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Statistical Evaluation of the 1984–88 Seeding Experiment in Northern Greece

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Abstract. A randomized crossover hail suppression seeding experiment conducted in northern Greece during 1984–88 was evaluated using hailpads distributed over approximately 2000 km^2 with a mean separation of 4.5 km. A total of 196 hailpads were collected on 37 hail days and a Wilcoxon Signed Rank test was applied to 10 target and control hailpad parameters. All parameters showed a reduction due to treatment ranging from 19 to 85%. The associated P–values range from 0.003 to 0.392. Three hail crop insurance parameters showed reductions from 18 to 59% with associated P–values between 0.11 and 0.54. Reductions due to treatment were evident in the five year aggregate size distributions in which target hailstones were 38 to 100% fewer than control hailstones in 12 size categories. The average size reduction was 55% with a P–value of 0.002. Similar reductions were observed in each year of the experiment.

1. INTRODUCTION

Those familiar only with the glorious summer sun and sandy beaches of the Greek islands may be surprised by the need for a hail suppression program in that country. Yet vacationers to northern Greece will recall the rugged terrain – broad river valleys ringed by 2 km high mountain ridges – that forms the breeding ground of almost daily convective activity in the April to July period and beyond. These same fertile river valleys are the backbone of Greek agriculture where farmers grow a wide assortment of fruits, vegetables, cotton, tobacco, rice and cereal crops.

The Greek National Hail Suppression Program (GNHSP) was established in 1984 under the auspices of the National Agricultural Insurance Institute, now known as EL.G.A. The primary objectives of the program were to reduce hail damage to crops in the agricultural valleys of northern Greece using airborne seeding technology and to evaluate the program by means of a fully randomized crossover seeding experiment. This paper summarizes the statistical evaluation of the seeding experiment conducted during 1984–88.

2. GNHSP PROGRAM OVERVIEW

2.1 Experimental Design

The GNHSP was designed to protect three agricultural areas of northern Greece (Karacostas, 1984, 1989). Area 1 was designated as the experimental area (Fig. 1) where randomized crossover seeding was conducted while Areas 2 and 3 were fully seeded. Area 1 was divided into approximately equal northern and southern sub–areas, with the orientation of the dividing line determined by mean storm motion, terrain and the spatial variability of crops. No buffer zone seperated the two sub–areas. Hence, contamination of pads could occur if seeded cells crossed the dividing line, consequently reducing the distinction between target and control estimates. Partly because the sub–areas are physically adjacent, the correlation of hail occurrence is expected to be high and thus reduce the variance of target–control differences.

The experimental unit was a declared "hail day." On each day meeting seeding criteria, operations were conducted in either the northern or southern sub–area, depending on the random number of the day. The seeding criteria was a reflectivity of 35 dBZ or more measured in convective cells located either inside, or within 20 minutes of entering, the designated target area at altitudes corresponding to temperatures between -5° and -30°C (Flueck *et al.*, 1986). A hailpad network provided an objective measure of target–control differences.

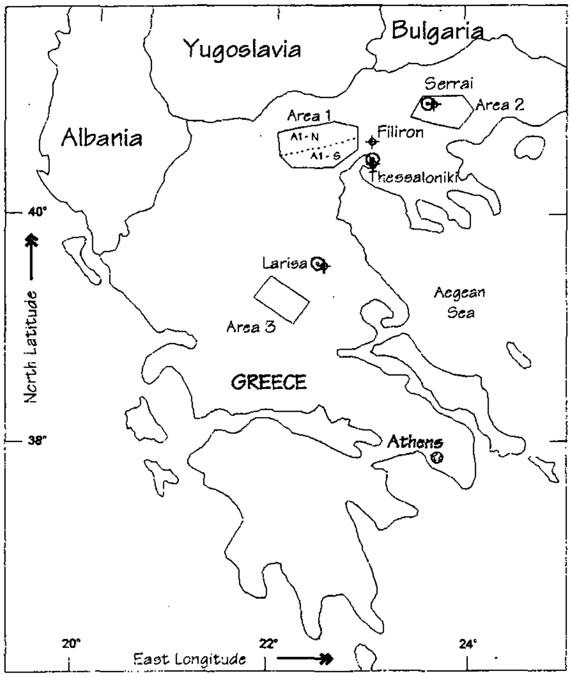

Fig. 1. The three areas of the GNHSP, circa 1984. Crossed circles indicate locations of project radars over the course of the experiment. Area One was divided into northern and southern sub–areas for the randomized experiment. (After Henderson, 1986.)

