Seeding Tests on Supercooled Stratus Using Vertical Fall Pyrotechnics

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ABSTRACT

In Michigan in early 1977, an experiment was conducted to test the ability of silver iodide (AgI) ice nucleus curtains generated by vertical-fall pyrotechnics to produce clearings in supercooled stratus. A second objective of the experiment was to determine how well a clearing could be targeted over a preselected ground location. Previous stratus clearing tests had primarily involved curtains of dry ice particles or horizontal lines of AgI nuclei. Silver iodide pyrotechnics were chosen because of their logistical advantages over dry ice.

Results of the Michigan testing were favorable. Clearings were produced in cloud decks up to 1400 m thick and as warm as −8°C. In thicker cloud decks, glaciation occurred only to a depth equal to the fall distance of the pyrotechnics. There were indications of "overseeding" from the relatively poor visibility through the cleared area that likely was caused by high ice-crystal concentrations. Targeting was successful when accurate wind data were available.

1. Introduction

Supercooled stratus clouds have been the subject of numerous weather modification experiments, ranging back to the exploratory work of Schaefer (1948). These experiments have typically been directed toward dispersal of elevated stratus decks. Seeding agents have included dry ice and silver iodide, both released from aircraft. Seeding with dry ice was accomplished by dropping sized dry ice particles through the cloud. Particle sizes on the order of 1 cm^3 and seeding rates of 1–2 kg km^{-1} were found to produce optimum results (Vickers and Church, 1966). Silver iodide seeding has been conducted by burning a spray containing silver iodide, thus producing a horizontal plume of artificial nuclei as the aircraft flew through the cloud. aufm Kampe *et al.* (1957) found a slightly colder threshold for seeding effects to occur for silver iodide than for dry ice (−5 to −10°C for silver iodide versus −3 to −4°C for dry ice).

In these earlier experiments, dry ice had the advantage of affecting a larger cloud volume than silver iodide, since the falling dry-ice particles produced curtains of ice crystals, while silver iodide produced a horizontal plume of ice crystals. However, dry ice has the disadvantages of handling problems and availability, especially in less populated areas. Also, the earlier experiments did not involve positioning the clearings over a predetermined ground location. For these reasons, the Air Force Geophysics Laboratory (AFGL) initiated a research effort to develop a stratus clearing technique using seeding agents having minimal logistical problems and using a procedure that would assure, with a high probability of success, targeting the clearing over a preselected ground location. North American Weather Consultants (NAWC) was contracted to perform the research.

2. Seeding system

A variety of seeding systems was considered in order to select the simplest in terms of logistics. These included acetone burners, end-burning silver iodide flares, organic nuclei generators, and vertical-fall pyrotechnic flares. The vertical-fall flares were determined to have the fewest logistical problems and also had the advantage of producing a curtain of artificial ice nuclei when dropped at short intervals.

The seeding flares used in the testing came in three sizes. Silver iodide output was 10, 20 or 30 g and fall distances correspondingly ranged from 600 to 1800 m. The pyrotechnic material was a chlorine-doped version of the Naval Weapons Center TB-1 formulation. Chlorine doping (with hexachlorobenzene) appears to enhance nucleating effectiveness at warmer temperatures (Sax *et al.*, 1979). As determined in the Colorado State University cloud chamber, effectiveness ranged from $\sim 10^8$ nuclei g^{-1} at −5°C to 10^{12} nuclei g^{-1} at −10°C to 10^{14} nuclei g^{-1} at −20°C (Wisner *et al.*, 1978).

To estimate required seeding rates, the dry-ice results of Vickers and Church (1966) were combined with the dry-ice nucleation efficiency of Fukuta *et al.* (1971) to determine that 1 kg km^{-1} of dry ice was equivalent to about 10^{15} nuclei km^{-1}. That number was then used with the vertical fall pyrotechnic

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FIG. 1. Belly-mounted rack containing silver iodide pyrotechnics.

efficiency mentioned above to compute AgI seeding rate as a function of cloud temperature. For example, at $-10°C$, about 10^3 g km^{-1} or fifty 20 g flares per kilometer would be used. Actual seeding rates were bracketed around the computed rate.

3. Summary of operations

The seeding tests were conducted in February and March 1977 in northern Michigan. The location was based on a site selection process involving the following criteria: incidence of proper cloud conditions; lack of frequent air traffic; relatively flat terrain; and, because the time from contract award to the field tests was short, ease in satisfying state weather modification laws.

Two aircraft were used in the seeding tests—a Piper Aztec for seeding just above cloud top and a Cessna 210 for coordination and photography. The belly-mounted rack containing the pyrotechnics is shown in Fig. 1. The Aztec was also equipped with an MRI Universal Turbulence Probe.

