Silver Iodide Plume Characteristics Over the Bridger Mountain Range, Montana

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ABSTRACT

A modified NCAR acoustical ice nucleus counter was used in an airborne mode to measure the characteristics of silver iodide plumes released in mountainous terrain. These measurements were a supplement to a winter randomized cloud seeding experiment conducted in the Bridger Range, Montana. It was found that the silver iodide was generally transported upslope from the seeding sites, over the Main Ridge of the Bridger Range some 1400 ft higher, and toward the intended target area. Plume widths were found to average 28° above the Main Ridge, while most of the seeding agent was confined to the lowest 1500 ft above the ridgeline. Ice nuclei concentrations were typically in the range of 100–1000 liter^{-1}, effective at -20C. This is estimated to correspond to about 10–100 nuclei liter^{-1} at the warmer temperatures prevalent in the lowest 1500 ft above the Main Ridge during winter storms. The flux of ice nuclei was estimated on three occasions. Agreement was good, both from day to day and with the generator output as calibrated in a large isothermal cloud chamber.

1. Introduction

One of the greatest uncertainties associated with winter orographic cloud seeding programs has been the targeting of the seeding material in the concentrations desired. The complexity and variability of mountain airflow is well-known. Ground-released seeding agents may be trapped for extended periods by low-level inversions, or may flow around rather than over mountain barriers. Changes in plume width, depth and location occur as atmospheric stability, wind speed and wind direction vary. The concentration of seeding material will therefore also be altered. In addition, the concentration of effective nuclei may change by one or more orders of magnitude with temperature variations in time and space.

Several experimental and operational cloud seeding programs have utilized ground-based silver iodide generators. However, verification that the seeding material was transported toward the intended target area has been infrequent even though at least limited airborne tracing of silver iodide plumes has been possible for two decades. The numerical experiments performed by Milly *et al.* (1969) clearly illustrate the need for field sampling to determine whether adequate concentrations of seeding material reach the intended region of the atmosphere.

Prior investigations of silver iodide transport and diffusion include a series of airborne plume tracing experiments reported by Smith and Heffernan (1954, 1956) and Smith *et al.* (1955) in which a large mixing chamber was used to measure ice nucleus concentrations. Plume tracing was largely conducted over flat terrain although mountain top releases were used in the latter study. A small portable cold box was used by MacCready and Smith (1956), by Schaefer and Dieterich (1959), and by Henderson (1967), with limited data being presented from each study. The first airborne use of a continuous ice nucleus counter was described by Langer *et al.* (1967) who presented silver iodide plume cross sections measured over mountainous terrain in Colorado. Additional plume tracing in the same area was reported by Rhea *et al.* (1969). Auer *et al.* (1968) and Veal (1969) discussed plume tracing experiments over the isolated peak of Elk Mountain, Wyo. A continuous acoustical ice nucleus counter was also used for measurements near Climax, Colo., as reported by Orgill *et al.* (1971). Preliminary results of silver iodide plume tracing over the Bridger Range, Montana, were discussed by Super *et al.* (1971).

A program of airborne tracing of silver iodide plumes was conducted over the Bridger Mountain Range of southwestern Montana during the winter of 1970–71. The purpose of the program was to increase knowledge concerning the probable transport and diffusion of the seeding material released during the Bridger Range randomized seeding experiment. Prior to the start of the experiment in 1969, it was necessary to make several assumptions regarding transport and diffusion to determine a rate of production of silver iodide smoke which would generally produce a desired range of ice nucleus concentrations in the orographic cloud above the Main Ridge of the Bridger Range. For the typical range of conditions anticipated, the model of Grant *et al.* (1968) predicted that optimum ice nuclei concentrations would be about 10–100 liter^{-1}. Generator burn rates for the experiment were set at 30 gm AgI hr^{-1}, the amount estimated as necessary to achieve this concentration range. Plume tracing experiments were initiated to provide the data with which to check the validity of the assumptions which had been made.

It was also anticipated that knowledge gained from the plume tracing would aid in interpretation of the results from statistical analyses of the randomized experiment which are currently ongoing. For example, let us assume that a particular statistical analysis indicated that significant snowfall increases were associated with cloud seeding for a specific range of 700-mb wind direction. This statistical finding would gain considerable additional credence if physical measurements indicated proper targeting of the silver iodide for the same range of wind directions.