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2.2 Seeding Hypothesis

The GNHSP was not designed with an "official" seeding hypothesis but pragmatic versions have evolved during the program. In 1984–85, Atmospherics Incorporated applied the concept of Limiting Supercooled Liquid Water as the rationale for operations. As the name implies, this approach aims to reduce the amount of supercooled water available to the storm by converting it to ice so that it is then unavailable for hailstone growth (Solak *et al.*, 1985). Since that time, the working hypothesis has been broadly based on Beneficial Competition Theory which assumes a lack of natural ice nuclei in the environment. Adding silver iodide (AgI) is thought to result in the production of a substantial number of "artificial" ice nuclei. The natural and artificial nuclei then compete for the available supercooled water in the hailstone growth regions within the storm. If enough nuclei are added it is possible that the hailstones will be small enough to melt completely before reaching the ground. No additional microphysical details of a hypothesis have been introduced because of the limited in–cloud measurements made on the program.

Operationally, the cloud seeding experiment concentrated on the time–evolving updrafts of ordinary (single) cells and on the updrafts of developing feeder clouds that flank mature multicell storms. Stated most simply (Henderson, 1986), this technique limits the available supercooled liquid water within those cloud volumes where hailstone birth and growth are assumed to occur.

Limited microphysical observations in Greek convective clouds (Krauss and Papamanolis, 1989) support the ice phase or graupel embryo precipitation process and are consistent with the beneficial competition theory. These observations include the presence of conical graupel embryos, average cloud base temperatures near 10°C and a continental drop size distribution. Furthermore, convective clouds with tops warmer than -10°C have not been observed to produce rain. The presence of an active coalescence process, which does not appear likely from observations, would invalidate the beneficial competition premise that seeded cloud volumes and volumes where hailstone embryo formation and growth occur are coincident.

2.3 Experimental Conduct

The experiment was operated during 1 May to 30 September in each of the years 1984–88. Seeding was conducted with five light, twin–engined (Cessna 340A or Piper Aztec) aircraft equipped with seeding racks containing both ejectable and end–burning AgI flares. TB–1 pyrotechnic mixtures were used in all years. At most, three aircraft seeded a single storm (in 1984) but typically no more than two aircraft could conduct seeding operations in the experimental area at any one time due to operating logistics and Air Traffic Control policy.

Weather surveillance in the experimental area was provided by two radars, an Enterprise WSR74 10 cm S–band set located at Macedonia International Airport in Thessaloniki with backup from an Enterprise WR100 5 cm C–band radar located near the town of Serres in 1984–85 and near the village of Filiron in 1986–88. A radar watch was maintained as required by forecast and observed convection 7 days per week during 1984–86. During 1987–88 the watch was standardized at 20 hours per day (0600 to 0200 local) and was extended to 24 hours if cells were observed or forecast. Storms were not observed to generate hail large enough to damage hailpads after 2300 local.

Several seeding methodologies were used depending on factors such as storm type, visibility, terrain proximity and time of day to enable delivery of seeding material to actively growing storm regions in as many conditions as possible. Seeding material was released in one or more of the following locations:

- growing cloud towers (feeder cells) on the upshear flanks of mature multicell storms;
- regions of identifiable liquid water and/or updraft in single convective cells;
- weak updraft regions below the base of feeder cells;
- the main updraft region below the base of single convective cells; and
- regions of expected storm inflow based on ground radar information in the absence of good visibility.

In practise, seeding was begun on storms that moved or propagated toward the experimental area when the leading edge of the storm above seeding criteria first entered the buffer zone (1984–85) or when the leading edge of the 35 dBZ contour first entered the buffer zone (1986–88). Storms frequently reached seeding criteria within the area and were seeded as soon as possible thereafter.

