Main Results of Grossversuch IV*

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ABSTRACT

The main results of a randomized hail suppression experiment, Grossversuch IV, are presented in this paper. Grossversuch IV tested the "Soviet" hail prevention method during five years (1977–81). The field experiment took place in central Switzerland with the participation of research groups from France, Italy and Switzerland.

A very dense hailpad network (330 hailpads over 1300 km^2) and a carefully calibrated 10-cm radar were used to measure in two independent ways the hail kinetic energy of seeded and unseeded hail cells. The total sample included 216 cells. The main result of the confirmatory as well as most of the exploratory analyses is that there is no statistically significant difference between seeded and unseeded hail cells. A detailed discussion of the reliability of the measurements, tests and methods is given together with a discussion about possibilities of future evaluations of the Grossversuch IV data and other cloud seeding experiments.

1. Introduction

Weather modification using artificial ice or condensation nuclei still remains a field in which positive results, scientifically approved, are few and often much debated. The group of experts on weather modification of the World Meteorological Organization[1] summarized the situation as follows: "It must be considered at present that with the exception of the dispersal of supercooled fog, artificial weather modification is still at a research level." Hail prevention, an integral part of scientific weather modification, is no exception in terms of this general conclusion. There are many reasons for this. Some problems are an incomplete knowledge of both microphysical and dynamical aspects of hail formation, concepts of modification that are based on oversimplified models, unreliable seeding techniques, inadequate control of experiments, and many others.

This unclear scientific situation of the problem of hail prevention on one hand and the demand from the agricultural community for a "successful" hail suppression method on the other were the reasons for starting an international hail prevention experiment in Switzerland. The origins are as follows: In the Soviet Union and other countries in East Europe, operational programs of hail suppression claimed and still claim hail damage reductions of 70% to 90% (Burtsev et al., 1974; Burtsev, 1980), although the Bulgarian evaluations of hail prevention programs showed lower reductions in recent years (Stanchev and Simeonow, 1980). Since the design components (modification hy-

* Dedicated to Bruno Federer, deceased on 24 December 1982.

[1] "Report on the present status of weather modification," May 1981, WMO report, Geneva.

pothesis, seeding technology, etc.) of all these projects looked very promising, a test of the seeding method seemed to be worthwhile. The modification hypothesis is based on the theory of a so-called water accumulation zone, which is supported by updrafts and in which hail is growing from embryos of large supercooled raindrops. The idea of artificially producing more small hailstones instead of some large ones is called the concept of "competition of the embryos" (Sulakvelidze et al., 1974). A sophisticated technique of massive seeding with silver iodide, by means of high altitude ground/air rockets, completes the method. The theory, together with the seeding technique, interested scientists outside the USSR especially because of the high reported rates of success. However, rigorous scientific assessment seemed indispensable because the estimated effects are based on evaluations which are not convincing. They were not obtained from the comparison of a treated and a control group determined by a randomized procedure, and they used insurance data which are an unreliable measure of hail (Federer, 1977).

A controlled experiment which was mainly inspired by Soviet modification concepts [without, however, being an exact reproduction of the Soviet procedure (Foote and Knight, 1979)], was made in Colorado within the framework of NHRE (National Hail Research Experiment). However, although the NHRE experiment gave very valuable knowledge about the formation and structure of hailstorms, as can be seen in the nine-part paper by Foote (79) and Knight et al. (1979), the question of the success of hail suppression by seeding remained open; indeed, the main result did not allow one to decide if a reduction in hail damage existed at all. They obtained very wide 90% confidence intervals that extended from a possible 500% increase to a 60% decrease of hail kinetic energy. The apparent inefficiency of the seeding could be explained partly by the absence of the water accumulation zone in the Colorado storms.

This first assessment called for a more rigorous examination of the Soviet method of hail prevention with European storms. In 1975 it was decided to carry out a randomized experiment reproducing the Soviet technique exactly and using sophisticated physical measurement of the precipitation. The project, called Grossversuch IV, was launched by the departments of agriculture of Switzerland, France and Italy, the Federal Institute of Technology (ETH) of Switzerland, and the Swiss and French hail insurance companies.

The field operations took place in central Switzerland. Figure 1 shows the geographical location of the experimental area and the sites of the rocket-launching posts. The experiment lasted from May 1977 till September 1981. The 5-year duration was fixed originally in order to obtain a satisfactory statistical period to demonstrate a potential 60% decrease of hail kinetic energy. The operations were an *exact copy* of the Soviet method, using the same radar wavelength to detect the hail cells, the same type of seeding criterion, and Soviet rockets and launchers. The radar and rocket launching crews were educated and trained by the Soviet hail-prevention specialists in the years 1975–76. Diplomas which approved the ability to carry out hail suppression were handed out by the Soviet experts to the Grossversuch IV crew in August 1976 (Cloud Physics Group, 1977).

During the 5-year period, a total of 76 days with real or control operations of hail suppression occurred, 33 with seeding and 43 without seeding. The operations (forecast, randomization and hail suppression operations, etc.) followed the design of the statistical experiment that was published before any data could be analyzed. (See Federer et al., 1978/79.) This publication will be referred to as "the design" in the following.

In the present paper we first give (section 2) an overview of the basic concepts and the available data obtained during the randomized experiment Grossversuch IV. Section 3 presents the statistical test based on the hail kinetic energy measured by radar, strictly following the procedure described in the design along with an improved variant of it. Another confirmatory analysis, using hailpad data, is given in section 4. Sections 5 and 6 consist of ideas for, and first results of, exploratory evaluations and sensitivity analyses. A summarizing discussion (section 7) concludes the paper.

The principal result of Grossversuch IV is that seeding clouds by the Soviet method in an operational manner did not lead to a statistically significant effect on the cloud's hail energy. We can tell that the seeding method does not realize a 70% decrease of hail kinetic energy. With this result, Grossversuch IV allows us to answer the initial question asked at the beginning of the experiment. It is clear that this statistical fact calls for detailed and thorough cloud physics and statistical analyses of the data in the hope of detecting at least some hints to help explain the present finding. It can, however, be added that exploratory evaluations show interesting statistical effects with mean intensity variables obtained by the hailpads. The purpose of this paper is therefore not only to present the results of the confirmatory test of Grossversuch IV but also to trigger future investigations and discussions about Grossversuch IV.

2. Basic concepts and description of data

The design contains a detailed description of the conduct of the experiment and the most important characteristics of Grossversuch IV. These aspects will not be repeated here but only summarized briefly. Table 1 gives a short description of the variables used.

a. Definitions

The *experimental unit* is the time from 1200 to 2100 central European time (CET) when thunderstorm probability was estimated at 0915 to be larger than 30% north of the Alps. If the assessment was positive,

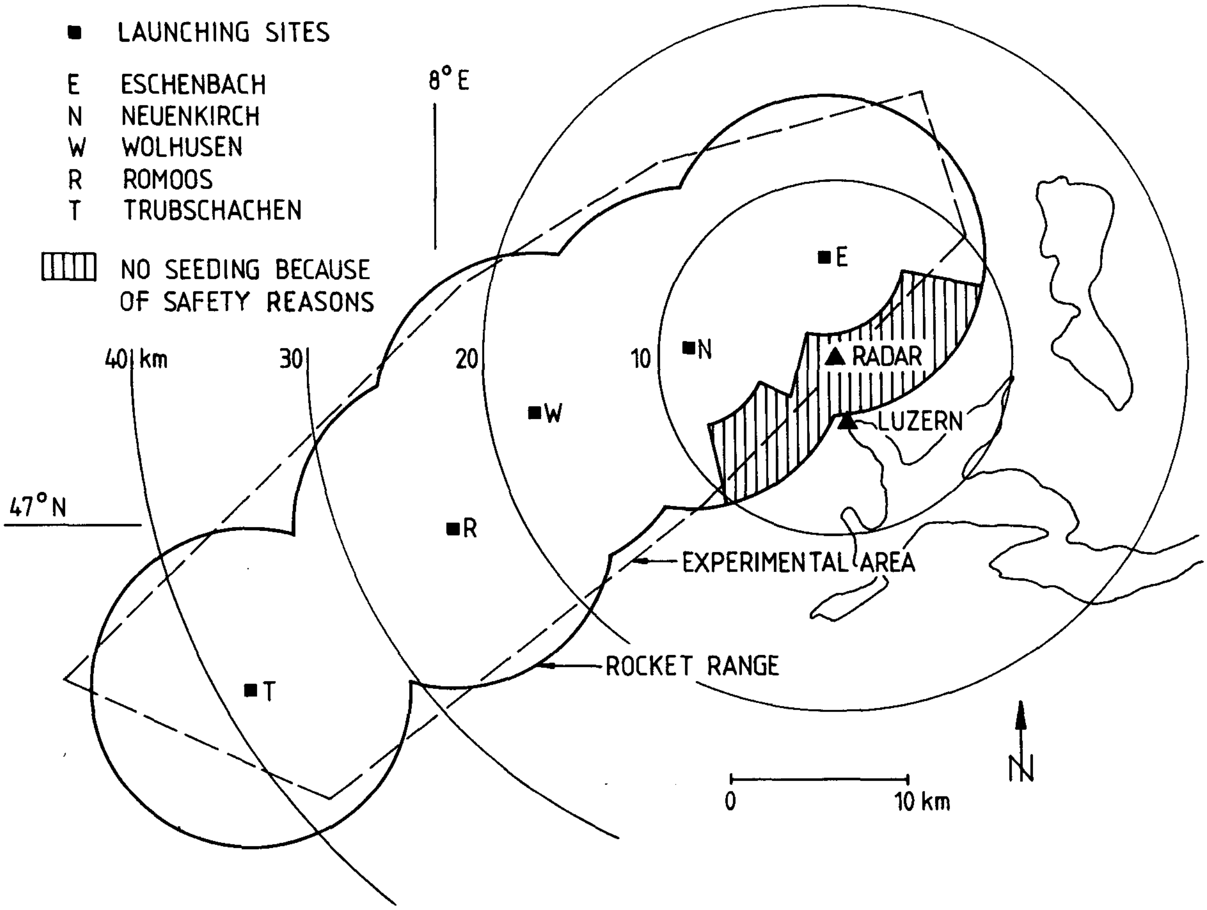

FIG. 1. The geographical location of the experimental area of Grossversuch IV with the rocket launching sites.

a randomized 1:1 decision was made whether seeding or control operations were to be conducted during the experimental unit.

