ON "GROSSVERSUCH III," A RANDOMIZED HAIL SUPPRESSION EXPERIMENT IN SWITZERLAND

PAUL SCHMID
SWISS FOREST RESEARCH INSTITUTE, ZÜRICH
and UNIVERSITY OF BASEL

1. Introduction

A randomized weather modification experiment, "Grossversuch III," was conducted in Switzerland for seven years, 1957–63, to study whether it is possible to prevent hail by releasing large amounts of silver iodide smoke from ground based generators. The test area was the Canton Ticino and the adjoining Mesolcina Valley. This region covers about 3500 square km on the southern slopes of the Alps, ranging in altitude from 200 m to 3400 m above sea level.

This is a final report. The first three sections give a brief account of the design, execution, and hail results of the experiment. Since natural precipitation in this region is high (1400–2400 mm per year), the possibility of rain stimulation was not the subject of the experiment. Nevertheless, rainfall was recorded, the records were evaluated, and sections 4 and 5 explain the methodology and summarize the results.

The agency responsible for Grossversuch III was the *Eidgenössische Kommission zum Studium der Hagelbildung und der Hagelabwehr*, a federal Commission originally presided over by the late Professor R. Sänger and subsequently by Mr. P. Hohl. The actual execution of the experiment was the responsibility of the Osservatorio Ticinese at Locarno-Monti, with Mr. J. C. Thams as its Scientific Director.

2. The design of the experiment

Previous to Grossversuch III, from 1953 to 1956, the Eidgenössische Kommission performed another cloud seeding experiment with hail prevention, "Grossversuch II," which was not randomized. The test area was a valley in the Canton Ticino. On days when hail was expected, silver iodide smoke was released from ground based generators and it was hoped that the effectiveness of the method could be established by comparing the incidence of hail on seeded days either with the incidence in the earlier years or with that in some control areas, not influenced by seeding. In 1956 it became clear that, because of the lack of randomization, whatever differences in hail incidence could have been established by this method, these differences could not be unambiguously ascribed to seeding. Therefore, the Commission decided to abstain from the evaluation of Grossversuch II and to embark on a new experiment, Grossversuch III, a randomized experiment [5].

In designing Grossversuch III it was decided to maintain the organization of cloud seeding operations and of observations that were well established in connection with Grossversuch II. However, it was decided to increase the number of silver iodide smoke generators so as to enlarge the target. The map of the target area, the distribution of silver iodide smoke generators and of raingages, are given in figures 2 to 6.

The design of Grossversuch III is explained in the appendix to the first annual report [12]. (Also see [4].) The more important details are described below.

(1) Grossversuch III was planned for summer months, May to September, for a period of at least five years. Each day of this general test period could be a "test day." According to plans, the determination, whether any given day is to be considered a test day or not, was to be made on the previous evening by a meteorologist of the Osservatorio Ticinese. If, according to this meteorologist's forecast, hail storms were to be expected during the next day, this next day was to be counted as a test day.

All evaluations of the experiment were to be based on observations made during test days and no others.

(2) The seeding was to be performed on randomly selected test days from 0730 to 2130 hours.

(3) The randomization of the experiment was to consist of the preparation of a set of cards, one half of them bearing the word "ja" and the other half the word "nein." These cards were to be sealed in envelopes which were to be arranged in a random order and numbered. The identity of envelopes with cards bearing "ja" or "nein," were to be kept unknown to the forecasters. After the first test day was established, the envelope No. 1 was to be opened and the first test day was to be seeded or not depending upon whether the card in envelope No. 1 was marked with "ja" or "nein." Similar randomized decision was to be made on all subsequently determined test days.

The name of the forecaster, responsible for the determination that a given day is a test day, and also the name of the person who opened the corresponding envelope with the random decision, were to be recorded for each test day.

(4) As in Grossversuch II, voluntary observers in all parts of Ticino and in the adjoining Mesolcina Valley were to report on the general weather conditions and, in particular, on hail storms. The hour, the duration and the intensity of hail storms, as well as the dimensions of hail stones were to be reported. Since there are no established objective methods of measuring the last two quantities, the observers were trained to make estimates in a uniform manner.

(5) As a different aspect of hail incidence, the Swiss Hail Insurance Company was expected to report on its estimates of sustained damage by hail. These reports will be evaluated in another paper.

(6) The idea of using a comparison area was considered and abandoned. It was judged that a comparison area suitable for the Ticino target would be in Italy where the recruitment of observers and organizational matters would present difficulties. Also, it was taken into account that hail storms occur only sporadically, that often they are restricted to a few square kilometers and that the correlation between meteorological stations in the Canton Ticino only some 20 km apart is very small. On the other hand, in order that a comparison area be safe from contamination by seeding in the target, it would have to be selected a few hundred kilometers away from the target. As a result of these and other similar considerations, it was decided that not much information about the effect of seeding on incidence of hail could be gained through the use of a comparison area.

(7) It was judged that meteorological variables, strongly correlated with hail incidence but unaffected by seeding, would have been useful. However, an effort to establish such predictor variables would have meant the postponement of the experiment for several years. On the other hand, in order to create some possibility of a deeper analysis *ex post*, it was decided to include in the annual reports the direction and velocity of winds, as measured on each test day in Milan at 1500 m and at 5500 m above sea level.

(8) Because the cloud seeding expected to suppress hail in Ticino is used elsewhere with the hope of stimulating rain, it was decided to include in the annual reports the daily precipitation data (0730 to 0730) obtained by a number of raingages in the target. In addition two recording gages, one at Locarno-Monti and the other at Melera, would provide precipitation amounts for the test time, from 0800 to 2230 hours.

(9) The final decision as to whether to continue the experiment after the first five years, was to be taken at the end of this period.