The nominal seeding rate during 1986–88 for penetrations near -10°C was one 20 g flare every 5 s, resulting in a seeding rate of 240 g/min. In practise, these rates were adjusted both upwards and downwards by up to 50% depending on conditions. Seeding at cloud base was conducted by burning one or two 150 g flares over a 4 minute period for a seeding rate of 40 or 80 g/min.

3. EVALUATION DATASETS

3.1 Hailpad Network Installation and Service

Each hailpad site in the Area 1 network consisted of a levelled aluminum frame designed to firmly hold a piece of styrofoam with an exposed surface of 27 x 27 cm at a height of 1.5 m above ground. The network varied considerably during the 5 years of the experiment. In 1984, the network was established with a 4.5 km mean spacing with 123 sites distributed within approximately 2300 km^2. Of these sites, 56 lay in the north (1150 km^2), 60 in the south and 7 were located outside of Area 1 and excluded from the analysis.

At the beginning of 1985, the northeast portion of the area was expanded by about 40 km^2; 6 new sites were added and several were removed. The result was 63 sites in the north and 62 in the south. On 1 June, the boundary between north and south was moved southward to re–equalize the size of the sub–areas, leaving 69 sites in the north and 57 in the south.

Before the start of the 1986 season, approximately 100 additional sites were added to the "regular" network to create two, small "dense" networks with a mean spacing of 1.5 km for improved hailswath resolution. A standard rain gauge was also installed at each regular site and several sites were relocated. During the season, most of the sites were upgraded to improve hailstand stability with little interruption in service. The final

1986 configuration consisted of 69 regular sites in the north, 59 in the south and 1 outside the boundaries of the area.

The 1987 and 1988 networks were similar to that of 1986 although one site was relocated due to flooding. For these years, the network consisted of 68 sites in the north, 60 in the south and 1 outside of the area. Fig. 2 is a map of the 1988 network.

Pads were routinely changed within 24 hours of possible storm damage as indicated by radar, or within 10 days (14 days in 1984–85) of deployment if no storms occurred. In practice, a new experimental day was not declared until hailpad crews reported that all damaged pads from previous storms had been changed.

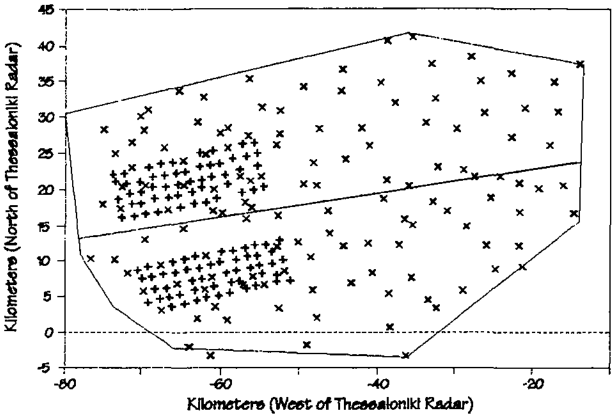

Fig. 2. The 1988 hailpad network in Area One showing the distribution of regular (x) and dense (+) sites.

3.2 Hailpad Data Set

Hailpad styrofoam varied somewhat in composition from year to year and batch to batch according to availability. To account for changing characteristics, all types of hailpad material used on the program were calibrated using steel balls dropped from varying heights to match hailstone energy (Dalezios *et al.*, 1991; Lozowski *et al.*, 1978). Hailstone size was calculated based on the calibration data and stones less than 5 mm in diameter (the minimum detectable stone size of the least sensitive pad material) were excluded from analysis.

Methods of digitizing hailstone dents varied somewhat during the experiment. In 1984–85, pads were inked and dents measured using a video scanning technique (Henderson, 1986). In 1986–88, pads were inked and dents were measured using a digitizing tablet (bitpad). In both techniques, artifacts (e.g., bird damage and pebble impact dents) were either not digitized or were removed graphically based on the experience of the operator.