2. Equipment description

A commercially manufactured acoustical ice nucleus counter was obtained during 1969 for the purpose of tracing silver iodide plumes. However, considerable modification of the unit was found to be necessary before reliable operation was possible. The majority of the modifications were accomplished during the 1969-70 winter season under the direction of the original system's designer, Dr. Gerhard Langer of NCAR. Procedures for utilizing the system in an airborne mode were largely developed during the same season.

An early model of the ice nucleus counter and its operation were discussed by Langer *et al.* (1967). The model used in the present study was similar to that described by Langer and Weickmann (1971) with the exception of a somewhat smaller cloud chamber. Langer (1973) reports excellent agreement between a counter similar to that used here and the isothermal cloud chamber at Colorado State University.

The counter was flown in a Piper Apache aircraft. This light twin aircraft was well-suited for plume tracing. Installation of the acoustical counter, associated battery package (2–200 ampere-hour tractor batteries), a dc-to-ac rotary converter, and a flight crew of three (pilot, counter operator, and location monitor) left little additional space. However, the relatively small size and slow speed of the aircraft allowed for a degree of maneuverability in mountainous terrain that could not be achieved with a larger or faster airplane.

3. Sampling procedures and data reduction

Two seeding sites were utilized during the Bridger Range seeding experiment. The Springhill (SH) site, located 1 mi west of the Main Ridge, and the Temperature Ridge (TR) site some 3 mi from the crest are shown in Fig. 1. Both sites were about 1400 ft lower than the Main Ridge which has an average elevation of 8600 ft (all elevations MSL). Both sites were located above the level of frequent valley inversions (Super *et al.*, 1970) so that the seeding material would not be trapped during operations.

Plume tracing flights were made only when the Main Ridge was free of clouds and when the winds aloft had a westerly component. Thus, material released from the seeding sites was likely to be transported eastward over the Main Ridge and toward the intended target area on the Bangtail Ridge (see Fig. 1).

The majority of plume tracing was accomplished directly above the Main Ridge to determine where, and in what quantity, ice nuclei from the seeding sites were crossing the Ridge. These flights were made according to the following procedure. A pass would be made at 8500 ft, directly above the ridgeline where safe flight was practical, or slightly upwind. The pass would follow the north-south trending ridgeline from a few miles north of the northern generator site (SH) to a few miles south of the southern generator site (TR) for a total distance of about 11 mi. A second pass would immediately be made along the same flight path and elevation as the first, but in the opposite direction. A third pass would then be made along the same path as the first, but 500 ft higher, i.e., at 9000 ft, while a fourth pass would be identical to the second except that it would be made at 9000 ft. The same scheme would be followed at 500-ft height increments until the measured ice nucleus concentration approached background levels along the entire flight path. All heights were measured with the aircraft altimeter which was adjusted to field elevation prior to takeoff.

Repeating passes in opposite directions at the same elevation has two advantages. It yields a better average of actual ice nucleus concentrations at a particular level than a single pass, and it also establishes the positions of the edges of the silver iodide plume more precisely than possible with one pass. Ground tests have revealed that first detection of ice crystals by the acoustical sensor occurs 23±2 sec after injection of silver iodide smoke into the intake tube in the nose of the aircraft. However, Langer *et al.* (1967) indicate that about 1 min is required for the bulk of the ice crystals to pass through the sensor after passage of the ice nuclei into the system intake. This results in considerable blurring of the plume width. Entering the plume from both sides and using the average time lag of 23 sec to determine the leading edges provides a better estimate of actual plume width.

During the data reduction process, ice nucleus concentrations indicated by the acoustical counter system were increased by a factor of 10. This procedure, also used by Orgill *et al.* (1971), has been suggested by Langer and Weickmann (1971) to compensate for