Seeding was conducted in two modes. Line tests involved varying seeding rates along a line normal to the wind. After 30 min of observation, the rate which produced the best results (i.e., glaciation or clearing with the minimum amount of silver iodide) was selected for use in a raster test, in which three to five lines were seeded to produce maximum areal clearing. Line and raster tests are shown schematically in Fig. 2. During both types of testing, targeting of the seeded area for a specified ground location was considered. The seeded area was tracked and photographed for up to 90 min.

Targeting the clearing over a preselected ground location requires accurate wind measurements. In these tests, wind estimates were obtained by measuring the drift of the aircraft as it flew via the autopilot along a VOR radial at constant altitude and airspeed. The estimates were then adjusted after each line test by observing the drift of the clearing. The new wind estimates were then used in the raster tests.

4. Results

By definition, a clearing occurred during a test if the ground could be seen through the seeded area

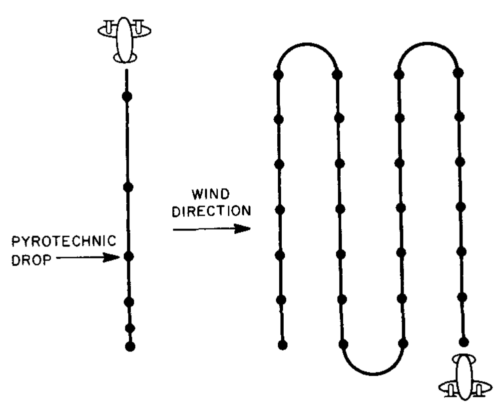

FIG. 2. Schematic of flight pattern in line (left) and raster (right) tests.

TABLE 1. Cloud and seeding parameters for stratus tests.

Date (1977)	Type	General results: Clearing	General results: Targeting	Line length (km)	Flares per line	Seeding amount[1] (g km^{-2})	Cloud base: Height (km)	Cloud base: Temperature (°C)	Cloud top: Height (km)	Cloud top: Temperature (°C)	Cloud depth (km)	Time to clearing (min)
5 Feb	Line	NA[2]	Miss[3]	3.7	13	89 to 9	1.0	−19.0	1.5	−21.5	0.5	—
16 Feb	Line	Yes	None	1.9	36	531 to 53	0.8	−17.5	1.1	−17.0	0.3	13
17 Feb	Line	Yes	Miss	1.9	11	142 to 14	2.5	−13.5	3.2	−15.5	0.7	30
17 Feb	Raster	Yes	Miss	3.7	19	78	2.5	−13.5	3.4	−17.5	0.9	37
18 Feb	Line	Yes	Miss	1.9	24	354 to 35	0.6	−3.0	2.0	−9.5	1.2	35
18 Feb	Raster	Yes	Hit	5.6	19	53	0.7	−3.0	1.8	−8.5	1.1	39
19 Feb	Line	Yes	Miss	3.7	18	124 to 12	0.9	−10.5	1.4	−12.0	0.5	12
22 Feb	Line	No	—	1.9	24	354 to 35	0.8	−6.0	1.1	−6.0	0.3	—
22 Feb	Line	No	—	1.9	24	354 to 35	1.0	−4.0	1.4	−3.0	0.4	—
26 Feb	Line	Yes	None	1.9	12	159 to 16	0.8	−11.5	1.3	−14.0	0.5	30
26 Feb	Raster	Yes	Hit	5.6	23	65	0.8	−11.5	1.6	−11.0	0.8	45
5 Mar	Line	Partial[4]	Hit	1.9	36	531 to 53	0.7	−3.0	2.6	−8.5	1.9	35
6 Mar	Line	Partial	Miss	3.7	24	177 to 18	0.7	−4.5	1.9	−9.0	1.2	—
6 Mar	Raster	Yes	Hit	5.6	43	124	0.7	−4.5	2.0	−10.0	1.3	60
6 Mar	Raster	Yes	Hit	5.6	49	142	0.6	−4.5	2.0	−9.5	1.4	40

[1] Seeding amount is amount of silver iodide per square kilometer of original curtain. Line test used varying rates along the line.
[2] Glaciation occurred but entire cloud deck dissipated before artificial clearing developed.
[3] A hit (miss) occurred if the seeded area did (did not) pass over a pre-selected ground location.
[4] Depression developed in cloud to depth of fall of flare but not below.

within a 90 min period following seeding. The clearings that did occur developed fairly slowly. The seeded lines were observed to become glaciated within 5–10 min following seeding. However, holes within the glaciated areas typically developed from 30 to 45 min after seeding. In most tests, the holes did not cover the full glaciated area.