In 1984–86, random numbers (i.e., the identification of the target/control sub–areas) were known ahead of time by the aircraft controllers who worked from an authorized list of such numbers. To our knowledge, this information did not result in any effort to conduct seeding operations in other than an objective manner. Furthermore, due to penalty clauses in the operations contract for not seeding on hail damage days, crew alert status was very high. This knowledge of the target was eliminated in 1987–88 by using sealed envelopes which were opened only when seeding criteria were met. Random numbers were drawn twice on three days in 1986 due to incorrect instructions but in all cases, the first number drawn was used to identify the target area for analysis and no seeding was conducted after the second number was drawn.

Four datasets were originally identified for analysis of the 1984–88 period. The SC (Seeding Criteria) dataset included all days when seeding criteria were met (119 days including all days in 1984 when seeding or reconnaissance flights occurred). The DR (Days at Risk) dataset included all days at risk, consisting of 76 days when hail damage to pads was observed and/or seeding operations were conducted. The DE (Damage in Either) dataset contained 37 days with damage to hailpads in either the target or control. A fourth dataset (DB) consisted of 12 days with hailpad damage in both target and control. This fourth dataset was considered only in preliminary analyses (Rudolph *et al.*, 1989a) and because of its small size is not discussed further in the present paper. It is recognized that events following the randomization decision should generally not determine the composition of the evaluation database. This suggests that SC should be the dataset of choice for evaluation. However, as will be seen, the results were independent of whether the SC, DR, or DE dataset was used.

Hailpad estimators were summed for each day in the dataset, weighted by the slight differences in pad placement density in the northern and southern sub–areas, and normalized by the total number of *regular* network pads exposed. Weighting factors for pad density ranged from 0.963 to 1.124. Table 1 contains a summary of the hailday and hailpad dataset (for details of the dataset, see Rudolph *et al.*, 1989b). Dense network pads have not been included in this analysis.

Table 1. Number of days in each dataset and number of regular network hailpads collected.

		Days		Hailpads	
Season	**SC**	**DR**	**DE**	**Target**	**Control**
1984	26	16	6	15	18
1985	21	13	5	14	24
1986	26	11	6	6	7
1987	22	16	4	19	24
1988	24	20	15	36	33
Total	119	76	37	90	106

At the end of the exploratory phase of the experiment and based on physical appropriateness, ten estimators of treatment effect were identified during the 1986 season. Most estimators chosen (summed over a hail day, weighted and normalized) were functions of hailstone diameter and included:

- number of damaged pads (Pad);
- total number of hailstones (Stone);
- median hailstone diameter (Med);
- maximum hailstone diameter (Max);
- total pad area covered by hailstones (Cov);
- total hailstone volume (Vol);
- impact energy (KE); and
- reflectivity (Refl, defined as hailstone diameter to the sixth power).

Two additional estimators, SSI (Spatial Severity Index) and AVA (AVerage Area), were multiplicative functions of several simpler estimators (Solak *et al.*, 1985). While somewhat redundant, they are intended to identify small variations in the other parameters.

The list of estimators above represents all of the hailpad parameters examined in the evaluation, not a subset. Many of the estimators are therefore expected to be correlated since all those of higher order were calculated from stone diameter. Specifically, this includes the area of the pad covered by hailstone damage, stone volume, kinetic energy, and reflectivity. It is also expected that SSI and AVA will be correlated with other, simpler, estimators. While kinetic energy was formally identified as the primary parameter in the seeding experiment, it has not been used as the sole determinant of experimental success.

3.3 Hail Crop Insurance Data

All agricultural land within the project areas is covered by mandatory government hail crop insurance, with EL.G.A. collecting and archiving all claims. The mandatory nature of the insurance eliminates many of the policy coverage problems normally associated with accurately determining treatment effects (Changnon, 1985). Insurance payouts are governed by crop type, stage of growth, commodity prices, agricultural subsidies and currency fluctuations and therefore do not strictly reflect physical characteristics of hail damage. However, the program is funded with the explicit goal of reducing payouts and therefore crop insurance data are relevant to the evaluation.

Insurance data made available to the GNHSP include the storm (damage) date, the number of reports for each village but not the exact location of the damage, the number of fruit trees or field crop area damaged and the total payout. Claims must be filed within 48 hours of the storm. No payments are made when damage is less than 20% of the value of the crop, which accounts for records of damage with no payout. The procedures of the field adjustors did not change significantly during the experimental period.

