EXPERIMENTS WITH PULSED SEEDING BY AGI AND LIQUID PROPANE IN SLIGHTLY SUPERCOOLED WINTER OROGRAPHIC CLOUDS OVER UTAH'S WASATCH PLATEAU

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Abstract. A series of orographic cloud seeding experiments were conducted on Utah's Wasatch Plateau during the 1994-95 and 1995-96 winters. Their purpose was to permit physical assessment of the effects of both silver iodide and liquid propane seeding, particularly at only slightly supercooled temperatures. Seeding materials were released in 1-hour and half-hour pulses from a location well up the plateau's windward slope. The terrain often channeled the seeding plumes to an observation site, or target, located at a canyon head on the Plateau top's windward edge. Snow particles were detected at the target with a vane-mounted 2D-C optical array probe whose strobing speed was governed by a heated anemometer. AgI nuclei were detected there by an NCAR ice nucleus counter to confirm the presence and successful targeting of seeding materials.

The experiments were carried out in conditions both favorable and unfavorable for expected effectiveness of the seeding agents. There was no evidence for the effectiveness of AgI plumes injected into clouds at a release site temperature warmer than about -3 °C and target temperature of about -5 °C. Increases in ice particle concentrations and precipitation rates were observable for AgI seeding with target air temperatures colder than -6 °C.

Liquid propane was released into air at temperatures of -0.4 to -3.4 °C, resulting in about 10 ice particles L^{-1} at the target with only one release nozzle and about 20 L^{-1} for two nozzles. The difference in ice particle concentrations formed by adding the second nozzle was statistically detectable at a 6 percent level or better, depending on the measurement type. While a temperature dependence of the liquid propane was not observable over such a small temperature range, the experiments have shown that liquid propane is an effective seeding agent for slightly supercooled clouds at temperatures where AgI is ineffective.

Seeding plume detection appeared to be limited during periods of abundant natural snowfall. The larger natural crystals appeared to compete for the available supercooled liquid water and may have removed many of the seeded embryos by aggregation.

1. INTRODUCTION

The first half of a 2-winter orographic cloud seeding program over Utah's Wasatch Plateau was reported by Super and Holroyd (1997). They described a series of experiments that released AgI and liquid propane directly into, or just below, orographic cloud from a high altitude site (HAS) well up the windward (west) slope. The results were detected 315 m uphill and 4.2 km downwind at the Plateau crest target site (TAR). The terrain routinely channeled the flow from most southwest winds at the HAS to cross the crest at or near the TAR. During the first winter of experiments the seeding materials were released in one-hour pulses so that microphysical changes could be monitored between the seeded plume and the period of natural snowfall before seeding. During both winters clouds with TAR temperatures colder than about -4°C were treated with AgI in order to document the limits of effectiveness of that seeding agent at relatively warm temperatures. Warmer clouds were treated with liquid propane. Super and Holroyd (1997) presented a few detailed case studies and briefly mentioned the other experiments.

During the second winter season, 1995-1996, seeding pulses were shortened to half-hour in order to increase the number of cases. Unlike the previous winter, field technicians were instructed to wait for periods of limited natural snowfall before undertaking seeding experiments, the intention being to maximize any "seeding signal." However, review of the data suggests that instruction was often ignored.

Except for the first seeding date in November, two nozzles were used during the second season for releasing the liquid propane in order to double the potential production rate of ice particles compared with the prior winter. Other aspects of the experiments remained the same. AgI was released for about 3 minutes at the start and end of the releases of liquid propane to provide a "tag" by which to verify proper targeting and the arrival times of the edges of the plume at the TAR site. AgI ice nuclei (IN) were detected with an NCAR IN counter operated continuously at TAR. Snow particles were detected there with a tower-mounted optical array probe (2D-C) with resolution of 0.025 mm. A vane oriented the 2D-C probe into the wind and a nearby anemometer provided the wind speed for proper strobing of the instrument. Precipitation gages were operated near the TAR and at sites downwind and crosswind. Further details of the experimental design, including a map of the area, were described by Super and Holroyd (1997).

The two winters yielded a total of 31 AgI and 39 propane experiments. The 70 experiments, of varying quality, are described in detail in the attached appendices in order to help readers to perform their own reanalyses if they choose to do so.

2. PRECIPITATION RATE MEASUREMENTS

Two types of instruments were used to measure the precipitation rate at the Target. Nearby the Target in a sheltered clearing was the Belfort Universal Gage with an enlarged orifice and Alter Shield. The paper charts had a one-day rotation period and were operated for about one week between changes. Dry periods had an overwritten ink trace but storm periods were easily resolvable. The enlarged orifice allowed measurements with twice the normal 0.01 inch resolution. Its charts were scanned into a computer image file at 200 dots per inch, allowing a reading resolution of 0.0025 inch of precipitation and time resolution of 38 seconds. Accuracy, however, was much less than that. The ink trace on the chart paper frequently exhibited jumps of over 0.01 inch of precipitation. Some jumps may have resulted from caked snow falling from the sides of the orifice into the measurement bucket. Other jumps may have resulted from frictional releases in the levers and axles between the bucket and the pen tip. The timing errors at the start and end of the week of measurements often differed by many minutes, probably attributable to a variable amount of slack in the gears at the start of the measurement period. The gage is still highly important because it gives a nearly absolute measurement of snowfall onto the ground.

The 2D-C optical array probe was mounted horizontally 8 m above ground on a tower in an intentionally windy location. It could sometimes be affected by blowing and drifting snow if the wind lifted it to above the instrument height. It obviously could not sample the identical snow falling into the sheltered gage 250 m away from the tower. The probe had a physical limit to its field of view of 0.8 mm. Snow particles intersecting either edge of the field of view had their lengths estimated primarily by transit time (determined by wind speed) of the visible part of the particle. Large particles were excluded from consideration if their centers were estimated to be outside of the field of view. The analysis program (Holroyd, 1987) estimated the size, concentration, and habit of the snow particles. From those measurements the masses and terminal velocities were estimated and a precipitation rate was derived. The calibration constants used were measured from a limited number of snow periods sampled on top of the Grand Mesa in Colorado using snowboards, which had more accuracy and resolution than the gage, and a gage with an orifice of five times the sampling area of a standard orifice. The habits tended to be planar on the Grand Mesa during those measurements and only a limited number of columnar and needle events were documented. The Utah experimental measurements were usually at warmer temperatures at which columnar and needle habits would dominate. Therefore it is to be expected that precipitation estimates from the 2D-C may not agree with those from the gage. The 2D-C is important to these studies because it can give a continuous precipitation record of high resolution (particle-by-particle) which can be further examined by size and habit classifications. The calibration uncertainties mean that the data are best understood as relative measurements, typically within about a factor of two of gage measurements.

3. A NATURAL DATA SET

While the case studies presented by Super and Holroyd (1997) show some obvious seeding effects, much of the ice particle production over the two winters of study was partly masked by natural variability of precipitation. A natural data set for understanding the variability of the snowfall and the

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two measurement techniques was selected from the two years of measurements on the Wasatch Plateau. It was restricted to half-hour intervals of natural snow. Periods of potential seeding effects were excluded. The intervals could start on any five-minute mark within an hour and they could be separated in time from adjacent intervals. Furthermore, there had to be three such half-hour periods within an experimental storm period measured by the 2D-C for simulating "control-plume-control" measurement ratios when there were no seeding effects at all. That way the natural variability of the precipitation could be compared to the size of the estimated effects of the cloud seeding. The natural data set time intervals and precipitation rates from the two instruments are listed in Appendix 1, Table A1.1. Different sets of time intervals are possible, but they should result in similar statistics.

Precipitation measurements were made for the same time periods for both the gage and 2D-C; no allowance was made for timing differences resulting from transit time between the 2D-C and the nearby gage. The transit times from the HAS to the TAR (4.2 km) had a median of 17 minutes and a typical range of 10 to 30 minutes. The gage was about 250 m beyond the TAR instruments or about 60 s further in transit time. Using a terminal velocity of about 0.5 m s^{-1} for typical snow crystals from the seeding experiments, crystals passing by the 2D-C instrument 8 m above the ground would reach the ground 16 s later about 66 m downwind, far short of the gage. Larger natural particles will reach the ground even faster. Therefore the gage cannot be sampling the same snow particles as the 2D-C and differences in measurements should be expected.

4. AN 0.8 MM SIZE MAXIMUM

Snow particles resulting from seeding were expected to be small because of their limited growth time. Several data sets were examined in which the effects of seeding appeared to be very obvious, with enhanced concentrations many times background values (see Super and Holroyd, 1997). There were a variety of transit times and air temperatures for those sets. It was expected that snow particles with faster growth rates and/or longer transit times would have larger sizes at the TAR. However, the median sizes and 90-percentile large sizes did not vary much among experiments. Nearly all of the particle sizes that appeared to be produced by seeding were smaller than 0.8 mm, regardless of the size predictions based on transit time and growth rates. This result, from a more diverse data set, is different from the presentation in the previous paper in which a maximum growth was expected to be predictable from the available growth time.

It is likely that larger particles from seeding hit the ground before they reached the Target. At 0.5 m s^{-1} fall speed and 17 min transit time, typical particles will fall about 0.5 km relative to non-convecting air. Some small particles produced by seeding did not necessarily grow much during their transit if they happened to linger in dry parts of the clouds or amongst the trees. Particles larger than predicted may have convected to higher and colder parts of the cloud and experienced faster growth rates before falling back to the surface. It appears that such natural causes produced a similar size distribution for seeded snow particles, regardless of conditions, by the time they reached the target. In order to make the 2D-C estimates of precipitation more sensitive to the snow particles produced locally, rather than those natural particles advecting in from great distances, a size maximum of 0.8 mm was applied to the analyses for the seeded data sets and comparison analyses of the natural data set. Such 2D-C measurements will be labeled with the word "small", as opposed to "all", particles.

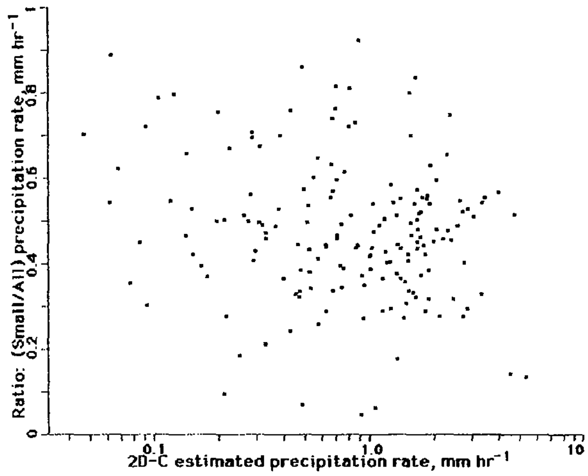

Figure 1. The ratio of precipitation rates for small versus all particles does not vary much with the precipitation rate itself.

The natural half-hour data set was examined with and without the 0.8 mm maximum size limit. A ratio of the precipitation rate for the smaller particles was made to that of all particles. If the ratio was near unity, then most of the particles contributing to the precipitation rate were small. Likewise, if the ratio was near zero, then most of the precipitation was coming from large particles. Figure 1 shows a plot of that ratio versus the precipitation rate estimate for all particles. Half-hour intervals with 2D-C precipitation rates of less than 0.04 mm hr^{-1} and/or with gage measurements of zero were excluded as being too light to properly resolve. The plot of 172 points shows essentially pure scatter with only a slight tendency for a smaller ratio with the heavier precipitation rates.

It was expected that a stronger trend would emerge because the 2D-C has greater difficulty assessing the larger snow particles that contribute most strongly to the heavier snowfall rates. However, it appears that the use of analyses based on the 0.8 mm maximum size limit will not be adversely biased by the precipitation rate itself or the presence of the large sizes apart from the intentional exclusion of those large particles.

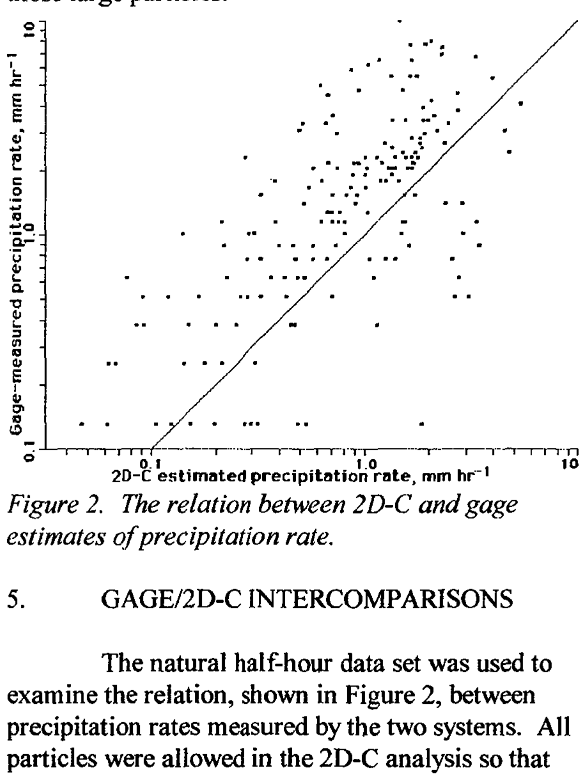

Figure 2. The relation between 2D-C and gage estimates of precipitation rate.

5. GAGE/2D-C INTERCOMPARISONS

The natural half-hour data set was used to examine the relation, shown in Figure 2, between precipitation rates measured by the two systems. All particles were allowed in the 2D-C analysis so that the results would come closest to the gage measurements. The latter were not adjusted for an extra minute of transit time between the 2D-C and gage. The diagonal line is for a perfect match. Gage values of zero (less than 0.13 mm h^{-1}) and 2D-C values less than 0.04 mm h^{-1} were excluded to facilitate the use of logarithmic scales while plotting the data. It is seen that 2D-C rates are typically lighter than those measured by the gage but the general tendency has about the same slope as the diagonal line. Furthermore, there is an abundance of scatter. The original 2D-C calibrations on the Grand Mesa (Holroyd, 1987) also had considerable scatter in the relation between precipitation totals measured by snowboards and gages and totals estimated from the 2D-C data. That scatter had a standard deviation equivalent to a factor of about 2.

The 172 points were partitioned by the small/all precipitation ratio shown in Figure 1 in order to see if particular sizes had different characteristics in the scatter of points. The results are shown in Table 1. The r^2 is the square of the correlation coefficient for a linear least squares fit of the logarithms of the precipitation rates. The means and medians indicate that the 2D-C precipitation rate estimates are generally between half and three-quarters the rates measured by the gage. The standard deviation of the scatter is usually more than twice the size of the gage precipitation rate measurements.

The best correlations are for the extreme sizes. When typical ice particle sizes are large, then the 2D-C estimates are about 63 to 72 percent of the gage measurements with a scatter of a factor of 2.12. When typical sizes are small (mostly smaller than 0.8 mm) the 2D-C estimates are about 52 to 56 percent of the gage measurements with a tighter scatter of a factor of 1.68. The worst scatter (factor of 2.80) is for snowfalls of mostly small particles with a few large ones present.

The general offset seen in Figure 2 of 2D-C measurements from gage values indicates that the mass and terminal velocity estimates assigned by the software need adjustments for the Utah clouds. One day in particular, 30 December 1995, had 2D-C

Table 1. Relationships between 2D-C and gage measurements of precipitation rate. The mean, median, and standard deviation are expressed as a factor times the gage values.

Precip.Ratio	r^2	mean	median	std.dev.	count	sizes
All	.4489	.61	.60	2.30	172	all
0 to 1/3	.5050	.72	.63	2.12	31	large
1/3 to .5	.4048	.58	.59	2.26	72	
.5 to 2/3	.2945	.64	.61	2.80	45	
2/3 to 1	.7720	.56	.52	1.68	24	small

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estimates much greater than gage measurements for needle particles. No calibration adjustments to the constants in Holroyd (1987) will be made for the 2D-C rate estimates presented here. In the results to follow it must be remembered that the 2D-C estimates will generally (but not always) be less than the gage measurements.