The *experimental cell* (called simply "cell" in the following) is the experimental subunit. It is defined as a 45-dBZ radar-reflectivity contour of the precipitation, inside of which a series of vertical sections indicates that the seeding criterion is met at least once within the experimental area (see Fig. 1).

A *hail day* is an experimental unit with at least one experimental cell.

A *seed* or *no-seed day* is a hail day with seeding or control operations, respectively.

The Soviet seeding criterion turned out to be very satisfactory (Waldvogel et al., 1979) in detecting cells early in their development from an ensemble of convective radar echos. Every cell was seeded on a seed day and only carefully observed on a no-seed day. Seeding was done with rockets at about the −5°C isotherm in the center of a cell if it was axisymmetrical, and in the feeder clouds and forward overhang if it was asymmetrical. The working model of this seeding technique is the Soviet implementation of the beneficial competition concept with an "accumulation zone" of large supercooled drops.

Figure 2 shows an example of the seeding procedure of a seeded cell. The evolution and displacement of the cell and the trajectories of the fired rockets are plotted; 2 of the 15 trajectories have to be counted twice because two rockets were launched in the same direction. Several important events are indicated in the figure: t_0 is the moment when the seeding criterion is met for the first time inside the experimental area; t_{fs} is the time when the first and t_{ls} when the last rocket is fired; and t_f defines the moment when the criterion is not met any longer or the cell leaves the experimental area. The differences between t_0 and t_{fs} and between t_{ls} and t_f are due to technical reasons and to the "seeding prescription," which demands that one rocket has to be fired every 5 min as long as the seeding criterion is fulfilled.

The *response variable R* is the logarithm of the global hail kinetic energy E_{GR} of an experimental cell which, in turn, is derived from radar data by the methods developed by Waldvogel et al. (1978), Waldvogel and Schmid (1982):

TABLE 1. List of symbols.

	Stability indices
BI	Boyden-index = $H_{700} - H_{1000} - T_{700} - 200$ (H = height of the indexed mbar-level in deka-m, T in °C)
ENGY	net buoyancy energy (J kg^{-1})
KI	K-index = $T_{850} + T_{d850} - (T_{500} + T_{700} - T_{d700})$ (T_d = dew point in the indexed mbar-level in °C)
Sh	mean wind shear cloud base − cloud top [$(10^3$ s$)^{-1}$]
SI	modified Showalter index (i.e., instead of 850 mbar, lowest 50 mbar average properties used) (°C)
TTI	TT-index = $T_{850} + T_{d850} - 2T_{500}$ (°C)
WV	water vapor in the lowest 50 mbar (g kg^{-1})
	Response variables
D	prediction error (R-f)
$\dot{E}$	flux of hail kinetic energy (J m^{-2} s^{-1})
E_G	global hailpad kinetic energy (10^6 J)
E_{GR}	radar-derived hail kinetic energy of a hail cell (gradual method) (10^6 J)
E_T	hailpad kinetic energy (J m^{-2})
R	response variable [$\ln(E_{GR} + 1)$]
	Secondary response variables
$D_{\max}$	maximum diameter of hailstones (mm)
$E_{T\max}$	maximum point value of kinetic energy (J m^{-2})
M_G	global hail mass (10^6 kg)
$M_{T\max}$	maximum point value of hail mass (kg m^{-2})
N_G	global number of hailstones (10^6)
$N_{T\max}$	maximal point value of hailstone number (m^{-2})
S_G	area of hailfall (km^2)
	Predictor variables
A_{45}	area within the 45-dBZ contour at time t_0 (km^2)
d	discriminant function (see design)
E_0	logarithm of the average kinetic energy between (t_0 − 20 min) and (t_0 + 4 min)
f_1, f_2, f_3	predictor functions
F^I	indicator variable for a frontal day
F^IM^I	indicator variable: 1, for days with frontal triggering of deep convection and moving cells (mean velocity ≥ 4 m s^{-1}); 0, otherwise
G_0	growth parameter at t_0 (see design)
G_2	growth parameter at (t_0 + 2 min)
H_V	cloud top height at time t_0 (km)
L	distance of cell from radar at t_0 (km)
M^I	indicator variable for a moving cell (mean velocity ≥ 4 m s^{-1})
t^I	indicator variable: 1, if first 45-dBZ contour appears between 1300–1500 or 1900–2100 (CET); 0, otherwise
T_B	concomitant variable (cloud base temperature, convective condensation level) (°C)
$\bar{T}_B$	mean cloud-base temperature (7.46°C)
T_R	indicator variable: 1, for cells penetrating the experimental area; 0, otherwise (cells developing inside the experimental area)
T_V	temperature at cloud top (°C)
Z^I_{51}	indicator variable: 1, if the maximum radar reflectivity at $t_0 \geq 51$ dBZ; 0, otherwise
Δt_{45}	time interval between the first appearance of 45 dBZ (PPI) and t_0 (set to zero if negative)
	Other variables
H_B	height of cloud base (CCL) (km)
H_0	height of 0°C level (km)
t_0	first time the seeding criterion is met
t_f	last time the seeding criterion is met
t_{fs}	first seeding time of a cell
t_{ls}	last seeding time of a cell
S	indicator variable: 1 for seeded cells,0 for no-seeded cells
Z	radar reflectivity (dBZ)
$\alpha, \beta, \gamma, \eta$ $\Delta\beta, \Delta\gamma$	coefficients in confirmatory test model

$$\dot{E}_{GR} = 5 \times 10^{-6} \times 10^{0.084Z} W(Z) \qquad (1)$$

where,

$$W(Z) = \begin{cases} 0 & \text{for} \quad Z \leq 55 \\ 0.1(Z - 55) & \text{for} \quad 56 \leq Z \leq 64 \\ 1 & \text{for} \quad Z \geq 65. \end{cases}$$

Here Z is in dBZ, $\dot{E}_{GR}$ in J m^{-2} s^{-1}. The value of E_{GR} can be obtained by integrating over the corresponding area and time interval as defined in the design:

$$E_{GR} = \int_{t_0+5\text{ min}}^{t_f+20\text{ min}} \int_{\text{area of cell}} \dot{E}_{GR}(x, y, t)dxdydt. \qquad (2)$$

Because of the extremely high skewness of the distri-

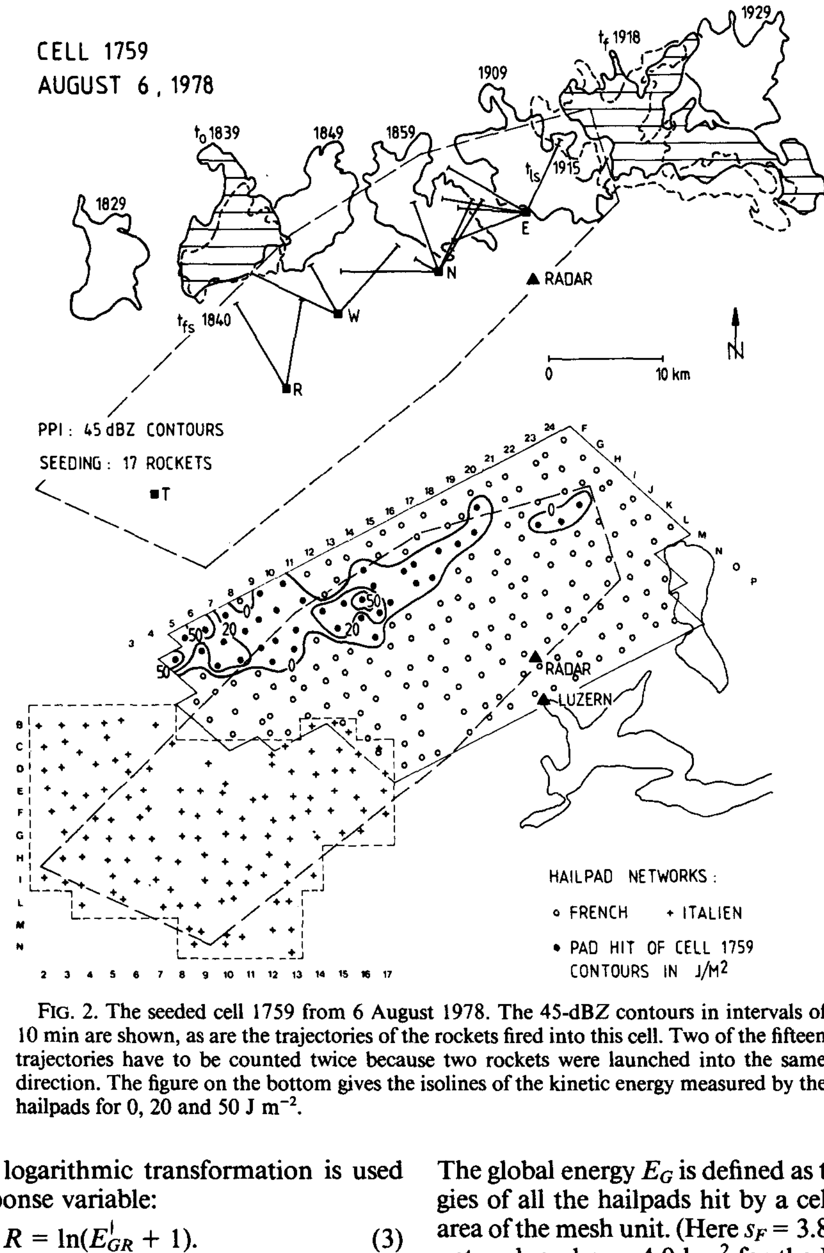

FIG. 2. The seeded cell 1759 from 6 August 1978. The 45-dBZ contours in intervals of 10 min are shown, as are the trajectories of the rockets fired into this cell. Two of the fifteen trajectories have to be counted twice because two rockets were launched into the same direction. The figure on the bottom gives the isolines of the kinetic energy measured by the hailpads for 0, 20 and 50 J m^{-2}.

bution of E_{GR}, a logarithmic transformation is used for the actual response variable:

$$R = \ln(E'_{GR} + 1). \qquad (3)$$

Another *response variable, E_G*, is the corresponding hailpad-derived global kinetic energy. It is obtained from the number and diameter of hailstones which have fallen onto each hailpad within the swath of an experimental cell. Figure 2 shows a picture of the two hailpad networks used in Grossversuch IV: the French network in the northeast and the Italian network in the southwest of the experimental area. The point kinetic energy value E_{Ti} of hailpad i is calculated according to Mezeix and Doras (1981):

$$E_{Ti} = 4.58 \times 10^{-6} \sum_j n_j d_j^4. \qquad (4)$$

Here n_j is the number of hailstones of class j (m^{-2}) and d_j is the middle of the jth class diameter in millimeters. The global energy E_G is defined as the sum of the energies of all the hailpads hit by a cell multiplied by the area of the mesh unit. (Here $s_F = 3.8$ km^2 for the French network and $s_I = 4.0$ km^2 for the Italian network:)

$$E_G = \sum_{\substack{i\text{: in}\\ \text{cell and}\\ \text{French}\\ \text{network}}} E_{Ti} s_F + \sum_{\substack{i\text{: in}\\ \text{cell and}\\ \text{Italian}\\ \text{network}}} E_{Ti} s_I. \qquad (5)$$

The agreement between the two independently measured kinetic energies (radar and hailpad) will be discussed in section 6.