Three insurance parameters were considered: payout (Pay); damaged area (Area); and number of reporting villages (Vill). On some occasions the number of damaged trees was reported instead of the size of the damaged area. In these cases, the area was determined on the basis of 30 trees per 1000 m^2. Payout was based on the value of 1988 drachmas with inflationary adjustments for earlier years (Rudolph and Ganniaris-Papageorgiou, 1991).

4. RESULTS

4.1 Treatment Effect

Means (M) of target and control daily values were used to define a relative target–control difference (D) such that:

$$D = M_t / M_c - 1$$

where t and c refer to target and control values respectively. Results for 1984–88 (Fig. 3) show that target estimates of hailpad damage and insurance parameters are consistently less than those in the control, in the direction of a beneficial (negative) treatment effect.

Negative differences ranged from 19 to 85% for the five-year hailpad dataset and from 18 to 59% for the insurance dataset. These results are similar to those of Flueck *et al.* (1986) and Rudolph *et al.* (1989a) who performed analyses for subsets of the data. Furthermore, the results were identical for the SC, DR, and DE datasets because of the paired differences.

It is clear that not all of the reductions in hailpad parameters shown in Fig. 3 are independent. As stated earlier, higher order parameters were calculated functions of hailstone diameter and are expected therefore to be highly correlated. One would expect differences for these variables to be of the same sign.

4.2 Significance of Results

The Wilcoxon Signed Rank test (WSR) examined the strength of the target–control relative differences (Fig. 4). The WSR test was chosen because of its nonparametric character and robustness, and because the randomized experiment produced pairs of target-control values. Values for the SC, DR and DE datasets were identical because paired zeroes are ignored. Two-tailed P-values (probabilities) ranged from 0.003 to 0.392 for the hailpad dataset, indicating the treatment effects were not due to chance for most variables. P-values for the insurance dataset ranged from 0.11 to 0.54.

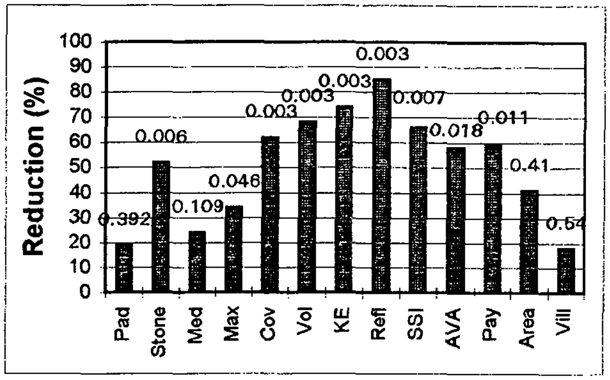

Fig. 3. Hailpad and crop insurance estimated treatment effects. Associated P-values are shown above the column.

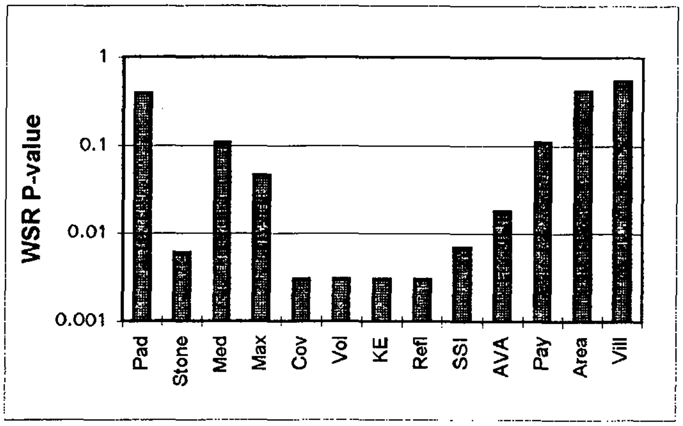

Fig. 4. Hailpad and crop insurance WSR P-values.

