"REVIEWED"

SOME CHARACTERISTICS OF AERIALLY-RELEASED AgI PLUMES IN ALBERTA

James A. Heimbach, Jr.
University of North Carolina
Asheville, NC 28804

ABSTRACT

Two cases of tracing aerially-released plumes using a Langer ice nucleus detector are described. In one, plumes from 2AgI-NH$_4$I-acetone, NEI-TB1 wing flares and NEI-TB1 drop flare sources are compared. For the other, a plume from a single seeding pass is traced for three hours and seven minutes. The results show the acetone source to be very efficient, producing as many ice nuclei as the NEI-TB1 wing flares (effective at -20°C). The drop flare curtain was difficult to detect. The linear seeding mode was found to treat large volumes and the spread of the plumes was consistent with current understanding of transport and dispersion.

1. INTRODUCTION

This paper deals with two case studies in which aerially-released AgI plumes were traced. These were conducted during the summers of 1984 and 1985 as an adjunct to tracing surface-released plumes during the Ground Generator Assessment Program (GGAP) which was part of the Alberta Hail Project (AHP).

Four means of convective cloud treatment have been applied operationally in Alberta: cloud top (drop flares), cloud base, surface release, and aerial line seeding. The first two were the primary treatments during the AHP managed by the Alberta Research Council (ARC) whose operations were based in Red Deer. The last two were applied by I.P. Krick Assoc. of Canada, Ltd., during earlier operations from 1956 through 1968 sponsored by the Alberta Weather Modification, Coop. Surface-based releases were again tested in 1975, and 1977 - 1985 by the same under the sponsorship of AHP. Although cloud-top and cloud-base are accurate in terms of assuring some part of the cloud is seeded, concerns remain regarding the timeliness of treatment and whether the AgI has been sufficiently dispersed (see for example Dennis, 1980; and Stith and Griffith, 1986).

The line, or patrol seeding mode enables the rapid treatment of a large air mass for convective elements to draw upon and time for the AgI plumes to disperse within the volume. Line seeding has been done in Israel since 1960 and a computer simulation of its effectiveness was reported by Gagen and Aroyo (1985). They concluded that aerial seeding can provide sufficient concentrations of ice nuclei (IN) in target volumes and that maximum exposure times to threshold concentrations are 20 to 50 km downwind of the seeded line. To increase area coverage, the modeling showed multiple aircraft to be better than a single aircraft with higher output.

The relative effectiveness of three types of airborne AgI sources is addressed for the first case study. This is relevant to the economics of an operational program. The second case study examines the long-term plume dispersal from a single aircraft.

2. INSTRUMENTATION

The tracking platform for both cases was a Beechcraft Baron B58, a twin reciprocal-engine aircraft. Air speed during tracing was 56 to 62 m s^{-1} and 15 deg wing flaps were used to maintain a level attitude at this speed. Vacuum was provided by an 8 in Hg venturi. Height was determined accurately below 1000m AGL with a radar altimeter. Positions were recorded manually using a system of checkpoints announced by the pilot. Since the Baron was used mainly in support of surface-released plume tracing over a target to the southeast of Calgary, it was based in Okotoks, 160 km south of Penhold.

Ice nuclei were traced using a Langer (1973) acoustical IN detector belonging to Colorado State University (CSU). Table 1 summarizes the counter's specifications. For both cases presented in this paper, IN counts were recorded on strip charts along with checkpoint encounters. The electronics for the IN counter indicated cumulative count which was reset for each penetration. Estimates of the time lag to plume edge, which is the time between initial plume contact and the first indicated IN detection, were made during ground tests. Estimates of lag to mean IN detection and smoothing characteristics of the counter were also found but these parameters were not as consistent as the lag to edge. The plume edge calibrations found in ground tests agreed with aerial observations of known plume positions in the air.

Table 1. Characteristics of IN counter for 1984 and 1985 field seasons. Parameters are for 2AgI-NH$_4$I.

	1984	1985
Cloud chamber temperature (C)	-20	-20
Vacuum (mb)	160	160
Sample flow rate (L min^{-1})	9.0	10.3
Atomizer flow rate (L min^{-1})	2.5	0.85
Atomizer pressure (lbs in^{2})	Not recorded	3.7
Humidifier temperature (C)	25-27	20-24
Efficiency factor	100:1	less than 100:1
Time to edge (s)	25	34.50-.0125S or 20*

S = total number of counts registered during pass through plume.
*Use whichever is less.