In addition to the primary test variable, hail kinetic energy, we define (compare Crow et al., 1979) several *secondary response variables* measured by the hailpad network. Three global variables can be calculated for each hailfall by summing the respective point values and multiplying by the area s of the mesh unit:

TABLE 2. Data and data storage.

		Data storage					
		ETH*			GNEFA/UCEA*		SMA Swiss Meteor. Service, Zurich
Operation	Data	Tape	Film	Reports	Tape	Reports	
Operational decisions	Alarm day yes/no			×	×		
	Randomization N/S			×	×		
	Criterion met yes/no			×	×		
Radar	PPI (10 cm)	×	×		×		
	RHI (3 cm)	×	×	×(1)			
	PPI (5 cm) SMA		×				
	Calibration			×			
	Cell information	×		×	×		
Hailpads	French network	×			×	×(5)	
	Italian network	×			×	×(5)	
Seeding information	Trajectories			×	×		
	Seeding parameters	×		×			
Meteorology	Sounding Payerne	×		×(2)	×		×
	Mesonet SMA (Stations: Luzern, Napf: Temp., pressure, wind etc.)			(3)			×
	Disdrometer fix	×		×			
	Rain data	×		×	×	×	×
	Temp., wind (radar base)			×(4)			
Microphysics	Hailstone analysis			×(5)		×(5)	
	Ice nuclei sampling at radar base			×			
	T-28 (1982, 1983)	×(6)					

* Other sources 1) planchettes, 2) drawings, 3) listings, 4) stripcharts, 5) photographs, 6) tapes from South Dakota School of Mines.

$$\text{Hail area:} \quad S_G = Ps; \tag{6}$$

$$\text{Hail mass:} \quad M_G = s \sum_{i=1}^{P} M_{Ti}; \tag{7}$$

$$\text{Number of hailstones:} \quad N_G = s \sum_{i=1}^{P} N_{Ti}. \tag{8}$$

Here P is the total number of hailpads hit by a cell, M_{Ti} the mass of hail recorded by hailpad i, and N_{Ti} the total number of hailstones recorded by hailpad i.

Four maximum point variables are also used: $N_{T\max}$, $E_{T\max}$, $M_{T\max}$ and $D_{\max}$. They represent the maximum values of the number of hailstones per square meter, kinetic energy, mass and hailstone diameter observed by one of the P hailpads hit by a cell.

b. The data

A large amount of ground measurements, radar data and other meteorological information was collected during the field experiment of Grossversuch IV. Most of the data are available on magnetic tape in the computer center of the ETH. A cell-oriented data bank has been developed which contains the relevant information for the confirmatory and exploratory analyses of the experiment.

Other information is stored in the form of sequential data files or published in the annual reports of the different research groups (Swiss, French and Italian). An overview of the available data is given in Table 2. For further information on data format and storage we refer to the annual reports (Cloud Physics Group, 1976–83; GNEFA, 1978–82; UCEA-IILA[2], 1980, 1981, 1983).

The raw data for the confirmatory test and the relevant parameters for each cell are listed in the Appendix. Table A1 presents for every cell the values of the parameters of the day, i.e., seed or no-seed, frontal or thermal thunderstorms, an indicator variable about the cell movement, and the cloud base temperature. Every experimental cell is identified with an identification number which is the time of its first observation on the radar screen. Furthermore, the table contains for every identified cell an indicator variable about the place of origin; the height of the cloud (echo) top at t_0; the most important operational parameters, such as the times t_0, t_f, t_{fs}, t_{ls}; the number of rockets fired into

[2] Istituto Italo Latino Americano (Roma).

TABLE 3. Number of hail days and experimental cells (derived from radar) for each operational year, the total for each year, the total for the period 1977–81 (confirmatory analyses) and for the period 1977–82 (future exploratory analyses).

Randomization	1977		1978		1979		1980		1981		Total 1977–81		1982		Total 1977–82	
	Days	Cells	Days	Cells	Days	Cells	Days	Cells	Days	Cells	Days	Cells	Days	Cells	Days	Cells
No-seed (N)	7	18	12	31	11	34	4	18	9	21	43	122	3	18	46	140
Seed (S)	9	26	8	16	4	12	4	11	8	29	33	94	4	19	37	113
Total	16	44	20	47	15	46	8	29	17	50	76	216	7	37	83	253

the cell, and the resulting seeding coverage. The values of the two response variables and the discriminant and predictor functions (see section 3) are also given.

The tests presented in this paper are restricted to the measurements collected during the 5-year period 1977–81 as determined in the design. In the last year, 1982, the randomization and the operations continued as in the previous years for two months, except that the hailpad network could be maintained only in a reduced extent due to financial reasons. Thus there exists an extended dataset containing the data of a 6-year randomized seeding experiment with a total of 253 cells. This set will be used for exploratory analyses.

The numbers of hail days and cells are presented in Table 3. They reveal that more no-seed than seed days were obtained (43 versus 33 days for 1977–81). The difference, however, is not significant. The probability of obtaining 43 or more no-seed days out of a total sample of 76 days by a 1:1 unrestricted randomization is 0.15. One finds the same ratio (1.30) for the cells as for the days. This ratio is smaller (1.24) for days and cells for the 6-year period. Also, in the last year, the average number of cells per day was five as opposed to three in the previous years.

In the design, a total of 260 cells was estimated to occur in the experimental area during a 5-year period. Obviously, this goal has not been reached completely, with only 216 cells actually observed. With the additional year (1982), however, the desired number could be attained very closely.

It is informative to compare seed with no-seed days on the basis of parameters which cannot possibly be influenced by seeding, like the synoptic variables; we discuss this "representative draw" analysis (Summers et al., 1979) in section 6a.

3. Confirmatory test using radar data

a. Introduction

This section describes the procedure and results of the statistical test which motivated Grossversuch IV and was outlined in the design. (See also Hampel et al., 1983.) Using terms introduced in section 2, the basic question may be formulated more precisely as follows: Do the experimental cells on seed days and no-seed days differ in the response variable R in a statistically significant way?

Before going into a discussion of the statistical test that provides the scientific answer to this question, let us compare the seed and no-seed cells. Figure 3 shows that both the median and the mean value of R for the seeded group are larger than for the no-seed group. While this would suggest that seeding leads to an increase of the hail kinetic energy (by a factor of 2.7 and 4.3, respectively), the difference is far from being statistically significant. A Wilcoxon–Mann–Whitney test, applied to the first cell of the hail days, produced a P-value of 0.51.

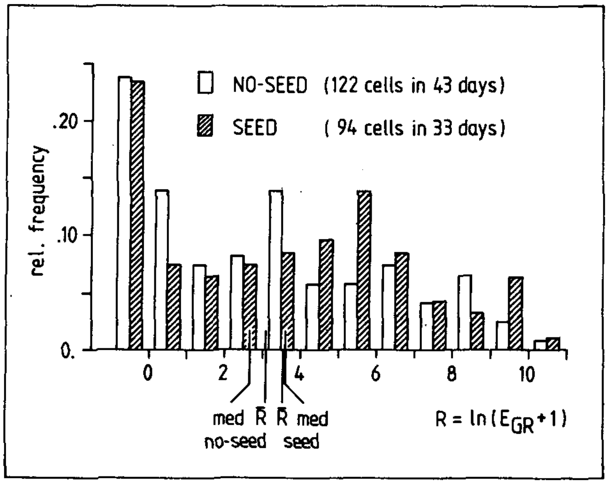

FIG. 3. Histogram of $R = \ln(E_{GR} + 1)$ for seed and no-seed cells; $\bar{R}$: arithmetic mean; med: median.

It would be quite astonishing and difficult to interpret if, under such circumstances, a refined analysis demonstrated a significant reduction of hail energy by seeding. In order to obtain more precise information, we will, nevertheless, go through this analysis. If a question like the one asked at the beginning of this section is to be tested with a well-defined probability of an error of the first kind, it is essential to fix the exact testing procedure before looking at the data to be used for the test. Therefore, the plan for this confirmatory analysis was published in the design.

The main ideas of this test are recapitulated in section 3b. The results appear in section 3c. Section 3d presents the alternative test, which incorporates a theoretical statistical insight that came up after the publication of the design but before examining the data. Finally, in section 3e, confidence intervals for the true seeding effect are derived.

b. *Main ideas of the test*

The hail kinetic energy is so variable that an exceedingly large number of observed cells would have been required in order to get a satisfactory power of the test. When planning the experiment, we therefore resorted to a statistical device to reduce the variability: A function f was developed which should predict the response variable R, using variables which characterize the development of the cell up to the time t_0 + 5 min of a first potential seeding effect. The function was obtained by regression methods using data of preliminary observations of untreated cells. Instead of R, the deviations $D = R - f$ are now examined in the main experiment. Clearly, a potential reduction of the R-values by seeding should be reflected by a similar decrease in the deviations D, but these have a lower variability if the prediction is effective.