(10) At the time of planning Grossversuch III, the questions to be answered and the methods of evaluation of hail results have been stated. These are being dealt with in section 4, below. On the other hand, the evaluation methods for rain records have not been fixed in advance. The hope was expressed that these records will indicate where and in what situations the seeding of clouds could be expected to affect the precipitation.

3. Execution of the experiment

Because of the experience gained during the four year long Grossversuch II performed immediately before Grossversuch III, the orderly execution of the latter did not present much difficulty. Nevertheless, as is usual in a prolonged effort involving many instruments and many individuals, there occurred various deviations from the original plan. These are recorded in the annual reports.

Especially in the first years of Grossversuch III, some of the generators were repeatedly out of order for hours and even for days. In the last years of the experiments, four new generators, in the south of the Canton Ticino, were installed. However, it is thought that these changes did not influence the results to a noticeable extent.

Of the 55 recruited volunteer observers only 20 continued over seven years of the experiment to send in their daily reports on the general weather conditions and on incidence of hail. In order to maintain uniformity, the reports of the remaining observers have been eliminated from these evaluations.

After five years of experimentation it was decided to prolong Grossversuch III for another two years. The main reason for this decision was the small number of thunderstorms in the earlier years.

In this connection it should be mentioned that out of the 292 test days of the seven years of Grossversuch III, there were 46 days with no hail and without any storm situation at all. In fact, hail occurred on only 99 experimental days. On the other hand, there were at least 81 nontest days on which some hail fell in the target. In our evaluation an even smaller number of test days with hail had to be used because the above number 99 includes days with hail reported only by the Swiss Hail Insurance Company and/or by the observers who did not work steadily over the seven years of the experiment, and whose reports had to be eliminated from the evaluation. Also, on some of the 99 days, hailfalls occurred only at night and these days were not taken into account.

As mentioned, the details of hail occurrences and of general weather conditions on test days are meticulously recorded in the annual reports of the Eidgenössische

TABLE I

SAMPLE PAGE OF RECORDS PUBLISHED IN THE TÄTIGKEITSBERICHTE OF THE EIDG. KOMMISSION

Test day No. 212					29/7/1962		
Forecast:		seedable storm			Forecaster: Zenone		
Random decision:		seed			Envelope opened by: Pedrazzini		
Hail reports							
Region	Location	Time		Intensity	Remarks		
III	S. Antonio	1924–1926		0	Ø 3 mm		
	Indemini	2115–2140		2	Ø 6–8 mm hail with rain		
Inoperative generators					Time		
Ispra					2045–2130		
Mottarone					0730–2130		
Indemini					0730–2130		
Wind velocities, km/h							
		29/7/62				30/7/62	
		01*h*		13*h*		01*h*	
Milano, 1500 m		W	19	E	15	ESE	30
Milano, 5500 m		NW	42	W	26	W	14
Payerne, 5500 m		NW	26	WNW	13	NW	11
Meteorological Remarks							
Local thunderstorms. Low pressure center over the Gulf of Genoa.							

Kommission [12]. Table I reproduces a page from these reports. In addition, special tables of the annual reports give daily precipitation amounts for each test day and for each of the raingages in the target. Finally, each of the reports gives preliminary statistical evaluations both of hail and precipitation records.

4. Hail results

It has been mentioned that only 20 hail observation posts were reporting during all seven years. We will neglect the records of the other stations for the evaluation. This simplifies the evaluation considerably and makes the results more reliable.

The stations recorded 0 to 14 hail falls for the total of 145 days with seeding and 147 experiment days without seeding. With such small numbers we could hardly hope to find any significant differences. Therefore it was decided at the beginning of the experiment that the test area, the Canton Ticino, and the adjoining Mesolcina Valley, would be divided into four sections *A* to *D* from south to north, from the plain to the high Alps. If at least one station in a section reported hail (from 0800 to 2230), this day would count as a "hail day" for this section. Table II summarizes the observations.

TABLE II

HAIL INCIDENCE ON SEEDED AND NOT SEEDED TEST DAYS

Section	No. of Observers	No. of Hail Days: Without Seeding	No. of Hail Days: With Seeding	Total	$P(\chi^2)$
A	2	7	8	15	—
B	4	14	15	29	—
C	5	5	14	19	<.06
D	9	9	19	28	<.07
Total test area	20	23	38	61	<.04
Total no. of test days		147	145		

In sections A and B the number of hail days is about the same in both series (table II). The seeding operation may not have been very effective or it may have had opposite effects depending on the weather conditions. In sections C and D however the number of hail days is more than twice as large with seeding than without seeding. Such large differences could occur without any seeding effect with probabilities of about 5 and 7 per cent, respectively. For the total test area the corresponding probability is less than 4 per cent.

There is little doubt that seeding has been very effective in increasing the number of hail days. But it may be worthwhile to look at the results in some more detail.

The danger of hailfall depends on the weather conditions. Also the effect of seeding might be different for different kinds of storms. Therefore the experiment days have been classified into five categories according to the prevalent general weather situations: days with local thunderstorms, with a passing cold front, with a barrage situation, with more than one storm situation and without any storm situation. The classification has been done at the end of the experiment according to objective criteria which could not be influenced by seeding operations. The different types of weather situations are more or less evenly distributed on days with seeding and days without seeding. The hail frequencies are very different, but with all types of weather situations more hail days with seeding than without seeding have been counted. Table III summarizes the

TABLE III

FREQUENCIES OF DAYS WITH HAIL IN TOTAL TEST AREA IN DIFFERENT KINDS OF GENERAL WEATHER SITUATIONS

	Without Seeding			With Seeding		
	No. of Test	Hail Days		No. of Test	Hail Days	
General Weather Situation	Days	No.	Frequency	Days	No.	Frequency
No storm situation	24	0	0.00	22	0	0.00
Cold front	45	5	0.11	45	6	0.13
Local thunderstorms	28	6	0.21	31	10	0.32
Barrage situation	30	2	0.07	22	5	0.23
More than one storm situation	20	10	0.50	25	17	0.68
Total	147	23	0.16	145	38	0.26

results. The effect of seeding is not necessarily different for the different types of general weather situations. At least it is not possible to make any such statement since there are not enough experiment days for each type.