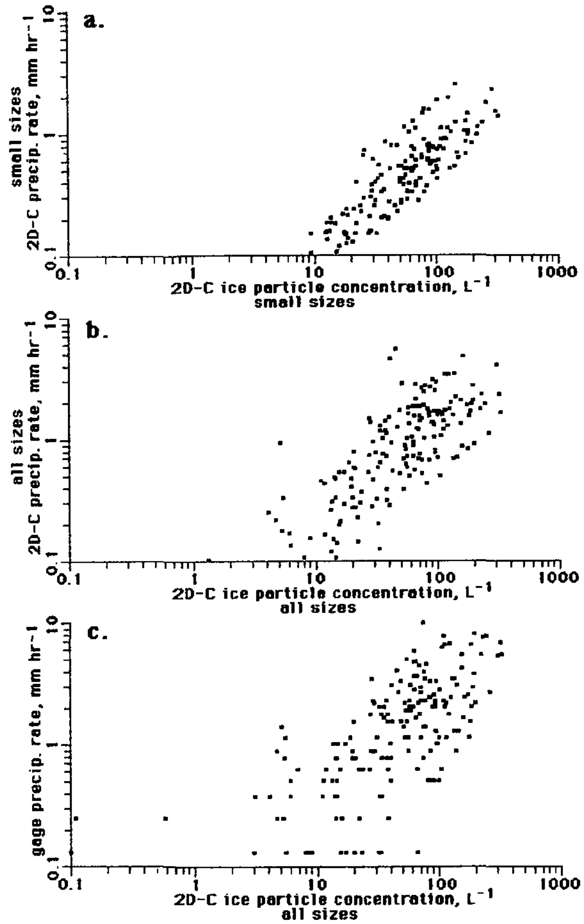

Figure 3. The precipitation rate for three measurement styles is proportional to the ice particle concentration measured by the 2D-C. The natural variability of masses for the particles contributes much of the scatter.

The 2D-C calculation of precipitation rate is dependent upon the ice particle concentration (IPC), as shown by the relatively small amount of scatter in Figure 3 a and b for the "small" and "all" partitions of the natural data set. However, the 2D-C and the gage are independent instruments. Figure 3 c shows the scattered relationship between the 2D-C IPC and the gage precipitation rate. In all three panels the precipitation rates of trace (<0.1 mm h^{-1}) and zero have been deleted. Ignoring the noisy data points in the lower left, it appears that a natural IPC of less than 3 L^{-1} does not produce snowfall that can be reliably measured by the gage over the typical duration of the experiments. (The data at half-hour intervals with doubled orifice area are equivalent to use of a standard orifice at 1-hour intervals.) Seeded ice particles are typically smaller than natural particles because of shorter growth times. Therefore it requires a greater concentration of them to produce a precipitation rate comparable to that measured in a precipitation gage by a lesser number of the larger, natural particles.

The data of Figure 3 reveal that all but a small portion of the samples had an IPC in excess of 10 L^{-1} associated with hourly snow water equivalents of 0.25 mm h^{-1} (0.01 in h^{-1}) or more. Most of the population had IPC values between 10 to 200 L^{-1}, with a general increase in IPC as the snowfall rate increased. These natural observations provide further confirmation for the estimates of Super (1994) that winter orographic seeding must produce an IPC in excess of 10 L^{-1} to be effective.

6. NATURAL SAMPLE RATIOS

Preliminary analyses (Super and Holroyd, 1997) of the first winter of the data set compared concentrations and precipitation rates in the seeding plume with those in the control interval before the plume time. Those intervals were about 1 hr in duration. The experiments in the second season were about 0.5 hr for each segment. Buffer periods between the plume and control intervals were of short and variable length, depending on wind speed. A control period after the plume was also examined though not included in the previous results. Comparing the plume properties with the average of the controls on either side is sometimes superior to using the prior control only, because natural temporal precipitation gradients are taken into consideration so long as the seeding plume does not linger to contaminate the later control. In the analyses presented in this report, "plume ratios" of 2*P/(C1+C2) were calculated, where P is the plume value, C1 the prior control value and C2 the subsequent control value. Ratio values of 1 indicate that measurements in the plume are the same as that in the average of the controls. The plume ratio is a measurement of the apparent effectiveness of the seeding pulse in increasing precipitation.

There are no seeding plumes in the half-hour *natural* data set. However, "sample ratios" that are otherwise equivalent to plume ratios can be calculated for numerous combinations of adjacent intervals. They thereby measure the apparent effectiveness of simulated seeding experiments. A particular half-hour interval can be used as either a simulated plume or a control. Intervals at the start and end of an experimental day were used only as controls. Five sets of sample ratios were calculated and presented in Appendix 1, Table A1.1. The 2D-C data provided ratios for concentrations and precipitation rates based on both the small sizes and all sizes. The fifth set of ratios was from the gage precipitation rates.

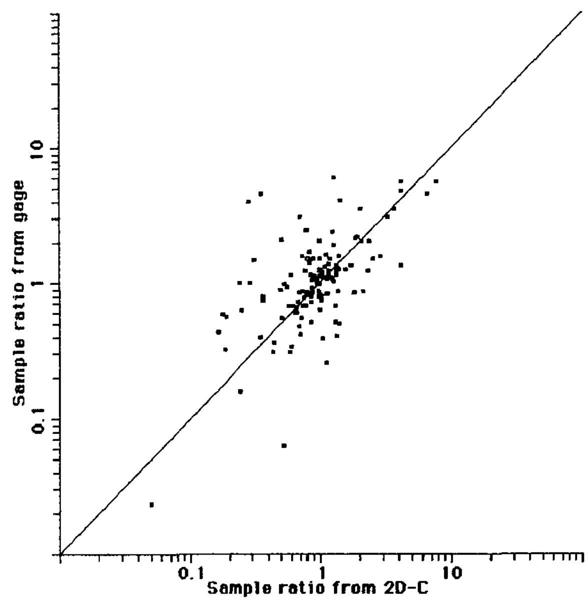

Figure 4. The relation between sample ratios calculated from 2D-C and gage data for the same combinations of control and plume intervals for the natural data set.

The precipitation rate from the 2D-C using all particles is comparable to the precipitation rate from the gage. Their sample ratio relation (simulated seeding effectiveness) is plotted on logarithmic scales in Figure 4. Both 2D-C and gage sample ratios were excluded if the ratio for the gage was calculated as infinite or as zero. There is a great amount of scatter. Further exclusion of the two data points having the gage ratio less than 0.1 removes two outliers but worsens the correlation. Then, with 131 points, the r^2 was 0.304. The sample ratios (simulating the seeding effectiveness) for the 2D-C were 91, rather than 100, percent of those for the gages, which is probably the result of statistical noise. The ratios should be independent of calibration factors and ideally should be identical for the 2D-C and gage measurements of the same time intervals. The scatter of points in Figure 4 shows differences with a standard deviation equivalent to a factor of 1.88. That means that the simulated seeding effectiveness based on the 2D-C typically ranges by a factor of 1.88 greater or smaller than the effectiveness based on the gage. The scatter in the sample ratios for each instrument separately is equivalent to a factor of 1.97 for the 2D-C and 1.94 for the gage.

The same size scatter seems to recur in this analysis. The 2D-C precipitation estimates have a calibration scatter of about a factor of 2 with respect to the gage measurements. That should not matter when the sample ratios are calculated because the same calibration applies to the simulated controls and plume calculations. The sample ratios also have a scatter of about a factor of 2, showing the large natural variability of snowfalls. While the sample ratios from the two instruments should be nearly identical for the same combinations of simulated control and plume intervals, that relationship also has a scatter of about a factor of 2. This data set is entirely natural and has no real seeding effects in it. For seeding effects to be recognizable with only a few experiments the plume ratio will need to be frequently and significantly offset from unity by more than about a factor of 2. The above analysis provides yet another example of the difficulty of demonstrating a "seeding signal" within large but typical natural variability.

Figure 5 shows the sample ratio of the natural data set of Table A1.1 as cumulative distributions on a logarithmic scale for all five sets of measurements and then combined in the lower right. The gage precipitation rate in the lower left has its lower left portion above the positions of the data points in the other graphs because of numerous zero values. Otherwise the curves are all about the same. These natural data set curves will be used as a reference for seeding results. Sample ratios less than unity indicate that the value in the simulated plume, or central measurement, was less than that in the average of the adjacent controls.

7. SEEDING EXPERIMENT DESIGN

Seeding experiments during the first winter had a release of liquid propane or AgI in 1-hour intervals. The second year used half-hour intervals. Each propane interval was tagged with a release of AgI nuclei for about 3 min at the start and at the end

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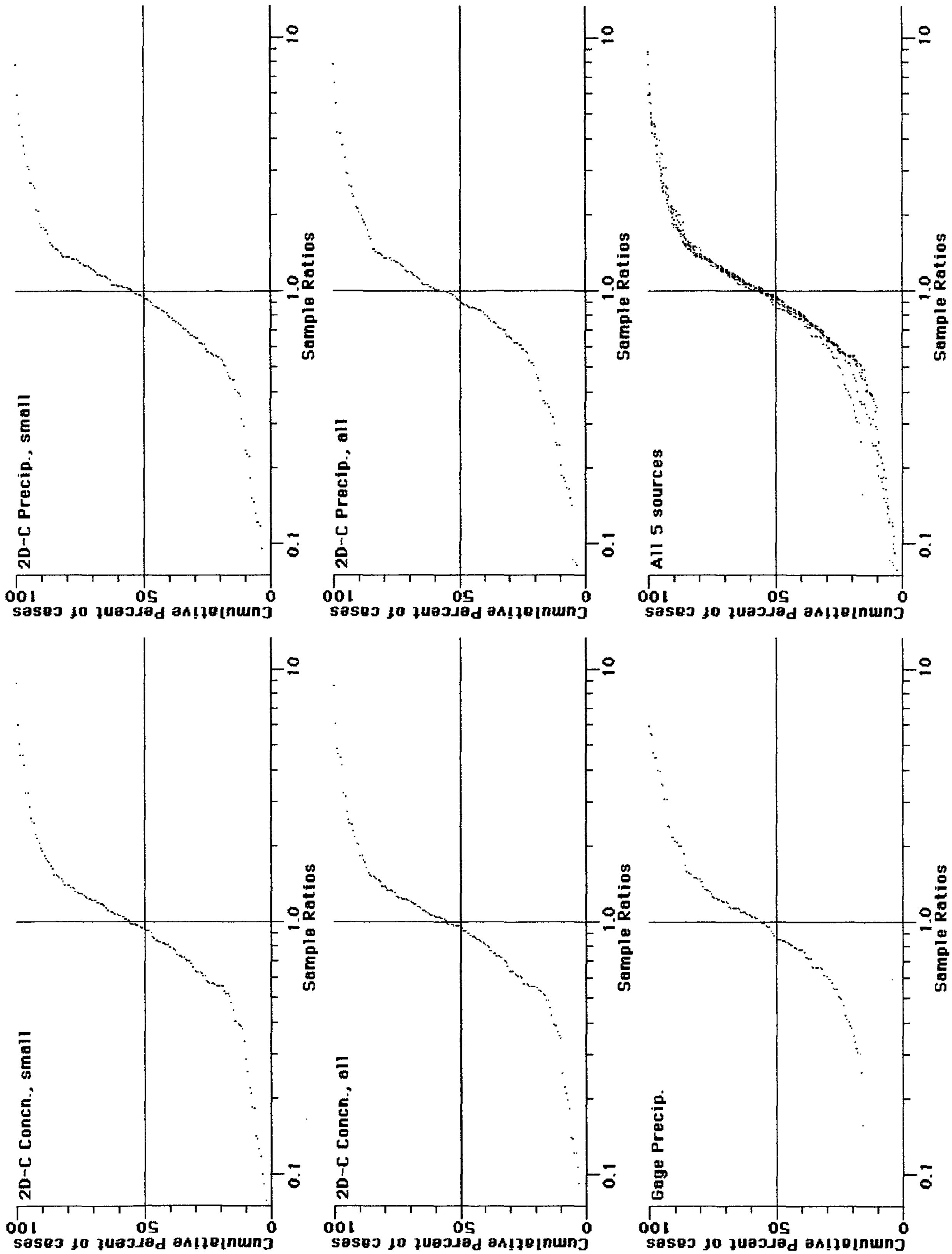

Figure 5. The cumulative distributions of sample ratios in the natural data set according to the five measurement sets and combined in the lower right panel.

of the propane release. A few propane experiments ended with a continuous AgI release indicating an immediate transition into an AgI experiment.

The previous paper presented definitions for the start and stop times of the propane and AgI plumes. It also suggested a need for refinements. The timing definitions in this paper remain essentially the same but with refined notation and calculations of the transit times from the wind speeds.

At the TAR the propane plume start and stop times are declared (as before) to be the clock times of AgI tag ice nuclei peaks. (The IN data are adjusted back 1 min for instrumental delays.) The propane tag peaks correspond to the midpoint of the AgI release interval.

In contrast, there are no tags in an AgI experiment and only an initial time of arrival of IN at the TAR, corresponding to the start of release of AgI, is identifiable. Initial arrival times can also be identified for propane experiments. For consistency, therefore, times are referenced to the start of AgI release, whether for a plume or a tag.

When tags are detectable, a transit time from the HAS to the TAR, T2, is defined as the difference in clock times between the start of AgI release at the HAS and the IN detection peak at the TAR. For a complete propane experiment there is a T2 for the starting tag and another T2 for the ending tag. Those two transit times are averaged in the tables of Appendix 2 for summary purposes. Another transit time, T1, is defined for both tags and AgI plumes as the difference in clock times between the start of AgI release at the HAS and the initial IN detection at the TAR. T1 is always identifiable for both propane and AgI experiments if IN are detected. With the larger, 2-year, data set of propane tags, it was found that $T2 = 1.5 * T1$ with $r^2 = 0.74$. This relation was used to calculate the starting T2 for all AgI experiments for which a T1 was identifiable. One might expect T1 and T2 to differ by only about two minutes, the time from the start to the mid-point of the AgI release, but the difference is much greater. This is attributed to diffusion effects, including a more rapid transport for AgI that diffuses to higher altitudes where there are faster wind speeds. That allows some of the AgI to arrive at the TAR much sooner than the main pulse of seeding materials.

Some propane experiments lacked the detection of one or both AgI tags. All AgI experiments lack a direct means of identifying the ending T2 (transit time) for defining the end of the plume. Therefore an alternate relation, based upon propane tags, was calculated expressing an estimated AgI transit time, T2, from HAS to TAR in terms of the wind speeds at both sites. For wind speeds, S in m s^{-1}, the transit time, T in min, for the 4.2 km is $T=70/S$. A least squares fit with measured AgI transit times with the average wind transit times was found to be $T2=(T_{HAS} + T_{TAR})/2 + 2$ with $r^2 = 0.68$. The extra 2 min comes mostly from measuring the transit time from the start of the AgI release rather than its midpoint. Deriving a T2 based on the average of the wind speeds rather than the average of individual transit times produced different values with less correlation. Deriving a relation for T2 based on only one wind speed also had less correlation. There were a few cases in which the anemometer at the HAS was iced or otherwise indicated calm air but for them a T2 was able to be estimated from T1. Use of T2 based upon wind speeds is not ideal. However, the individual propane experiments requiring this alternate calculation are those which were marginal anyway. One or both of the tags missed the TAR. The use of the wind speed equation was routine for estimating T2 for the end of all AgI experiments. Again, this is not critical. AgI IN presence at the TAR remained abundant after the end of the plume and thereafter began a long exponential decay. It matters little what time is chosen for the end of the AgI plumes.