Prior to the 1984 field season, the efficiency of the CSU counter was determined at the CSU Cloud Physics Lab (Sackiw et al, 1984). An efficiency factor of approximately 100 was determined, depending on the type of nucleant. That is, for every IN detected, 99 were undetected. Several modifications were made to the counter prior to use in 1985. These included rebuilding the humidifier and the atomizer. Higher counts in 1985, including far more efficient detection of the Krick arc source, suggest a better efficiency for the 1985 season, however, the degree was not quantified. Background IN counts were consistently less than 1 L^{-1}.

3. SEEDING AGENTS

Three types of IN were dispersed for the cases reported herein. The Aerosystems, Inc. E-16 airborne wing-tip acetone generator was used for both cases. It burned 2% by weight AgI in a $2AgI-NH_4I$-acetone solution consuming 138 gm AgI per hour. NEI-TB1 wing-mounted flares and drop flares were used in 1984. The former burned 150 gms AgI in 4 min. and the latter burned 20 gm AgI in approximately 40 sec which corresponds to approximately 1.5 km. It was assumed that there was no delay time on the drop flares. The source strength effective at -20°C for the wing-tip acetone generators, wing flares and drop flares were $7.4X10^{15}$ (140 kn wind) (Demott and Grant, 1986), $5.6X10^{12}$ and $5.6X10^{12}$ IN s^{-1} respectively (Garvey, 1975).

4. COMPARISON OF THREE PLUME TYPES, JULY 27, 1984

On July 27, 1984, three aerially-released plumes were traced. During this period the winds were from the SW at the surface, veering to WNW at 1.8 km (all elevations are given in MSL). The terrain in the vicinity of the flights averaged about 1.1 km. Figure 1 illustrates the flight tracks and plume encounters. Two AHP seeding aircraft made three linear passes. The acetone pass was N - S, 1.8 km directly over the airport at 1129 (all times MDT). Only one acetone generator was operated. The drop flare run by the second seeding aircraft started at Delburne 45 km to the east of the airport, and 32 flares were released at 5 sec intervals from 3.4 km on a N - S run. The second aircraft then maneuvered to the NW and made a run at 1.8 km burning wing-mounted flares from N - S 25 km to the E of the airport. The tracing aircraft flew W - E traverses at 1.8 km with the Penhold Airport on the western leg. The tracing aircraft had previously taken off from Penhold at 1123 and passed over the airport approximately 5 min after the acetone plume was released there. A total of four tracing passes were made.

Although the westward passes through the acetone plume were well-defined with high counts, the eastward passes through this plume were inconclusive. Ice nuclei detected on the second W - E pass may have been a residual from the previous westward pass. All four passes through the wing-mounted flares were well-defined. None of the passes through the drop flares were satisfactory in terms of a clear plume edge and one of the encounters was made during course reversal. Figure 2 shows an example of three plume penetrations for the final E - W pass of 27 July 1984. The curves are calibrated IN concentrations not compensated for lag.

Pairs of plume edges taken during sequential flights in the same direction show the acetone plume to have moved approximately 6 m s^{-1} to the east and the wing-mounted flare plume to have moved at approximately 3 m s^{-1}. This suggests horizontal convergence on the order of 10^{-4} s^{-1}.

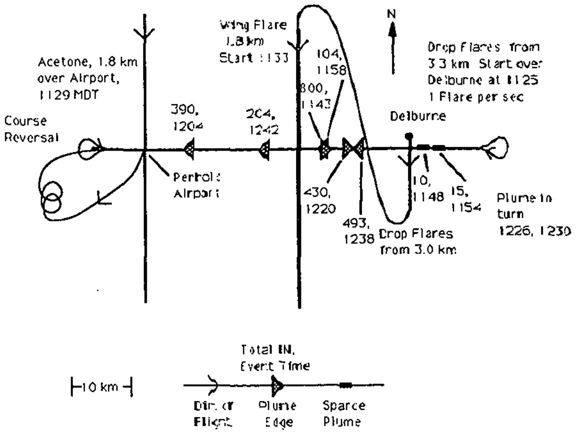

Fig. 1. Flight paths and details of plume encounters for aerially-released plumes of July 27, 1984.