Another possibility for estimating the danger of hail is to give the wind velocities at 5500 m from the ground, measured in Milan, 40 km to the south of the test area. The wind velocities have been measured each day at 0100 and 1300 hours. The maximum of the recordings at 0100, 1300, and 0100 of the following day will give a better estimate for the wind velocities in the storm than any single measurement. Even so, these estimates give entirely wrong results when the storms have passed between the times of the measurements. Nevertheless, on days with very high measured wind velocities the relative frequency of hail is much greater than on the other days as shown in table IV, for all classes of wind velocities the hail frequency is greater on days with seeding than on days without seeding.

If general weather condition and wind velocity are combined, this gives an even better classification. But there are too many classes, and the frequencies of

TABLE IV

FREQUENCIES OF DAYS WITH HAIL IN TOTAL TEST AREA ACCORDING TO DIFFERENT WIND VELOCITIES AT 5500 m ABOVE SEA LEVEL

Max. Wind Velocity km/h	Without Seeding			With Seeding		
	No. Exp. Days	No. Hail Days	Frequency	No. Exp. Days	No. Hail Days	Frequency
0–40	41	5	0.12	36	8	0.22
40–80	60	5	0.08	72	15	0.21
>80	46	13	0.28	37	15	0.41
Total	147	23		145	38	

hail days in the classes are too small. Only if there were a better single predictor variable, would it be possible to test the differences with more power.

Of course, the number of days with hail need not be indicative of the damage. In fact it is possible that, while increasing the frequency of hail days, the seeding changes the intensity characteristics of hailfalls, with the final effect of reducing the damage caused. However, the analysis of duration, areal extent, and intensity of hailfall shows that these characteristics were not significantly changed by seeding [8].

5. Evaluation methods for precipitation amounts

There is no best procedure to test a hypothesis so long as the possible alternatives are not known. The physicists have not yet been able to state precisely enough what kind of alternatives to the null hypothesis could be expected. Therefore, we have applied a few different test procedures to find out more about when and where seeding effects could be expected.

It has been stated repeatedly that the empirical distribution of the daily precipitation amounts may successfully be approximated by Gamma distributions [11], [1]. Some meteorologists stated that the seeding operations would have mainly a triggering effect. So it was expected that the number of days with nonzero precipitation would be augmented. In this case, it would not be good practice to restrict the analysis to days with precipitation. Therefore, we tried to use a truncated Gamma distribution for approximation.

$$(5.1)\qquad G(x; -\alpha, \beta, \lambda) = \frac{\beta^\lambda}{\Gamma(\lambda)} \int_{-\alpha}^{x} (x + \alpha)^{\lambda-1} e^{-\beta(x+\alpha)}\, dx, \qquad -\alpha \leqq x < \infty, \qquad \beta > 0, \qquad \lambda > 0.$$

For almost all our recording stations the fit is better than should be expected.

Once the premise that the precipitation amounts are Gamma distributed is accepted, a statistician hopes that the seeding operations influence the precipitation amounts in such a way that only one parameter of the distribution function would be influenced. If the seeding effect is multiplicative, this parameter is β.

On this assumption, we proceeded to set up the equations to estimate the parameter values α, β_1, β_2 and λ of the Gamma distribution functions for the experiment days with and without seeding by the maximum likelihood method.

The relevant equations can be solved by an iteration method and using suitable initial estimates. This approximation method has been developed on the assumption of censored data, of a truncated distribution and for a mixed model [7].

As test functions for the hypothesis $\beta_1 = \beta_2$ against the alternatives $\beta_1 > \beta_2$, we have applied

$$y = \frac{\hat{\beta}_1}{\hat{\beta}_2}. \tag{5.2}$$

For $\alpha = 0$,

$$\{y > c\} \tag{5.3}$$

is an asymptotically best critical region. Since in this case

$$\hat{\beta}_i = \frac{\hat{\lambda}}{\bar{x}_i}, \qquad i = 1, 2, \tag{5.4}$$

the test statistic is

$$y = \frac{\bar{x}_2}{\bar{x}_1} \tag{5.5}$$

and follows approximately an F distribution.

For the case of censored data, $\alpha \neq 0$, the means have to be adjusted by the expectation of the unknown (in our case negative) values. The adjustment for the variances, however, is usually very small and not necessary.

As soon as the program was set up and all results were available, the parameter values have been calculated on the Control Data 1604 Computer of the Federal Institute of Technology in Zurich.

Remark. All our calculations for the rain and hail results have been done on this computer and all programs, written in FORTRAN 64(IV), are available.

The results have been disappointing. We found that by fitting the empirical distributions of the days with seeding and the days without seeding by Gamma distributions with the same values of α and λ, we neglected a large part of the differences, as shown in figure 1.

We concluded that λ may also be changed by the silver iodide seeding. Also we gave the empirical distributions a closer look and found that the seeding operation may not have influenced the number of days with precipitation.