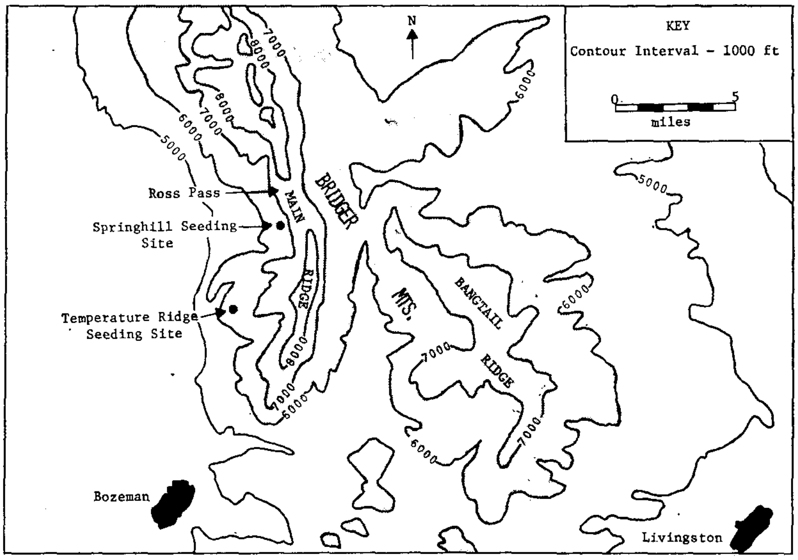

FIG. 1. Bridger Range experimental area.

known instrument losses. While the degree to which any ice nucleus counter represents actual ice nucleus concentrations is still not firmly known (see Bigg, 1971, and Isaac and Douglas, 1972), this procedure seems to be the most reasonable in view of current knowledge.

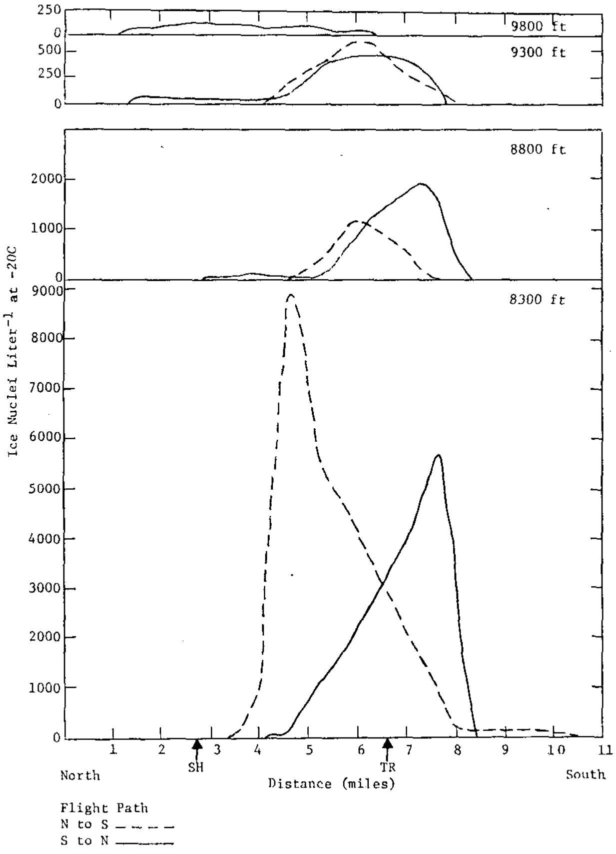

FIG. 2. Ice nucleus concentrations above the main Bridger Ridge, 12 February 1971.

As previously noted, the mean holding time for ice nuclei in the NCAR acoustical counter is about 1 min, resulting in considerable averaging and blurring of the actual plume structure. The data presented in the following figures were spacially adjusted by flight distance equivalent to 1 min to compensate for the delay in instrument response. Thus, the actual ice nucleus plumes were narrower, had higher maximum concentrations, and more detail than the figures indicate.

The corrected and adjusted data were plotted as a function of distance along the ridgeline, relative to an arbitrary starting point, by the following procedure. During each flight pass the location monitor noted the time, to the nearest second, that the aircraft passed over each of five easily identifiable checkpoints along the flight path. At the same instant, the counter operator marked the recorder chart to indicate the exact moment of checkpoint passage. The checkpoints used were evident on a 1:62,500 scale map of the area, and the distances between them were obtained from the map. The aircraft ground speed was calculated between each pair of checkpoints along the route, and the recorder chart data were then related to ground position by assuming that the ground speed was constant between checkpoints.