The seeding criterion attempts to distinguish cells that will eventually produce hail from ordinary rain cells. Applying the seeding treatment to cells which would not produce hail in any case is preferable to not seeding actual hail cells. The seeding criterion is therefore conservative, and there are many cells that have a zero response value ($R = 0$) even if unseeded. These zero cases dilute any apparent effect of seeding; i.e., they reduce the power of the test. Along the lines followed for the prediction of the response variable, a discriminant function d was developed to distinguish between zero and nonzero cells, using information obtained before t_0 + 5 min only. The cells that were predicted as zero cases by d were then dropped from the sample for the main test. It was hoped that the discriminant function would be more effective than the seeding criterion because it was based on more detailed information about the early development of the cells, which was not available in real time.

Based on cloud physics, it was anticipated that a possible seeding effect might be different for low and high values of the cloud base temperature T_B. Therefore, the alternative hypotheses for which the test was designed included not only an overall difference between seed and no-seed cells, but also a linear dependence of the difference on T_B.

In order to devise a model which reflects these considerations, an indicator variable for seed and no-seed days is needed. Let

$$S_{jk} = \begin{cases} 1 & \text{if day } k \text{ of year } j \text{ was a seed day} \\ 0 & \text{otherwise,} \end{cases}$$

and let $D_{jkm} = R_{jkm} - f_{jkm}$ be the difference between the response variable and the value of the predictor function for cell m on day k of year j. Then a model that covers all the mentioned alternatives is as follows:

$$D_{jkm} = \alpha + \beta[(T_B)_{jk} - \bar{T}_B] + \Delta\gamma S_{jk} + \Delta\beta[(T_B)_{jk} - \bar{T}_B]S_{jk} + \epsilon_{jkm}. \quad (9)$$

The first two terms on the right side of (9) allow a nonzero mean of the D-values for no-seed cells, and this mean may depend on T_B. The third term reflects a potential mean effect of seeding, and the fourth, its dependence on T_B; $\bar{T}_B$ stands for the mean cloud base temperature. The last term is the random error.

This model was refined to include: (a) a possible year effect which might be caused by climatic and instrumental changes; and (b) a possible difference between average D-values for cells originating within and outside the experimental area, since these D-values are based on different predictor functions. The final model is now

$$D_{jkm} = \alpha_j + \eta H_{jkm} + \beta[(T_B)_{jk} - \bar{T}_B] + \Delta\gamma S_{jk} + \Delta\beta[(T_B)_{jk} - \bar{T}_B]S_{jk} + \epsilon_{jkm}, \quad (10)$$

where H_{jkm} is zero or unity for cells originating within or outside the area, respectively. Introducing such covariate terms into the model has an effect similar to using the predictor function. It improves the statistical power of the test by reducing the variability of the error term if they really have some influence on the dependent variable. The decision as to which terms should be included was based on plausibility considerations only, without using data of the main experiment; this was in order to preserve the strictly confirmatory nature of the procedure.

The test examines whether $\Delta\beta$ and $\Delta\gamma$ may be zero. The classical t- or F-tests of such hypotheses assume normal distribution, equal variance and independence of the random errors ϵ_{jkm}. Previous data showed that the distribution is not normal. It is plausible that cells within the same day can be correlated. Even though the "intraday correlation" was estimated to be quite low in the preliminary study ($r = 0.09$), independence cannot be assumed. Similarly, the variance of the errors could be a function of the concomitant variable T_B.

It is known that randomization tests do not need these assumptions (Cox and Hinkley, 1979, Chapter 6; Brillinger et al., 1978, p. F1 ff). They keep the desired statistical level under very general conditions. At the same time, their flexibility allows for easy adjustment to relevant alternative hypotheses and to robustness requirements.

Here is a brief explanation of the basic idea of the randomization test as applied to the present situation. Assume that the randomization procedure which was applied to determine the seed and no-seed days had produced a different choice of seed days than the actual one. Under the null hypothesis of no seeding effect, exactly the same data would have been observed anyway. Specifically, in model (10), only the S_{jk}-values would be different, corresponding to the different hypothetical randomizations. Now, consider all possible hypothetical randomizations or, technically speaking, all 0–1 sequences of length 76 (the number of experimental days) as candidates for the 76 S_{jk}-values. This leads to a probability model in which only the S_{jk} values are random, whereas the D_{jkm}, H_{jkm} and $(T_B)_{jk}$ values are fixed numbers. The randomization procedure entails equal probability for all the 0–1 sequences. For each of these sequences, the parameters $\Delta\beta$ and $\Delta\gamma$ in model (10) can be estimated. This leads to a probability distribution for the estimates $(\widehat{\Delta\beta}, \widehat{\Delta\gamma})$ that is valid under the null hypothesis. It is called the randomization distribution of $(\widehat{\Delta\beta}, \widehat{\Delta\gamma})$. In our case the distribution is two-dimensional.

Under the alternative hypothesis that the seeding procedure is effective, the $\widehat{\Delta\gamma}$-value for the randomization realized in the experiment is expected to be more negative than most of the $\widehat{\Delta\gamma}$-values for the hypothetical randomizations. Similarly, under other alternatives, large values of $\widehat{\Delta\gamma}$ or extreme values of $\widehat{\Delta\beta}$ are to be expected. The test is thus specified by delimiting a rejection region of extreme values in the $(\widehat{\Delta\beta}, \widehat{\Delta\gamma})$ plane that includes 5% of the randomization distribution. The test result is significant if the $(\widehat{\Delta\beta}, \widehat{\Delta\gamma})$ pair for the actual randomization falls into the rejection region. Following the design, the region was determined to contain the 3.5% most negative and the 0.5% most positive $\widehat{\Delta\gamma}$ and the 0.5% most extreme $\widehat{\Delta\beta}$ on each side of the rest (see Fig. 5). The asymmetry in this definition provides more statistical power for the *a priori* most likely alternative. This construction ensures that the probability of an error of the first kind—rejection of the null hypothesis when it is true—is indeed 5%. The only assumption needed is that all the randomizations have equal probability of being realized in the actual experiment. Hitherto we failed to specify which estimators should be used. Least-squares estimators would be optimal if the errors ϵ were normally distributed. Since this is not true, an analogy with the classical testing and estimation problem suggests that using robust estimators will increase the power. We used a Huber estimator (Huber, 1973, p. 815; $k = 1.5$). These considerations show how the randomization test is adjusted to alternatives on an intuitive basis, even if formal power calculations would need more assumptions and work than we can afford.

The randomization distribution cannot be obtained analytically. If the number of possible randomizations is small enough, the statistic $(\widehat{\Delta\beta}, \widehat{\Delta\gamma})$ could be calculated on the computer for all of them; this would yield the exact randomization distribution numerically. Since the number of possible choices of seed days is exceedingly large, the distribution is approximated by simulation: The value of the statistic is calculated for a reasonably large number of randomly generated selections of seed days. Although this introduces some additional randomness into the test procedure, its effect is negligible when using 3000 random selections (compare Brillinger et al., 1978). The randomizations were restricted to provide the same number of seed and no-seed days in each year as the randomization used in the experiment.

This testing procedure is the specification of the nonparametric test corresponding to the F-test which was planned in the design. It was worked out by the statistics group at ETH down to the details of programming before they got involved in the analysis of the data of the main experiment (Schweingruber, 1981). There is one point in which the procedure does not conform to the design. The intention was to exclude from the analysis those cells for which the seeding procedure had not been carried out successfully. Specifically, the seeding coverage was defined as the ratio of the number of rockets which were launched successfully to the number required by the Soviet method. For technical reasons, this ratio could be quite low in some cases and 0.33 was specified as the threshold for un-

TABLE 4. Effect of the discriminant function d.

	Hail ($R > 0$)			Rain ($R = 0$)			
Cells	Seed	No-seed	Total	Seed	No-seed	Total	Total
Included	48	44	92	4	9	13	105
Excluded	24	49	73	18	20	38	111
Total	72	93	165	22	29	51	216

satisfactory seeding. Now, the seeding coverage can be determined properly for seed days only and, thus, only seeded cells would be deleted. It became clear soon after the publication of the design that this would introduce a bias into the test if the seeding coverage was correlated with the energy of the cell. Thus we decided to disregard the seeding coverage for the test. Therefore, all cells on seed days will be treated as seeded cells in this section, even if they actually were not seeded at all due to technical difficulties. The seeding coverage will be used for exploratory analyses, and in section 6 we shall show that it is actually correlated with the response variable R.

c. The result of the confirmatory test

The discrimination rule developed with the intention of excluding rain cells from the ensemble was defined in the design as

$$d = -0.17 + 0.024\Delta t_{45} + 0.025A_{45}^{+} + 0.045G_0 + 0.018Z_{51}^{I} \leqslant 0.4. \quad (11)$$

Table 4 shows that 51% of the cells were ruled out; 66% of these produced hail, nevertheless ($R > 0$), whereas 12% of the remaining cells turned out to be rain cells ($R = 0$). Despite this poor result, the function will be applied in the confirmatory test in order to follow the design strictly. (The results obtained from all the cells will be given in section 6.)

The predictor functions, as obtained by Morgenthaler (1980), were

$$f_{IT} = -2.15 + 1.43 \ln(A_{45}^{+} + 1) + 0.18G_0 + 2.64F^{I}M^{I} + 0.99H_V + 0.13T_B \quad (12)$$

for cells which originated in the experimental area and

$$f_{IR} = -2.02 + 2.43 \ln(A_{45}^{+} + 1) + 0.22G_0 + 0.78F^{I}M^{I} \quad (13)$$

for those penetrating the area. The reduction of the variability was smaller than anticipated [var(D)/var(R) = 0.77].

In Fig. 4 the prediction errors D are plotted against the cloud base temperature T_B. We do not find anything peculiar nor is there an obvious effect of seeding.

