Historical Perspective and References

Operational weather modification projects have benefitted from the results of numerous research experiments that have been conducted since the 1950's and 1960's. Many of the early experiments relied on statistical evaluation of precipitation data to determine if cloud seeding was having a positive impact. As techniques and instrumentation evolved, the impacts of cloud seeding began to be documented from the initiation of ice in clouds to the measurement of precipitation at the surface.

Wintertime cloud seeding for snowpack augmentation has historically involved a variety of techniques, seeding materials and dispensing methods. The research has been conducted in numerous mountainous areas of the western U.S., including the Rocky Mountains of Colorado and Montana, the Cascade Mountains of Washington, and the Sierra Nevada of California. Research results can be found in the references listed below:

Hess, W. N., 1974:
Weather and Climate Modification. John Wiley & Sons, Inc., 842 pp.
Hobbs, P.V., 1975:
The nature of winter clouds and precipitation in the Cascade Mountains and their modification by artificial seeding. Parts I and III. J. Appl. Meteor., 14, 783-804 and 819-858.
Dennis, A. S., 1980:
Weather Modification by Cloud Seeding. Academic Press, 267 pp.
Braham, R., Jr., 1986:
Precipitation Enhancement - A Scientific Challenge. Amer. Met. Soc., Meteorological Monographs, 31, 171 pp.
Reynolds, D.W., 1988:
A report on winter snowpack-augmentation. Bull. Of the Amer. Met. Soc., 69, 1290-1300.
Super, A.B. and J.A. Heimbach, Jr., 1988:
Microphysical effects of wintertime cloud seeding with silver iodide over the Rocky Mountains. Part II. Observations over the Bridger Range, Montana. J. Appl. Meteor., 27, 1152-1165.
Super, A.B., and B.A. Boe, 1988:
Microphysical effects of wintertime cloud seeding with silver iodide over the Rocky Mountains. Part III. Observations over the Grand Mesa, Colorado. J. Appl. Meteor., 27, 1166-1182.

Deshler, T., D.W. Reynolds and A.W. Huggins, 1990:
Physical response of winter orographic clouds over the Sierra Nevada to airborne seeding using dry ice and silver iodide. J. Appl. Meteor., 29, 288-330.

Some Newer Methodologies

More recent research has dealt with trace chemistry techniques for detecting seeding effects in the snowpacks of mountainous areas, the use of microwave radiometers for evaluating cloud seeding potential, and the use of numerical models for simulating the dispersion of cloud seeding material. Examples are as follows:

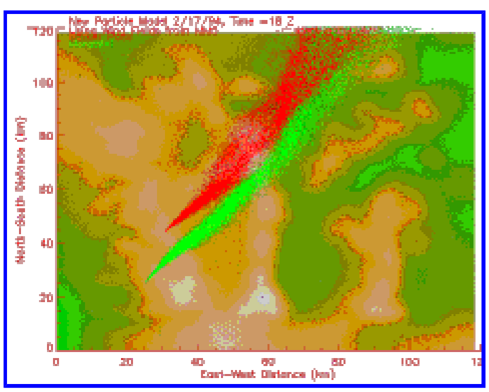
Warburton, J.A., L.G. Young and R.H. Stone, 1995:
Assessment of seeding effects in snowpack augmentation programs: Ice nucleation and scavenging of seeding aerosols. J. Appl. Meteor., 34, 121-130.

Huggins, A.W., 1995:
Mobile microwave radiometer observations: Spatial characteristics of supercooled cloud water and cloud seeding implications. J. Appl. Meteor., 34, 432-446.

Long, A.B. and A.W. Huggins, 1992:
Australian Winter Storms Experiment (AWSE) I: Supercooled liquid water and precipitation-enhancement opportunities. J. Appl. Meteor., 1041-1055.

Holroyd, E.W., III, J.A. Heimbach, Jr. and A.B. Super:
Observations and model simulation of AgI seeding with a winter storm over Utah's Wasatch Plateau. J. Wea. Mod., 27, 36-56.

Model Animation of a Seeding Plume in the Sierra Nevada



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[Atmospheric and Dispersion Modeling]

A Case Study of AgI Seeding Effects in a Winter Storm

The following case study of a ground-based silver iodide (AgI) seeding experiment was developed from data collected during a field research project conducted by the NOAA-Utah Atmospheric Modification Program (a cooperative venture between the State of Utah and the National Oceanic and Atmospheric Administration). The experiment took place on the Wasatch Plateau of central Utah. The State of Utah Department of Water Resources, the U. S. Bureau of Reclamation, the Desert Research Institute, the

NOAA Air Resources Laboratory, the University of North Carolina - Asheville, and North American Weather Consultants participated in the project. The results shown here were taken from two sources (Huggins, 1996a and 1996b)*, as part of the Desert Research Institute's contributions to program.