For all experiments, AgI and liquid propane, the plume interval was defined as between the clock times of the two observed tag peaks, corresponding to T2, or their estimates based upon winds or initial rise time from T1. For all experiments a first buffer interval, with intermediate potential of seeding effects, was defined as between the clock times corresponding to T1 and T2 for the first tag or their calculated equivalents. For all propane experiments a second buffer interval was defined as the 5 min after the time of the second tag peak, at T2, or its calculated equivalent if the tag was missing. For all AgI experiments the second buffer began at the clock time corresponding to the calculated T2 for the end of the plume and ended when AgI nuclei appeared to have returned to a background value. That could be a large portion of an hour, depending on wind speed.

For all experiments a first control period extended back from the time of the initial T1 (start of first buffer) by up to an hour. Shorter periods were necessarily caused by the recording start of the 2D-C data or the ending time of a prior second buffer. If a natural control period between two experiments exceeded 1 hr, then it was divided into two equal halves. In a few cases the controls were truncated to avoid a strong natural shower. Examination of graphs of snow concentration and precipitation rate with time suggested that the strong natural showers were a differing environment from the rest of the control and the seeded interval. Their inclusion would distort the evaluation of the experiment. The second control began at the end of the second buffer and ended up to 1 hr later. It was truncated by a data cessation, a subsequent first buffer, a control subdivision, or a strong natural shower. Such variability in the definition of controls would not be permitted in a statistical confirmatory experiment but can be allowed in a physical exploratory experiment.

The full list of the times separating the controls, buffers, and plumes is listed in Appendix 2, Table A2.1, along with the average of the two transit times (T2) for each experiment and the air temperatures at the HAS and the TAR. The seeding agent is listed as A for AgI and P for liquid propane. The experimental results are listed in Appendix 2, Table A2.2. Control intervals are labeled with a C, buffers with a B, and plumes with a P. In order to accentuate any possible seeding effects, only the "small" particle 2D-C data set was used so as to exclude the large and presumably natural particles. The gage, however, necessarily samples particles of all sizes and should be less sensitive to seeding effects. For all experiments in which two adjacent controls were available, the plume ratios were calculated for the 2D-C concentrations and precipitation rates, and the gage precipitation rates. "INF" is used to indicate that both controls had values of zero, yielding an infinite plume ratio. Plumes lacking one of the controls have dashes instead of plume ratio numbers. It is possible to salvage such experiments by using only one control, as was done in Super and Holroyd (1997), rather than the average of two controls.

8. EXPERIMENTAL RESULTS

8.1 EXPERIMENT PARTITIONING

Though the equipment operators were instructed during the second winter to seed only supercooled clouds, preferably with little natural snow, that was not always the case. Furthermore, wind direction shifts caused the plume to miss the target, TAR, in some cases. The seeding data set therefore needs to be partitioned to exclude bad experiments from serious analysis. That is done in Appendix 2, Table A2.3, without omitting the results of those experiments.

The targeting was evaluated on the strength of the AgI IN detected at the TAR. For the AgI seeding cases it was found that there was a natural break for partitioning at a value of peak IN < 2500 L^{-1}, effective at the NCAR IN counter cloud chamber temperature of -20°C. Peak IN concentrations of less than that were considered the result of bad targeting. The AgI tags for the propane cases were brief and did not produce as great concentrations. A threshold for bad targeting was selected as <u>both</u> tags having peak IN < 1230 L^{-1}. Weak targeting for the AgI cases was defined as having 2500 L^{-1} < peak IN < 10,000 L^{-1}. Weak targeting for the propane cases was defined as having for one tag peak IN<1230 L^{-1}. Table A2.3 thereby partitions the experiments according to bad, fair, and good based on targeting for the AgI and propane cases separately.

No production of ice particles by either technique <u>at</u> the HAS release site is possible for temperatures warmer than 0°C or relative humidities less than ice saturation. Table A2.3 also partitions a set of "bad" experiments by release conditions. Six were too warm and one was too dry. However, AgI could still be transported higher into clouds where appropriately cold temperatures existed for nucleation.

Table A2.3 repeats much of the data from Table A2.2 (control and buffer data are not listed) and adds the HAS relative humidity (RH) and air temperatures at the HAS and TAR from Table A2.1. It is seen that there is great variability in the measured concentrations and precipitation rates as well as in the plume ratio comparisons to the adjacent controls. Only a few experiments have plume ratios exceeding an arbitrary 5. Some of the detailed case studies of Super and Holroyd (1997) are among those. For the experiments with plume ratios near unity it is difficult to know how much is attributable to seeding and how much to natural variability.

8.2 PLUME RATIO RESULTS

The partitioned seeding data set was therefore examined in the style of cumulative distributions of plume ratios as in Figure 5. To reduce data noise the fair and good targeting cases were considered together for each of the seeding styles, AgI and propane. Furthermore all "bad" cases for any reason were considered as "reject" and comparable to natural conditions. Cases lacking one control period were ignored. That left 21 reject, 15 AgI, and 25 propane cases. The results are presented in Figure 6 as three graphs (for three measurements), each with three lines representing the types of cases. In each there is a dotted line showing the curve from the appropriate natural data set of Figure 5.

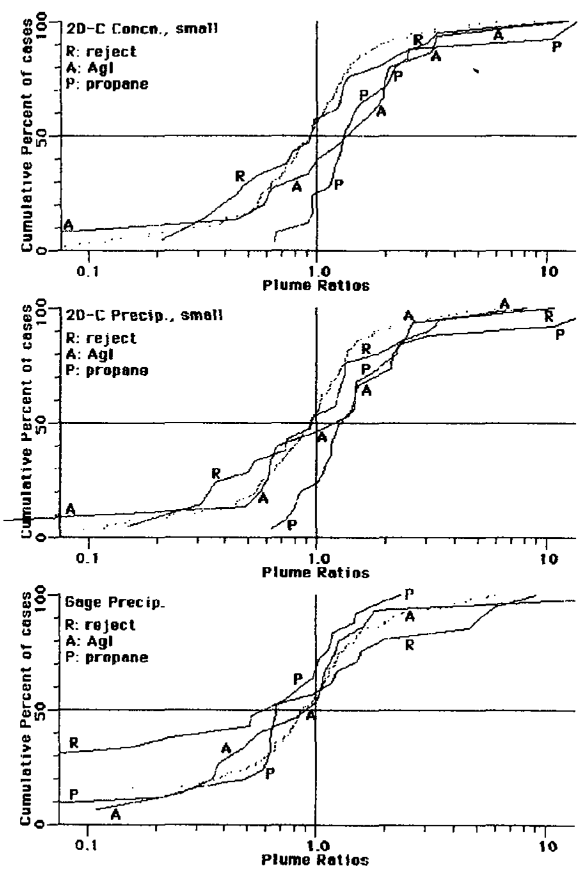

Figure 6. The cumulative distributions of plume ratios in the seeded data set. The three graphs are for the different measurement parameters: 2D-C concentrations and precipitation rates and gage precipitation rates. The dotted lines in each are from the natural data set of Figure 5. The three solid lines in each are for the reject (R), AgI (A), and propane (P) cases.

The top graph of Figure 6 shows the plume ratios based on the 2D-C concentration measurements for particles smaller than 0.8 mm. The reject (R) curve generally follows the dotted natural data set, as should be expected. The AgI (A) curve is offset to larger plume ratios for the middle of the data set but not for the extremes. That suggests that there might be some concentration increases of small particles of about 30 percent, compared to the natural data set, for the typical experiment. The propane (P) curve is everywhere offset to plume ratio values greater than the natural data set, suggesting a routine increase in concentration of small particles of about 60 percent. As shown in Figure 3, precipitation rates are strongly related to concentrations, so the curves of the middle graph are similar to the top graph. In each graph, the lower left is for cases in which the plume value is less than the average control value. That is like the seeding taking place in a time interval between two natural showers. For such cases, while the seeding results, if any, are less than natural production in the adjacent controls, the strongly offset propane curve shows that seeding routinely produced increases over what might have been expected from natural snowfall.

The bottom graph of Figure 6 is different. The reject curve has a lesser slope than the natural cases (dotted) and crosses over, indicated a greater variability in the plume ratios than expected. That results mostly from values of zero precipitation read from the gage charts for both the plumes and the controls. The natural data set, however, should have had the same proportion of resolution problems, and so these results are somewhat puzzling. The AgI and propane curves seem to vary close to the natural data set. The gage measurements include all particles, large and small, with the precipitation rate being dominated by the large, presumably natural, particles. Therefore any seeding increases could be masked by natural snowfalls, of which there were many during the experiments.

Figure 6 shows that the seeding experiments produced detectable increases in particle concentrations and precipitation rates as measured by the 2D-C when only the small particles were considered. The AgI increases were small and only for some of the cases. The propane increases were routine. Seeding effects on snowfall were not detectable in the gage data because it is not possible to separate the relative contributions of the small seeded particles and the large natural particles.

8.3 PLUME INCREASE RESULTS

The seeding results are presented in Appendix 2, Table A2.4, as the plume value minus the average of the control values. The values, labeled as an "increase", may actually be a decrease if negative. It is also apparent if the increase, if any, is of a use-

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ful magnitude. The plume ratio may show a many-fold increase, but if the background value is small, there may only be trace precipitation in the plume. Some environmental data are also presented.

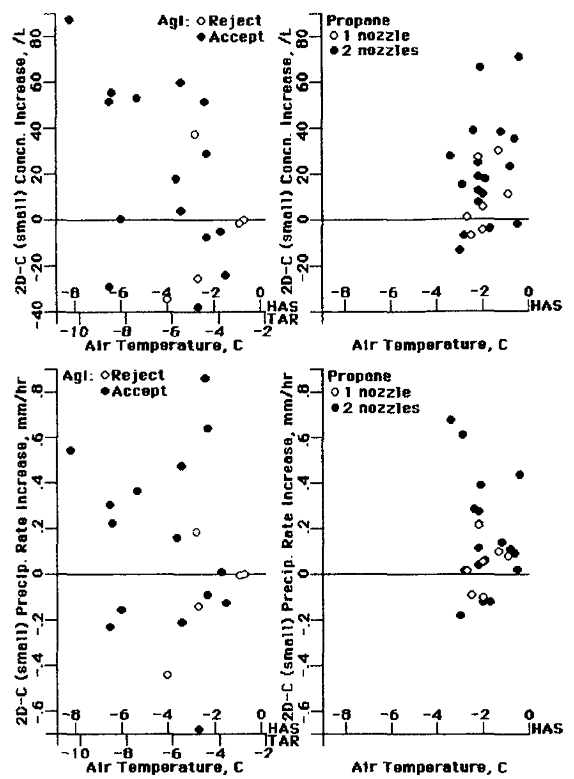

Figure 7. The temperature dependence of concentration and precipitation rate increases for the AgI and liquid propane experiments.

Plots were made of the relations between the "increases" and the environmental values of background concentration or precipitation rate, transit time (wind speed), and air temperatures at HAS and TAR. Only the latter are presented in Figure 7. Linear least squares fits were made to the data to see trends and randomness. After removing case 950305C as an outlier, almost all relationships showed strong randomness, with r^2, the square of the correlation coefficient, less than 0.15. However, for the "bad" experiments the relationship between the concentration "increase" in small particles had a negative slope and $r^2 = 0.52$, with plume values becoming much less than controls with increasing background concentrations. Similarly the 2D-C precipitation rate increase was negatively correlated with the precipitation rate with $r^2 = 0.45$. Such results are puzzling because the "bad" cases are those of missed targeting and warm or dry conditions at the HAS release site. One would expect only natural variations for these cases and therefore randomness in the relationships. The natural in-"plume" concentrations and precipitation rates should not be progressively less than the control values as the snowfalls become heavier.

The only other statistically significant relationship was for the snow concentration (small particles) to be negatively correlated to the air temperature at the HAS ($r^2 = 0.21$) and TAR ($r^2 = 0.22$) for the AgI cases (see Figure 7). This indicates less production of ice crystals at warmer temperatures, as expected, but the scatter in the relationship is large. No increases were observed for AgI releases at HAS temperatures warmer than -2.5 °C, according to Table A2.4.

No other statistically significant relationships were found between the snow concentration, 2D-C precipitation rate, and gage precipitation rate for the reject, AgI, and propane cases and the magnitude of the background values, the transit time or the temperatures.

As a summary, Table 2 presents the median, mean, standard deviation, and number of cases for various data sets and measurement types. The standard deviations in the natural data set are always greater or equal to those in the seeded data set, possibly because the greater number of cases was able to include more of the extreme values. The natural data set was selected to have no seeding effects. Therefore the "increase" values should average to zero in a large data set. In order to evaluate changes produced by seeding the standard error of estimate, z, was calculated by

$$z = (m - \mu) / (s / \sqrt{n}) \qquad (1)$$

where m is the mean measurement, μ is the mean in the natural data set (assumed zero: no increase), s is the standard deviation of the natural data set, and n is the number of measurements. The z is a measure used to evaluate how much the sample mean might statistically depart from the population mean from which the sample is drawn. In the natural data set, summarized in the second group of Table 2, the measured mean concentration "increase" is about 2 ice particles per liter. The variability is large. Therefore the z value of about 0.5 indicates that a measurement of 2 when the actual mean value is zero is within the expectations of natural variability. Similarly, the "increase" in the precipitation rates of 0.02 to 0.05 mm h^{-1} can also be attributed to natural variability when the true "increase" should be zero.

Table 2. The median, mean, standard deviation, and number of cases for the indicated data sets and experimental classes. Concentration units are in snow particles L^{-1} and precipitation rates in mm hr^{-1}. For the "increase" means the standard error of estimate, z, is given under the assumption that the real "increase" in the natural data set is exactly zero.

Part 1: Descriptions of the values, typical of controls, to which changes may be compared.

natural data set type	median	mean	std.dev.	cases
small , 2D-C concentration	40.6	59.7	62.	198
all , 2D-C concentration	46.8	64.2	65.	198
small , 2D-C precip. rate	.341	.464	0.45	198
all , 2D-C precip. rate	.723	1.011	0.97	198
gage , precipitation rate	1.14	1.75	1.87	198

Part 2: Descriptions of departures (increases) from the actual control values.

natural data set type	median	mean	std.dev.	cases	z
small , 2D-C concentration	-.5	2.0	53.	154	0.47
all , 2D-C concentration	-.1	2.2	55.	154	0.50
small , 2D-C precip. rate	.001	.020	0.40	154	0.62
all , 2D-C precip. rate	-.006	.047	0.89	154	0.66
gage , precipitation rate	-.04	.02	1.67	154	0.15

seeded data set type	median	mean	std.dev.	cases	z
Reject , 2D-C concentration	-.8	-2.2	28.	20	-.19
AgI , 2D-C concentration	18.3	20.5	38.	15	1.50
Propane, 2D-C concentration	15.0	17.7	21.	25	1.67
Reject , 2D-C precip. rate	-.002	-.011	0.21	20	-.12
AgI , 2D-C precip. rate	.162	.139	0.40	15	1.35
Propane, 2D-C precip. rate	.090	.134	0.22	25	1.68
Reject , gage precip. rate	-.04	-.03	0.54	20	-.08
AgI , gage precip. rate	.00	-.08	0.96	15	-.19
Propane, gage precip. rate	-.10	-.13	0.67	25	-.39

Propane: 1 nozzle	median	mean	std.dev.	cases	z
Propane, 2D-C concentration	5.6	9.0	15.	7	0.45
Propane, 2D-C precip. rate	.056	.039	0.11	7	0.26
Propane, gage precip. rate	-.38	-.68	0.66	7	-1.08

Propane: 2 nozzles	median	mean	std.dev.	cases	z
Propane, 2D-C concentration	18.0	21.0	23.	18	1.68
Propane, 2D-C precip. rate	.113	.170	0.24	18	1.81
Propane, gage precip. rate	-.03	.08	0.55	18	0.21

The seeded data set has a smaller number of cases and less variability. The "reject" cases should resemble the natural data set in that no seeding effects should be detected; the plume missed the target and/or the air was too warm or too dry at the release site. The z values for the concentrations and the precipitation rate "increases" are quite small (-.19 to -.08), indicating a consistency with a seeding effect of zero. There appears to be a strong signal for AgI increases in 2D-C concentration and precipitation rates (determined from the "small" particles) with z values of 1.50 and 1.35. However, significance at the 5% level (one-tailed test because a positive increase is expected) requires a z value of 1.65. The propane seeding increases in 2D-C concentration and precipitation rate have z values of 1.67 and 1.68, just crossing the 5% significance threshold. However, neither the AgI nor the propane cases produced any detectable increases in the gage measurements of precipitation rate. Those values were probably masked in part by large particles from the natural background.