Figure 5 shows the distribution of the 3000 simulated values of ($\widehat{\Delta\beta}$, $\widehat{\Delta\gamma}$) and the resulting rejection region. The point representing the actual randomization is marked by a black square and is not in the rejection region. Thus the effect of seeding, if any, is not statistically significant in terms of the confirmatory test corresponding to the design. The value $\widehat{\Delta\gamma} = 0.93$ for the actual randomization is exceeded by only 8% of the randomization distribution, suggesting that seeding might even increase the hail energy.

d. An alternative test

It was mentioned above that the predictor function was not as effective as expected in the design. One reason may be that the dataset on which the function was developed included cells from outside the experimental area and only contained cells which had been observed by radar during their whole lifetime. Another reason might be that while the variables of the function were

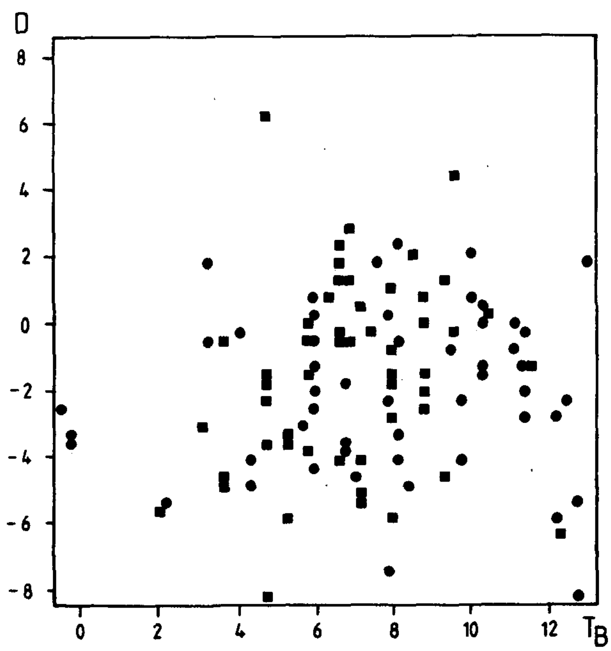

FIG. 4. Scatterplot of the prediction error D on the concomitant variable T_B. Square represents seed; circle, no-seed cells.

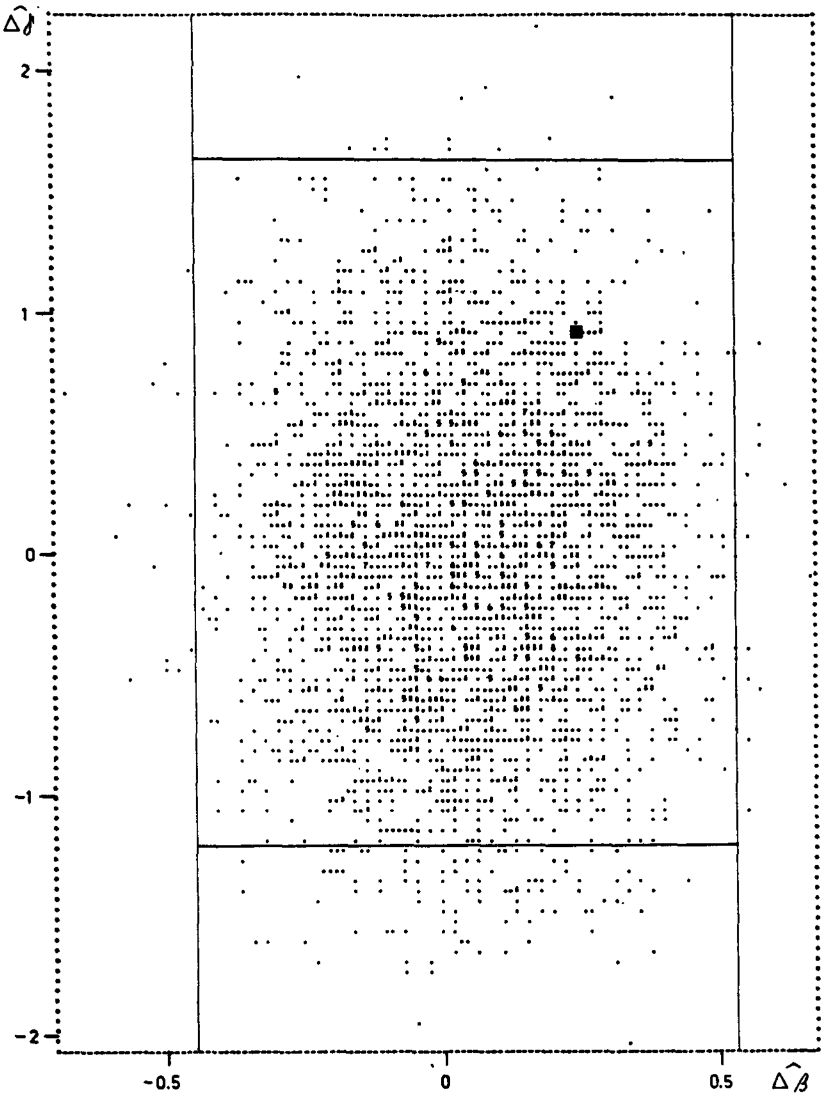

FIG. 5. Randomization distribution and rejection region for the confirmatory test ($3000\widehat{\Delta\beta}$- and $\widehat{\Delta\gamma}$-values). Square, ($\widehat{\Delta\beta}$, $\widehat{\Delta\gamma}$) for the actual randomization; 5–9 represent the respective number of superimposed points.

selected using a dataset of 74 cells, the coefficients were estimated using only 20 cells.

The randomization test allows us to derive a predictor function from the data of the main experiment as long as no attention is paid to the days on which seeding occurred, as is clear from the discussion in section 3b (see also Hampel et al., 1983). For the alternative test, a different set of potential predictor variables was chosen, including those mentioned in the design. A C_p-search (Daniel and Wood, 1980) was applied separately for cells originating within and outside the experimental area to select those variables which would enter the equation. The coefficients were then estimated using the Huber estimator with parameter 1.5. Because the process of obtaining radar measurements had been improved considerably after the first year (1977), only the data of the years 1978–81 have been used for this task. The resulting predictor functions were

$$f_{2T} = \alpha_j + 0.75H_V + 0.075T_V + 0.84E_0 + 0.76\ln(A_{45}^{+} + 1) + 0.19G_2 - 0.023L, \quad (14)$$

with

$$\alpha_2 = -2.33,\ \alpha_3 = -2.25,\ \alpha_4 = -2.98,\ \alpha_5 = -3.49$$

for cells originating in the experimental area and

$$f_{2R} = \alpha_j + 0.98E_0, \quad (15)$$

with

$$\alpha_2 = 3.15, \quad \alpha_3 = 2.78, \quad \alpha_4 = 0.4, \quad \alpha_5 = 2.74$$

for those penetrating it. The reduction of the variance using this predictor was $\mathrm{var}(D)/\mathrm{var}(R) = 0.54$.

The concomitant variable T_B was replaced by the predictor function f of the cell in order that any dependence of the seeding effect on the size of the cell could be detected. Such a dependence would also hint at a different seeding effect for supercell and multicell storms, which was assumed beforehand. Finally, the discrimination of hail and rain cells was dropped for simplicity, although it would have been possible to obtain a better rule from the main dataset in the same way as the prediction given by f.

When using the new predictor functions, it would have been possible to reduce the model (10) to (9), since the additional terms in (10) are reflected in the predictor functions. We continued with the extended form for our convenience, and further analyses were carried out exactly as for the previous test.

The result of the alternative test, given in Fig. 6, shows that the point corresponding to the actual randomization is not situated in the rejection region, meaning that this test also failed to show an effect of seeding. There is a tendency toward a larger effect of seeding (in the unfavorable direction) for larger cells, since only 4% of the randomization distribution have a $\Delta\beta$-value larger than the observed one.

e. Estimated effects and confidence sets

The estimated parameters in model (10) are included in Table 5. A point estimate for the effect of seeding for an average cell can be obtained from $\widehat{\Delta\gamma}$. Seeding seems to increase hail by a factor of $e^{\widehat{\Delta\gamma}} = 2.5$ according

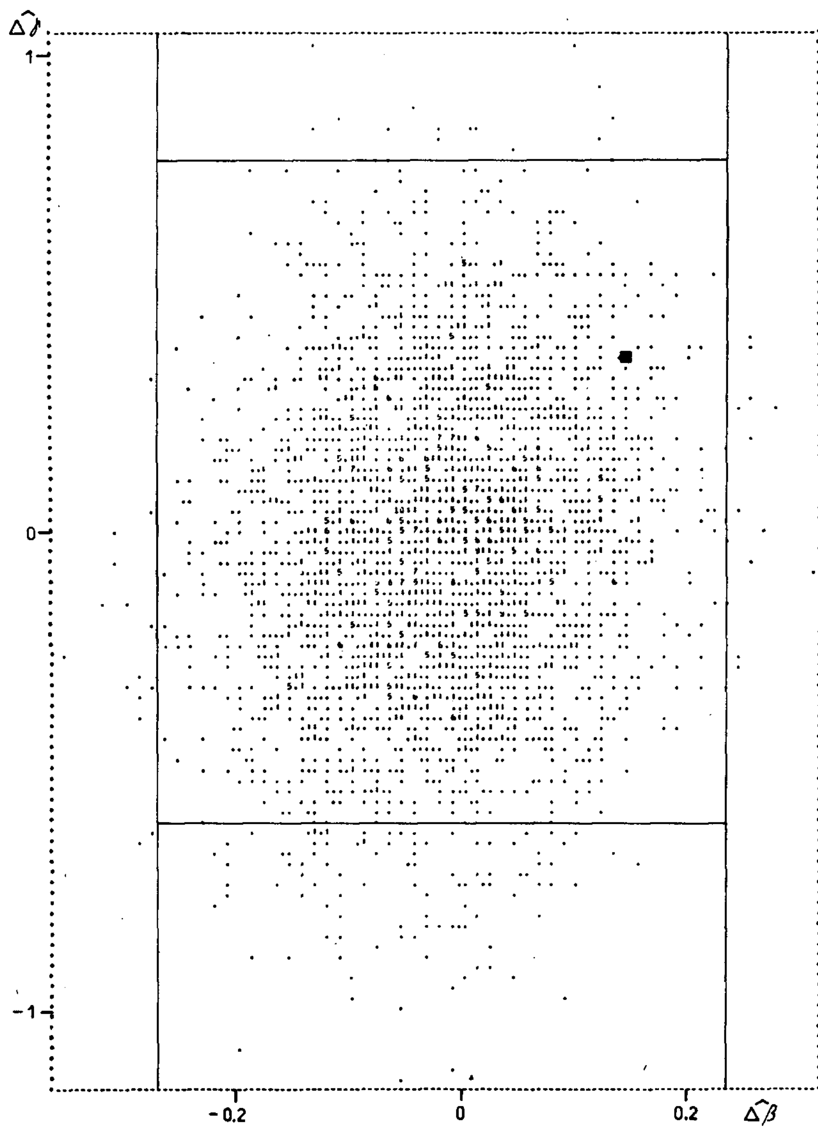

FIG. 6. Randomization distribution and rejection region for the alternative test. (Compare Fig. 5.)

