

OR CROSS-CONTAMINATION

IN CLOUD SEEDING EXPERIMENTS

By

J. A. Warburton and L. G. Young

Introduction

It would appear that there are several outstanding dilemmas in the results of weather modification experiments. There are large discrepancies between successful results in some locations obtained from seeding isolated cumulus clouds with silver iodide or dry ice and an apparent failure to produce such increases in nominally like cases elsewhere. Similar, but somewhat lower magnitude discrepancies have been observed when seeding extended volumes of cloud over thousands of square miles of countryside.

Bethwaite, et al (1967) ^{1/} have reported increases in precipitation of 100 to 500% when isolated cumulus clouds were seeded with several grams of silver iodide. On the other hand, Battan and Kassander (1962) ^{2/} have reported no such increases. Investigators who have conducted large scale weather modification experiments (Gabriel (1967) ^{3/}; Henderson (1966) ^{4/}, Elliott (1962) ^{5/}, Smith et al (1963) ^{6/}, 1965^{7/}) have reported increases not exceeding 20% whereas others (Smith et al (1963) ^{8/} have reported no increases at all.

One can speculate on causes, such as dispersion of seeding material, although other possible reasons have been suggested to explain these results. Bowen (1966) ^{9/} has reported on evidence that seeding is apparently more successful in producing precipitation increases in the early years of an experiment compared with the later years of the same experiment. Grant (1963) ^{10/} reported large numbers of ice nuclei in the atmosphere in seeding areas in Colorado even though the AgI seeding generators had not been operating for some days, or even weeks, prior to the observations. This result has been referred to by Grant as "persistence". If such persistence is a physical reality in terms of its possible effects on precipitation, a statistical analysis recently reported by Bowen (1966) carries real implications for results of weather modification experiments throughout the world. Gabriel et al (1967) ^{11/}, however, did not find statistical evidence of persistence in the Israel experiment.

Recently, Reinking and Grant (1967) ^{12/} have reported the observation of considerable numbers of ice nuclei in the Rabbit Ears Pass, Colorado area of the U.S.A. when no local seeding was occurring. They have suggested that these nuclei may have had their origin some 300 to 400 miles upwind of their target area in another cloud-seeding region.

A series of observations of silver content in precipitation has just been made with precipitation samples collected from various locations in the Western United States. The details of these observations which are presented in this paper provide additional evidence that either cross-contamination of seeding material is occurring between separate cloud seeding areas or persistence within the same area may be occurring.

Observational Data

The data presented is composed of results from five geographical areas. The total number of samples is about 150. The samples of snow, hail and rain were collected in a variety of ways all of which attempted to avoid metallic surface contact. Most of the samples were collected during major snow-falls over a period of five months; December, 1966 to April, 1967. Some samples were taken from areas where extensive ground-based silver iodide seeding was occurring; some were from areas where no local seeding had occurred. The samples were from Reno, Nevada; Hungry Horse, Montana; Elko, Nevada; Climax, Colorado; and Rapid City, South Dakota.

All samples were analyzed by the same method, a detailed description of which has been given by Warburton and Young (1968a) ^{13/}. After concentration of the silver from solution, it is analyzed by thermal neutron activation analysis. The lower limit of

concentration which is detectable, using a one liter sample of snow, is about 3×10^{-12} gm ml⁻¹. The analysis was randomized as much as possible treating a few samples from each geographical region in each analysis batch.

Results

All Data

Figure 1 shows the results, by geographical location, of all silver masses measured.

It can be seen that these silver masses range from 6×10^{-9} grams to 2×10^{-6} grams. A mass of 10^{-9} grams can be measured to an accuracy of $\pm 80\%$ whereas a mass of 10^{-6} grams can be determined to an accuracy of $\pm 2\%$. This information provides the degree of confidence with which each data point in Figure 1 has been determined.

In general, it can be said that the concentration of silver in snow collected from areas where extensive seeding is being carried out, for example Montana and Colorado, is 10 to 100 times that in snow collected from locations where no such seeding is occurring (e.g., Reno, Nevada).

Analysis of results by individual geographical areas

RENO, NEVADA

The results for this area of the Eastern Sierra presented in Figure 1 (c), show that eighty percent of the samples contain masses of silver less than 6×10^{-8} grams and 9 samples (20%) have silver masses greater than this. This mass of silver (6×10^{-8} gm) has been chosen arbitrarily for the purposes of comparison of silver mass distributions from the several locations listed. Since most of the samples were collected on towers raised 10 to 15 feet above the surface of the ground, it has been possible to identify the storms from which the snow fell. Of the nine samples which contained silver significantly in excess of the fairly regular $2-3 \times 10^{-8}$ grams "background", seven are identifiable by storm date. The other two were for snow taken from a snow pit and it has not been possible to determine with any degree of accuracy when this snow fell. Table I presents information on seeding times and locations as well as on general wind flow in this area of the Sierra on the days of interest.