4. Plume characteristics over the Bridger Range

Figs. 2–6 portray cross sections through the silver iodide plumes above the Main Ridge obtained in the manner previously discussed. The intersections of east-west lines through the seeding sites with the flight paths above the Main Ridge are depicted by small

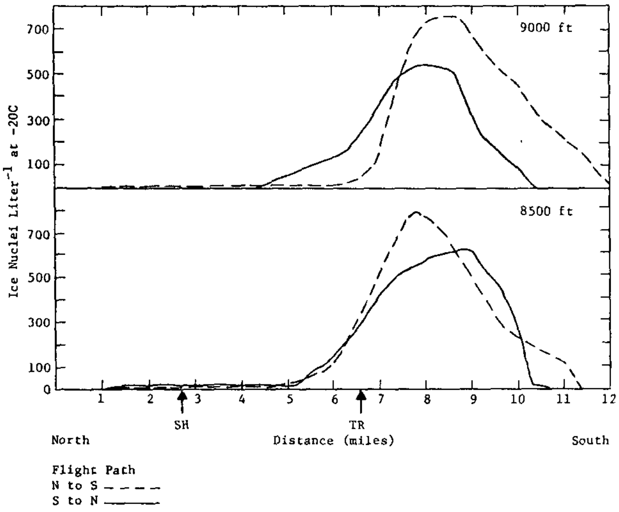

FIG. 3. Ice nucleus concentrations above the main Bridger Ridge, 22 February 1971.

arrows labeled SH (Springhill) and TR (Temperature Ridge), respectively. Measurements were not made above the elevations indicated.

Examination of the figures reveals several interesting features. First, a plume of silver iodide was detected on every pass made downwind of the TR seeding site, except possibly the 9800-ft pass made on 12 February 1971. The bulk of the seeding material was found below 10,000 ft, or within 1500 ft above the Main Ridge, on the three days where data were obtained above 9500 ft.

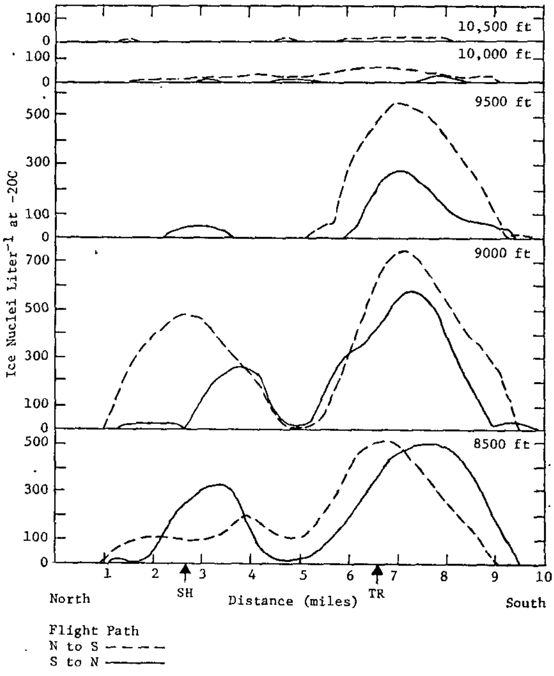

FIG. 4. Ice nucleus concentrations above the main Bridger Ridge, 19 March 1971.

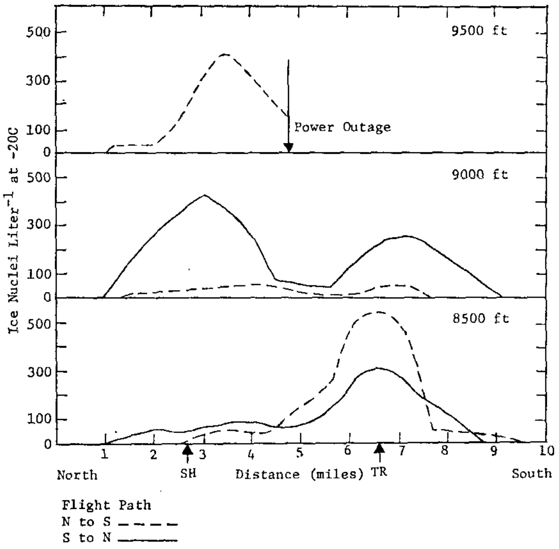

FIG. 5. Ice nucleus concentrations above the main Bridger Ridge, 20 March 1971.