TABLE 5. Summary of the numerical results of the confirmatory and alternative tests for the mean effect $\Delta\gamma$ and the dependence of the effect on the concomitant variable (T_B): $\Delta\beta$.

	Confirmatory test			Alternative test		
	Robust	Classical	More extreme randomizations (%)	Robust	Classical	More extreme randomizations (%)
Estimate $\widehat{\Delta\gamma}$	0.930	0.792	8	0.377	0.280	11
Estimated factor $e^{\widehat{\Delta\gamma}}$ for the energy E	2.53	2.221		1.46	1.32	
Confidence intervals for $\Delta\gamma$	(−0.36/2.31)	(−0.58/2.16)			(−0.37/0.93)	
Confidence intervals for the factor $e^{\Delta\gamma}$	(0.70/10.1)	(0.56/8.70)			(0.69/2.54)	
Estimate $\widehat{\Delta\beta}$	0.224	0.170	18	0.147	0.158	4
Estimated factor $e^{\widehat{\Delta\beta}}$	1.25	1.19		1.16	1.17	
Confidence intervals for $\Delta\beta$	(−0.22/0.65)	(−0.29/0.63)			(−0.12/0.44)	

to the values obtained in the confirmatory test, but this increase is not significant.

Confidence intervals can be obtained in two different ways. The simpler way uses the classical methods. Standard textbooks on regression provide the methods for obtaining confidence intervals for the individual parameters $\Delta\beta$ and $\Delta\gamma$ or confidence ellipses for both of them simultaneously, assuming that the errors ϵ_{jkm} are normally distributed with a known correlation structure. We allowed for a nonzero intraday correlation which was estimated by an ad hoc procedure in the spirit of Daniel and Wood (1980, chapter 8) to be 0.33 for the data used in the first test. Figures 7 and 8 show the confidence intervals and ellipses. The confidence interval for the mean seeding effect $e^{\widehat{\Delta\gamma}}$ extends from a reduction by 40% to an increase by a factor of 8.7 for the first dataset. Note that a reduction of 60 or 80%, as it appeared in the Soviet reports, is outside of the actual intervals. Using the alternative way to obtain the predictor function yields a narrower interval which extends from a 30% reduction to an increase by a factor of 2.5.

A second way to obtain confidence sets follows the spirit of the randomization test. With a slight modification, this method can also be used to test the

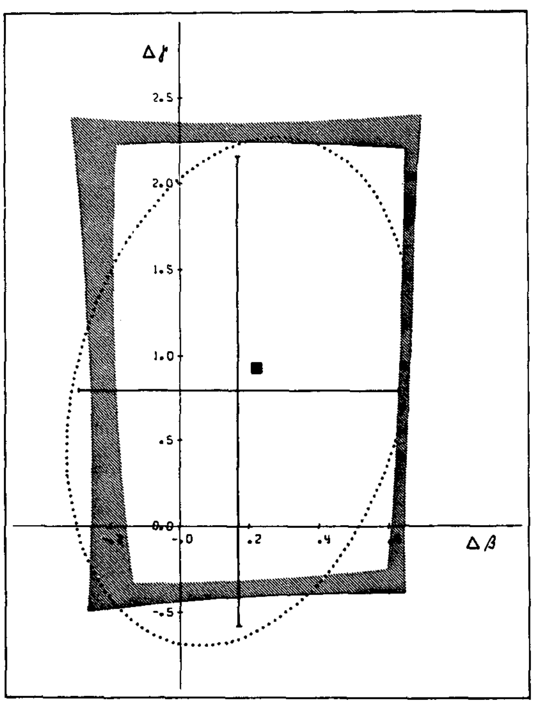

FIG. 7. Confidence sets for $\Delta\beta$ and $\Delta\gamma$ corresponding to the confirmatory test. Lines indicate 90% confidence region obtained from randomization tests; dotted circle and cross indicate 90% confidence region and 95% confidence intervals obtained by classical methods; square indicates robust estimate ($\widehat{\Delta\beta}$, $\widehat{\Delta\gamma}$).

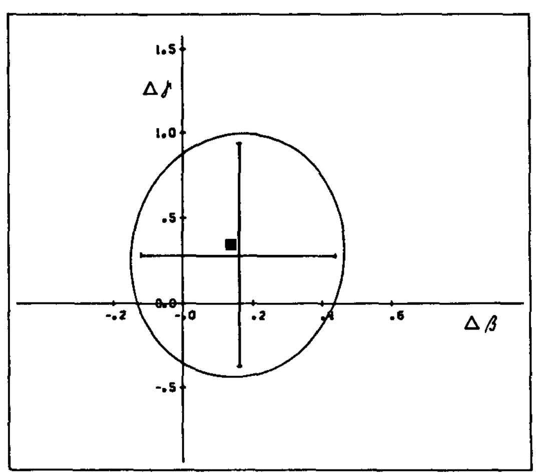

FIG. 8. Classical confidence sets for $\Delta\beta$ and $\Delta\gamma$ corresponding to the alternative test (compare Fig. 7).

hypothesis $\Delta\beta = \Delta\beta^*$, $\Delta\gamma = \Delta\gamma^*$ for any fixed pair $(\Delta\beta^*, \Delta\gamma^*)$. One just replaces the D_{jkm}-values by $D_{jkm} - \Delta\gamma^* S_{jk} - \Delta\beta^* S_{jk}(C_{jk} - \bar{C})$, where C is the concomitant variable, and applies the randomization test as described above. Then, in principle, the confidence set for $\Delta\beta$ and $\Delta\gamma$ is the set of all $(\Delta\beta^*, \Delta\gamma^*)$ values which are not rejected by the test. The rejection region for each test was determined to include the 2.5% most extreme $\widehat{\Delta\beta}$ and $\widehat{\Delta\gamma}$ values on each side rather than the asymmetric percentages used in the main test. This leads to a 90% confidence set and approximately 95% confidence intervals for the two parameters separately. In practice, this confidence region could be determined only with limited precision. We calculated P-values of 36 tests near the assumed border lines, using 200 randomization replicates in each. Assuming the border lines were approximately straight, we calculated them using an elaborate ad hoc regression procedure. The remaining uncertainty about their exact position is represented in Fig. 7 by the shaded strip delineating the confidence quadrilateral.

We applied the procedure to the data used for the first test only. The resulting confidence interval for the mean effect of seeding ($e^{\widehat{\Delta\gamma}}$) is similar to the result obtained with classical methods but shifted towards higher values. It extends from a reduction of 30% to an increase by a factor of 10.

f. Conclusions

The confirmatory test of Grossversuch IV, as described in the design, fails to show any statistically significant effect of the Soviet method of cloud seeding on hail kinetic energy measured by radar. A reduction by more than 30% is excluded by our results using a confidence level of 95% (two-sided). There is an indication that seeding may even increase the energy. A second, alternative test leads to the same qualitative conclusions but yields narrower confidence intervals. (See Table 5.)

4. Test with hailpad data

The null hypothesis of the confirmatory evaluation to be tested with hailpad data is as follows: the seeding of hailstorms according to the Soviet rocket seeding technique during the experimental unit causes no difference in the distributions of kinetic energy of hail produced by a cell between no-seed and seed cases. The test variable used is the global hailpad kinetic energy E_G [see (5), section 2] of a cell. It is clear that this hailpad variable has the advantage of representing the real ground truth of the hailfall as opposed to radar measurements, which include both rain and hail information, but has the disadvantage of being a discrete time-integrated measurement. The procedure used in obtaining this cell-oriented information from hailpad measurements is described in section 4a. Section 4b gives the results of the confirmatory evaluation comparing the two groups. First, a test on a contingency table (comparing hail and zero cases) is conducted for qualitative information; then, the result of the confirmatory test is given for the hail kinetic energy (E_G) of each cell. We add a result with the cell E_G-values cumulated over one day. In section 4c, zero and nonzero cases are simultaneously considered. As it is possible to obtain other physical variables with hailpads, the results of testing secondary response variables are presented in section 4d.

a. Procedure used for the determination of hail zones

The quality of hail measurements is crucial to the whole experiment. Therefore, a major effort was made to ensure the use of reliable instruments and maintenance procedures and to obtain maximum accuracy in processing and analysis (Vento, 1976; Mezeix and Admirat, 1978; Admirat et al., 1980; Doras, 1983).

1) Experimental apparatus

The data come from a dense and regular network. The northeastern part includes 211 hailpads with a regular lozenge-shaped mesh area of 3.8 km^2 covering 802 km^2; the southwestern part has 122 hailpads with a mesh area of 4.0 km^2 covering 488 km^2 (Figs. 2 and 9). The hailpads have a sensitive surface of 0.1 m^2. In 1977, the material consisted of a sheet of aluminium foil (0.2 mm thick for French and 0.03 mm for Italian pads) rebacked and glued on to emalene foam. Since 1978, all those hailpads were replaced by 2-cm thick plates of "roofmate" (polystyrene). The use of roofmate requires special preparation and a series of checks: coating with white paint to avoid decomposition of the surface, calibration of each batch of roofmate pads, postfall inking to increase the sharpness of the imprints for easier measurement and, finally, conservation and photographing of the pads.