Meanwhile Neyman and Scott [1] have proposed an optimal test on the same premises about the distribution and the parameter values, but in restricting the evaluation to days with precipitation. It is possible that under this restriction the assumptions are better fulfilled. Therefore we have calculated the parameter

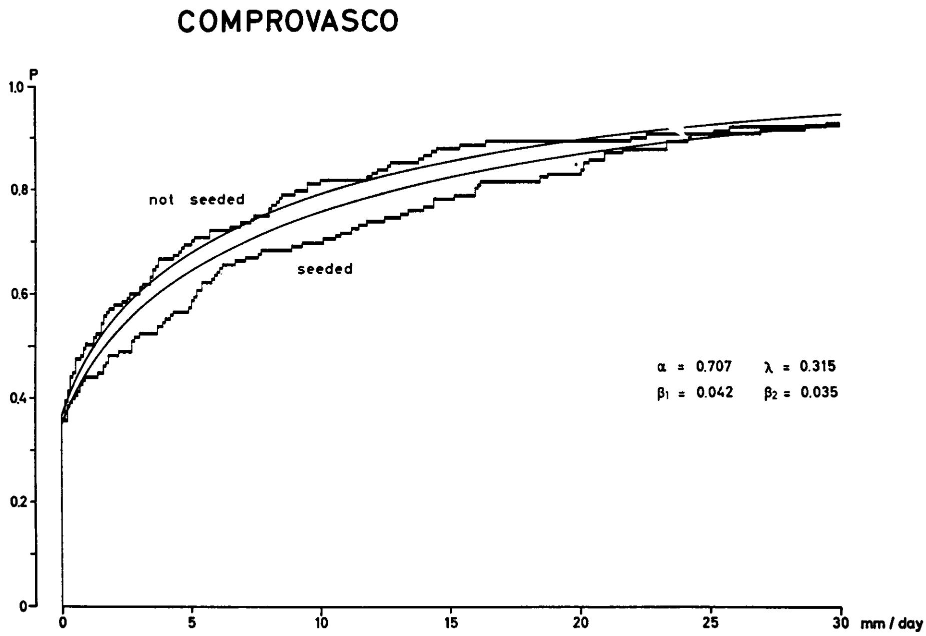

FIGURE 1

Cumulative frequency distribution of precipitation observed for seeded and for not seeded days. Comparison with Gamma distributions using same values of α and of λ.

estimates for this case for some stations. These estimates (see table V) are given for the six stations which show the greatest apparent effects of seeding. Unfortunately, in this case also λ seems to be influenced by the seeding operation, as well as β.

Due to the fact that no satisfactory test could be found under the assumption

TABLE V

ESTIMATES OF PARAMETERS OF A NONTRUNCATED GAMMA DISTRIBUTION

Station	Without Seeding			With Seeding		
	No. Days with Rain	$\hat{\beta}$ (mm^{-1})	$\hat{\lambda}$	No. Days with Rain	$\hat{\beta}$ (mm^{-1})	$\hat{\lambda}$
Comprovasco	94	0.051	0.55	93	0.058	0.77
Biasca	80	0.050	0.72	82	0.049	0.96
Locarno-Monti	89	0.032	0.57	84	0.026	0.65
S. Bernardino	98	0.065	0.90	88	0.050	0.97
Bellinzona	95	0.039	0.57	86	0.030	0.65
Frasco	98	0.034	0.58	89	0.033	0.78

of Gamma distributed variables, several distribution free tests were applied. We applied the test of Kolmogorov and Smirnov for all experimental days though we knew that the power of this test can be very low for special alternatives. As the experiment had to go on, it was not necessary to come to final conclusions. In the final evaluation however we wanted to apply a better suited test. We applied the Wilcoxon and Mann-Whitney test but did not think that it was a good test either. Since the distribution is extremely skew this test statistic is very much influenced by minor changes in the small values and almost insensible to great changes in the large values.

According to these considerations and still thinking that the effect of seeding was increasing with the amount of natural precipitation, we decided to apply a test which gives greater weights to the high ranks than to the ranks of the small values. My collaborator Taha has been successful in proposing such a test with some valuable qualities [10].

The amounts of precipitation of all experimental days are arranged according to their magnitudes and given the ranks R_i according to this order. The test statistic is

$$L = \sum R_i^2, \tag{5.6}$$

where the sum is taken over all values belonging to the first of the two samples.

The expectation and variance of this test statistic are

$$E(L) = n(s + 1)(2s + 1)/6 \tag{5.7}$$

and

$$\text{Var}\,(L) = nm(s + 1)(2s + 1)(8s + 11)/180, \tag{5.8}$$

if n and m are the sample sizes and $s = m + n$. Even for relatively small sizes the distribution of L may well be approximated by the normal distribution.

For Gamma distribution functions and alternatives which assume multiplicative effects, the L test is more effective than the Wilcoxon test. The asymptotic relative efficiency of the L test compared to the Wilcoxon test is, for $\lambda = 0.7$, $e_{L,W} = 1.096$.

The practical results of the different tests have almost been the same. Probably this shows that we did not succeed in finding a test which is really appropriate for the kind of effect that seeding has. The results have however been very different when the evaluation was restricted to days with nonzero precipitation. In the next section, therefore, only the results of the L test for the days with precipitation are given.

In our evaluations we have not considered thus far the application of results from a control area. In fact we did receive the precipitation records of some stations in Italy. Unfortunately, most of them lie too near to the test area to serve as a control. With the rest we have made a regression analysis using about the same procedure as Neyman, Scott and Vasilevskis [3] for the Santa Barbara experiment. Unfortunately, with these control stations it does not seem to be possible to improve the power of the test.

6. The precipitation results

The effect of seeding on the amounts of precipitation is important by itself and in comparison to the effect on the danger of hail. From figure 2 we see that