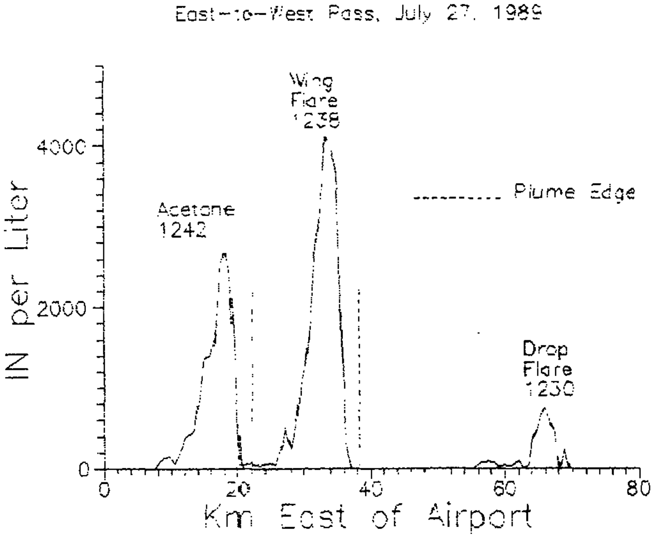

Fig. 2. Plume encounters of final E - W pass, 1230 - 1242, July 27, 1984.

The sparse showing of the acetone plume on two passes illustrates a limited vertical diffusion for 35 min which made plume detection difficult although the aircraft maintained the same altitude as the seeder. The poor showing of the drop flares could be expected for three reasons. First the IN were immediately spread vertically over 1.5 km, second, the flares were spaced 334 m, and third, the north edge of the curtain was over Delburne and WNW winds would have transported it south of the tracing pass. That any drop flare IN were detected is attributable to wind shear.

An economic conclusion drawn from this flight is that the single acetone burner produced approximately the same concentrations of IN effective at -20°C as the wing-mounted flares. In 1984 prices, this corresponds to approximately seventy-five and three dollars per 4 min seeding for wing flare and acetone sources.

"REVIEWED"

5. DISPERSION AND LONGEVITY OF LINE PLUME: JULY 18, 1985

The dispersion characteristics of one seeded line were measured in the flight of July 18, 1985. On this day, an upper level ridge was building over British Columbia, and on the surface the western portions of Alberta were coming under the influence of high pressure. In the vicinity of Penhold, the morning was clear, and convective mixing was not evident until the afternoon. The first Cu's were noted by the Baron's crew at 1244 and light turbulence at 2.3 km was first noted at the same time. Figure 3 shows the details of the flight paths. The AgI source was a wing-tip acetone generator. The seeding aircraft, a Piper Aztec, had two of these generators but only one was used with the other held as a backup. Since there was a strong zonal component, the seeding aircraft flew N - S passes just west of the Penhold airport at 2.4 km on a 28 km path. A total of seven passes were made starting at 1140. Only one pass, the first heading south, released AgI. This conclusion was drawn because only one plume was detected and the western edge of the plume was 10 km to the east of the traverse before the last traverse was completed. Flame outs of this type of generator were common and there was not a flame indicator.

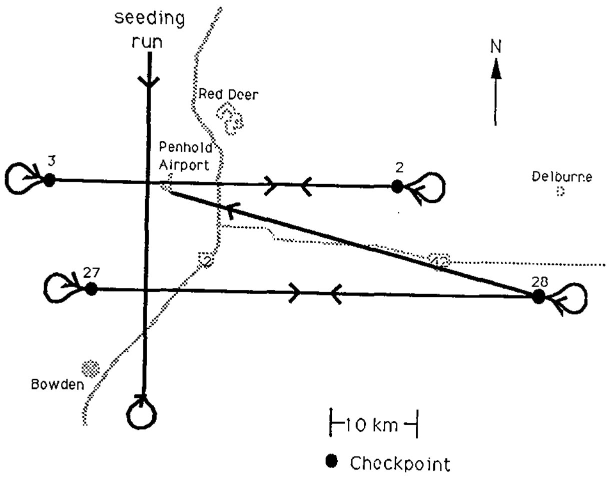

Fig. 3. July 18, 1985 flight patterns.

The tracing aircraft took off from Okotoks at 1055 with the IN detector cooled to operating temperature. The Baron passed through the AgI track shortly after the seeding aircraft passed the airport heading south. The first series of passes was W - E with the airport on the west end of the leg. A second series of W - E passes was made approximately 12 km to the south of the first. The move to the south was necessitated by a northerly component to the wind. Several elevations were sampled in both series.