HUNGRY HORSE, MONTANA

All of the samples analyzed from the Montana area were collected on days when silver iodide seeding was occurring. North American Weather Consultants collected these snow samples and forwarded them in the frozen state to Reno for analysis. Figure 1 (a) shows that only one of these forty samples contained less than 6×10^{-8} grams of silver. These results demonstrate that the silver iodide released by ground generators in this mountainous area has appeared in the snow collected in and around the target area. The highest mass of silver detected in a 1-liter sample was 8 micrograms, >1000 times the minimum detectable amount. It would have been very desirable to have had comparative samples collected well away from the seeding area and this is planned in future sampling programs.

ELKO, NEVADA

Eighteen samples of snow were analyzed from this geographical area (see Figure 1 (d)). It is an area where ground-based AgI seeding generators are operating. All samples were collected in the north target area from snow pits. It is not known on which days this snow fell and hence relationships with the seeding program cannot be attempted. All Elko samples, except one, contained masses of silver less than 6×10^{-8} grams. It remains to be determined (as for the other geographical areas) whether this mass is the natural background for this region or not. The silver masses were, on the average, $1/30$ those in snow collected in Montana where similar seeding methods were being employed. The results do suggest that the seeding material is not flowing consistently from the generators into the target area.

CLIMAX, COLORADO

Approximately 40 samples of snow were collected in towers well above the ground. These were collected by Colorado State University staff and sent frozen to Reno for analysis. Collection in the towers enabled identification of the dates and times of snow fall. Ground-based AgI generators are also used in this geographical region.

Figure 1 (b) illustrates the distribution of silver mass determined in these samples. Sixty percent of the samples contain silver in excess of 6×10^{-8} grams. The distribution is not unlike that obtained with the samples from Montana where a similar type of seeding operation had occurred.

Some of these samples from Colorado were collected on days when seeding was occurring, others when it was not. When the results are divided by this criterion they are distributed in the manner shown in Figure 2 (a). There appears to be as much silver in precipitation in this area on unseeded days as there is on seeded days.

RAPID CITY, SOUTH DAKOTA

Results of analysis of hail and rain collected from this area has already been reported by Warburton and Young (1968b) 14/. These results are plotted on the same Figure 1 for comparison purposes. The amount of silver in the samples was such that 50% have masses $> 6 \times 10^{-8}$ gm.

When these are divided by seeding criteria, they are distributed as in Figure 2 (b). Again, both seeded and unseeded samples showed similar silver concentrations.

Discussion

The precipitation samples collected from seeded areas have been found to contain silver in concentrations up to 1,000 times that found in precipitation collected from unseeded locations. There is, therefore, very little doubt that the silver iodide being used in these seeded areas is being detected at least in some measure in the samples analyzed. More measurements are obviously needed to determine the extent to which the silver content in the precipitation in a particular seeding area exceeds the natural background level for that area. The mechanisms by which the silver gets into the precipitation are still to be determined.

A. Lower Level "Background"

A very large proportion (some 80%) of the precipitation samples analyzed contain silver in amounts greater than 6×10^{-9} grams. In the unseeded area, Reno (see Figure 1 (c)), the general "background" appears to be around $2-3 \times 10^{-8}$ grams from a volume of one liter of snow melt. This level of "background" has also been found in snow collected in the Elko area of Nevada. It might be expected that the natural background of silver would vary with geographical location, but the results obtained so far are consistently around 10^{-11} gm ml⁻¹.

B. Contamination of nominally unseeded areas

(a) Figure 1 (c), showing the activation analysis for the Reno-Mt. Rose area, includes several samples with silver concentrations greater than twice "background". The snow of these samples fell from storms occurring on the dates and in atmospheric and up-wind seeding conditions listed in Table I.

(1) Storm of 14-15 February 1967

As seen in Table I, seeding with silver iodide occurred in the Lake Almanor, San Joaquin and Kern River districts of California. The precipitation which fell in the Mt. Rose area occurred between 2300 hours on 13 February and 0700 hours on 14 February. In the altitude range 4,000 to 15,000 feet, winds were between 240° and 340°. Reference to the map in Figure 3 shows that Lake Almanor seeding could be the possible source of silver arriving in the snow at Reno.

Figure 3. Locations of seeding operations in relation to Mt. Rose-Reno, Nevada.