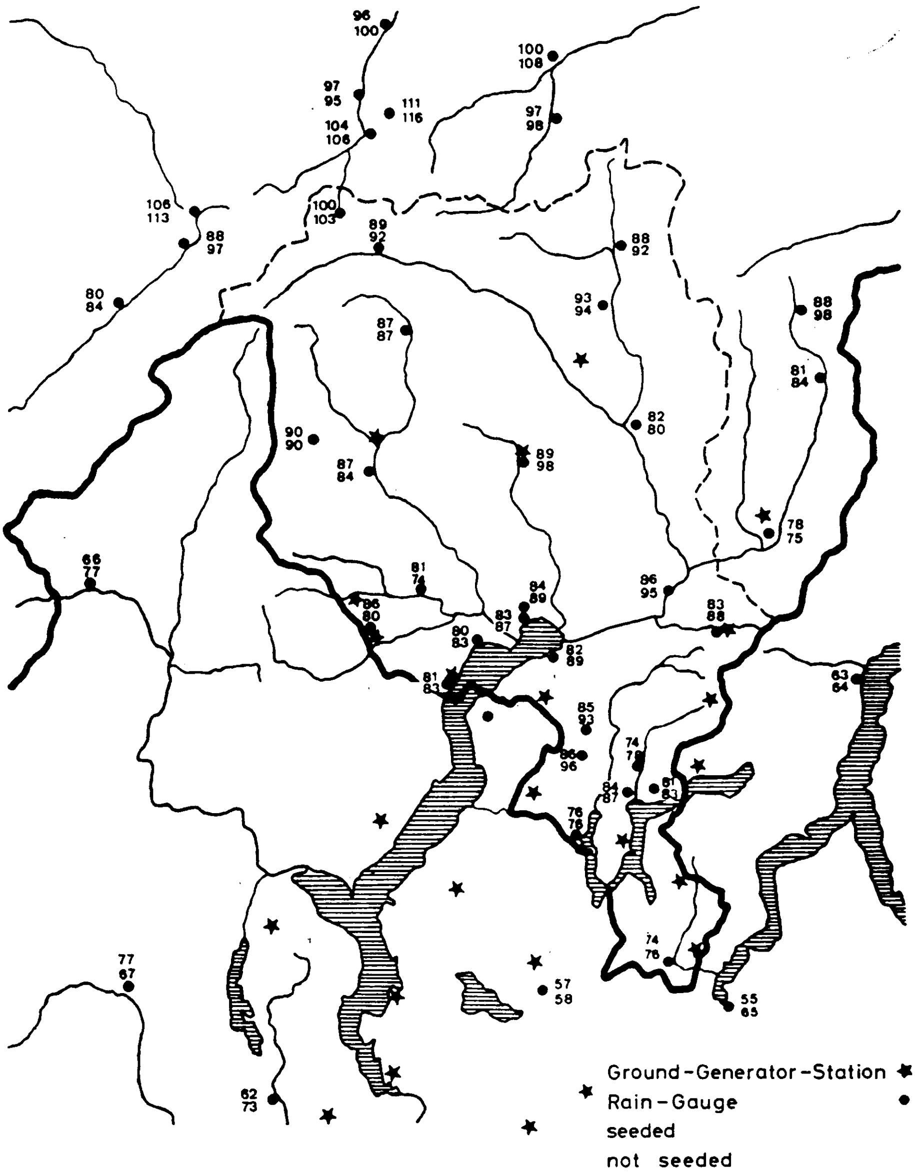

FIGURE 2

Number of days with precipitation at different stations.

the number of days with nonzero precipitation is everywhere nearly the same in the two comparison series. Figure 3 shows, however, that the daily precipitation amounts are very different. Except for the southern part of the Canton Ticino and for some stations on the northern side of the Alps (outside the test