The lapse rates from ridgeline elevation to above the silver iodide plumes were conditionally unstable

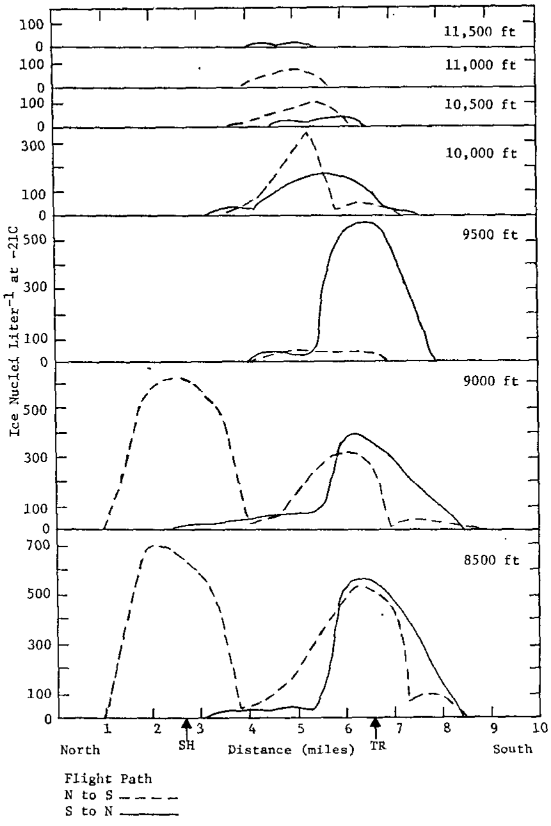

FIG. 6. Ice nucleus concentrations above the main Bridger Ridge, 29 March 1971.

during all five sampling periods portrayed in Figs. 2–6. However, sky cover was broken or overcast on all days, with ceilings usually well above flight levels. Thus, the cloud-free atmospheric layer in which the silver iodide was being transported was slightly stable in all cases, but inversions were not present. It is likely that mechanical turbulence was primarily responsible for the vertical diffusion of the seeding material.

A shortcoming of the airborne tracing program was that it was impractical to fly near the mountainous terrain and make measurements under actual storm conditions. Typically, the Main Ridge and both seeding sites were in cloud during snowfall periods. Rawinsonde measurements made during storm conditions indicated that conditionally unstable lapse rates often existed in the region of the orographic cloud through which transport of the seeding agent would be expected. In this situation, vertical convective mixing would have occurred. The extent to which convective mixing would transport the seeding material upward in excess of mechanical mixing alone, cannot be determined from the data presently available. However, rawinsondes which passed through clouds above the windward slope of the Main Ridge have been used to estimate the mean vertical velocities present. These estimates suggest little additional uplift from that observed during non-cloud periods with similar winds and stabilities. It is noteworthy that even in the absence of convective activity, the silver iodide released at the TR site was transported more than 1500 ft above the Main Ridge.

Examination of Figs. 2–6 also reveals differences in the characteristics of the silver iodide plumes from the two seeding sites as measured over the Main Ridge. The TR plume was detected on practically every pass above the Main Ridge. However, the SH plume was frequently found in weak concentrations or not detected at all, even though it might be found in high concentrations on a pass made at the same altitude a few minutes earlier or later.

On two occasions (12 and 22 February) the SH plume was not definitely detected on the regular flight paths above the Main Ridge. Because of the apparent lack of a significant plume on 12 February, a pass was made at low level over the generator to insure that it was operating. This resulted in ice nucleus counts in excess of the NCAR counter's capacity.

A low-level pass was then made through Ross Pass (see Fig. 1) to determine if the seeding material was funneling through the pass at levels below that of the lowest flight path elevation. Ice nucleus concentrations in the pass were found to be only slightly in excess of background. A pass was then made along a generally north-south line over the intended Bangtail Ridge target area at 8000 ft. The flight path was approximately parallel to the Main Ridge and about 8 mi east of it. A broad plume was found which had ice nucleus concentrations exceeding 50 nuclei liter^{-1} (at -20C) for a few miles along the north-south path, and a peak concentration of 170 nuclei liter^{-1}. The center of the plume was found too far northward to be from the TR generator for the prevailing airflow. The plume from the TR generator was not definitely detected, probably because it was at a higher level. No further passes were possible due to exhaustion of available battery power.

Thus, it appears that the seeding material released from the SH site, although not found over the Main Ridge on 12 February, was being transported over the Bangtail Ridge target area. It is postulated that the seeding material was confined to a very shallow layer flowing just above the windward slope of the Main Ridge.

Two north-south passes at 8500 ft were also made over the Bangtail Ridge on 22 February after passes over the Main Ridge failed to detect a marked plume from the SH site (see Fig. 3). Ice nucleus concentrations were found to be fairly uniform over the entire target area, ranging from 20 to 60 liter^{-1} (at -20C). The north-south extent of this range concentration exceeded 20 mi. The very broad extent of the ice nuclei suggests that the seeding material from the SH site was again being transported over the target area. It is again speculated that the material was contained in a very shallow layer while flowing over the Main Ridge.