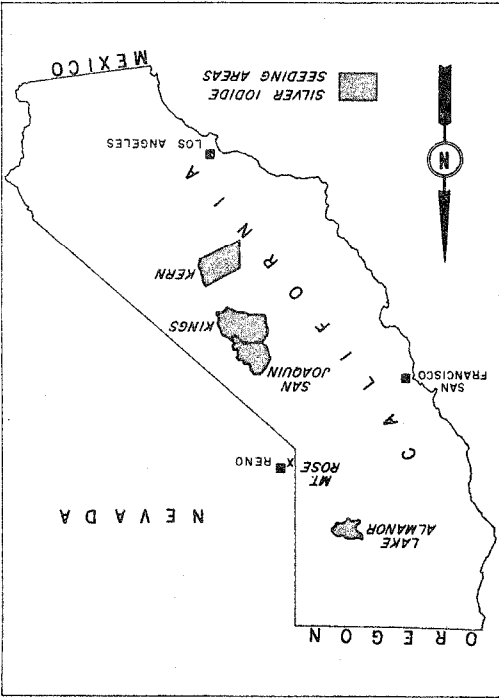


Figure 2. Sample silver in snow as function of seeding operations.

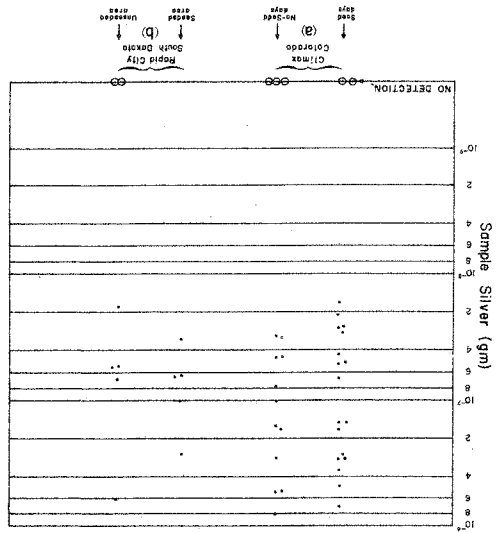
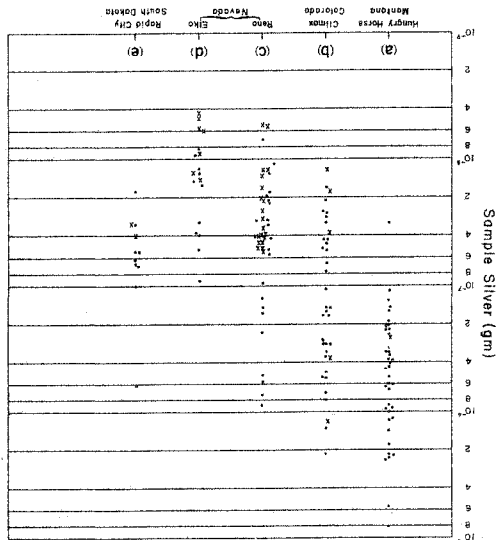


Figure 1. Silver measured in snow samples from geographical regions of western United States.



Sample	Location	Seeding Area	Seeding Date	Seeding Time	Seeding Rate	Seeding Method	Seeding Equipment	Seeding Operator	Seeding Supervisor	Seeding Agency	Seeding Purpose
1	Almanor	Almanor	10 February	11:15	1000	Hand	Hand	John F. H. H.	John F. H. H.	U.S. Forest Service	Seeding
2	Almanor	Almanor	10 February	11:15	1000	Hand	Hand	John F. H. H.	John F. H. H.	U.S. Forest Service	Seeding
3	Almanor	Almanor	10 February	11:15	1000	Hand	Hand	John F. H. H.	John F. H. H.	U.S. Forest Service	Seeding
4	Almanor	Almanor	10 February	11:15	1000	Hand	Hand	John F. H. H.	John F. H. H.	U.S. Forest Service	Seeding
5	Almanor	Almanor	10 February	11:15	1000	Hand	Hand	John F. H. H.	John F. H. H.	U.S. Forest Service	Seeding
6	Almanor	Almanor	10 February	11:15	1000	Hand	Hand	John F. H. H.	John F. H. H.	U.S. Forest Service	Seeding
7	Almanor	Almanor	10 February	11:15	1000	Hand	Hand	John F. H. H.	John F. H. H.	U.S. Forest Service	Seeding
8	Almanor	Almanor	10 February	11:15	1000	Hand	Hand	John F. H. H.	John F. H. H.	U.S. Forest Service	Seeding
9	Almanor	Almanor	10 February	11:15	1000	Hand	Hand	John F. H. H.	John F. H. H.	U.S. Forest Service	Seeding
10	Almanor	Almanor	10 February	11:15	1000	Hand	Hand	John F. H. H.	John F. H. H.	U.S. Forest Service	Seeding

(2) Storm of 3-4 March 1967

References to Table I and Figure 3 indicate that the silver in the Reno snow could have come from one of the three southern California seeding areas. A low pressure system had developed with its center near Reno, Nevada. Winds flowed into Reno from all sectors during the operational seeding periods given in Table I.