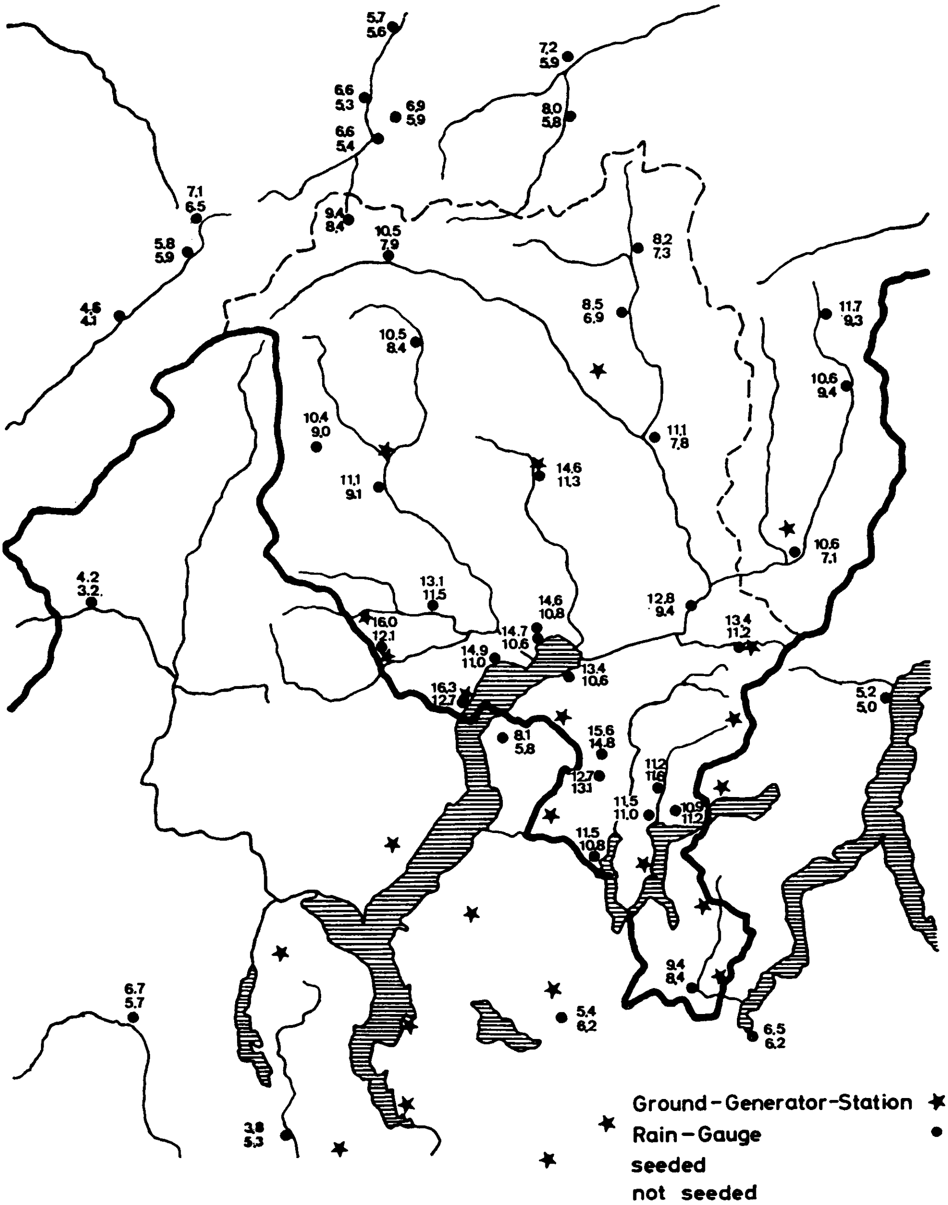

FIGURE 3

Average daily precipitation in mm at different stations.

area), the average amount of rain per experiment day is 20 to 40 per cent greater on days with seeding than on days without seeding. This suggests that seeding was not effective when there would not have been rain anyway, but that it has largely increased precipitation on rainy days.

If the L test is applied on the daily amounts, it shows that the differences are significant in a large part of the test area. Figure 4 shows the probabilities P of an error of the first kind in testing the hypothesis of no effect against the alternative that seeding has increased precipitation. Since on rainy days western and southern winds are predominant, this part may well be best protected by the seeding operations. These stations lie 40 to 80 km behind the first generator posts in the southwest.

The seeding effect can be estimated much better if the general weather situations are taken into consideration. In table VI the average daily precipitation amounts are given for different general weather situations, for the total test area, and the different sections.

TABLE VI

AVERAGE DAILY PRECIPITATION AMOUNTS FOR DIFFERENT GENERAL WEATHER SITUATIONS, IN mm

The first number gives the average for days without seeding, the second for days with seeding.

Section	Cold Front		Local Thunderstorms		Barrage Situation		More than One Storm Situation	
	NS	S	NS	S	NS	S	NS	S
A	7.9	9.8	5.1	5.4	9.7	13.2	18.5	17.0
B	10.6	12.9	6.3	7.4	15.5	20.3	30.7	20.0
C	9.0	13.4	4.6	3.4	14.9	29.4	29.7	29.0
D	6.1	8.2	4.7	4.4	12.6	24.9	26.1	22.5
Total test area	7.9	10.5	4.9	4.9	13.7	24.5	27.7	23.2

On days with cold fronts, the daily amounts are more than 20 per cent greater for days with seeding in all sections. The differences are even greater for barrage situations. Here, the average daily amounts are, in sections C and D, twice as great on days with seeding than on days without seeding.

The differences between days with and without seeding are not significant for the days with local thunderstorms and for the days with more than one storm situation. For the days with more than one storm situation this is statistically understandable because this is a very heterogenous set of weather situations. For the days with local thunderstorms, the differences are small and seeding probably has not been very effective.

For the experiment days with a passing cold front the results of the L test are given in figure 5. In spite of the much smaller number of days, the probabilities of an error of the first kind are almost the same as in the general evaluation.