By quick and regular maintenance of the hailpad network, we have been able to obtain data on the production of hail assigned to individual cells. This is an improvement on daily recording.

2) Procedure

After the determination of the times t_0 and t_f for each cell by 3-cm radar, the 10-cm PPI radar reflectivity contours (45, 55, 60, 65 and 70 dBZ, according to the cases) were digitized and drawn on a map of the experimental area along with the mass center of each isoecho contour with the corresponding time. A very exact account, hailpad by hailpad, of the potentially hailed zone is then obtained by superimposing the PPI data of the cell with the hail pattern data (Fig. 9). When no hailpad received hail, the cell was considered to be a zero case.

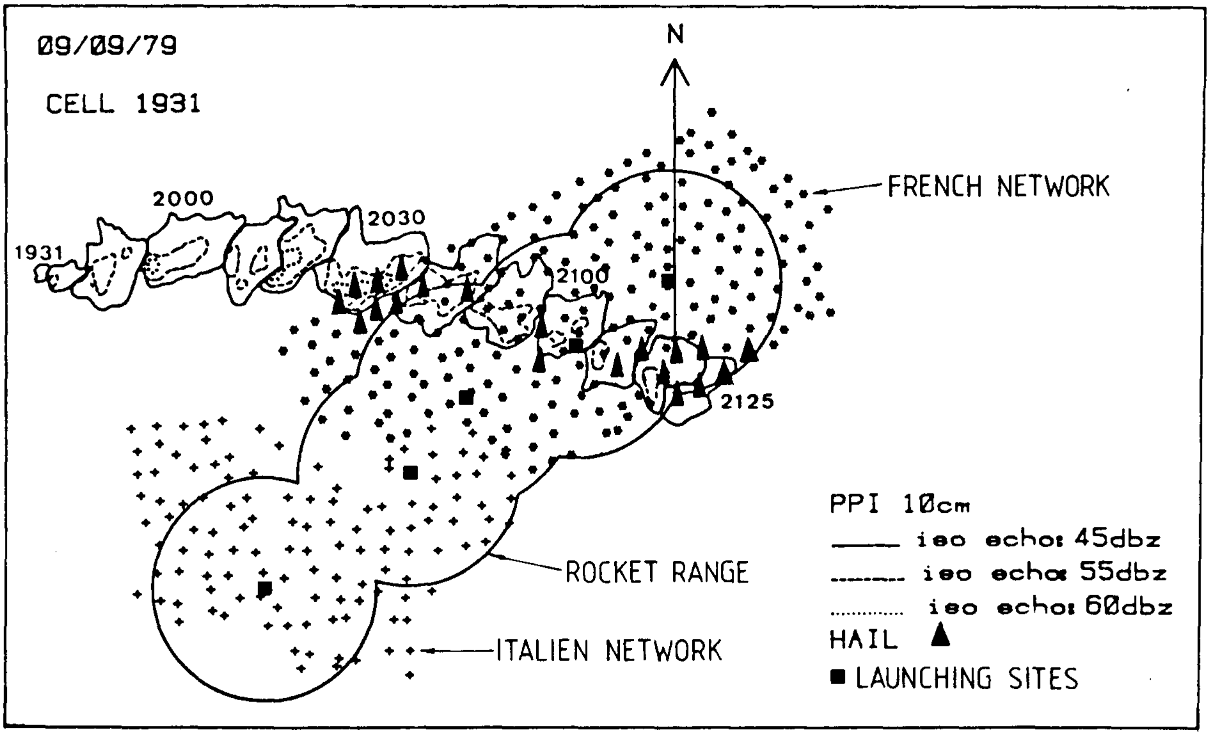

FIG. 9. French and Italian hailpad networks covering the experimental area. Radar reflectivity contours (PPI 5°) of hailcell 1931 from 9 September 1979 associated with impacted hailpads.

As a first approximation, the most probable average time representing a hailfall on a hailpad corresponds to the time when the centroid of the 55-dBZ echo was above the hailpad. In some cases where there was no 55-dBZ echo, we took the mass center of the 45-dBZ echo. With this procedure, all the hailpads are assigned an average fall-time. The various response variables can then be calculated in any time interval.

Among the 216 previously discussed cells, 11 are not taken into account for the test with hailpad data. Table 6 shows the date, identification number, randomization, kinetic energy E_G and the reasons for discarding these 11 cells. Thus, 205 cells remain: 122 no-seed (59.5%) and 83 seed cells (40.5%).

In the (t_0 + 5 min) to (t_f + 20 min) interval, out of 122 no-seed cells, 62 (51%) gave hail and 60 (49%) did not. Among the 83 seed cells, 47 (57%) gave hail and 36 (43%) did not. (See Table 7.)

The 49% of cells with the seeding criterion satisfied but without any hail detected on the ground is close to the 50% of hailcells without hail on the ground found by Waldvogel et al. (1979) with a different sample of cells. The 62 no-seed cells with hail on the ground come from 31 days and the 47 seed cells from 26 days. In addition to the sample of 62 no-seed cells and 47 seed cells with hail, we shall also consider the sample of 31 no-seed and 26 seed hail days for which the values of the cell response variables will be cumulated daily.

TABLE 6. The 11 cells not taken into account for the hailpad data tests.

Date	Identification number	Randomization	E_G	Reason for discarding
18 Jun 1977	1305	seed	0.00	not seeded
4 Jul 1977	1921	seed	0.00	not seeded
8 Jul 1977	1538	seed	0.00	not seeded
7 Aug 1977	1320	seed	0.00	not seeded
14 Sep 1979	1355	seed	—	network not in operation
14 Sep 1979	1437	seed	—	network not in operation
14 Sep 1979	1731	seed	—	network not in operation
19 Aug 1980	2037	seed	0.00	not seeded
16 May 1981	1413	seed	0.00	not seeded
9 Jul 1981	1629	seed	0.00	not seeded
8 Aug 1981	1735	seed	0.00	not seeded

TABLE 7. Number of cells with and without hail on the pad network for the (t_0 + 5 min) to (t_f + 20 min) time interval.

	Number of cells		
	Seed	No-seed	Total
With hail	47	62	109
Zero hail	36	60	96
Total	83	122	205

b. Results of the confirmatory test

The confirmatory test is the t-test applied to a lognormal transformation of the E_G-values as stated in the prior hypothesis (Federer et al., 1978/79). The Kolmogorov–Smirnov test shows that the fit of E_G-values to a theoretical lognormal distribution is possible. It calculates the maximum deviation d_{max} between the values of the distribution of the cumulative frequency function for the sample and the values of that function for the population. When d_{max} is less than $0.886/(n + 1.5)^{1/2}$, the hypothesis of variables fitting the theoretical distribution can be accepted at the 5% level (Dagnélie, 1975). But as the numbers of values in the seed and no-seed samples remain small, the goodness of fit to a theoretical lognormal distribution is weak. Thus, on the same data, we also use the Mann–Whitney nonparametric test whenever the probability density function is not specified. This test is added to the confirmatory evaluation for a complementary validation.

1) TEST OF SEEDING EFFECT ON THE FREQUENCY OF ZERO CASES

A χ^2-test applied to Table 7 ($\chi^2 = 0.45$; $P = 0.51$) and a χ^2-test with Yate's correction ($\chi^2 = 0.27$; $P = 0.60$) do not allow the rejection of the hypothesis that the samples are homogeneous. The proportion of zero cases is not statistically different in the no-seed and the seed ensemble. To show an effect at the 5% level with this test, 14 of the 47 seed cells with hail would have to become 14 additional zero cases.

2) CONFIRMATORY TEST OF THE SEEDING EFFECT ON CELLS WITH HAIL (62 no-seed, 47 seed cells)

The Kolmogorov–Smirnov test does not allow the rejection of the lognormal hypothesis concerning the two distributions, seed and no-seed, (Fig. 10 and Table 8) at the 5% level, where the critical values of d_{max} are 0.127 and 0.111, respectively.

As the primary test variable E_G is lognormal, we can use the student t-test for the confirmatory evaluation. If

$$\bar{x}_1 = \overline{\log E_{G1}} \quad \text{and} \quad \bar{x}_2 = \overline{\log E_{G2}} \qquad (16)$$

are the means of the logarithmic kinetic energy of the two samples, no-seed (E_{G1}) and seed (E_{G2}), an unbiased estimator of D, the difference between the true mean values, is calculated by $\tilde{D} = \bar{x}_2 - \bar{x}_1$ and the median-unbiased estimate of ρ (the ratio seed/no-seed of the two real geometric means) is calculated by $\tilde{\rho} = 10^{\tilde{D}}$. We can define 90 or 95% confidence limits for ρ by the power of 10 function of

$$\bar{x}_2 - \bar{x}_1 \pm t_{n1+n2-2,\alpha}\, \mathrm{sd}\left(\frac{1}{n1} + \frac{1}{n2}\right)^{1/2},$$

where $n1$ and $n2$ are the numbers of the no-seed and seed samples, sd is the pooled estimate of the standard deviation and $t_{n1+n2-2,\alpha}$ the upper 100α percentage point of the student t distribution with $n1 + n2 - 2$ degrees of freedom (Crow et al., 1979). This confidence interval must be used with care because the lognormal hypothesis does not consider that $\overline{\log E_G}$ and sd are location and scale statistics (Bury, 1975). The calculation of $\tilde{\rho}$ is valuable as a practical indication of the ratio (seed/no-seed) of the two geometric means and of the percentage P of increase or reduction of the variables; P is linked to $\tilde{\rho}$ by $P = (\tilde{\rho} - 1)100$.