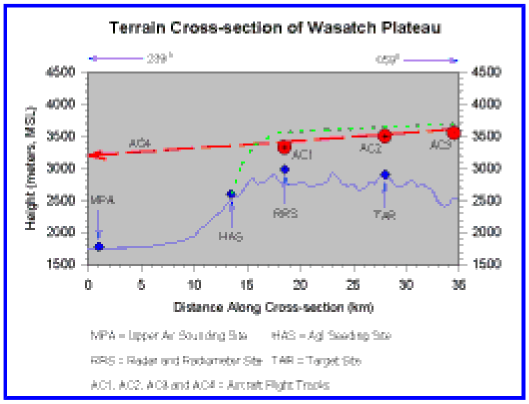


Figure 1. Shown here is a southwest to northeast cross-section of Utah's Wasatch Plateau. The locations of the main instrument sites and the cloud seeding generator site are noted. The NOAA research aircraft flew tracks through this cross-section at AC1, AC2 and AC3, and one track along the cross-section (AC4).

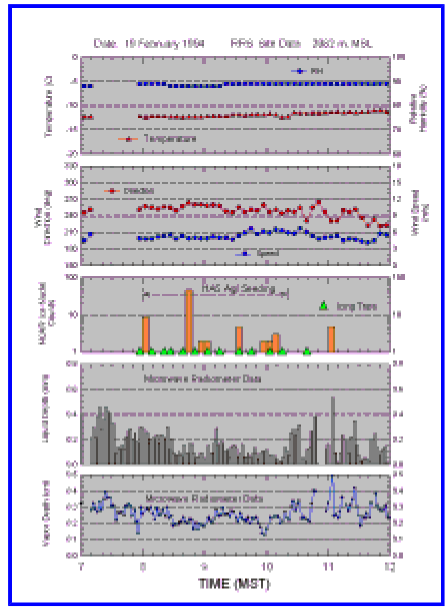


Figure 2. Data from the RRS site at the top of the Wasatch Plateau show the atmospheric conditions in which the cloud seeding experiment was conducted. The temperature was relatively steady at about -12° C (top panel), the wind was relatively light and blowing from the southwest (along the cross-section in Figure 1), and supercooled cloud liquid detected by a microwave radiometer was present in small amounts (4th panel). These conditions indicated that the potential for producing a seeding effect was very good. The seeding material being used (AgI) can produce ice crystals in the presence of supercooled cloud water, provided the temperature is colder than about -5° C. The relatively slow wind speed suggested there would be adequate time for ice crystals created by seeding to grow and fall out over the top of the plateau. The third data panel shows ice nucleus counts and the occurrence of icing at RRS. The low ice nucleus counts indicate that the AgI seeding material did not pass across RRS (see Figure 3). The indication of icing shows that the RRS site was frequently in the cloud that formed over the plateau.

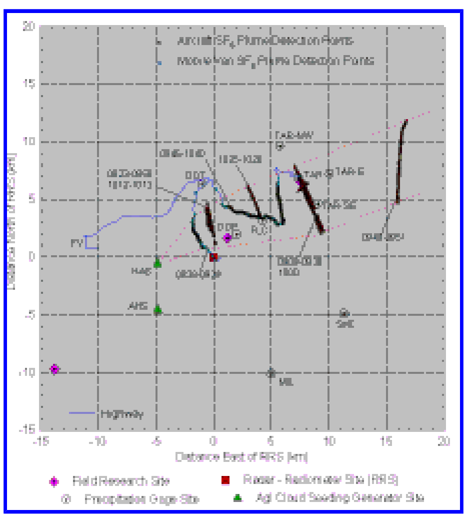
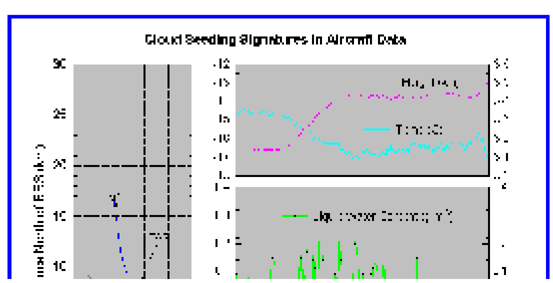


Figure 3. The transport and dispersion of an aerosol plume across the Wasatch Plateau from a single ground seeding source at HAS is depicted. The seeding experiment consisted of the simultaneous release of AgI and a tracer gas, sulfur hexaflouride (SF6). An instrumented van was operated on roads on top of the plateau and a NOAA research aircraft was flown 300 to 600 m above the plateau (see Figure 1). The van and aircraft were equipped with sensors to detect both ice nuclei (AgI) and SF6, and documented the seeding plume at the locations shown here. Seeding occurred from 0800 until 1020 PST. Although both ice nuclei and SF6 were detected, the figure shows only the SF6 plume interceptions. The top of the seeding plume determined from all aircraft passes through the plume is shown by the dashed green line in Figure 1. Note that four of the project precipitation gages were within the area covered by the seeding plume.