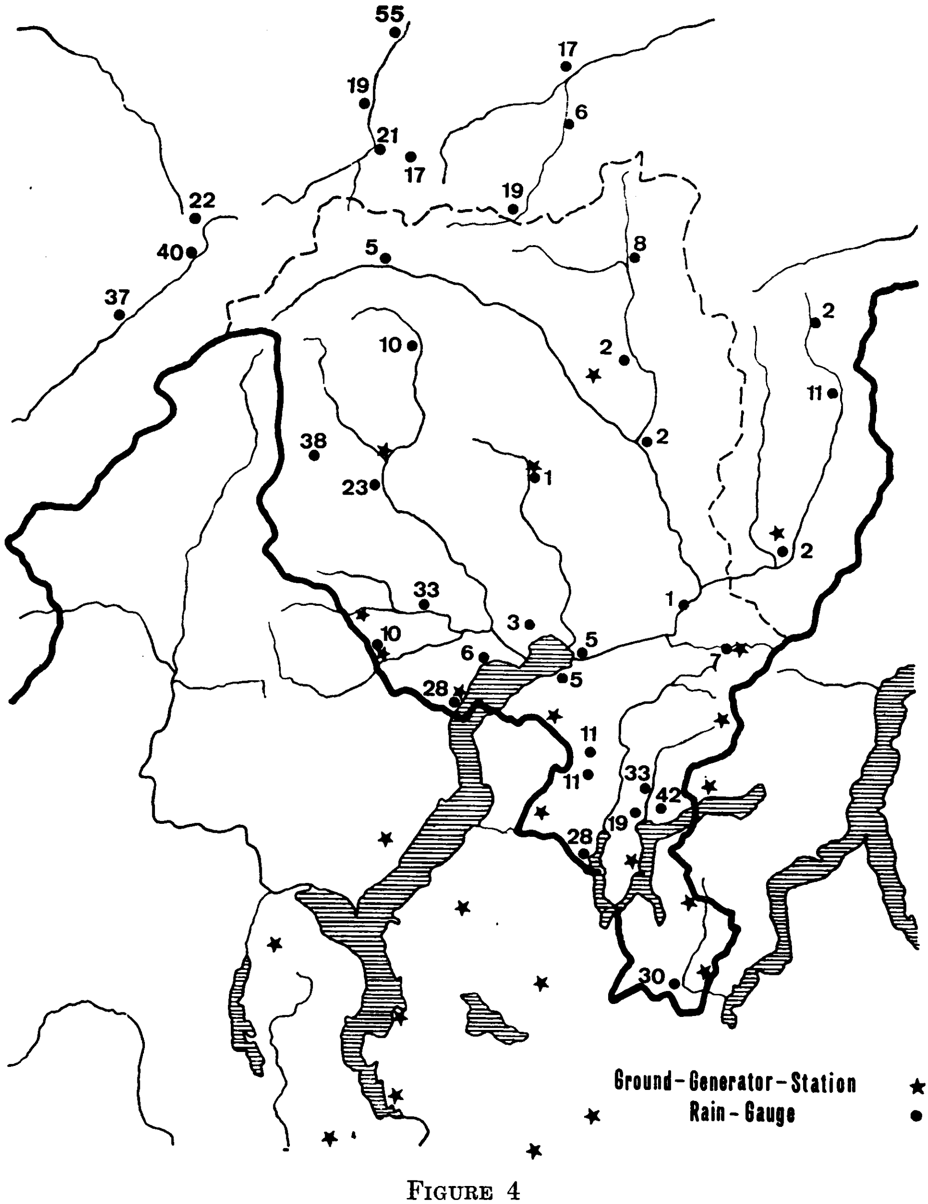

FIGURE 4

Results of L test for days with precipitation for different stations. Probabilities in per cent.

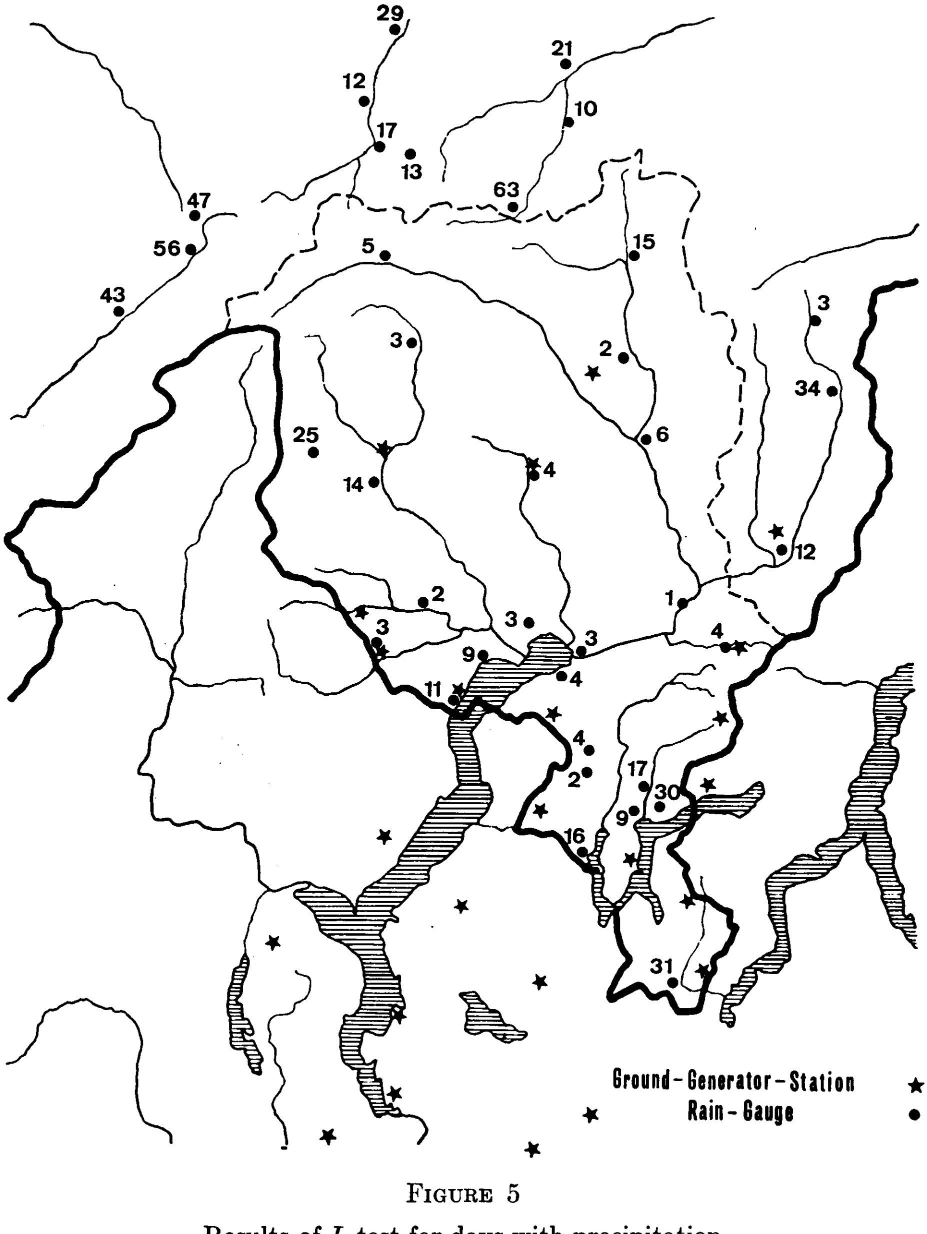

FIGURE 5

Results of L test for days with precipitation and cold front.
Probabilities in per cent.