The last two classes of Table 2 separate the propane experiments according to the number of nozzles used. During the first season and the first experiment of the second only one nozzle was used to generate ice particles at the HAS. For the rest of the second season two nozzles were used in an attempt to double the ice particle production. It is reasonable to investigate whether or not a boost in production is detectable.

For the cases with one nozzle the z values indicate an increase over the controls which is not statistically significant. The number of cases is quite small, possibly contributing to the ambiguity. The gage values actually show a decrease in production with respect to the controls. For the cases with two nozzles the z values for the small particles detected by the 2D-C show strong significance for being greater than the natural data set.

The formula for z for comparing the means of two data sets is

$$z = ((m_2 - m_1) - (\mu_2 - \mu_1))/\sqrt{(s_2^2/n_2 + s_1^2/n_1)} \qquad (2)$$

which is similar to (1) but with subscripts for the two data sets. This comparison does not reference the natural data set, so the n values are 7 and 18, the means are 9 and 21, and the s values are 15 and 23 for the concentrations, for example. The statistical question is whether the increases for two nozzles are greater than the increases for one nozzle. The μ values are assumed to be the same for the null hypothesis. The z values for comparing the means are 1.55 for the 2D-C concentration, 1.93 for the 2D-C precipitation rate. Those numbers are greatly significant (one-tailed probabilities of .061 and .027, respectively) in showing that the doubling of the nozzles produced boosts in the plume increases. Not only has this set of experiments indicated that liquid propane is an effective seeding agent for increasing small particle concentrations and precipitation rates, it has also detected a difference in the number of nozzles used to produce those particles. The concentration means confirm a doubling from the additional nozzle. The boost is even greater for the precipitation rates.

The z value using data for the gage precipitation rate is an unexpected 2.70, with one-tailed probability of .004. This is caused by the strong statistical decrease shown for the small data set with the single nozzle. The gage has been shown to be insensitive to the tiny crystals produced by seeding if there is an abundance of large natural snow particles. We interpret this as a strange statistical result, mentioned here for completeness of the data set, and do not use it as added proof for detecting the second nozzle.

8.4 TEMPERATURE DEPENDENCE

Some of the data of Appendix 2, Table A2.4 are plotted in Figure 7 to show possible temperature dependencies of 2D-C concentration and precipitation rate increases for the "small" particles for the AgI and propane experiments. The temperatures at which the AgI nuclei were activated cannot be known. They could have been activated between the HAS and TAR temperatures, but some particles may have been transported to colder temperatures higher in the cloud. For the AgI experiments the increases are plotted against the colder TAR temperatures. An approximate HAS temperature scale is also included based on the average lapse rate for those experiments. The graphs for concentration and precipitation rate increases show considerable scatter with a slight trend for the concentration increase to become smaller for warmer temperatures. Five experiments that were rejected for being too dry or warm at the HAS for forced-condensation freezing are included. The nuclei might have been activated higher in the cloud, but there seems to have been no effect.

Table A2.1 of Appendix 2 lists all 31 AgI seeding experiments. It shows that TAR (plateau top) air temperatures were colder than -7 °C in less than 20 percent of all experiments. Previous work has demonstrated that ground-released plumes seldom reach more than 1 km above the plateau top, where temperatures are about 6.5 °C colder than at TAR, and that plume top concentrations are much less than those at the plateau top. This raises the serious concern that AgI seeding will often be ineffective over Utah's mountains, as previously discussed in a number of papers (e.g., Sassen and Zhao, 1993, and Super, 1994).

The 39 propane cases, which can only create embryonic ice crystals at the release site, were conducted within a narrow band of HAS temperatures. As a result, no trend can be discerned. The early experiments with only one nozzle are identified by hollow circles. Their increases should have been greater if two nozzles had been used. The clustering of points above the zero line indicates that the effectiveness of liquid propane at such warm air temperatures at the release site is reasonably reliable. By contrast, there is little confidence that AgI is effective for those same release temperatures warmer than -3 °C.

9. SUMMARY AND CONCLUSIONS

The previous results on the first winter of experiments (Super and Holroyd, 1997) stressed case studies, particularly for those examples with an obvious seeding effect. This paper examines the entire set more from an operational point of view, searching for consistency of increases in concentrations and precipitation rates over all experiments. A natural data set was created to provide an indication of natural variability.

The seeded data set was partitioned into a set of "reject" cases which should appear natural, the AgI cases which should have limited effects at warm temperatures, and the propane cases. The "reject" cases indeed appeared similar to the natural data set. Both the AgI and propane cases showed increases in ice particle concentrations and precipitation rates as measured by the 2D-C for particles up to 0.8 mm sizes. All three partitions showed the same relationships (not presented) and scatter as in Figure 3 between ice particle concentration and precipitation rate for the natural data set. That indicates that the mass and terminal velocity relationships for seeded crystals were about the same as for natural particles.

The strongest increases were for the propane cases, which had HAS release temperatures ranging only between -0.4 and -3.4 °C. The use of one nozzle produced concentration increases for small particles of about ten L^{-1} and two nozzles about twenty L^{-1}. Precipitation rate increases of 0.17 mm h^{-1} for 2 nozzles are admittedly small, but they are a 37% increase over that in the natural data set for the same sizes. Additional growth times for a traverse greater than the 4.2 km should further boost the precipitation rate until the crystals hit the ground somewhere downwind.

No increases were found in the gage measurements for the AgI and propane cases, though the nozzle number analysis showed a strong difference when the second nozzle was added.

The seeded volume of cloud is not known and therefore the total production rate of ice particles cannot be accurately compared to the rate of release of the seeding agents. However, an estimate can be made to examine the order of magnitude. Holroyd *et al.* (1988) found a plume dispersion angle of about 15 degrees at distances close to the surface release site of AgI generators on the Grand Mesa of Colorado. Using a half-angle from the center line of 7.5 degrees in both the horizontal and vertical directions, the plume cross section at the TAR, 4.2 km downwind from the HAS, can be approximated by a half circle of radius 550 m. The average transit time for the propane experiments was 17.0 min, yielding an average wind speed between the HAS and TAR of 4.1 m s^{-1}. Two nozzles released liquid propane at about 6 to 8 gal h^{-1} or about 3.7 g s^{-1}, producing about 21 ice particles L^{-1}. Combining the flux of particles through the plume cross section at the TAR and the release rate yields a production rate for liquid propane of about 1.1×10^{10} particles g^{-1} between -0.4 and -3.4 °C. Super and Holroyd (1997) quoted other investigators of liquid propane production rates of 10^{10} to 3×10^{11}, 10^{8} to 10^{11}, and 10^{12} particles g^{-1} at similar temperatures. Finding 10^{10} particles g^{-1} remaining 4.2 km downwind after losses to coagulation and evaporation, and to the trees and ground, appears to be of comparable magnitude to those previous estimates.

Operational use of liquid propane, costing \$0.80 gal^{-1}, using two nozzles at 7 gal h^{-1} indicates a materials cost of \$5.60 h^{-1} for a seeding unit that produces a plume about a kilometer wide at 4.2 km downwind with an increase of about twenty particles L^{-1} at only slightly supercooled conditions. The precipitation rate increase according to the 2D-C was 0.17 mm hr^{-1}. According to Table 1, the gage equivalent rate (dividing by 0.56 to convert from 2D-C rates to gage rates) is 0.30 mm hr^{-1} for the small particles. Additional growth time could result in larger amounts of precipitation.

For comparison, the materials costs for operating a NAWC AgI generator at 8 g h^{-1} is about \$20 h^{-1}. The production from such a generator is highly dependent on the nucleation temperature.

These experiments show that AgI appears to have no effect when released at similar temperatures and comparable or greater effect at TAR temperatures colder than about -6 °C, though the data are noisy. Therefore the use of liquid propane as a seeding agent at only slightly supercooled temperatures is an effective and inexpensive means to boost ice particle concentrations downwind in orographic clouds.

A future experiment should try to document the fallout pattern with downwind distance of precipitation generated by the use of liquid propane. That could be accomplished in a straight canyon with road from the generator to the crest and beyond. The best experiments will be with only trace natural snowfall, permitting the use of numerous snowboards scattered downwind and crosswind to supplement recording precipitation gages and a mobile 2D-C probe.

These Wasatch Plateau experiments had a relatively simple design involving pulsed seeding from an elevated site on the upwind slopes of a major plateau. The local terrain channeled the plume towards the target 4.2 km away at the windward edge of the crest with good probability of actually hitting that instrumented target. Admittedly, observations taken over the middle or downwind portion of the Wasatch Plateau top likely would have demonstrated increased growth of seeded crystals and associated increases in seeded snowfall. However, such a design, while providing a better simulation of operational seeding from high altitude sites, would greatly reduce the odds of proper targeting. The pulsed seeding style, with AgI tags for the liquid propane cases, allowed numerous experiments during most storm periods. Even so, natural variability of snowfall made it challenging to detect the results of seeding. Periods with none to trace natural snow did show obvious seeding effects. Periods with an abundance of snow or strong showers tended to mask the seeding signal. The large natural crystals 1) dominated the precipitation gage measurements, 2) presumably swept out many of the small seeded crystals through aggregation, thereby lessening their detectability by the 2D-C, and 3) consumed orographic supercooled liquid water (SLW), thereby starving the growing seeded embryos.

The experiments described by Holroyd *et al.* (1988) showed that AgI released from similar sites on the Grand Mesa were easily detectable at aircraft levels from an abundance of small, growing ice particles. Those experiments had a more complex design (Super, *et al.*, 1988) and were more expensive to carry out in terms of equipment and manpower. Super and Boe (1988) describe some of those experiments during a period of little natural snowfall. Seeding effects were readily observable at aircraft levels, but observations at the surface had variable success in demonstrating the presence of the seeding plume. They suggested that in the "failed" experiments the embryo ice crystals did not have sufficient residence time in the presence of SLW to grow to sizes that would fall to the surface. The Bridger Range experiments described by Super and Heimbach (1988) used aircraft to detect ground-released AgI seeding effects. They were present when SLW was available and absent when it was minimal. It therefore appears that detection of seeding effects is strongly influenced by the amount of time that seeded crystals spend in the presence of SLW. The competition for that SLW by larger natural snow particles and the sweeping action (aggregation) whereby natural crystals remove seeded embryos from the air mean that there may be little or no seeding effects to detect at the surface if there is an abundance of natural snow.

In conclusion, it remains highly desirable to further physically document the effectiveness of winter orographic cloud seeding under various conditions. However, this goal remains challenging even with sophisticated equipment and abundant manpower. Progress has been made under NOAA's Atmospheric Modification Program. However, it seems that future progress in physically verifying weather modification effectiveness will depend on other sources of support, at least in the near-term.

10. ACKNOWLEDGMENTS

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APPENDIX 1. THE NATURAL HALF-HOUR DATA SET.

In Table A1.1 the concentrations (L^{-1}) and precipitation rates (mm h^{-1}) and their plume ratios are for natural half-hour intervals. An experimental period had to have at least three such intervals within the measurement period to be included in this table. "Small 2D-C" values were restricted to particles up to 0.8 mm sizes. "All 2D-C" values were not restricted. Except for very light snowfall rates, 2D-C measurements are all listed to 4 significant figures because they may sum thousands of individual snow particles. The gage resolution restricts the smallest non-zero rate measurement to 0.13 mm h^{-1}. The sample ratios were calculated as the concentration or precipitation in the half-hour interval divided by the average of the values in the two adjacent intervals within the same observational period. Ratios of unity indicate that the sample had the same value as the average of the controls. Shut-downs at the end of storms interrupt the sequence. There may be some trace overlaps with buffer or plume intervals in Appendix 2 but any seeding contamination of this table appears insignificant. Some discrepancies between the 2D-C and gage are caused by the sticking or jumps in the gage chart record, others by 2D-C calibration inaccuracies.

Table A1.1. Actual values and sample ratios for the natural data set.

		actual values					Sample ratios				
	times	small 2D-C		all 2D-C		gage	small 2D-C		all 2D-C		gage
date	start end	conc.	prec.	conc.	prec.	prec.	conc.	prec.	conc.	prec.	prec.
941213	0815-0845	23.69	0.2545	29.95	0.9399	2.15	-	-	-	-	-
	0845-0915	49.28	0.5253	57.88	1.590	2.03	1.296	1.339	1.231	1.147	0.822
	1130-1200	52.37	0.5303	64.11	1.832	2.79	0.797	0.849	0.839	1.122	1.295
	1200-1230	87.24	0.7246	94.92	1.675	2.28	1.666	1.522	1.583	1.260	1.058
	1400-1430	52.39	0.4220	55.81	0.8274	1.52	0.574	0.565	0.566	0.511	0.889
	1430-1500	95.35	0.7703	102.2	1.561	1.14	2.883	2.549	2.734	2.139	0.857
	1730-1800	13.75	0.1823	18.96	0.6320	1.14	-	-	-	-	-
950105	0725-0755	2.779	0.04563	4.120	0.2487	0.38	-	-	-	-	-
	0755-0825	3.467	0.06020	4.764	0.2187	0.89	1.023	1.047	0.995	0.758	1.561
	0825-0855	4.002	0.06940	5.452	0.3280	0.76	1.368	1.347	1.100	0.577	0.667
	0855-0925	2.382	0.04282	5.152	0.9178	1.39	0.288	0.387	0.541	2.898	1.571
	1200-1230	12.56	0.1517	13.58	0.3055	1.01	0.684	0.518	0.626	0.301	1.000
	1440-1510	34.35	0.5425	38.26	1.111	0.63	1.120	1.155	1.065	1.063	0.383
	1510-1540	48.79	0.7880	58.26	1.785	2.28	-	-	-	-	-
950107	0910-0940	18.96	0.1374	20.06	0.2750	0.13	-	-	-	-	-
	0940-1010	15.29	0.1070	15.97	0.2136	0.25	0.742	0.675	0.731	0.662	0.658
	1010-1040	22.24	0.1796	23.65	0.3700	0.63	2.471	2.661	2.479	2.416	2.000
	1200-1230	2.711	0.02801	3.112	0.09265	0.38	0.100	0.122	0.108	0.184	0.317
	1230-1300	31.85	0.2794	34.00	0.6352	1.77	8.842	7.933	8.659	7.895	5.619
	1415-1445	4.493	0.04243	4.741	0.06827	0.25	-	-	-	-	-
950126	0845-0915	22.02	0.3942	27.56	1.448	1.77	-	-	-	-	-
	0915-0945	38.89	0.8446	51.73	2.881	1.39	1.228	1.422	1.334	1.820	0.845
	1200-1230	42.94	0.7941	49.99	1.718	1.52	1.906	1.744	1.727	1.127	1.600
	1510-1540	5.178	0.06588	6.151	0.1675	0.51	0.219	0.153	0.223	0.177	0.576
	1540-1610	4.381	0.06512	5.299	0.1766	0.25	0.184	0.228	0.198	0.248	0.158
	1800-1830	42.43	0.5053	47.26	1.255	2.66	2.230	2.070	2.183	1.878	2.103
	1830-1900	33.67	0.4230	37.99	1.160	2.28	0.633	0.663	0.643	0.753	0.857
	2045-2115	64.02	0.7712	70.96	1.827	2.66	0.713	0.535	0.706	0.615	1.134
	2115-2145	145.8	2.458	162.9	4.786	2.41	-	-	-	-	-
950214	0830-0900	8.516	0.03327	8.623	0.04886	0.13	-	-	-	-	-
	0900-0930	14.28	0.06519	14.53	0.1070	0.76	1.320	1.326	1.320	1.275	2.375
	0930-1000	13.12	0.06508	13.39	0.1190	0.51	0.616	0.582	0.616	0.612	0.336
	1000-1030	28.31	0.1584	28.94	0.2817	2.28	1.110	1.158	1.114	1.315	6.000