Figure 4. An example of a seeding effect detected by the research aircraft is shown here at a location about 38 minutes downwind of the seeding generator. The left panel shows the aircraft flight track with the box indicating where the aerosol seeding plume was detected. The panels on the right show the aircraft height and air temperature (top); the liquid water content in the cloud (2nd); the concentration of ice particles



greater than 0.1 mm in diameter (3rd) as measured by an optical array probe (OAP); and the SF6 and ice nucleus concentrations (bottom). The ice nuclei counter takes about 1 minute to process an air sample, resulting in the time difference in detection of the two plumes. The dashed red lines in the right panels show the seeding aerosol plume locations. The seeding effect is clearly seen as an enhancement in the ice crystal concentration (about 5-20 crystals per liter of air) within the plume, as compared to cloud regions on either side of the plume.

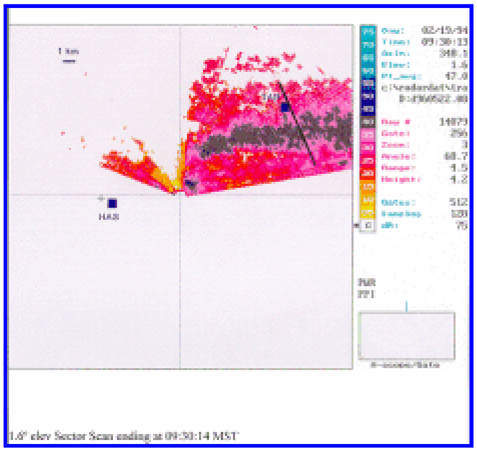


Figure 5. Once ice crystals grow to sufficient size they can be detected by radar. The radar used for this Utah project was the DRI Ka-band radar, a special short wavelength (8.6 mm) radar used primarily for cloud physics studies, and capable of detecting cloud particles even before they reach precipitation size. This image shows the radar echo plume that evolved as a result of ice crystals created by the AgI seeding from HAS. The plume-like radar echo was found to coincide with both the aerosol plume (Figure 3) and the aircraft ice crystal plume locations (Figure 4). The aircraft SF6 plume location matching this radar image time is shown by the line segment near the TAR site. This low level scan detected ice particles within a few hundred meters of the surface, and therefore also gives an indication of the areal coverage of precipitation that was being produced by the seeding.

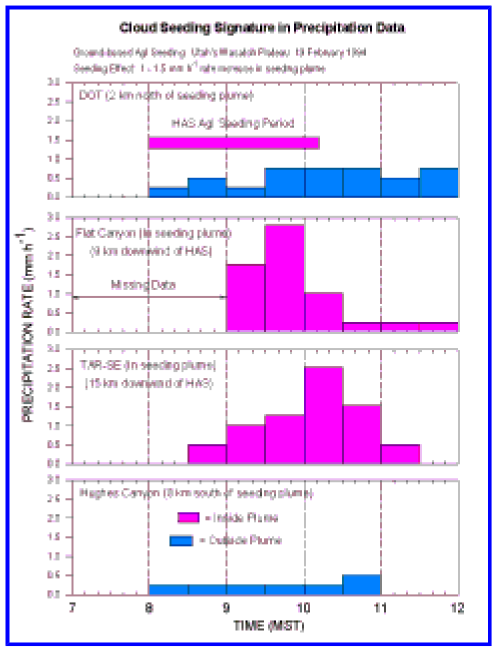


Figure 6. This final figure compares precipitation from gages beneath the seeding plume (as determined by the data in Figures 3 and 5) to precipitation from gages to the north and south of the seeding plume. The seeding during this experiment accounted for a precipitation rate increase of about 1-1.5 mm h-1. Using 1.25 mm h-1 as the average increase, the two hour experiment would have produced 2.5 additional millimeters of snow water over the area affected by the plume. The radar plume areal dimension was about 50 km2. The volumetric amount of snow water produced by seeding can then be estimated as being 125,000 m3, or about 100 acre-ft.

*

Huggins, A. W., 1996a:
Use of radiometry in orographic cloud studies and the evaluation of ground-based cloud seeding plumes. Preprints 13th Conference on Planned and Inadvertent Weather Modification, Atlanta, Georgia, Amer. Met. Soc., 142-149.

Huggins, A. W., 1996b:
Investigations of winter storms over the Wasatch Plateau during the 1994 NOAA-Utah Field Research Program. Final Report to State of Utah Dept. of Water Resources, Desert Research Institute, Reno, Nev., 133 pp.

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