Figure 4 details the plume encounters of this flight. The first portion of the flight was smooth and two passes at 2.6 km found no IN. Earlier a haze layer topping at this level was noted. Ice nuclei were found at 2.1 km indicating subsidence. By the time the southern traverses were completed, convective mixing dispersed the plume to at least 3 km and down to the lowest level sampled, 1.4 km. An aircraft sounding taken at 1433 showed lapse conditions existed to above 3.0 km. Three areas of sparse counts were found significantly west of the main plume. All were found after convection had started, suggesting they were residuals from slow IN flushing near the surface. Tracing was halted due to fuel and crew limitations.

IN were found in high concentrations for 3 hr 7 min. The vertical spread of the plume was clearly limited until convection was established, then the vertical motion appeared to be rapid. Plume edge positions indicate that the westerly wind component increased from 1.1 to 3.6 m s^{-1} at 2.4 km during the northern tracing traverses. In the southern traverses this increased to 5 m s^{-1} between 2.6 and 3.0 km.

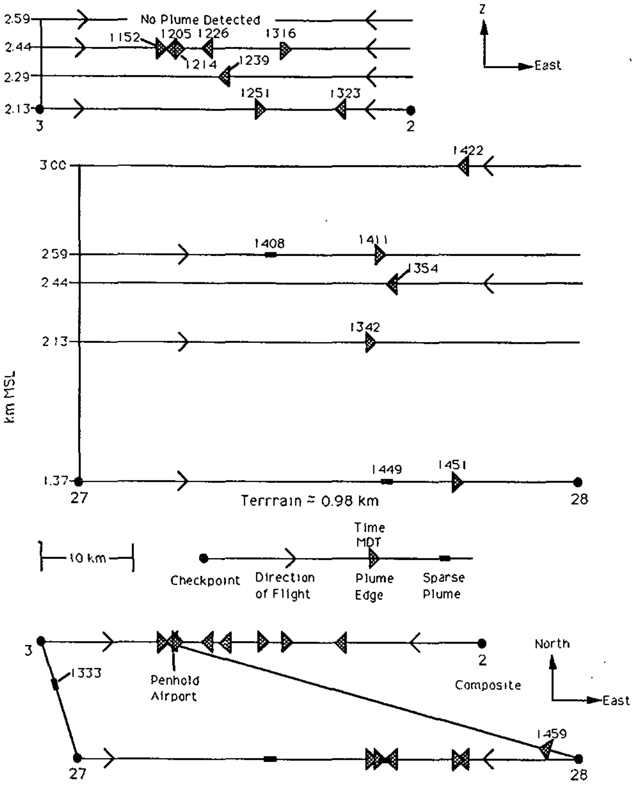

Fig. 4. Details of aerially-released IN plume on July 18, 1985.

6. DISCUSSION

Sequential pairs of plume edges sampled in opposite directions were used to define plume widths in the W - E (approximately downwind) direction listed in Table 2. Representative downwind distances and times are averages of the edges. Pairs were disqualified from consideration if there were insufficient IN to define an edge and if the edges forming a pair were not within 15 min. Downwind dispersion rates on the order of 0.2 to 2.0 m s^{-1} are shown, excluding the 1338 width of the 1985 case which showed a decrease.

The downwind component of dispersion for a line source has two contributions: the initial dispersion of the sequence of seeded lines in moving air, and turbulent diffusion (molecular can be neglected). In mathematical form,

$$\sigma_t = (\sigma_i^2 + \sigma_x^2)^{0.5}, \qquad (1)$$

where $\sigma_{()}$ indicates the standard deviations of total, initial and turbulent spread in the downwind direction in the order found in (1). If a box (or "top hat") distribution is assumed within the initial plume width, w_i,

$$\sigma_i^2 = w_i^2/12. \tag{2}$$

For the case studies, w_i of a single line was set somewhat arbitrarily at 100m, implying σ_i = 29 m, and for the scales involved this is negligible.

The parameter for downwind dispersion, σ_x, was assumed to be equal to σ_y, which is listed by Turner (1969) as a function of downwind distance for various stabilities. The spread of the plumes found experimentally can be parameterized in the same terms by assuming that sequential pairs of edges taken in opposite directions contain 95% of the plume, or σ_t = width/4. For the two cases, the "B" stability class was assumed (unstable). Table 2 compares the quantities derived accordingly.