	1030-1100	37.87	0.2086	38.57	0.3096	0.25	0.845	0.769	0.828	0.533	0.062
	1100-1130	61.36	0.3840	64.21	0.8791	5.83	1.301	0.963	1.211	0.721	3.068
	1130-1200	56.48	0.5886	67.47	2.129	3.55	1.294	1.066	1.220	0.679	0.718
	1200-1230	25.96	0.7198	46.38	5.395	4.06	0.636	1.166	0.855	1.611	1.232
	1230-1300	25.20	0.6465	41.06	4.569	3.04	0.447	0.862	0.573	1.163	0.826
	1300-1330	86.91	0.7804	96.84	2.464	3.30	1.719	1.207	1.537	0.781	1.211
	1330-1400	75.93	0.6464	84.92	1.742	2.41	0.933	0.925	0.933	0.875	0.844
	1400-1430	75.91	0.6171	85.15	1.518	2.41	-	-	-	-	-
950303	1800-1830	0.110	0.00087	0.112	0.00091	0.25	-	-	-	-	-
	1830-1900	0.197	0.00155	0.202	0.00201	0.00	0.575	0.622	0.572	0.591	0.000
	1900-1930	0.576	0.00411	0.593	0.00588	0.25	1.517	1.685	1.520	1.476	INF
	1930-2000	0.562	0.00333	0.579	0.00596	0.00	0.664	0.660	0.670	0.833	0.000
	2210-2240	1.116	0.00599	1.135	0.00844	0.00	0.142	0.118	0.139	0.083	0.000
950304	0045-0115	15.16	0.09848	15.72	0.1971	0.13	0.739	0.942	0.752	1.331	0.510
	0115-0145	39.91	0.2030	40.66	0.2877	0.51	1.450	1.366	1.447	1.189	1.146
	0145-0215	39.88	0.1987	40.49	0.2868	0.76	0.741	0.671	0.736	0.591	0.307
	0215-0245	67.77	0.3891	69.40	0.6831	4.44	0.405	0.316	0.396	0.319	1.461
	0245-0315	294.7	2.263	309.8	3.993	5.32	1.797	2.095	1.834	2.614	1.499
	0315-0345	260.2	1.771	268.4	1.104	2.66	1.104	1.013	1.090	0.857	0.778
	0345-0415	176.7	1.234	182.7	1.543	1.52	0.983	1.051	0.987	1.002	0.959
	0415-0445	99.23	0.5762	101.7	0.7074	0.51	1.058	0.886	1.049	0.865	0.502
	0445-0515	10.96	0.06617	11.28	0.09210	0.51	0.209	0.222	0.210	0.253	0.618
	0515-0545	5.532	0.02004	5.544	0.02130	1.14	0.614	0.447	0.603	0.360	4.471
	0545-0615	7.069	0.02359	7.102	0.02627	0.00	1.638	1.562	1.641	1.643	0.000
	0615-0645	3.101	0.01016	3.113	0.01068	0.00	-	-	-	-	-
950305	1100-1130	51.77	0.2689	52.56	0.3850	1.14	-	-	-	-	-
	1220-1250	241.5	1.224	246.5	1.949	7.73	4.173	4.085	4.183	4.169	5.541
	1250-1320	63.98	0.3304	65.31	0.5501	1.65	-	-	-	-	-
950311	1700-1730	0.081	0.00056	0.100	0.00568	0.13	-	-	-	-	-
	1730-1800	18.55	0.1509	20.07	0.3294	1.52	0.537	0.573	0.531	0.445	0.303
	1800-1830	68.95	0.5262	75.44	1.476	9.89	1.068	0.844	1.038	0.804	2.400
	1830-1900	110.6	1.096	125.3	3.343	6.72	2.159	3.507	2.295	4.178	1.341
	2030-2100	33.50	0.09875	33.75	0.1241	0.13	0.396	0.123	0.355	0.051	0.023
	2230-2300	58.63	0.5090	64.89	1.516	4.69	0.978	1.453	1.038	2.046	3.526
	2300-2330	86.34	0.6021	91.30	1.358	2.53	0.984	0.968	0.982	0.978	0.783
950312	0035-0105	116.9	0.7346	121.0	1.260	1.77	-	-	-	-	-
951128	0800-0830	0.342	0.00214	0.354	0.00260	0.00	-	-	-	-	-
	0830-0900	3.832	0.03594	4.097	0.06743	0.00	0.559	0.455	0.543	0.406	0.000
	0945-1015	13.36	0.1558	14.73	0.3299	0.51	1.168	1.252	1.160	1.032	INF
	1015-1045	19.05	0.2129	21.29	0.5720	0.00	0.880	0.802	0.865	0.714	0.000
	1130-1200	29.95	0.3752	34.49	1.272	0.76	1.218	1.368	1.241	1.471	4.000
	1200-1230	30.14	0.3356	34.29	1.158	0.38	1.411	1.259	1.396	1.325	0.667
	1315-1345	12.77	0.1581	14.63	0.4754	0.38	0.388	0.401	0.391	0.360	0.547
	1430-1500	35.67	0.4534	40.59	1.481	1.01	2.586	2.669	2.561	2.937	3.961
	1500-1530	14.82	0.1816	17.07	0.5331	0.13	0.563	0.542	0.558	0.471	0.257
	1530-1600	17.00	0.2165	20.60	0.7809	0.00	-	-	-	-	-
951207	0945-1015	27.95	0.1498	32.76	0.5789	2.03	-	-	-	-	-
	1115-1145	71.47	0.2799	74.81	0.5242	1.39	1.081	0.974	1.081	0.976	1.045
	1245-1315	104.3	0.4252	105.7	0.4951	0.63	0.924	0.934	0.903	0.713	0.414
	1400-1430	154.2	0.6305	159.3	0.8655	1.65	1.099	1.158	1.112	1.315	1.864
	1430-1500	176.2	0.6636	180.9	0.8210	1.14	1.186	1.139	1.182	1.047	0.781
	1500-1530	142.9	0.5343	146.8	0.7029	1.27	0.932	0.917	0.929	0.937	1.054
	1530-1600	130.6	0.5013	135.3	0.6795	1.27	1.747	1.786	1.759	1.743	1.337
	1655-1725	6.633	0.02719	6.997	0.07697	0.63	0.092	0.096	0.093	0.188	0.553
	1730-1800	13.96	0.06517	14.87	0.1403	1.01	0.507	0.509	0.492	0.370	0.727
	1800-1830	48.43	0.2289	53.50	0.6820	2.15	-	-	-	-	-
951230	0720-0750	7.797	0.08276	8.000	0.1052	0.13	-	-	-	-	-
	0845-0915	60.41	1.022	66.54	1.857	0.13	1.397	1.342	1.390	1.355	0.406
	0915-0945	78.66	1.440	87.77	2.636	0.51	1.251	1.265	1.241	1.190	1.146
	1030-1100	65.32	1.255	74.88	2.573	0.76	0.824	0.838	0.835	0.904	1.490
	1100-1130	79.88	1.554	91.54	3.059	0.51	0.826	0.982	0.854	1.016	0.618
	1215-1245	128.1	1.909	139.4	3.446	0.89	1.400	1.129	1.344	1.072	1.079
	1245-1315	103.1	1.828	115.9	3.371	1.14	0.951	1.065	0.972	1.063	1.200
	1315-1345	88.72	1.523	99.00	2.894	1.01	1.031	1.044	1.016	1.003	0.798
	1345-1415	68.93	1.090	78.98	2.400	1.39	0.954	0.825	0.954	0.846	1.695
	1415-1445	55.77	1.118	66.59	2.782	0.63	0.840	1.291	0.881	1.418	0.498
	1530-1600	63.91	0.6422	72.14	1.523	1.14	0.847	0.754	0.883	0.847	1.390
	1655-1725	95.11	0.5847	96.86	0.8124	1.01	1.196	1.046	1.141	0.707	0.838
	1725-1755	95.20	0.4757	97.64	0.7747	1.27	0.994	0.714	0.972	0.627	0.668
	1840-1910	96.53	0.7469	104.0	1.660	2.79	1.184	1.389	1.187	1.245	1.073
	1910-1940	67.89	0.5998	77.60	1.893	3.93	0.795	1.024	0.848	1.415	1.550
	1940-2010	74.24	0.4242	79.06	1.016	2.28	-	-	-	-	-
960103	2130-2200	3.006	0.03286	3.078	0.04692	0.13	-	-	-	-	-
	2250-2320	0.452	0.00141	0.452	0.00141	0.00	0.079	0.029	0.075	0.014	0.000
960104	0000-0030	8.475	0.06417	9.039	0.1526	0.13	-	-	-	-	-

960116	1915-1945	51.78	0.2789	55.02	0.6292	4.94	-	-	-	-	-
	1945-2015	46.38	0.2554	49.35	0.5144	3.30	0.684	0.791	0.697	0.797	0.801
	2015-2045	83.81	0.3671	86.49	0.6619	3.30	1.096	0.868	1.061	0.784	0.676
	2130-2200	106.6	0.5907	113.7	1.175	6.46	0.791	0.877	0.800	0.868	1.144
	2200-2230	185.7	0.9801	197.6	2.045	7.99	1.314	1.375	1.316	1.440	1.237
	2230-2300	176.0	0.8344	186.5	1.665	6.46	0.951	1.001	1.053	0.981	0.961
	2300-2330	148.4	0.6876	156.7	1.348	5.45	1.062	1.031	1.059	0.992	0.860
	2330-2400	103.4	0.4997	109.3	1.054	6.21	0.820	0.947	0.956	1.005	1.484
960117	0000-0030	67.86	0.3677	72.02	0.7494	2.92	0.975	1.049	0.977	1.044	0.732
	0030-0100	35.76	0.2012	38.17	0.3820	1.77	0.560	0.579	0.561	0.523	0.547
	0145-0215	59.95	0.3274	64.01	0.7118	3.55	1.267	1.228	1.246	1.066	1.099
	0215-0245	58.87	0.3321	64.55	0.9532	4.69	0.731	0.774	0.733	0.807	0.841
	0245-0315	101.2	0.5309	112.1	1.650	7.60	0.727	0.738	0.752	1.006	1.249
	0315-0345	219.6	1.106	233.4	2.327	7.48	1.376	1.467	1.373	1.363	1.146
	0345-0415	218.1	0.9766	227.9	1.765	5.45	0.821	0.746	0.815	0.761	0.761
	0415-0445	311.9	1.512	325.8	2.310	6.84	1.140	1.289	1.156	1.356	1.255
	0445-0515	328.9	1.370	335.6	1.643	5.45	1.287	1.170	1.273	1.023	1.212
	0515-0545	199.2	0.8298	201.6	0.9015	2.15	0.975	0.978	0.967	0.869	0.721
	0545-0615	79.53	0.3270	81.32	0.4328	0.51	-	-	-	-	-
960118	2000-2030	13.15	0.07904	13.88	0.1504	0.38	-	-	-	-	-
	2030-2100	18.07	0.1466	19.85	0.4018	0.89	1.954	2.609	2.039	3.789	3.490
	2100-2130	5.343	0.03335	5.590	0.06166	0.13	-	-	-	-	-
960119	0810-0840	73.54	0.4262	75.66	0.6747	0.76	-	-	-	-	-
	0900-0930	90.16	0.5612	93.59	1.040	1.27	0.703	0.811	0.710	0.885	0.910
	0930-1000	182.9	0.9583	188.0	1.675	2.03	1.404	1.195	1.389	1.153	1.068
	1000-1030	170.4	1.043	177.2	1.866	2.53	1.078	1.062	1.069	0.963	0.998
	1030-1100	133.2	1.006	143.4	2.199	3.04	0.960	1.115	0.985	1.354	1.333
	1100-1130	107.2	0.7610	114.0	1.383	2.03	1.360	1.234	1.335	1.014	1.106
	1130-1200	24.47	0.2275	27.42	0.5275	0.63	0.338	0.411	0.350	0.456	0.355
	1200-1230	37.40	0.3465	42.63	0.9311	1.52	0.583	0.719	0.616	0.885	1.045
	1330-1400	103.8	0.7358	110.9	1.576	2.28	-	-	-	-	-
960121	1730-1800	185.4	1.428	198.4	2.746	3.80	-	-	-	-	-
	1930-2000	53.73	0.4224	57.15	0.7087	1.14	0.392	0.396	0.390	0.350	0.391
	2000-2030	88.54	0.7047	94.55	1.302	2.03	1.031	1.059	1.031	1.060	1.144
	2030-2100	118.1	0.9085	126.2	1.749	2.41	1.535	1.501	1.530	1.404	1.268
	2100-2130	65.35	0.5059	70.45	1.189	1.77	0.772	0.762	0.770	0.864	0.821
	2130-2200	51.16	0.4186	56.69	1.003	1.90	1.236	1.269	1.258	1.203	1.502
	2200-2230	17.46	0.1539	19.68	0.4783	0.76	0.575	0.589	0.574	0.667	0.601
	2230-2300	9.533	0.1039	11.83	0.4313	0.63	0.706	0.684	0.769	0.924	1.105
	2300-2330	9.534	0.1500	11.19	0.4553	0.38	-	-	-	-	-
960123	1950-2020	29.09	0.1556	31.76	0.3182	0.13	-	-	-	-	-
	2100-2130	20.48	0.1273	23.14	0.2969	0.13	0.861	0.906	0.873	1.005	2.000
	2130-2200	18.48	0.1253	21.23	0.2729	0.00	-	-	-	-	-
960130	1145-1215	50.51	0.3926	53.74	0.8885	1.90	-	-	-	-	-
	1300-1330	85.44	0.6026	90.53	1.357	2.03	1.496	1.374	1.487	1.295	1.002
	1330-1400	63.75	0.4847	68.00	1.207	2.15	0.906	0.878	0.905	0.896	1.094
	1440-1510	55.31	0.5020	59.67	1.336	1.90	1.194	1.283	1.198	1.356	1.155
	1510-1540	28.92	0.2976	31.60	0.7635	1.14	0.632	0.715	0.643	0.747	0.667
	1540-1610	36.22	0.3301	38.58	0.7088	1.52	0.521	0.558	0.521	0.573	0.924
	1700-1730	110.0	0.8859	116.4	1.712	2.15	3.254	3.027	3.129	2.358	1.211
	1900-1930	31.38	0.2553	35.81	0.7431	2.03	0.560	0.624	0.559	0.624	0.971
	1930-2000	56.93	0.4506	62.52	1.034	2.03	-	-	-	-	-
960131	1155-1225	12.67	0.1342	13.48	0.2623	0.51	-	-	-	-	-
	1310-1340	87.88	0.8054	93.46	1.685	2.15	4.583	3.801	4.485	3.379	3.071
	1430-1500	25.68	0.2896	28.10	0.7350	0.89	0.482	0.555	0.495	0.649	0.612
	1500-1530	18.59	0.2385	20.46	0.5787	0.76	0.644	0.698	0.641	0.660	0.598
	1530-1600	32.01	0.3936	35.66	1.019	1.65	2.043	1.857	2.052	1.920	2.171
	1640-1710	12.75	0.1853	14.30	0.4830	0.76	0.560	0.624	0.559	0.624	0.667
	1710-1740	13.50	0.2000	15.54	0.5288	0.63	-	-	-	-	-
960305	0940-1010	80.67	0.8747	86.03	1.625	0.89	-	-	-	-	-
	1010-1040	21.41	0.1506	21.91	0.2250	0.63	0.378	0.294	0.368	0.246	0.992
	1130-1200	32.67	0.1513	33.01	0.2006	0.38	1.837	1.466	1.827	1.393	0.864
	1200-1230	14.16	0.05587	14.22	0.06303	0.25	0.521	0.447	0.518	0.368	0.794
	1230-1300	21.66	0.09886	21.91	0.1416	0.25	1.498	1.749	1.505	2.128	2.000
	1400-1430	14.75	0.05716	14.90	0.07007	0.00	1.223	1.063	1.222	0.930	0.000
	1430-1500	2.463	0.00870	2.470	0.00906	0.00	0.256	0.236	0.254	0.205	0.000
	1500-1530	4.528	0.01656	4.549	0.01851	0.00	3.252	3.121	3.240	2.587	0.000
	1530-1600	0.322	0.00191	0.338	0.00523	0.00	0.010	0.013	0.011	0.020	0.000
	1600-1630	57.98	0.2862	59.62	0.4991	3.04	0.630	0.553	0.622	0.519	2.082
	1630-1700	183.7	1.034	190.9	1.917	2.92	-	-	-	-	-
960323	0645-0715	67.53	0.7262	78.55	1.897	3.42	-	-	-	-	-
	0715-0745	146.8	1.224	157.3	2.060	4.18	1.535	1.346	1.469	1.190	1.222
	0745-0815	123.7	1.093	135.6	1.565	3.42	1.233	1.369	1.264	1.187	1.349
	0815-0845	53.88	0.3727	57.25	0.5778	0.89	0.833	0.659	0.808	0.700	0.468
	0920-0950	5.727	0.03846	6.157	0.08573	0.38	0.139	0.133	0.141	0.165	0.427

