during expansion cooling. Snomax aerosols used as CCN for cloud formation in this example.

3.3 Preliminary Field Test Results

The results of the laboratory chamber tests were encouraging enough to warrant a preliminary aerial test. The test site chosen was in western Nevada, where occasional individual cumulus develop. The objectives of the test were to apply specific amounts of non-viable Snomax to a few small cumulus congestus and make some general observations and measurements of the subsequent cloud behavior as well as gain some experience in aerial dispersal of the product. The aerial tests were organized and directed by Atmospherics Incorporated (Fresno, CA). During a two day investigation (September 8th and 9th, 1988), it was demonstrated that Snomax dry powder can be dispersed from aircraft into the updraft region below cloud or injected directly into supercooled cloud at rates that are comparable with conventional silver iodide seeding applications. The method of generation produced a highly dispersed aerosol (the degree of dispersal is currently being quantified). In one case, visible glaciation effects were apparent as warm as the -5°C level. Liquid water data has not yet been analyzed. No ice crystal concentration data were collected. Future seeding tests will include detailed microphysical data.

4. POTENTIAL ADVANTAGES OF SNOMAX NUCLEI

Snomax Snow Inducer possesses some unique characteristics that may be advantageous to the weather modification community. First, Snomax is prepared in a powdered form that exhibits 10^{12} to 10^{13} ice nuclei per gram at temperatures less than -4°C and shows significant activity at temperatures as warm as -2.5°C. The activity of Snomax per gram at small supercooling is greater than that of silver iodide aerosols, which do not have a measurable response until about -5°C to -7°C. Secondly, Snomax, being a stable, aerosolizable powder can be used for seeding at cloud base at temperatures greater than 0°C. Dry ice cannot be used under these circumstances. Snomax may offer better dispersion characteristics than dry ice and should offer increased ease of material handling.

5. CONCLUSIONS

This preliminary investigation of the use of Snomax Snow Inducer as an artificial ice nucleus demonstrates its utility for cloud seeding. However, more seeding experiments need to be conducted in real clouds. There are several planned seeding targets: supercooled fog, wave clouds, stratus, and cumulus. Experimental procedures will be designed to investigate the advantages that Snomax should have over other seeding technologies based on the preliminary studies presented.

6. ACKNOWLEDGMENTS

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