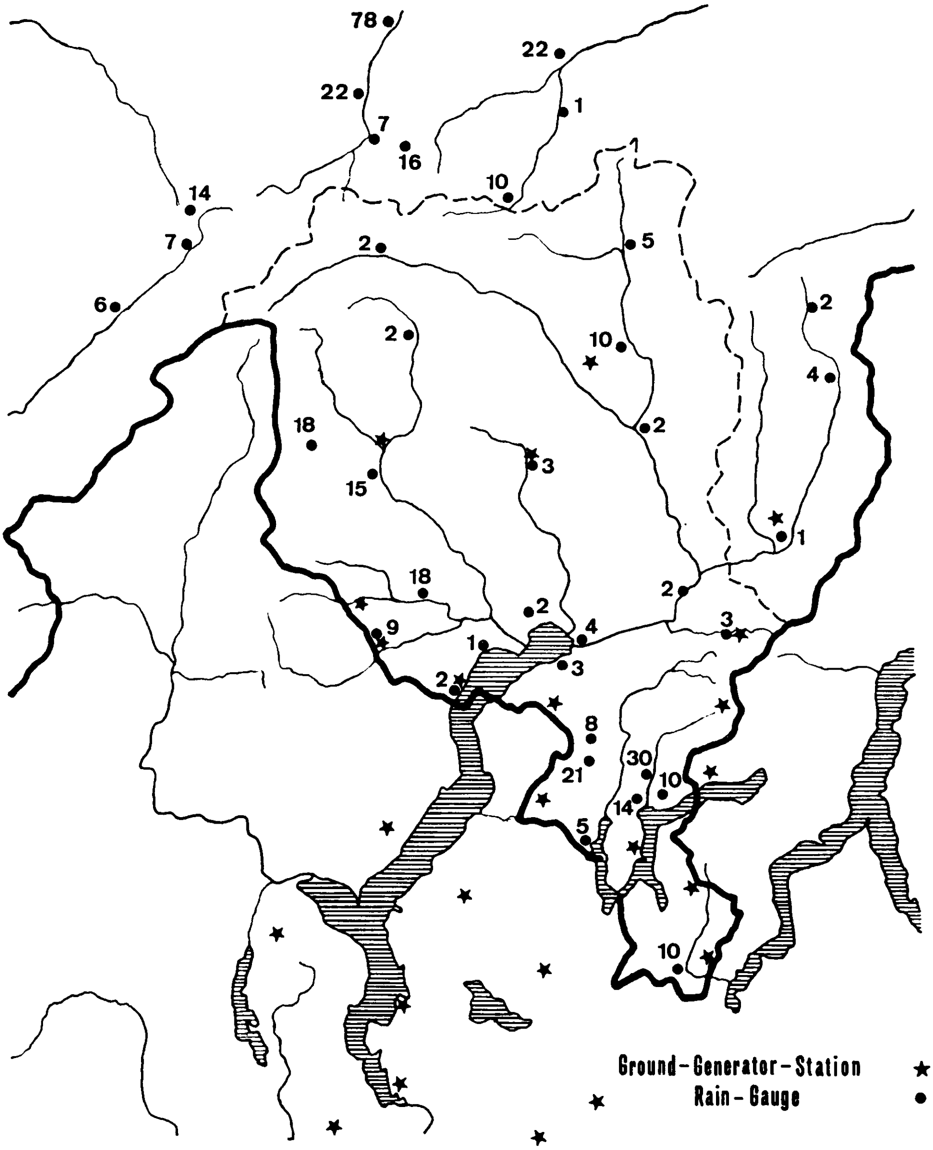

FIGURE 6

Results of L test for days with precipitation and barrage situations. Probabilities in per cent.

For the barrage situation we have almost the same general picture (figure 6). It should be noted that the results of figures 5 and 6 are entirely independent of one another, since different days are involved in the two evaluations.

There are a few stations north of the barrier of the Alps with smaller probabilities in the case of a barrage situation. Only with southern winds can the seeding be effective there. But, in general, greater differences should be expected and the results suggest that there are also southern winds on days with a passing cold front.

7. Conclusions

It is evident that silver iodide seeding has sometimes increased rain by large amounts. The days with a passing cold front or with a barrage situation have been especially favorable for such an effect.

The hail results are, of course, not as conclusive as the rain results. Nevertheless, at least the differences are significant for the number of hail days in the total test area. The number of days with hail was very different in the sections C and D. In these areas there were more than twice as many days with hail in the series with seeding than in the series without seeding. These differences exist more or less in the region in which seeding has increased precipitation and is due mainly to the days with the same weather situation. Precipitation amounts and hail frequencies are statistically correlated variables and the results of these two evaluations are not independent of one another. But, still, they are not entirely dependent and, if they give similar results, they support one another.

We have not given here all evaluations regarding hail and we have not given all arguments *pro* and *contra* seeding effects. Even so, most readers will agree with us that the seeding operations have been effective in the wrong way. In any case it is obvious that the applied method as a means of hail prevention should be abandoned immediately.

A few special ideas still should be mentioned. A hypothesis stated by Smith, Adderley, and Bethwaite [9] says that silver iodide seeding is very effective in the first year only. In the Swiss experiment the first year 1957 also showed very large differences, but it should be remembered that 1957 was not the first year with seeding operations. It was preceded by four years of Grossversuch II. It is not possible to estimate the effect of seeding in these previous years, because no randomization had taken place.

Some meteorologists expect other seeding effects on the precipitations in regions more than 1000 m above sea level. In our experiment, the few stations which lie 1000 to 2000 m above sea level lie at the border of the region of expectable seeding influence, and some of these stations are in mountain passes. The results do not show a considerable influence of the height above sea level on the seeding effect. But they cannot conclusively check this hypothesis.

Neyman and Scott [2] suggest that the seeding operations may have increased precipitation in some situations and decreased it in others. We have also found some situations for which the data suggest such a decrease, especially for some weather conditions with very large amounts of natural rainfall. But these occasions are rare and our evidence for negative effects has not been conclusive.

It may be reasoned that the seeding has not been intensive enough to prevent hail. In fact, hail may have been formed only because there were not enough silver iodide particles. But if seeding were much more intensive and if it could diminish hailfall in a certain area, it would perhaps have to be feared that in a much larger area, where the silver iodide particles would be less dense, hail would be increased.

An intensive study of the meteorological conditions on the 292 days of the experiment and a statistical evaluation of different hypotheses about the meteorological connection and the seeding effects would be desirable. It is possible that such a study would lead to a much better understanding of the results.

We are convinced that a combination of a few large scale experiments and a lot of laboratory research is necessary to find out more about cause and effect in these meteorological questions. Physicists should take part to a much greater degree than now in large scale experiments.

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