Examination of the data from 19, 20 and 29 March shows that although substantial concentrations of silver iodide were detected downwind of the SH site, there was a high degree of variability between passes at a given altitude. This again might be interpreted as being indicative of a shallow layer of seeding material which varied substantially in height above terrain over relatively short periods of time.

Data from three additional flights, during which insufficient precise checkpoint information was available to accurately estimate plume widths and positions, substantiate the measurements previously discussed. The results of these flights, reported by Super *et al.* (1972), qualitatively show that the TR plume was always distinct over the Main Ridge while the SH plume was evident only intermittently. These flights also showed that, in all cases, both plumes were in evidence over the Bangtail Ridge, either as distinct plumes or merged into a single broad plume.

The differing plume characteristics downwind of the two seeding sites is thought to be related to topographical differences between the sites. The Main Ridge east of the 7200 ft TR site has an average elevation of 8600 ft, while averaging 8400 ft east of the 7000 ft SH site. Thus, both seeding sites are 1400 ft lower than the top of the orographic barrier. However, the Main Ridge is 3 mi east of the TR site but only 1 mi east of the SH site. Therefore, the

Table 1. Summary of plume width estimates and associated meteorological conditions.

Plume release site	Date (1971)	Plume measurement elevation (ft)	Reciprocal azimuth to maximum plume concentration (deg)	Wind direction estimated from pibals (deg)	Wind speed estimated from pibals (m sec^{-1})	Lapse rate [°C (100 m)$^{-1}$]	Plume width (deg)
Temperature Ridge	12 Feb	8300	265				55
		8800	264	264	7.4	1.00	27
		9300	258				26
Temperature Ridge	22 Feb	8500	300	317	5.7	0.85	36
		9000	297				26
Temperature Ridge	19 Mar	8500	285				38
		9000	292	282	5.8	0.65	28
		9500	287				31
Temperature Ridge	20 Mar	8500	260	278	7.1	0.75	34
Temperature Ridge	29 Mar	8500	259				27
		9000	260	261	8.1	0.70	16
		9500	254				24
		10,000	257				13
Springhill	19 Mar	8500	264	265	6.4	0.65	80
		9000	258				88

seeding material from the TR site might be expected to diffuse substantially higher and have a greater vertical extent before passing over the Main Ridge than seeding material from SH.

In order to gain more realistic estimates of the actual width of the silver iodide plumes, the 23-sec lag was used to estimate the position of the leading edge of the plume whenever it was clearly discernible from a rapid increase in concentration as indicated by the chart record. When the leading edge could be identified for two alternate passes made at the same altitude, an estimate of plume width was made by assuming that the plume position remained stationary for the 4–7 min required to return to the plume for the second pass.

The resulting estimates of plume width for each pair of passes are given in Table 1 along with measurements of the lapse rate and wind speed and direction through the layer of interest. Air temperatures were measured with the aircraft, either by a thermistor in a vortex tube, or by a calibrated thermometer mounted through the windshield. Wind velocities were obtained from dual theodolite tracking of pibals released from the seeding sites. Each wind speed and direction estimate from the pibal data was based upon either two or three pibals. The wind speed estimate was made for the layer in which the plume width was measured (usually 8500–9000 ft), while the wind direction was the resultant from the seeding site to the top of the same layer over the Main Ridge.

Data were available from pibals launched at the seeding site producing the measured silver iodide plume in all cases. In three cases (12 February, 19 and 29 March), pibals were tracked during the plume tracing flights. However, pibal data were only available approximately 1½ hr before the plume tracing flight of 22 February and 2 hr after the flight of 20 March. It can be seen that the wind direction estimates from the pibals and the reciprocal azimuths to the maximum plume concentration showed less agreement on the latter two dates suggesting that the wind direction may have changed somewhat with time. Agreement on the other dates was quite good.

There is little evidence in Table 1 to support a widening of the plume with increased stability as found over Elk Mountain, Wyoming, by Auer *et al.* (1968) and Veal (1969). Also, the data from the Bridger Range suggest considerably wider plumes for the range of stabilities encountered than were found over Elk Mountain. The average angular width of plumes within the 8500–9000 ft layer was 28°. The two sites are, of course, quite different topographically. Elk Mountain is an isolated peak while the Bridger Range has an abrupt extended ridgeline lying across the prevailing westerly flow.