	1045-1115	28.37	0.2059	30.03	0.4630	0.89	5.075	4.520	4.866	4.249	4.684
	1230-1300	5.454	0.05265	6.186	0.1322	0.00	0.118	0.147	0.122	0.142	0.000
	1300-1330	64.26	0.5108	71.36	1.403	2.28	6.030	5.969	6.137	6.634	4.515
	1330-1400	15.86	0.1185	17.07	0.2908	1.01	-	-	-	-	-
960328	1900-1930	1.185	0.01189	1.330	0.1012	0.00	-	-	-	-	-
	1930-2000	0.477	0.00335	0.494	0.00770	0.00	0.784	0.560	0.726	0.152	0.000
	2000-2030	0.031	0.00007	0.031	0.00007	0.00	0.126	0.036	0.122	0.017	0.000
	2030-2100	0.017	0.00031	0.017	0.00031	0.00	0.556	0.617	0.431	0.087	0.000
	2100-2130	0.308	0.00093	0.049	0.00701	0.00	0.005	0.023	0.008	0.085	0.000
	2130-2200	11.28	0.08121	11.84	0.1644	0.00	0.186	0.182	0.183	0.166	0.000
	2315-2345	121.2	0.8896	129.5	1.973	3.42	4.607	5.047	4.673	5.544	INF
	2345-0015	41.33	0.2713	43.58	0.5473	0.00	0.580	0.481	0.552	0.328	0.000
960329	0015-0045	21.30	0.2395	28.36	1.364	3.42	0.404	0.464	0.459	0.826	1.500
	0045-0115	64.23	0.7617	79.93	2.754	4.56	2.488	1.789	2.428	1.986	2.182
	0115-0145	30.33	0.6122	37.49	1.409	0.76	-	-	-	-	-

APPENDIX 2. SEEDING EXPERIMENTS DATA SET

Table A2.1. The time intervals for the seeding experiments. The first control interval for an experiment may be the second control of the previous experiment. The transit times are in minutes from the HAS to the TAR. The air temperatures at the two sites are indicated.

		agent			times			transit	Temp.C	
date	case		control	buffer	plume	buffer	control	time min	HAS	TAR
941213	A	A	082830	092830	093745	104452	113230	120000	30	-6.0	-8.2
	B	A	120000	122730	123615	132425	135730	143600	17	-6.3	-8.7
	C	A	143600	151430	152145	161804	172130	180317	15	-6.1	-8.6
941215	A	A	093008	094230	094845	105022	110030	112835	19	-7.7	-10.4
950105	A	A	082530	092530	094545	103625	114839	123030	54	-3.5	-5.8
	B	A	-	123030	123815	133654	144230	154030	22	-3.2	-5.6
	C	A	-	154030	154545	165849	174200	175032	21	-4.1	-6.2
950107	A	P	095000	102900	110330	114520	115020	123500	16	-2.0	-4.1
	B	P	-	123530	132530	141230	142030	144419	15	-2.7	-5.1
950126	A	A	082643	092200	093030	103223	115030	123230	26	-2.6	-4.5
	B	P	-	123230	124030	133930	-	-	20	-.7	-4.0
	C	A	-	133930	135345	143819	151630	161130	21	-.7	-4.2
	D	A	-	161130	162215	170748	174430	182200	19	-2.1	-4.5
	E	A	182200	185930	190645	200525	203630	211400	18	-2.5	-4.6
	F	A	211400	215130	215445	230113	230613	-	13	-3.7	-5.8
950214	A	P	102029	112029	112314	123605	124105	134105	11	-3.1	-5.5
950303	A	A	191230	201230	201845	211248	220630	224030	12	+.8	-2.9
	B	A	-	224030	224545	234318	004530	005000	12	+.3	-3.1
950305	A	P	075142	081530	082130	091730	092230	094030	15	-2.2	-4.1
	B	A	-	094030	094545	103000	105130	113130	14	-1.3	-3.7
	C	P	-	113130	114230	121411	121911	131911	8	+.1	-2.7
950311	A	P	180930	190930	191430	201330	201830	204800	11	-1.3	-3.1
	B	P	204800	210830	211130	220830	221330	223600	11	-.9	-3.0
	C	P	223600	232930	233630	003030	003530	010500	11	-2.0	-4.0
951128	A	P	080054	085930	090830	093530	094030	101200	17	-5.2	-8.3
	B	P	101200	104348	105041	112521	113021	122930	21	-4.8	-5.9
	C	P	-	122930	124230	130640	131140	134430	20	-3.1	-4.7
	D	P	-	134430	135330	141852	142353	152141	17	-2.5	-4.4
	E	P	152141	161930	162545	165732	174603	-	18	-1.5	-3.6
951207	A	P	092629	101430	102430	105630	110130	112630	39	-.5	-2.0
	B	P	112630	115130	115630	123130	123630	125630	30	-.8	-2.2
	C	P	125630	131630	132830	135903	140403	150547	31	-1.2	-2.7
	D	P	150547	160730	161830	164814	165314	172523	25	-1.8	-3.4
951230	A	P	071757	074943	075935	082934	083434	091032	27	-3.5	-5.2
	B	P	091032	094630	095730	102630	103130	105930	25	-2.8	-4.5
	C	P	105930	112730	113330	120830	121330	131330	24	-2.2	-3.9
	D	P	134930	144930	145413	152033	152533	155132	20	-1.9	-3.6
	E	P	155132	161730	162330	165230	165730	172630	15	-2.0	-3.6
	F	P	172630	175530	180030	183430	183930	193930	17	-1.7	-3.3
960103	A	P	214700	220423	221105	224130	224630	230300	18	-2.2	-3.8
	B	P	230300	231930	232230	235630	000130	003929	14	-2.4	-4.0
960116	A	P	194530	204530	204930	211930	212430	222430	8	-.6	-2.1
960117	A	P	000930	010930	011330	014030	014530	024530	10	-1.2	-2.8
960118	A	A	211100	213030	213343	220244	223402	-	21	-7.8	-8.8
960119	A	A	080611	084030	084546	084946	085446	095446	14	-7.4	-9.4
	B	A	113443	123443	124204	131113	132830	135900	29	-6.3	-8.7
	C	A	135900	141506	142238	145357	145857	151102	21	-6.3	-8.8

960121	A	A	170814	175930	180415	184201	192530	202530	17	-5.6	-7.5
960123	A	P	195000	201756	202655	205448	205948	215948	24	-10.4	-12.3
960130	A	P	-	-	111621	114230	114730	122530	16	-2.3	-4.1
	B	P	-	122530	122930	130030	130530	133300	13	-2.2	-3.8
	C	P	133300	140030	140630	143630	144130	152600	13	-2.2	-3.7
	D	P	152600	161030	162030	165630	170130	174530	16	-2.1	-4.0
	E	A	-	174530	174724	181625	190030	192800	15	-2.1	-3.9
960131	B	P	110832	112030	112130	115330	115830	122518	13	-2.9	-4.8
	C	P	-	122518	123028	125930	130430	132230	14	-3.0	-5.0
	D	A	132230	134030	135400	141613	142730	151730	14	-2.9	-4.9
	E	P	151730	160730	161030	163930	164430	171400	17	-3.4	-5.3
	F	A	171400	174330	175015	182434	184430	190006	21	-3.8	-5.6
960304	A	A	124430	134430	135045	142208	143037	-	16	+1.3	-2.2
960305	A	A	080250	082530	083245	090359	093430	100657	18	+1.1	-6.2
	B	A	100657	103923	104845	111202	111702	121246	11	+.9	-4.9
	C	A	121246	130830	131045	134015	135530	145530	9	+.4	-5.0
960312	A	P	075803	082030	082811	085433	-	-	25	-1.4	-4.0
960323	A	A	082700	084630	085445	091556	092030	093630	17	-5.0	-7.0
	B	P	093630	095230	095430	102630	103130	110000	12	-5.4	-7.3
	C	P	110000	111630	112030	115434	-	-	17	-5.0	-6.8
	D	A	-	-	115434	122116	122616	130500	19	-4.8	-6.6
960328	A	P	223300	225435	230653	231305	231805	000813	24	-.4	-2.3
960329	A	A	005822	014830	020245	023840	024430	024451	41	-2.9	-4.1

Table A2.2. Concentrations (L^{-1}) and precipitation rates ($mm\ h^{-1}$) for the indicated time intervals for the control (C), buffer (B), and plume (P) intervals for the AgI (A) and propane (P) seeding agents. "Small 2D-C" values were restricted to particles up to 0.8 mm sizes. Except for very light snowfall rates, 2D-C measurements are all listed to 4 significant figures because they may sum thousands of individual snow particles. The gage resolution restricts the smallest non-zero rate measurement to 0.13. Some discrepancies between the 2D-C and gage are caused by the sticking or jumps in the gage chart record, others by 2D-C calibration inaccuracies. Plume Ratios are for 2D-C concentration and precipitation rates and for gage precipitation rates, expressed as the plume value / average of control values.

date	case	agent	int.	small 2D-C conc.	small 2D-C prec.	gage prec.	Plume Ratios conc.	Plume Ratios prec.	Plume Ratios gage
941213	A		C	39.68	0.4236	2.09			
	A		B	12.63	0.1569				
	A	A	P	46.44	0.3177	C.96	1.01	0.67	0.35
	A		B	84.16	0.6932				
	A		C	51.96	0.5260	3.32			
	B		C	88.91	0.7416	2.07			
	B		B	85.78	0.6867				
	B	A	P	122.9	0.8903	3.08	1.72	1.52	1.79
	B		B	90.42	0.6021				
	B		C	53.70	0.4264	1.38			
	C		C	100.0	0.7977	2.37			
	C		B	76.74	0.5697				
	C	A	P	112.2	0.7131	0.95	1.95	1.46	0.56
	C		B	44.98	0.3981				
	C		C	13.84	0.1806	1.00			
951215	A		C	11.22	0.1069	0.00			
	A		B	64.37	0.4946				
	A	A	P	95.50	0.6195	1.23	12.24	8.22	INF
	A		B	8.705	0.07537				
	A		C	4.380	0.04379	0.00			
950105	A		C	3.200	0.05635	1.01			
	A		B	5.391	0.06472				
	A	A	P	26.19	0.2629	0.98	3.30	2.61	1.08
	A		B	12.23	0.1310				
	AB		C	12.68	0.1450	0.81			
	B		B	18.72	0.2203				
	B	A	P	87.78	0.8876	1.23	3.18	2.14	1.06
	B		B	31.20	0.5060				
	BC		C	42.58	0.6837	1.51			
	C		B	41.28	0.8218				
	C	A	P	24.80	0.3701	1.61	0.97	0.95	0.98
	C		B	21.47	0.2652				
	C		C	8.518	0.09219	1.78			
950107	A		C	7.393	0.05889	0.40			
	A		B	62.43	0.5297		an excluded shower		
	A	P	P	10.97	0.1005	0.27	2.03	2.24	0.59
	A		B	0.383	0.00387				
	AB		C	3.409	0.03081	0.51			
	B		B	29.41	0.3099		an excluded shower		
	B	P	P	4.101	0.04499	0.16	1.25	1.48	0.63
	B		B	8.512	0.08146				
	B		C	3.129	0.02994	0.00			
950126	A		C	19.64	0.3657	1.58			
	A		B	33.10	0.5960				
	A	A	P	59.44	1.214	1.97	1.97	2.11	1.19
	A		B	46.26	0.8040				
	AB		C	40.77	0.7842	1.72			
	B		B	10.92	0.1952				
	B	P	P	11.90	0.1708	0.64	-	-	-
	BC		B	8.887	0.1405				
	C	A	P	10.97	0.1591	0.43	-	-	-
	C		B	3.950	0.05885				
	CD		C	4.742	0.06535	0.35			
	D		B	4.936	0.05832				
	D	A	P	12.97	0.1485	1.09	0.63	0.62	1.00
	D		B	15.72	0.1607				
	D		C	36.52	0.4158	1.83			
	E		C	31.37	0.4146	2.23			
	E		B	39.39	0.4505				
	E	A	P	99.76	1.463	3.76	2.07	2.42	1.61
	E		B	117.9	1.503				
	E		C	65.01	0.7943	2.43			
	F		C	134.1	2.238	2.53			
	F		B	60.63	1.115				
	F	A	P	36.00	0.7131	2.35	-	-	-
	F		B	49.66	1.106				
950214	A		C	45.67	0.2596	3.04			
	A		B	91.75	0.5671		both tags missed TAR		
	A	P	P	40.99	0.6274	3.71	0.74	1.27	1.21
	A		B	22.16	0.6726				
	A		C	65.73	0.7258	3.11			
950303	A		C	0.515	0.00336	0.06			
	A		B	0.214	0.00074				
	A	A	P	0.788	0.00433	0.00	0.78	0.73	0.00
	A		B	1.084	0.00679				
	AB		C	1.501	0.00856	0.00			
	B		B	10.62	0.04345				
	B	A	P	0.631	0.00284	0.00	0.32	0.31	0.00
	B		B	0.420	0.00298				
	B		C	2.399	0.00957	0.00			
950305	A		C	2.900	0.01573	0.00			
	A		B	22.44	0.1741				
	A	P	P	28.81	0.2216	0.14	11.88	24.84	0.67
	A		B	9.637	0.07290				
	AB		C	0.513	0.00211	0.42			
	B		B	0.299	0.00223				