Table 2. Sampled and estimated plume dimensions. (σ_t is sampled W - E standard deviation for plume and σ_x is that listed by Turner for B-stability.

Mean Time	Mean x (km)	Width (km)	Alt. of Pair (km)	σ_t (km)	σ_t (km)
			--27 July 1984--		
1151	4.2	1.0	1.8	0.3	0.6
1229	8.9	3.6	1.8	0.9	1.1
			--18 July 1985--		
1159	0.8	1.7	2.4	0.4	0.13
1220	3.8	4.3	2.4	1.1	0.5
1320	16.9	7.0	2.4/2.1	1.7	1.9
1348	21.1	4.0	2.1/2.4	1.0	2.3
1416	28.5	10.2	2.6/3.0	2.6	2.9
1455	37.8	11.1	1.4	2.8	3.6

The sampled standard deviations of the plume, σ_t, show an increase with time and distance and the calculated spreads, σ_x, match this with similar magnitudes excepting the 1348 penetration.

A conservative estimate of IN concentration can be made assuming all the detected IN of one pass were homogeneous within the boundaries of two sequential passes, i.e., a box distribution, and that the detector's efficiency factor for 1985 was 10:1: the highest referenced by Langer (1973). Applying the W - E pass of the final 1985 pair gives a concentration of 139 IN L^{-1}, effective at $-20^{\circ}C$. If a Gaussian distribution is applied to the same data, and lateral and vertical homogeneity are assumed, the mode concentration is estimated to be 221 IN L^{-1}.

Some conclusions can be drawn which have operational implications. In both cases, a single line dispersed rapidly both laterally and vertically. The lateral dispersion rates reached 2 m s^{-1} and the vertical spread was controlled by the mixing depth. The wing-tip acetone generator was shown to be a very effective source for airborne seeding. There were some problems with the type used due to clogging and some undissolved residual was found in the batch used. The use of wing-tip acetone generators is cheaper than flares because the former consume AgI slower and gets up to two orders of magnitude more IN per gm AgI than the flares. The 1985 case tracked a plume for 3 hr and 7 min, and throughout that period the plume remained strong and coherent. Photodeactivation or other losses were not a factor for the acetone source. The NEI-TB1 sources were not traced long enough for comment on this matter. In view of the rapid treatment possible for a volume of air, predictable dispersion and longevity, line seeding offers a legitimate strategy for operational cloud seeding.

7. ACKNOWLEDGEMENTS

James Renick and Frank Robitaille are gratefully acknowledged for their help during the field operations and fruitful discussions during the analysis. Arlin Super contributed ideas and encouragement in all the stages of this research. Frank Kingston was a source of historical perspective. This project was sponsored by the Alberta Hail Project.

8. REFERENCES

Demott, P.J. and L.O. Grant, 1986: Characteristics of the Various Ice Nucleating Aerosols in the Colorado State University Dynamic Cloud Chamber. Final Report to the Alberta Research Council, March, 59 pp.

Dennis, A.S., 1980: Weather Modification by Cloud Seeding. Academic Press, 267 pp.

Gagen, A. and M. Aroyo, 1985: Quantitative diffusion estimates of cloud seeding nuclei released from airborne generators. Jour. Wea. Mod. Assn. 17, 59-70.

Garvey, D.M., 1976: Testing of cloud seeding materials at the Cloud Simulation and Aerosol Laboratory, 1971-1973. J. Appl. Met., 14, 883-890.

Langer, G.L., 1973: Evaluation of NCAR ice nucleus counter, Part I: Basic operation. J. Appl. Met., 12, 1000-1010.

Sackiw, C.M., F.E. Robitaille, J.W. Mason, F.D. Barlow, W.G. Finnegan, R.D. Horn and J.A. Heimbach, Jr., 1984: Comparison tests of NCAR ice nucleus counters. Extended Abstracts, Ninth Conference on Weather Modification, May 21-23, Park City, UT, Amer. Met. Soc., 12-13.

Stith, J.L., D.A. Griffith, R.L. Rose, J.A. Flueck, J.R. Miller, Jr., and P.L. Smith, 1986: Aircraft observations of transport and diffusion in cumulus clouds. J. Clim. Appl. Met. 25, 1959-1970.

Turner, D.B., 1969: Workbook of Atmospheric Diffusion Estimates. U.S. Dept. of Health Education and Welfare; National Air Pollution Control Agency, Cincinnati, OH, 84 pp.