4.3 Hail Day Contingency Analysis

Following the methodology of Flueck *et al.* (1986), contingency tables were constructed for the presence of hail in the target and control sub-areas during 1984–88. The results, shown in Table 2, with two-tailed Fisher Exact probabilities of 0.31 for the DE dataset and X^2 significance level of 0.385 for the DR dataset, suggest that the control is indeed associated with more days with hail damage than the target, although not significantly so.

Table 2. Contingency analyses of target and control for DR and DE datasets

	DR		DE	
	No Hail	Hail	No Hail	Hail
Control	49	27	9	27
Target	54	22	14	22

The contingency coefficients for the five-year dataset were 0.12 and 0.06 for DE and DR, respectively, indicating a weak association between hail occurrence and sub-area. Two possible explanations for the magnitude of this coefficient are:

- seeding is not completely eliminating damage to hailpads or;
- an underlying relationship exists between hail in target and control.

The first explanation is clearly valid and in keeping with a hail suppression (as opposed to prevention) project. The second is also expected due to the immediate proximity of the sub-areas, although the contingency coefficient includes a treatment effect which will reduce the association.

Further examination of Table 2 for the DR dataset shows that 27 of 76 days (36%) were associated with hail in the control while 22 of 38 days (29%) were associated with hail in the target. For the DE dataset, 27 of 36 days (75%) were associated with hail in the control and 22 of 36 days (61%) with hail in the target.

4.4 Hailstone Size Distributions

Hailstone target–control count differences, divided by control counts, and partitioned into 12 stone diameter size categories (e.g., 5 to 7 mm, centered at 6 mm), are shown in Fig. 5. It is apparent that target counts are less than control counts in all 12 categories, from 38% less in the smallest size categories to 100% less in the largest size categories. The mean estimated treatment effect is 55% over the 12 size categories.

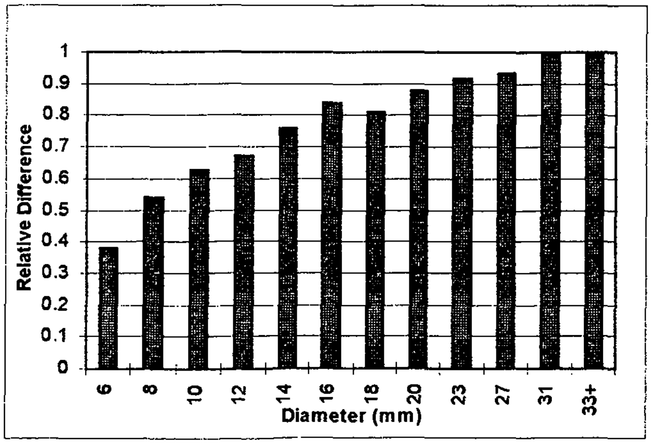

Fig. 5. Normalized target–control hailstone count differences in 12 size categories, 1984–88.

Table 3 presents size distribution estimated treatment effects for each of the 5 years of the experiment. With two exceptions (20 and 27 mm size categories in 1987), all of the size categories in each year indicated a positive treatment effect. Also, with the exception of 1987, each of the years indicated a stronger treatment effect in larger size categories. The evidence shows a decrease in the number of hailstones in the target, as compared to the control, in all size categories except the 27 mm group in 1987. With that sole exception, the larger sizes were not observed in the target area in all other years. In fact, for some years (e.g., 1984), the maximum stone size in the target was at least 33% smaller than in the control. Based on the size distribution data in Table 3, it appears that 1986 was the least severe hail year and 1987 was the most severe although 1988 produced the most damaged hailpads. However, it is worth noting that the large stones in 1987 occurred in association with one storm cell which developed in what is for Greece, an unusually convective environment. This storm was – perhaps – the only claimant to supercell status observed over the course of the experiment.

The WSR test was applied separately to the differences of each year. The resulting two-tailed P-values show very little probability (e.g., 0.01 in 1986) that the beneficial treatment effects are due to chance.

Further evidence on the possible physical effects of treatment on hailstone size is available by examining the number of stones in each category normalized by the total number of stones. Fig. 6 is a relative frequency diagram for the target and control sub-areas. In the 6 mm size category, the target had relatively more stones than the control. In the 8 mm category, relative frequencies were approximately equal. In all larger size categories, target relative frequencies were less than control. These observations are consistent with a beneficial competition process which inhibits the growth of large stones and increases the relative number of small stones (Sackiw, 1991).