Examination of the concentrations of ice nuclei on the figures previously presented shows that 100–1000 nuclei liter^{-1}, effective at −20C, were typical values above the Main Ridge. Based on thermograph records from the Main Ridge, the mean 8500-ft temperature was −10C during snowfall. If the bulk of the silver iodide released during storms passed within 1500 ft of the Main Ridge, it was, for average conditions, exposed to temperatures from about −13 to −10C.

A silver iodide generator of the type used at the seeding sites was calibrated with the Colorado State University isothermal cloud chamber during May 1972. The tests indicated that the output of effective nuclei per gram AgI was 3×10^{14} at -12C and 7×10^{14} at -20C for natural tunnel draft (almost calm). The output increased to 1×10^{15} at -12C and 2×10^{16} at -20C for maximum tunnel flow of 10 m sec^{-1} across the burner head. Wind speeds at the burner heads were typically 2 m sec^{-1} during seeding operations. Thus, one might expect the ratio of effective nuclei at -20C to that at -12C to be about 10:1. Assuming the 10:1 ratio is valid, it is estimated that the concentration of effective nuclei over the Main Ridge for typical temperatures during snowfall was approximately 10–100 nuclei liter^{-1}. This is the range originally designed for in the Bridger Range cloud seeding experiment, although measured plume widths and depths were greater than anticipated. This was compensated for by a higher generator output than originally estimated.

5. Rate of ice nucleus transport over Main Ridge

On three occasions (12 February, 19 and 29 March), ice nucleus concentrations were measured through the entire vertical extent of the TR plume above the Main Ridge. It is possible to estimate the amount of silver iodide passing over the Main Ridge per unit time using these data and wind speed measurements obtained from dual theodolite tracking of pibals. Such estimates were made to determine the extent to which the data from the NCAR acoustical counter agreed with the seeding generator output as determined with the Colorado State University isothermal cloud chamber. A comparison between the two methods of ice nucleus measurement is considered useful in view of the recent suggestion by Isaac and Douglas (1972) that ice nucleus counters using cloud chambers with residence times of a minute or two may underestimate the actual ice nucleus concentration by a considerable amount. Also, the validity of the data obtained with NCAR acoustical counters has been the subject of controversy (Hobbs and Locatelli, 1970; Bigg, 1970; Langer, 1971).

Estimates of the amount of silver iodide per unit time passing over the Main Ridge downwind of the TR site were made in the following manner. The acoustical counter data were plotted as a function of distance along the Main Ridge, using a 60-sec mean residence time and a factor of 10 correction for chamber losses as previously discussed. The results, given in Figs. 2, 4 and 6, show the measurements made at 500-ft vertical intervals. The indicated ice nucleus concentration was extracted from the plot for each flight pass at intervals of 0.2 mi. Each such data point was assumed to represent the concentration of silver iodide in a rectangular volume, centered on the point, of 0.2 mi (322 m) wide (crosswind), by 500 ft (152 m) high, by 1 m deep, or about 4.9×10^{7} liters. Two exceptions were that data obtained at 8500 ft were assumed to represent the 150-ft depth from 8600 ft (mean ridgeline elevation downwind of TR) to 8750 ft, while measurements made at 8800 ft on 12 February were assumed as representative of the 8600–9050 ft layer. Data obtained below the 8500-ft level were not used because these passes were made a significant distance west of the Main Ridge in order to clear the terrain.

The wind direction in the layer of interest was within ±20° of perpendicular to the flight path above the Main Ridge on all three dates. It was assumed that all measurement passes were made perpendicular to the plume axis since resulting errors in estimating total ice nuclei present would be slight.

The northern extent of the TR plume at each flight level was estimated by examination of the plotted data for all levels. The total number of ice nuclei in each 4.9×10^{7} liter subvolume (less for 8500- and 8800-ft passes) was summed from the northern to the southern boundary of the plume. If two passes were made at the same level, the totals were averaged. The total number of ice nuclei represented by each flight level were then summed over the entire vertical extent of the plume, yielding an estimate of the total number of ice nuclei located in a 1 m thick vertical cross section through the plume of silver iodide. Background concentrations of natural ice nuclei were insignificant when compared to silver iodide concentrations, so it was assumed that the measured ice nucleus concentrations were composed entirely of silver iodide.