(3) Storm of 10-11 March 1967

Heaviest precipitation in the Reno-Mt. Rose area occurred between 0400 on 10 March and 0300 hours on 12 March. The snow, as in the other cases was collected in a tower mounted about 15 feet above the ground. This snow was not taken from the tower until March 20 and was covered by precipitation from later snow falls. However, we are confident that the snow analyzed fell during the March 10-11 storm period. Reference to Table I and Figure 3 indicate possible sources of contamination as the southern Sierra seeding projects. Winds were from the sector 180° to 240° in the altitude range 4,000 to 15,000 feet.

(4) Storm of 15-16 March 1967

Heaviest precipitation in the Reno area was from 1800 hours 15 March to 2200 hours 16 March. The wind sector during the period of the storm was 170° to 240°. Possible sources of contamination in the Reno snow were San Joaquin or King's River.

(5) Storm 28-29 March 1967

References to Table I and Figure 3 indicate the possible sources of contamination in Reno as the southern Sierra. The seeding times and wind directions were consistent with the arrival of silver in snow falling in the Reno area.

In summary, it is seen that considerable amounts of silver iodide seeding have occurred on all days when snow samples collected in the Reno-Mt. Rose area contained silver in concentrations higher than "background". The seeding times and wind directions were such that seeding material from these operational programs could have drifted into the nominally unseeded area at Mt. Rose.

(b) Figure 2 (b) indicates that the precipitation samples from the unseeded area in South Dakota, contained quantities of silver comparable with those in samples collected in the adjacent seeded area. These results could be interpreted as contamination by seeding material which had drifted into the unseeded area from the target area on seeding days. However, some of these results are not so readily explained. Reference to a case study report by Vickers and Goyer^{15/} (1966), which describes, in considerable detail, the seeding operations on the Project Hailswath days in question, show that it is not possible, readily, to account for the presence of high concentrations of silver in the control area on days when such high concentrations were observed.

C. "Persistence" in Seeded Areas on Unseeded Days

Smith^{16/}, et al (1958) have shown that silver iodide decays as an ice nucleant under the action of ultraviolet radiation. It is therefore debatable that particles, released from seeding generators, can survive in an ice-nucleating form for extensive time periods. The detection of silver in precipitation does not provide information on the chemical form in which the silver existed when it entered the precipitation, but merely that it is there.

(a) The Hailswath results described above and illustrated in Figures 1 (e) and 2 (b), suggest that the silver is still present in the atmosphere where the precipitation has formed. It is therefore possible that the large silver concentrations observed in this nominally unseeded rain and hail originated at an earlier seeding time, and has persisted in some way in the atmosphere in the vicinity of the silver iodide seeding generators.

(2) Figures 1 (b) and 2 (a), giving analysis results for the Climax, Colorado area, show that the silver content in general is quite high, and is indicative of values obtained elsewhere in seeded target areas. However, the no-seed days' snowfalls contain as much silver as the seeded-day snowfalls. These snow samples were all collected in towers designed to avoid blowing snow entering the snow catcher.

This result is consistent with that of Grant (1963) who observed continuing high ice nuclei counts in the atmosphere on days when no seeding was occurring, but following days when it had occurred.

Conclusions

Results of silver analyses by thermal neutron activation have been presented for precipitation samples collected in five geographical regions of the western United States. Eighty percent of the samples which had volumes of about 1 liter of water, contained silver in quantities greater than 6×10^{-9} gm.

Precipitation from two of the mountainous regions seeded with silver iodide during the winter of 1966-1967, contained silver in quantities up to two orders of magnitude greater than was observed in a similar unseeded region.

Snow samples from one other mountainous region seeded by similar methods, consistently gave low silver content values. These results cast doubt on the accuracy with which the seeding material can be dispensed into the target area involved.

In two of the regions, where randomized seeding is occurring (with seeding periods of one day), the silver concentrations in the unseeded area or on "no-seed" days are found to be as high as those on "seed" days and in the seeded area.

In another mountainous area where no silver iodide seeding is being conducted, significant quantities (greater than 10^{-7} gm) of silver were detected in snow samples from particular storms. This silver may have originated in operational seeding areas upwind of the unseeded region.

Further work is needed to enable a distinction to be drawn between the conclusion that a "persistence" effect for silver may be occurring in the atmosphere in the general vicinity of silver iodide seeding generators, and the conclusion that the same results could be produced by contamination from an adjacent seeded area of the same experiment, or from another different seeding experiment, as appears to have occurred in the Reno-Mt. Rose area of the eastern Sierra Nevada.

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