Size distributions were further investigated by determining the inverse cumulative number concentration N(D) (Smith, 1982; Smith and Waldvogel, 1989) given by:

$$N(D) = \int_D^{\infty} n(D)dD$$

where n(D) is the hailstone number concentration. If the underlying size distribution for the population is of the Marshall–Palmer exponential form $n(D) = n_0 e^{-\Lambda D}$, then N(D) will have the same slope parameter Λ but intercept n_0/Λ compared to n(D).

Target and control values of five-year n(D) and N(D) distributions are shown in Table 4. N(D) distributions are closely exponential with R^2 values greater than 0.99 for each. Λ values were 0.42 and 0.31 mm^{-1}, with standard errors of 0.005 and 0.009 mm^{-1}, for target and control distributions, respectively. This suggests there is little likelihood that the differences are due to chance (P-value less than 0.005).

Values of the N(D) intercept, $\ln(n_0/\Lambda)$, were 11.31 and 11.28 mm^{-1}, with standard errors of 0.15 and 0.19 mm^{-1}, for target and control distributions, respectively. The intercepts are not significantly different and support the observation that the effect of treatment seems to be reducing the total number of hailstones, especially in the larger sizes.

Table 3. Annual size distribution estimated treatment effects.

Dia. (mm)	1984	1985	1986	1987	1988	1984–88
6	-0.41	-0.81	-0.74	-0.37	-0.08	-0.38
8	-0.35	-0.58	-0.94	-0.58	-0.36	-0.54
10	-0.49	-0.63	-0.98	-0.67	-0.49	-0.63
12	-0.42	-0.77	-0.97	-0.72	-0.57	-0.67
14	-0.64	-0.87	-1.00	-0.77	-0.71	-0.76
16	-0.85	-0.94	-1.00	-0.73	-0.90	-0.84
18	-0.79	-0.94	-1.00	-0.64	-0.85	-0.81
20	-0.97	-1.00		-0.50	-1.00	-0.88
23	-1.00	-1.00		-0.44	-1.00	-0.92
27	-1.00	-1.00		0.00		-0.93
31	-1.00	-1.00				-1.00
≥33	-1.00					-1.00
Wilcoxon Sign–Rank Two-tailed P–values						
	0.002	0.003	0.01	0.02	0.006	0.002

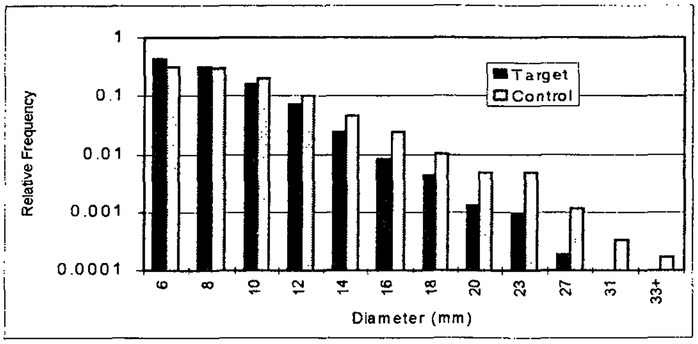

Fig. 6. Target and control relative differences in 12 hailstone size categories, 1984–88.

Table 4. Five–year hailstone size distributions.

Size Range (mm)	n(D) Target	n(D) Control	N(D) Target	N(D) Control
5–7	2251	3639	5335	11793
7–9	1641	3593	3084	8154
9–11	854	2332	1443	4561
11–13	380	1148	589	2229
13–15	127	537	209	1081
15–17	45	283	82	544
17–19	24	124	37	261
19–21	7	58	13	137
21–25	5	59	6	79
25–29	1	14	1	20
29–33		4		6
>33		2		2

5. SUMMARY AND DISCUSSION

The results presented in this paper summarize a five–year randomized–crossover seeding experiment conducted during 1984–88 in northern Greece within the context of the GNHSP. The experiment was evaluated using hailpads from a network with a mean spacing of 1 pad in 20 km^2.