The mean wind speed in the layer from the Main Ridge to the top of the silver iodide plume was estimated from the dual theodolite tracking of pibals released from the TR seeding site. This mean wind speed (m sec^{-1}) was multiplied by the total amount of silver iodide in the 1 m thick vertical cross section to yield an estimate of the total number of effective ice nuclei per second that were being transported over the Main Ridge downwind of the TR generator. The resulting estimates are given in Table 2.

It can be seen that the estimates of total ice nuclei crossing the Main Ridge per second range from 5.2 to 7.7×10^{12} (at -20C). In view of the method of estimation used, the excellent agreement among the three days is surprising and may be fortuitous. It does suggest that the seeding generator output was quite similar from day to day, and that data obtained with the particular ice nucleus counter used are reasonably reproducible.

The calibration carried out in the Colorado State University large isothermal cloud chamber indicates that the seeding generator output ranged from about 5 to 170×10^{12} nuclei sec^{-1} for natural tunnel draft, and for air flow of 10 m sec^{-1} across the burner head, respectively. This is for the burn rate of 30 gm AgI hr^{-1} used during all plume tracing experiments.

As the wind speed at the TR generator was probably less than 2 m sec^{-1} during the three experiments in question, the generator output is estimated as $\sim 10^{13}$ nuclei sec^{-1}. Thus, agreement is excellent between the estimated generator output and the estimated number of ice nuclei crossing the Main Ridge per unit time. The results may be interpreted in three ways:

1) The agreement is fortuitous because the NCAR acoustical counter and CSU isothermal cloud chamber are both in error by about the same amount.

2) The agreement is fortuitous because photolytic deactivation of the silver iodide was sufficient to bring the results based on the NCAR counter and CSU chamber in line.

3) Both the NCAR counter and CSU chamber closely approximate reality and the results shown are valid. This conclusion also implies that photolytic deactivation was not highly significant during the time required for silver iodide to be transported to above the Main Ridge.

The question of photolytic deactivation is still an open one. Mason (1971) summarized findings from a few laboratory and field experiments. Estimates of the rate of deactivation of silver iodide as effective ice nuclei range from two orders of magnitude per day to nine orders of magnitude per hour. It has been suggested that the rate of deactivation is related to the type of generating system, and probably to the chemical composition used. A 3% silver iodide, 1% ammonium iodide, 3% water, and 93% acetone solution was burned in a propane flame in the present study. According to St.-Amand *et al.* (1971), relatively pure silver iodide particles should have been produced. Recent field experiments conducted in south central Montana (Super and McPartland, 1973) suggest that photolytic deactivation of the particular seeding material used is quite limited.

6. Summary

On several occasions concentrations and dimensions of silver iodide plumes released over the Bridger Mountain Range were sampled using a modified NCAR acoustical ice nucleus counter in an airborne mode. The silver iodide was released from two sites each located about two-thirds of the way up the windward slope of the range. In all cases the plumes of ice nuclei appeared to be transported over the Main Ridge and toward the intended target area. The plumes were largely confined to the lowest 1500 ft over the Main Ridge.

The measured crosswind extent of the plumes ranged from 13° to 88°, with a mean value of 28°. Ice nucleus concentrations above the Main Ridge usually ranged from 100 to 1000 per liter, effective at −20C. It is estimated that this corresponded to about 10–100 nuclei liter^{-1} for temperatures typical of storm conditions.

TABLE 2. Number of ice nuclei, effective at −20C, crossing the Main Ridge.

Date	Wind speed (m sec^{-1})	Ice nuclei contained in 1 m thick vertical cross section above the Main Ridge ($\times 10^{11}$)	Ice nuclei crossing the Main Ridge per second ($\times 10^{12}$)
12 Feb 71	8.5	9.1	7.7
19 Mar 71	8.3	7.6	6.3
29 Mar 71	10.9	4.8	5.2

The flux of ice nuclei over the Main Ridge was estimated on three occasions when the complete vertical extent of the plumes was sampled and wind measurements were available. These estimates ranged from 5.2 to 7.7×10^{12} nuclei sec^{-1} which is in very good agreement with the generator output as determined with the Colorado State University isothermal cloud chamber. The close agreement from day to day suggests that the reproductibility of the acoustical counter is quite good. The agreement between the isothermal cloud chamber and the acoustical counter is encouraging. While the agreement may be fortuitous, it appears likely that the two ice nucleus counting systems at least perform in a similar manner with the type of silver iodide utilized.

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