The tests (10 line and 5 raster) are summarized in Table 1. In general, a clearing was produced in 10 of the 15 tests and partial clearing occurred in another three tests. Clearings occurred in clouds having depths between 300 and 1400 m. The two unsuccessful tests involved clouds with temperatures warmer than −6°C. In one of the partially successful tests, the clearing was observed to develop to the depth of fall of the seeding devices. The cloud below this level did not respond to the seeding.

All five raster tests produced clearings. Seeding amounts in those tests ranged from roughly 50 to 150 g km^{-2}. To obtain those amounts, from three to nine 20 g flares were deployed per kilometer of flight.

The clearings that were produced generally had good visibility to the ground when observed from a location directly over the clearing. However, the slant-line visibility through the clearing was poor. An example of a raster test that produced a clearing but poor slant-line visibility is shown in Fig. 3. The initial seeding pattern was a three-line raster (3.7 km × 4.4 km) in an 0.9 km thick deck of altostratus. The picture was taken 42 min after seeding began. Note the undersun in the glaciated area and the abrupt wall of cloud along the untreated edge. Portions of the ground were clearly visible near this wall. Eight minutes after this picture was taken, a timed flight by the seeding aircraft revealed that the treated area had dimensions of ~9 km × 11 km.

The sizes of the glaciated areas were determined from photogrammetric analysis and timed flights through the areas. From those measurements, the rate of growth of the glaciated areas was computed. Both lateral and longitudinal rates of growth averaged ~1 m s^{-1} (considering only one end or one edge of the line). aufm Kampe *et al.* (1957) reported an equivalent value of one mile spread to either side of the line in one-half hour for their dry ice seeding results (since 1 mi/0.5 h equals 0.9 m s^{-1}).

Turbulence measurements within the cloud generally ranged from 27 to 64 cm^2 s^{-3}. There was a strong negative correlation between turbulence and the time after seeding that a clearing appeared. However, turbulence and growth rate of the glaciated area were only weakly correlated.

Targeting was evaluated in 11 tests (ignoring the two unsuccessful tests). Only one out of six line test clearings hit their target, whereas four out of five raster test clearings passed over the pre-selected ground location. These results reflected the more accurate wind information obtained by measuring the drift of the glaciated line than by measuring the drift of the aircraft.

5. Conclusions

The seeding tests reported here have shown that vertical-fall silver iodide pyrotechnics can produce clearings in supercooled stratus clouds with depths up to 1400 m and with tops colder than −6°C. Vertical visibility through the clearings was good. Tar-

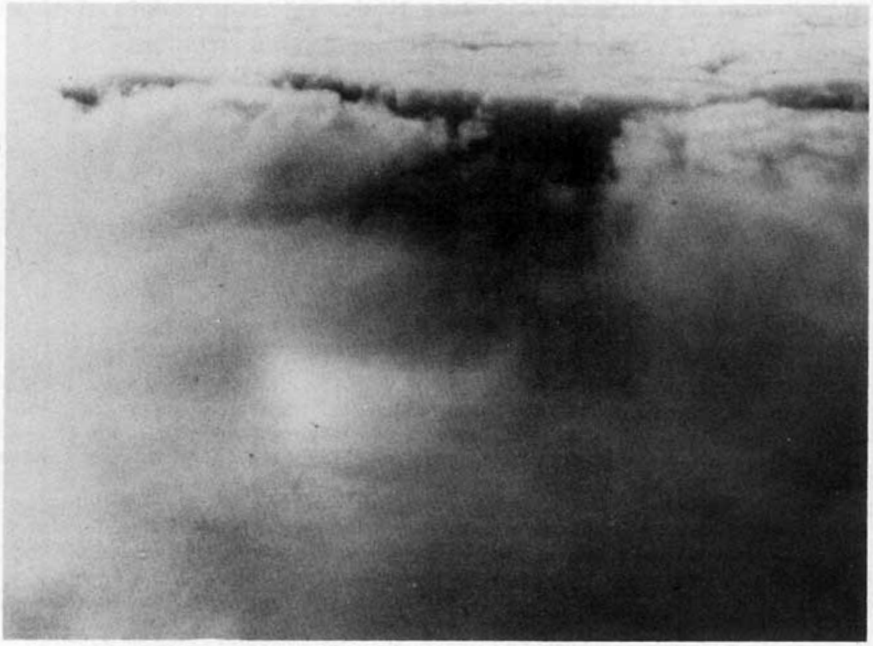

FIG. 3. Example of seeding-produced clearing. See text for details.

geting the clearing was feasible if accurate wind data were available.

The observations of glaciation 5–10 min after seeding, the subsequent relatively slow development of clearings (30–45 min) within the glaciated area, and the poor slant-line visibility through the clearing suggest that numerous, small ice crystals were produced, possibly indicating overseeding.

Additional seeding tests which include cloud physics measurements would be desirable to refine the operational techniques and to investigate the effects of different seeding rates on the slant-line visibility.

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