Target estimates of hail damage were consistently less than control estimates, with reductions in all hailpad parameters of 19 to 85%. Associated P–values ranged from 0.003 to 0.392. The reductions in hail crop insurance payout ranged from 18–59% with P–values of 0.11–0.54. The results suggest that the seeding treatment likely did not reduce the number of haildays in the target area (hailday contingency analysis P–value >0.3). Nor did it reduce the number or areal extent of the storms in the target area (number of damaged pads P–value 0.39), the number of villages claiming insurance damage (P–value 0.54), or the areal extent of insurance claims (P–value 0.41). However, there is strong support for concluding there was a real reduction in the intesity of the storms in the target area (P–values ≈ 0.1 or less) as indicated by all of the remaining hailpad and insurance parameters. These results are consistent with a seeding methodology that targets specific storms in or near the target area and reduces, but does not eliminate, hail in these storms rather than one which broadly seeds upwind in an effort to reduce the number of storms. It is also interesting to note that these lower P–values are associated with the parameters exhibiting the greatest reductions.

Hailstone size distributions showed clear evidence of beneficial treatment effects. Target counts ranged from 38 to 100% less than control counts in all 12 size categories, with an average reduction of 55%. On an annual basis, P–values of the treatment effect ranged from 0.002 to 0.02. The P–value for the five–year experiment was 0.002.

To put the results of the program in Greece into perspective, let us summarize the results from a few of the other major hail suppression programs. Mather (1977) reported on the Nelspruit, South Africa project which used airborne AgI seeding from 1970–1977. He found reductions in hail damage of 48 to 59% with P–values of 0.01 using a non–randomized single target method. In Switzerland, the 1977–81 Grossversuch IV results, as originally reported by Mezeix and Caillot (1983), showed no increase or decrease in hail damage in a randomized single target method using rockets. The National Hail Research Experiment (Crow *et al.*, 1979) reported a 75% non–significant increase in damage using randomized airborne seeding. North Dakota reported reductions in insurance parameters as a result of seeding that ranged from 17 to 41% (Miller and Fuhs, 1987). In Alberta, the hail suppression project reported a qualified 20% reduction in the insurance loss–risk ratio that could be attributed to cloud seeding (Humphries *et al.*, 1987).

While the hailpad and crop insurance data for treated GNHSP hailstorms support a conclusion of reduced damage, there is a lack of direct physical evidence to substantiate the statistical reductions. Nonetheless, the evidence at hand suggests the following possible chain of events. Krauss and Papamanolis (1989) documented a narrow, continental cloud drop distribution. Cloud base temperatures near 10°C suggest that coalescence is not the dominant precipitation growth process and therefore substantial broadening of the spectrum is not expected to occur. Federer and Waldvogel (1978), for storms with similar mean cloud base temperatures and cloud top heights, and an active coalescence process normally leading to larger hail, found 5% of hailstones to be larger than 25 mm in diameter. Table 4 shows <0.2% of Greek control hailstones and <0.02% of target hailstones to be "large." This too, suggests coalescence is not the dominant process in most storms although conical, ellipsoidal, and spherical graupel embryos have all been observed in Greek hailstones. In addition, GNHSP Λ values are somewhat smaller than those reported elsewhere. For example, Federer and Waldvogel (1978) indicated that an average value for Swiss hailstones is about 0.5 mm^{-1} and Cheng *et al.* (1985), showed a similar average number for Alberta hailstone size distributions. The combination of very low numbers of large stones and small Λ suggests relatively small n_0 values and low total hailstone numbers in natural Greek clouds. These factors suggest that Greek clouds are relatively inefficient, lending themselves well to a beneficial competition type of approach to seeding, and furthermore that the small stones are more likely to melt completely below cloud base.

Certainly, a great deal more remains to be learned about the hailstone formation process in Greece. The recent re-introduction of digitally recorded radar data on the GNHSP is a good step in that direction. A modest field program with an instrumented aircraft and time-resolved precipitation measurements would address several remaining questions about the statistical experiment.

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