date	case	agent	int.	small conc.	2D-C prec.	gage prec.	Plume Ratios conc.	Plume Ratios prec.	Plume Ratios gage
	B	A	P	1.126	0.00445	0.09	0.04	0.03	0.11
	B		B	20.58	0.1195				
	BC		C	49.59	0.2610	1.24			
	C		B	45.49	0.2391				
	C	P	P	38.64	0.1739	0.48	0.38	0.33	0.15
	C		B	190.1	0.7921				
	C		C	154.6	0.7829	5.01			
950311	A		C	101.3	0.9030	7.79			
	A		B	129.5	0.9364				
	A	P	P	106.1	0.6377	2.96	1.40	1.19	0.64
	A		B	66.87	0.2519				
	A		C	50.57	0.1707	1.42			
	B		C	6.328	0.02282	0.74			
	B		B	6.456	0.02767				
	B	P	P	18.10	0.1203	0.27	2.51	3.07	0.22
	B		B	5.917	0.03693				
	B		C	8.067	0.05562	1.69			
	C		C	78.83	0.6045	3.91			
	C		B	89.90	0.7344				
	C	P	P	93.17	0.5662	1.41	0.95	0.85	0.49
	C		B	113.2	0.7644				
	C		C	116.3	0.7305	1.80			
951128	A		C	2.123	0.01927	0.00			
	A		B	1.750	0.01960				
	A	P	P	9.441	0.1106	0.28	1.23	1.24	1.56
	A		B	8.373	0.09901				
	A		C	13.25	0.1585	0.36			
	B		C	18.06	0.1978	0.00			
	B		B	37.38	0.4608				
	B	P	P	31.35	0.3670	0.44	1.31	1.33	1.52
	B		B	48.25	0.6215				
	BC		C	29.96	0.3553	0.58			
	C		B	34.84	0.3421				
	C	P	P	19.33	0.1864	0.00	0.92	0.74	0.00
	C		B	7.070	0.09812				
	CD		C	12.18	0.1490	0.46			
	D		B	20.07	0.2866				
	D	P	P	13.19	0.1634	0.15	0.65	0.64	0.29
	D		B	24.88	0.2968				
	D		C	28.18	0.3589	0.59			
	E		C	13.63	0.1694	0.13			
	E		B	14.51	0.1500				
	E	A	P	20.17	0.1936	0.56	-	-	-
	E		B	1.032	0.00999				
951207	A		C	31.18	0.1643	1.90			
	A		B	38.79	0.2038				
	A	P	P	36.11	0.2015	2.26	0.95	1.10	1.16
	A		B	39.35	0.1797				
	A		C	44.73	0.2031	1.98			
	B		C	83.21	0.3414	1.22			
	B		B	75.32	0.3411				
	B	P	P	104.1	0.4424	1.41	1.29	1.32	2.31
	B		B	82.94	0.3351				
	B		C	78.67	0.3266	0.00			
	C		C	119.7	0.4787	0.95			
	C		B	78.02	0.3117				
	C	P	P	68.60	0.2823	0.75	0.48	0.50	0.67
	C		B	138.7	0.5919				
	C		C	165.9	0.6439	1.29			
	D		C	131.1	0.4973	1.42			
	D		B	84.61	0.3124				
	D	P	P	66.41	0.2444	0.51	0.96	0.93	0.51
	D		B	26.36	0.08870				
	D		C	6.919	0.02830	0.59			
951230	A		C	8.090	0.09018	0.36			
	A		B	10.72	0.1059				
	A	P	P	15.17	0.2066	0.00	0.44	0.36	0.00
	A		B	51.49	0.6849				
	A		C	60.95	1.050	0.11			
	B		C	77.69	1.397	0.42			
	B		B	62.69	1.256				
	B	P	P	64.46	1.342	0.52	0.90	1.01	0.85
	B		B	64.39	1.329				
	B		C	65.26	1.253	0.81			
	C		C	78.81	1.539	0.54			
	C		B	105.0	1.956				
	C	P	P	116.3	1.988	0.76	1.19	1.16	1.02
	C		B	144.4	2.081				
	C		C	117.3	1.888	0.95			
	D		C	60.43	1.091	1.08			
	D		B	51.10	1.008				
	D	P	P	79.71	0.9351	0.87	1.28	1.07	0.65
	D		B	75.91	0.7865				
	D		C	63.72	0.6569	1.61			
	E		C	70.77	0.7324	1.17			
	E		B	86.31	0.8535				
	E	P	P	93.55	0.5416	0.66	1.13	0.82	0.63
	E		B	97.73	0.4792				
	E		C	94.31	0.5870	0.92			
	F		C	94.55	0.4686	1.31			
	F		B	79.20	0.3294				

date	case	agent	int.	small conc.	2D-C prec.	gage prec.	Plume Ratios conc.	Plume Ratios prec.	Plume Ratios gage
	F	P	P	84.21	0.4530	1.57	0.95	0.79	0.67
	F		B	83.13	0.5692				
	F		C	82.19	0.6735	3.36			
960103	A		C	0.954	0.00547	0.22			
	A		B	0.876	0.00323				
	A	P	P	8.130	0.04254	0.00	13.66	14.04	0.00
	A		B	1.674	0.00926				
	A		C	0.237	0.00060	0.00			
	B		C	0.555	0.00198	0.00			
	B		B	35.78	0.2728				
	B	P	P	42.43	0.3130	0.00	10.51	10.73	0.00
	B		B	12.77	0.1212				
	B		C	7.519	0.05634	0.20			
960116	A		C	64.81	0.3094	3.30			
	A		B	28.20	0.1080				
	A	P	P	142.2	0.6530	6.46	1.33	1.16	1.19
	A		B	160.5	0.8467				
	A		C	149.6	0.8176	7.60			
960117	A		C	40.92	0.2229	1.96			
	A		B	49.39	0.1983				
	A	P	P	88.27	0.4163	2.39	1.75	1.50	0.77
	A		B	44.95	0.2601				
	A		C	59.78	0.3325	4.25			
960118	A		C	2.853	0.01326	0.00			
	A		B	2.106	0.01473				
	A	A	P	4.229	0.02618	0.39	-	-	-
	A		B	2.611	0.02033				
960119	A		C	71.58	0.4164	0.66			
	A		B	96.29	0.5544		Aborted experiment		
	A	A	P	53.96	0.3007	0.00	0.56	0.54	0.00
	A		B	49.58	0.2910				
	A		C	120.9	0.6892	1.46			
	B		C	32.51	0.2996	0.63			
	B		B	46.70	0.3644				
	B	A	P	41.04	0.3027	0.39	0.59	0.57	0.25
	B		B	100.3	0.7870				
	B		C	107.7	0.7658	2.49			
	C		C	11.39	0.07469	0.94			
	C		B	6.791	0.04744				
	C	A	P	30.94	0.2003	0.73	3.34	3.12	1.17
	C		B	18.35	0.1639				
	C		C	7.148	0.05362	0.31			
960121	A		C	161.8	1.268	3.34			
	A		B	171.3	1.205				
	A	A	P	167.3	1.262	3.02	1.46	1.40	1.24
	A		B	102.7	0.7487				
	A		C	67.25	0.5301	1.52			
960123	A		C	27.54	0.1483	0.15			
	A		B	28.29	0.1462				
	A	P	P	29.79	0.1646	0.95	1.27	1.20	9.05
	A		B	19.82	0.1299				
	A		C	19.51	0.1263	0.06			
960130	A	P	P	46.55	0.4033	1.31	-	-	-
	A		B	36.48	0.3321				
	AB		C	57.82	0.4385	2.00			
	B		B	78.31	0.5512				
	B	P	P	85.22	0.6375	1.84	1.18	1.23	0.97
	B		B	68.66	0.5471				
	B		C	87.20	0.6018	1.80			
	C		C	63.11	0.4860	2.21			
	C		B	64.77	0.5804				
	C	P	P	80.95	0.7013	2.79	1.44	1.46	1.46
	C		B	60.83	0.5640				
	C		C	49.43	0.4717	1.62			
	D		C	30.24	0.2825	1.37			
	D		B	77.95	0.7193				
	D	P	P	125.1	0.9107	1.90	2.12	1.76	1.00
	D		B	151.1	1.074				
	DE		C	88.01	0.7544	2.42			
	E		B	51.93	0.5290				
	E	A	P	52.94	0.5013	1.70	0.91	1.02	0.81
	E		B	30.07	0.2599				
	E		C	28.25	0.2263	1.80			
960131	B		C	74.96	1.002	1.91			
	B		B	81.79	1.743				
	B	P	P	58.61	1.226	1.31	1.53	1.48	1.12
	B		B	25.75	0.5592				
	BC		C	12.35	0.2317	0.43			
	C		B	6.468	0.1030				
	C	P	P	26.58	0.5091	0.52	0.66	0.74	0.61
	C		B	39.48	0.7682				
	C		C	67.63	1.148	1.27			
	D		C	110.3	2.002	2.75			
	D		B	86.08	1.519				
	D	A	P	29.99	0.6576	0.68	0.44	0.49	0.37
	D		B	28.43	0.6854				
	D		C	25.72	0.6746	0.91			
	E		C	31.66	0.9001	1.52			
	E		B	38.41	1.327				
	E	P	P	49.94	1.361	1.70	2.20	1.98	1.48
	E		B	17.07	0.5379				

date	case	agent	int.	small 2D-C conc.	small 2D-C prec.	gage prec.	Plume Ratios conc.	Plume Ratios prec.	Plume Ratios gage
	E		C	13.69	0.4741	0.77			
	F		C	15.78	0.5328	0.64			
	F		B	15.77	0.4088				
	F	A	P	20.98	0.3565	0.33	1.25	0.63	0.48
	F		B	10.89	0.2978				
	F		C	17.77	0.5956	0.73			
960304	A		C	4.712	0.02074	0.00			
	A		B	0.464	0.00261				
	A	A	P	19.53	0.09759	0.00	-	-	-
	A		B	18.53	0.09877				
960305	A		C	9.144	0.1131	0.00			
	A		B	5.478	0.02723				
	A	A	P	12.21	0.07743	0.12	0.26	0.15	0.23
	A		B	67.29	0.5876				
	A		C	84.36	0.9255	1.05			
	B		C	22.05	0.1596	0.59			
	B		B	11.57	0.07262				
	B	A	P	6.586	0.03850	0.00	0.21	0.21	0.00
	B		B	10.11	0.05056				
	B		C	42.00	0.1993	0.82			
	C		C	21.12	0.09296	0.20			
	C		B	3.837	0.02682				
	C	A	P	55.77	0.2625	0.52	3.01	3.41	5.20
	C		B	8.920	0.04446				
	C		C	15.89	0.06106	0.00			
960312	A		C	0.239	0.00150	0.00			
	A		B	0.799	0.01116				
	A	P	P	4.684	0.05064	0.00	-	-	-
960323	A		C	23.80	0.2236	0.39			
	A		B	19.92	0.2344				
	A	A	P	19.31	0.1686	0.90	1.38	1.34	4.62
	A		B	3.765	0.03410				
	A		C	4.166	0.02866	0.00			
	B		C	7.786	0.05071	0.71			
	B		B	18.29	0.1449				
	B	P	P	64.82	0.4606	0.71	2.27	2.33	0.52
	B		B	60.07	0.4548				
	B		C	49.23	0.3441	2.00			
	CD		C	4.267	0.03499	0.23			
	CD		B	35.12	0.3774				
	C	P	P	58.12	0.4726	0.33	12.00	10.89	2.00
	D	A	P	9.316	0.08463	1.00	1.92	1.95	6.06
	CD		B	8.769	0.08050				
	CD		C	5.422	0.05183	0.10			
960328	A		C	5.008	0.04255	0.00			
	A		B	41.82	0.3430				
	A	P	P	117.5	0.7782	1.84	2.49	2.27	1.80
	A		B	112.2	0.7400				
	A		C	89.42	0.6421	2.05			
960329	A		C	41.73	0.6537	2.43			
	A		B	19.45	0.4859				
	A	A	P	11.77	0.2967	1.06	-	-	-
	A		B	3.168	0.08743				
	A		C	0.486	0.00557	-	too brief (21 sec)		

Table A2.3. Partitioned experimental data--plume ratios. Concentrations (L^{-1}) and precipitation rates ($mm\ h^{-1}$) are for the plume intervals for the AgI (A) and propane (P) seeding agents. "Small 2D-C" values were restricted to particles up to 0.8 mm sizes. Plume Ratios are for 2D-C concentration and precipitation rates and for gage precipitation rates, expressed as the plume value / average of control values. Transit times, in minutes, are the average of the two measured or calculated T2 numbers. The relative humidity and air temperature at the HAS release site are included as is the air temperature at the TAR.

The partitioning is by the strength of the ice nuclei concentrations detected at the TAR and by the HAS release conditions.

Exclusions:

1. Bad targeting cases; AgI, with peak IN < 2500 L^{-1}

date	case	agent	small 2D-C conc.	small 2D-C prec.	gage prec.	Plume Ratios conc.	Plume Ratios prec.	Plume Ratios gage	tran. min	RH	Temp.C HAS	Temp.C TAR
950105	C	A	24.80	0.3701	1.61	0.97	0.95	0.98	21	96	-4.1	-6.2
960118	A	A	4.229	0.02618	0.39	-	-	-	21	92	-7.8	-8.8
960119	A	A	53.96	0.3007	0.00	0.56	0.54	0.00	14	93	-7.4	-9.4
960119	C	A	30.94	0.2003	0.73	3.34	3.12	1.17	21	93	-6.3	-8.8
960323	A	A	19.31	0.1686	0.90	1.38	1.34	4.62	17	95	-5.0	-7.0
960323	D	A	9.316	0.08463	1.00	1.92	1.95	6.06	19	95	-4.8	-6.6
960329	A	A	11.77	0.2967	1.06	-	-	-	41	98	-2.9	-4.1

2. Bad targeting cases; propane, with both tags having peak IN < 1230 L^{-1}

date	case	agent	small 2D-C conc.	small 2D-C prec.	gage prec.	Plume Ratios conc.	Plume Ratios prec.	Plume Ratios gage	tran. min	RH	Temp.C HAS	Temp.C TAR
950214	A	P	40.99	0.6274	3.71	0.74	1.27	1.21	11	98	-3.1	-5.5
951128	B	P	31.35	0.3670	0.44	1.31	1.33	1.52	21	90	-4.8	-5.9
951128	C	P	19.33	0.1864	0.00	0.92	0.74	0.00	20	94	-3.1	-4.7
951207	C	P	68.60	0.2823	0.75	0.48	0.50	0.67	31	98	-1.2	-2.7
951207	D	P	66.41	0.2444	0.51	0.96	0.93	0.51	25	98	-1.8	-3.4
951230	A	P	15.17	0.2066	0.00	0.44	0.36	0.00	27	96	-3.5	-5.2
960123	A	P	29.79	0.1646	0.95	1.27	1.20	9.05	24	90	-10.4	-12.3
960312	A	P	4.684	0.05064	0.00	-	-	-	25	99	-1.4	-4.0
960323	B	P	64.82	0.4606	0.71	2.27	2.33	0.52	12	95	-5.4	-7.3
960323	C	P	58.12	0.4726	0.33	12.00	10.89	2.00	17	95	-5.0	-6.8

3. Warm and/or dry; HAS temp. >0, RH < 90%

date	case	agent small conc.	2D-C prec.	gage prec.	Plume Ratios conc.	Plume Ratios prec.	Plume Ratios gage	tran. min	RH	Temp.C HAS	Temp.C TAR
950303	A A	0.788	0.00433	0.00	0.78	0.73	0.00	12	80	+.8	-2.9
950303	B A	0.631	0.00284	0.00	0.32	0.31	0.00	12	82	+.3	-3.1
950305	C P	38.64	0.1739	0.48	0.38	0.33	0.15	8	99	+.1	-2.7
951128	A P	9.441	0.1106	0.28	1.23	1.24	1.56	17	61	-5.2	-8.3
960304	A A	19.53	0.09759	0.00	-	-	-	16	39	+1.3	-2.2
960305	A A	12.21	0.07743	0.12	0.26	0.15	0.23	18	55	+1.1	-6.2
960305	B A	6.586	0.03850	0.00	0.21	0.21	0.00	11	58	+.9	-4.9
960305	C A	55.77	0.2625	0.52	3.01	3.41	5.20	9	58	+.4	-5.0

Acceptables:

1. GOOD AgI, strong targeting; peak in > 10,000 L^{-1}

date	case	agent small conc.	2D-C prec.	gage prec.	Plume Ratios conc.	Plume Ratios prec.	Plume Ratios gage	tran. min	RH	Temp.C HAS	Temp.C TAR
950105	A A	26.19	0.2629	0.98	3.30	2.61	1.08	54	96	-3.5	-5.8
950105	B A	87.78	0.8876	1.23	3.18	2.14	1.06	22	96	-3.2	-5.6
950126	A A	59.44	1.214	1.97	1.97	2.11	1.19	26	97	-2.6	-4.5
950126	D A	12.97	0.1485	1.09	0.63	0.62	1.00	19	97	-2.1	-4.5
950305	B A	1.126	0.00445	0.09	0.04	0.03	0.11	14	100	-1.3	-3.7
951128	E A	20.17	0.1936	0.56	-	-	-	18	90	-1.5	-3.6
960130	E A	52.94	0.5013	1.70	0.91	1.02	0.81	15	98	-2.1	-3.9
960131	F A	20.98	0.3565	0.33	1.25	0.63	0.48	21	97	-3.8	-5.6

2. FAIR AgI, weak targeting; 2500 L^{-1} < peak IN < 10,000 L^{-1}

date	case	agent small conc.	2D-C prec.	gage prec.	Plume Ratios conc.	Plume Ratios prec.	Plume Ratios gage	tran. min	RH	Temp.C HAS	Temp.C TAR
941213	A A	46.44	0.3177	0.96	1.01	0.67	0.35	30	94	-6.0	-8.2
941213	B A	122.9	0.8903	3.08	1.72	1.52	1.79	17	94	-6.3	-8.7
941213	C A	112.2	0.7131	0.95	1.95	1.46	0.56	15	94	-6.1	-8.6
941215	A A	95.50	0.6195	1.23	12.24	8.22	INF	19	92	-7.7	-10.4
950126	C A	10.97	0.1591	0.43	-	-	-	21	93	-.7	-4.2
950126	E A	99.76	1.463	3.76	2.07	2.42	1.61	18	98	-2.5	-4.6
950126	F A	36.00	0.7131	2.35	-	-	-	13	97	-3.7	-5.8
960119	B A	41.04	0.3027	0.39	0.59	0.57	0.25	29	93	-6.3	-8.7
960121	A A	167.3	1.262	3.02	1.46	1.40	1.24	17	95	-5.6	-7.5
960131	D A	29.99	0.6576	0.68	0.44	0.49	0.37	14	97	-2.9	-4.9

3. GOOD propane, strong targeting; peak IN for both tags > 1230 L^{-1}

date	case	agent small conc.	2D-C prec.	gage prec.	Plume Ratios conc.	Plume Ratios prec.	Plume Ratios gage	tran. min	RH	Temp.C HAS	Temp.C TAR
950107	A P	10.97	0.1005	0.27	2.03	2.24	0.59	16	97	-2.0	-4.1
950107	B P	4.101	0.04499	0.16	1.25	1.48	0.63	15	97	-2.7	-5.1
950305	A P	28.81	0.2216	0.14	11.88	24.84	0.67	15	99	-2.2	-4.1
950311	A P	106.1	0.6377	2.96	1.40	1.19	0.64	11	101	-1.3	-3.1
950311	B P	18.10	0.1203	0.27	2.51	3.07	0.22	11	101	-.9	-3.0
950311	C P	93.17	0.5662	1.41	0.95	0.85	0.49	11	100	-2.0	-4.0
951207	A P	36.11	0.2015	2.26	0.95	1.10	1.16	39	98	-.5	-2.0
951230	C P	116.3	1.988	0.76	1.19	1.16	1.02	24	97	-2.2	-3.9
951230	E P	93.55	0.5416	0.66	1.13	0.82	0.63	15	98	-2.0	-3.6
951230	F P	84.21	0.4530	1.57	0.95	0.79	0.67	17	98	-1.7	-3.3
960103	B P	42.43	0.3130	0.00	10.51	10.73	0.00	14	98	-2.4	-4.0
960116	A P	142.2	0.6530	6.46	1.33	1.16	1.19	8	99	-.6	-2.1
960117	A P	88.27	0.4163	2.39	1.75	1.50	0.77	10	99	-1.2	-2.8
960130	B P	85.22	0.6375	1.84	1.18	1.23	0.97	13	97	-2.2	-3.8
960130	C P	80.95	0.7013	2.79	1.44	1.46	1.46	13	98	-2.2	-3.7
960130	D P	125.1	0.9107	1.90	2.12	1.76	1.00	16	98	-2.1	-4.0
960328	A P	117.5	0.7782	1.84	2.49	2.27	1.80	24	94	-.4	-2.3

4. FAIR propane, weak targeting; peak IN for one tag < 1230 L^{-1}

date	case	agent	small conc.	2D-C prec.	gage prec.	Plume Ratios conc.	Plume Ratios prec.	Plume Ratios gage	tran. min	RH	Temp.C HAS	Temp.C TAR
950126	B	P	11.90	0.1708	0.64	-	-	-	20	94	-.7	-4.0
951128	D	P	13.19	0.1634	0.15	0.65	0.64	0.29	17	93	-2.5	-4.4
951207	B	P	104.1	0.4424	1.41	1.29	1.32	2.31	30	98	-.8	-2.2
951230	B	P	64.46	1.342	0.52	0.90	1.01	0.85	25	97	-2.8	-4.5
951230	D	P	79.71	0.9351	0.87	1.28	1.07	0.65	20	97	-1.9	-3.6
960103	A	P	8.130	0.04254	0.00	13.66	14.04	0.00	18	98	-2.2	-3.8
960130	A	P	46.55	0.4033	1.31	-	-	-	16	97	-2.3	-4.1
960131	B	P	58.61	1.226	1.31	1.53	1.48	1.12	13	98	-2.9	-4.8
960131	C	P	26.58	0.5091	0.52	0.66	0.74	0.61	14	97	-3.0	-5.0
960131	E	P	49.94	1.361	1.70	2.20	1.98	1.48	17	97	-3.4	-5.3

Table A2.4. Partitioned experimental data--increases. Concentrations (L^{-1}) and precipitation rates (mm h^{-1}) are for the average of the controls for the AgI (A) and propane (P) seeding agents. "Small 2D-C" values were restricted to particles up to 0.8 mm sizes. Plume increases are for 2D-C concentration and precipitation rates and for gage precipitation rates, expressed as the plume value minus the average of control values. Transit times, in minutes, are the average of the two measured or calculated T2 numbers. The relative humidity and air temperature at the HAS release site are included as is the air temperature at the TAR.

The partitioning is by the strength of the ice nuclei concentrations detected at the TAR and by the HAS release conditions.

Exclusions:

1. Bad targeting cases; AgI, with peak IN < 2500 L^{-1}

date	case	agent	average of controls small conc.	average of controls 2D-C prec.	average of controls gage prec.	Plume Increases conc.	Plume Increases prec.	Plume Increases gage	tran. min	RH	Temp.C HAS	Temp.C TAR
950105	C	A	25.50	.3879	1.65	-.75	-.0178	-.04	21	96	-4.1	-6.2
960118	A	A	-	-	-	-	-	-	21	92	-7.8	-8.8
960119	A	A	96.24	.5528	1.06	-42.28	-.2521	-1.06	14	93	-7.4	-9.4
960119	C	A	9.27	.0642	.63	21.67	.1361	.11	21	93	-6.3	-8.8
960323	A	A	13.98	.1261	.20	5.33	.0425	.71	17	95	-5.0	-7.0
960323	D	A	24.05	.0434	.17	4.47	.0412	.84	19	95	-4.8	-6.6
960329	A	A	-	-	-	-	-	-	41	98	-2.9	-4.1

2. Bad targeting cases; propane, with both tags having peak IN < 1230 L^{-1}

date	case	agent	average of controls small conc.	average of controls 2D-C prec.	average of controls gage prec.	Plume Increases conc.	Plume Increases prec.	Plume Increases gage	tran. min	RH	Temp.C HAS	Temp.C TAR
950214	A	P	55.70	.4927	3.08	-14.71	.1347	.64	11	98	-3.1	-5.5
951128	B	P	24.01	.2766	.29	7.34	.0905	.15	21	90	-4.8	-5.9
951128	C	P	21.07	.2522	.52	-1.74	-.0658	-.52	20	94	-3.1	-4.7
951207	C	P	142.80	.5613	1.12	-74.20	-.2790	-.37	31	98	-1.2	-2.7
951207	D	P	69.01	.2628	1.01	-2.60	-.0184	-.50	25	98	-1.8	-3.4
951230	A	P	34.52	.5701	.24	-19.35	-.3635	-.24	27	96	-3.5	-5.2
960123	A	P	23.53	.1373	.11	6.27	.0273	.85	24	90	-10.4	-12.3
960312	A	P	-	-	-	-	-	-	25	99	-1.4	-4.0
960323	B	P	28.51	.1974	1.36	36.31	.2632	-.65	12	95	-5.4	-7.3
960323	C	P	24.05	.0434	.17	53.28	.4292	.17	17	95	-5.0	-6.8

3. Warm and/or dry; HAS temp. >0, RH < 90%

date	case	agent	average of controls: small 2D-C conc.	average of controls: 2D-C prec.	average of controls: gage prec.	Plume Increases: conc.	Plume Increases: prec.	Plume Increases: gage	tran. min	RH	Temp.C HAS	Temp.C TAR
950303	A	A	1.01	.0060	.03	-.22	-.0016	-.13	12	80	+.8	-2.9
950303	B	A	1.95	.0091	.00	-1.32	-.0062	.00	12	82	+.3	-3.1
950305	C	P	102.10	.5220	3.13	-63.46	-.3481	-2.65	8	99	+.1	-2.7
951128	A	P	7.69	.0889	.18	1.75	.0217	.10	17	61	-5.2	-8.3
960304	A	A	-	-	-	-	-	-	16	39	+1.3	-2.2
960305	A	A	46.75	.5193	.53	-34.54	-.4419	-.41	18	55	+1.1	-6.2
960305	B	A	32.03	.1795	.71	-25.44	-.1410	-.71	11	58	+.9	-4.9
960305	C	A	18.51	.0770	.10	37.27	.1855	.42	9	58	+.4	-5.0

Acceptables:

1. GOOD AgI, strong targeting; peak in > 10,000 L^{-1}

date	case	agent	average of controls: small 2D-C conc.	average of controls: 2D-C prec.	average of controls: gage prec.	Plume Increases: conc.	Plume Increases: prec.	Plume Increases: gage	tran. min	RH	Temp.C HAS	Temp.C TAR
950105	A	A	7.94	.1007	.91	18.25	.1622	.07	54	96	-3.5	-5.8
950105	B	A	27.63	.4144	1.16	60.15	.4733	.07	22	96	-3.2	-5.6
950126	A	A	30.21	.5750	1.65	29.24	.6391	.32	26	97	-2.6	-4.5
950126	D	A	20.63	.2406	1.09	-7.66	-.0921	.00	19	97	-2.1	-4.5
950305	B	A	25.05	.1316	.83	-23.93	-.1271	-.74	14	100	-1.3	-3.7
951128	E	A	-	-	-	-	-	-	18	90	-1.5	-3.6
960130	E	A	58.13	.4904	2.11	-5.19	.0110	-.41	15	98	-2.1	-3.9
960131	F	A	16.78	.5642	.69	4.21	-.2077	-.36	21	97	-3.8	-5.6

2. FAIR AgI, weak targeting; 2500 L^{-1} < peak IN < 10,000 L^{-1}

date	case	agent	average of controls: small 2D-C conc.	average of controls: 2D-C prec.	average of controls: gage prec.	Plume Increases: conc.	Plume Increases: prec.	Plume Increases: gage	tran. min	RH	Temp.C HAS	Temp.C TAR
941213	A	A	45.82	.4748	2.71	.62	-.1571	-1.75	30	94	-6.0	-8.2
941213	B	A	71.31	.5840	1.73	51.60	.3063	1.36	17	94	-6.3	-8.7
941213	C	A	56.92	.4892	1.69	55.28	.2240	-.74	15	94	-6.1	-8.6
941215	A	A	7.80	.0753	.00	87.70	.5442	1.23	19	92	-7.7	-10.4
950126	C	A	-	-	-	-	-	-	21	93	-.7	-4.2
950126	E	A	48.19	.6045	2.33	51.57	.8586	1.43	18	98	-2.5	-4.6
950126	F	A	-	-	-	-	-	-	13	97	-3.7	-5.8
960119	B	A	70.11	.5327	1.56	-29.07	-.2300	-1.17	29	93	-6.3	-8.7
960121	A	A	114.53	.8991	2.43	52.78	.3630	.59	17	95	-5.6	-7.5
960131	D	A	68.01	1.3383	1.83	-38.02	-.6807	-1.15	14	97	-2.9	-4.9

3. GOOD propane, strong targeting; peak IN for both tags > 1230 L^{-1}

date	case	agent	average of controls: small 2D-C conc.	average of controls: 2D-C prec.	average of controls: gage prec.	Plume Increases: conc.	Plume Increases: prec.	Plume Increases: gage	tran. min	RH	Temp.C HAS	Temp.C TAR
950107	A	P	5.40	.0449	.46	5.57	.0557	-.19	16	97	-2.0	-4.1
950107	B	P	3.27	.0304	.26	.83	.0146	-.10	15	97	-2.7	-5.1
950305	A	P	1.71	.0089	.21	27.10	.2127	-.07	15	99	-2.2	-4.1
950311	A	P	75.94	.5369	4.61	30.17	.1009	-1.65	11	101	-1.3	-3.1
950311	B	P	7.20	.0392	1.22	10.90	.0811	-.95	11	101	-.9	-3.0
950311	C	P	97.57	.6675	2.86	-4.40	-.1013	-1.45	11	100	-2.0	-4.0
951207	A	P	37.96	.1837	1.94	-1.85	.0178	.32	39	98	-.5	-2.0
951230	C	P	98.06	1.7135	.75	18.26	.2745	.02	24	97	-2.2	-3.9
951230	E	P	82.54	.6597	1.05	11.01	-.1181	-.39	15	98	-2.0	-3.6
951230	F	P	88.37	.5711	2.34	-4.16	-.1181	-.77	17	98	-1.7	-3.3
960103	B	P	4.04	.0292	.10	38.39	.2839	-.10	14	98	-2.4	-4.0
960116	A	P	107.21	.5635	5.45	35.00	.0895	1.01	8	99	-.6	-2.1
960117	A	P	50.35	.2777	3.11	37.92	.1386	-.72	10	99	-1.2	-2.8
960130	B	P	72.51	.5202	1.90	12.71	.1174	-.06	13	97	-2.2	-3.8

960130	C	P	56.27	.4789	1.92	24.68	.2225	.88	13	98	-2.2	-3.7
960130	D	P	59.13	.5185	1.90	65.98	.3923	.01	16	98	-2.1	-4.0
960328	A	P	47.21	.3423	1.03	70.29	.4359	.82	24	94	-.4	-2.3

4. FAIR propane, weak targeting; peak IN for one tag < 1230 L^{-1}

			average of controls									
		agent	small	2D-C	gage	Plume Increases			tran.		Temp.C	
date	case		conc.	prec.	prec.	conc.	prec.	gage	min	RH	HAS	TAR
950126	B	P	-	-	-	-	-	-	20	94	-.7	-4.0
951128	D	P	20.18	.2540	.53	-6.99	-.0906	-.38	17	93	-2.5	-4.4
951207	B	P	80.94	.3340	.61	23.16	.1084	.80	30	98	-.8	-2.2
951230	B	P	71.48	1.3250	.62	-7.02	.0170	-.10	25	97	-2.8	-4.5
951230	D	P	62.08	.8740	1.35	17.64	.0612	-.48	20	97	-1.9	-3.6
960103	A	P	.60	.0030	.11	7.53	.0395	-.11	18	98	-2.2	-3.8
960130	A	P	-	-	-	-	-	-	16	97	-2.3	-4.1
960131	B	P	43.66	.6169	1.17	14.96	.6092	.14	13	98	-2.9	-4.8
960131	C	P	39.99	.6899	.85	-13.41	-.1808	-.33	14	97	-3.0	-5.0
960131	E	P	22.68	.6871	1.15	27.27	.6739	.56	17	97	-3.4	-5.3