The comparison of the two distributions of the hailpad kinetic energy (estimated in terms of geometrical mean) shows a nonsignificant trend toward a decrease ($\tilde{\rho} = 0.77$) for the seeded cells. The P-value of the t-test equals 0.59. The 90% confidence limits of ρ are 0.34 and 1.75, meaning that the possible effect can be

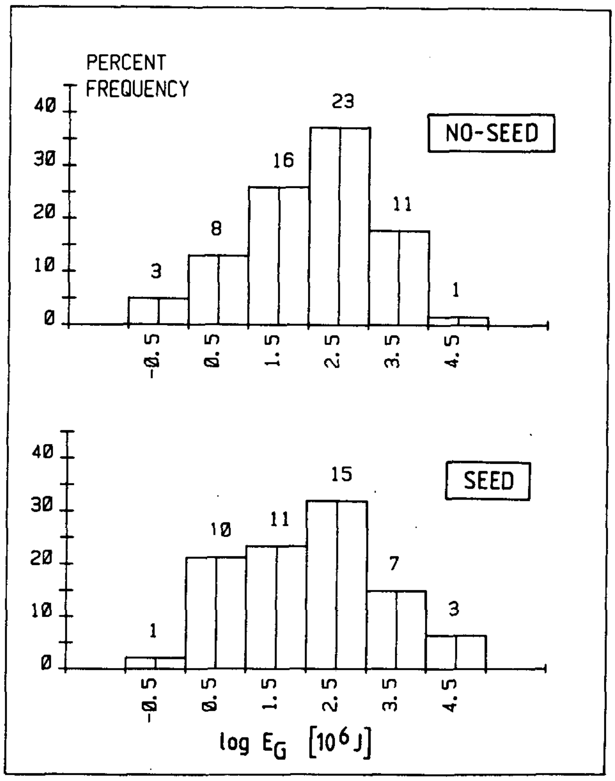

FIG. 10. Distributions of 62 no-seed and 47 seed hail kinetic energy values ($\log E_G$) measured by hailpad network.

TABLE 8. Results of the confirmatory test with the logarithmic value of hail kinetic energy ($\log E_G$) from cells with hail. The P-value is given for the two-tailed test.

Randomization	No. cells	$\overline{\log E_G}$	Lognormal distribution d_{max}	5% level	t-test t	P	$\tilde{\rho}$	90% confidence limits for ρ	
Seed	47	1.99 ± 1.13	0.07	yes	0.54	0.59	0.77	0.34	1.75
No-seed	62	2.10 ± 1.06	0.09	yes					

considered as being between a 66% decrease and a 75% increase. (See Table 8.)

As a first conclusion, this result does not allow rejection of the H_0-hypothesis expressing equality of means of kinetic energy. This result is identical to that of the NHRE (Crow et al., 1979), concluding the lack of evidence of an effect. Thus, it is not possible to show a seeding effect on hail kinetic energy for the Soviet method used in a routine way in Switzerland. Moreover, with $\alpha = 0.05$ (type I error) and $\beta = 0.2$ (type II error) we can say that the Soviet method does not reduce hail kinetic energy by 70% or more. The small number of cells considered does not allow the detection of a lower effect level with the test used. This can be explained in part by a lower climatological frequency of hail and in part by a variance of the test variable higher than anticipated. However, we observe a nonsignificant decreasing trend ($\tilde{\rho} = 0.77$) in Grossversuch IV rather than an increasing trend ($\tilde{\rho} = 2.45$) in NHRE, along with a much narrower 90% interval [0.34, 1.75] compared to [0.64, 9.41].

3) MANN–WHITNEY TEST

The Mann–Whitney test makes no assumption about the probability distribution of kinetic energy values. It does not allow rejection of the H_0-hypothesis with a P-value equal to 0.49. This is in agreement with the previous results; one cannot detect a significant effect on the observed sample.

4) TEST OF SEEDING EFFECT ON THE DAILY CUMULATED HAIL KINETIC ENERGY (31 no-seed, 26 seed hail days)

If we assume that there is no complete independence of the cells during one day, a comparison of the distributions of the test variable can be carried out by cumulating the data daily in the (t_0 + 5 min) to (t_f+ 20 min) time interval of each cell. Thus, the sample is reduced to 31 no-seed and 26 seed hail days.

The tendency for decreased mean logarithmic kinetic energy values remains ($\tilde{\rho} = 0.59$) without becoming significant ($P = 0.32$ for the t-test and 0.35 for the Mann–Whitney test). The 90% confidence interval for ρ is [0.24, 1.43]. (See Table 9.) With daily cumulated values, it is not possible to obtain statistical evidence of an effect of storm seeding because the true effect lies between a 76% decrease and a 43% increase.

c. C(α)-test with zero and nonzero cases

Previously, we examined separately the seeding effect on the frequency of cells without hail (zero cases) and on the values of kinetic energy of cells with hail. It would be interesting, from a consumer point of view, to address the question of the seeding effect on the average of kinetic energy of all experimental cells with and without hail. Neyman and Scott (1967) proposed the $C(\alpha)$-test with three successive criteria to take into account a possible combined seeding effect on the frequency of zero cases and on the amount of hail. The Z_1 and Z_2 criteria test, respectively, the H_1 and H_2 hypotheses that seeding 1) does not affect the frequency of cells and 2) does not affect the amount of hail. The Z_3 criterion is a linear combination of Z_1 and Z_2 used to test the hypothesis that seeding does not affect the test variable averaged over all experimental cells (zero and nonzero cases). Here Z_1 is the χ^2-test statistic on a 2×2 table with Yate's correction. When evaluating Z_2 and Z_3 it is assumed that the test variable is gamma distributed. The test statistic

TABLE 9. Results of tests with logarithmic values of daily cumulated hail kinetic energy ($\log E_G$). The P-values are given for two-tailed tests.

Randomization	No. days	$\overline{\log E_G}$	Lognormal distribution d_{max}	5% level	Test: Mann–Whitney U	P	t t	P	$\tilde{\rho}$	90% confidence limits for ρ	
Seed	26	2.52 ± 1.0	0.08	yes	0.95	0.35	1.01	0.32	0.59	0.24	1.43
No-seed	31	2.75 ± 0.71	0.07	yes							

$$Z_2 = \frac{2n1n2(\bar{E}_{G2} - \bar{E}_{G1})\bar{\gamma}^{1/2}}{(n1 + n2)^{1/2}(n1\bar{E}_{G1} + n2\bar{E}_{G2})} \tag{17}$$

must be compared with a percentage point of the standard normal distribution, where $\bar{E}_{G2}$ and $\bar{E}_{G1}$ are the mean values of kinetic energy for seed and no-seed cases and $\bar{\gamma}$ is the maximum likelihood estimator of γ from the combined sample (no-seed and seed). An iterative procedure given by Mielke (1976) allows the determination of $\bar{\gamma}$. Here

$$\tilde{\rho} = \frac{\bar{E}_{G2}}{\bar{E}_{G1}} \tag{18}$$

is the ratio of the mean of nonzero seed cases to the mean of nonzero no-seed cases.

The parameter

$$Z_3 = \frac{\chi\left(\bar{\gamma}\,\dfrac{n'1 + n'2}{n1 + n2}\right)^{1/2} + Z_2}{\left(1 + \bar{\gamma}\,\dfrac{n'1 + n'2}{n1 + n2}\right)^{1/2}} \tag{19}$$

(where $n'1$ and $n'2$ are the numbers of zero cases, no-seed and seed, respectively) must also be compared to the percentage point of the standard normal distribution and, in this case, the ratio $\tilde{\rho}$ is evaluated on nonzero and zero cases pooled together. The three tests result (with two-tailed P-values of 0.6, 0.203 and 0.15) in rejecting the hypothesis of a seeding effect respectively on frequency of cells, kinetic energy for cells with hail, and kinetic energy for all experimental cells (see Table 10) in spite of $\tilde{\rho}$ values greater than one ($\tilde{\rho}$ = 1.55 and 1.69). Thus, including zero cases and assuming gamma distribution for kinetic energy values, the $C(\alpha)$-test leads to the same conclusion as the confirmatory analysis. One cannot detect a seeding effect on our sample.

d. Tests of seeding effect with secondary response variables

This evaluation of seeding effect on several secondary response variables is intended to complete the confirmatory evaluation as in NHRE (Crow et al., 1979). The following seven variables are compared (see Table 1, list of symbols): three global measurements (M_G, N_G, S_G) and four maximum measurements ($D_{\max}$, $E_{T\max}$, $M_{T\max}$, $N_{T\max}$).

1) The t-test and Mann–Whitney test

Since the empirical distributions of the two variables S_G and $N_{T\max}$ could not be considered lognormal, only the Mann–Whitney test was used for these cases. For S_G (area of hailfall) a nonsignificant trend to increase ($\tilde{\rho}$ = 1.32, P = 0.32) was noted, as was also the case for $D_{\max}$, the maximum diameter of the hailstones ($\tilde{\rho}$ = 1.04, P = 0.64 for the t-test and P = 0.81 for the Mann–Whitney test). The other variables show nonsignificant decreases. (See Table 11.)

For all the secondary response variables, the P-values are greater than 0.10 and the hypothesis of equality of the distributions cannot be rejected for either the global variables or the maximum intensities. It is, however, interesting to note on one hand a trend to an increase for the area S_G and on the other hand a trend to a decrease for the parameters M_G, N_G, $E_{T\max}$, $M_{T\max}$ and $N_{T\max}$ measured independently of S_G. An exploratory analysis with two simultaneous response variables will endeavor to confirm or invalidate this suggested effect. (See section 5.)

For the sample of cumulated values per hail day (see Table 12) we again cannot reject the hypothesis of equality of the distribution means, except for $N_{T\max}$. The nonsignificant trend to increase is sustained for the area ($\tilde{\rho}$ = 1.15) and for the maximum diameter ($\tilde{\rho}$ = 1.01), whereas for all other variables the trend is to decrease. The P-values always remain greater than 0.10, except for $N_{T\max}$ where P = 0.04.

2) C(α)-test

Among the seven secondary response variables, S_G and M_G cannot be fit by a Γ-distribution (Table 13). Therefore, the P-value of 0.029 for S_G must be interpreted with caution. For the other variables such a fit was possible; but the P-values ($\geqslant$0.17) do not reveal a seeding effect. The ratio of mean values remain greatest for S_G ($\tilde{\rho}$ = 1.65 and 1.80) and smallest for $N_{T\max}$ ($\tilde{\rho}$ = 0.73 and 0.79).

e. Conclusions

Several tests were applied to hailpad data, but the t-test with kinetic energy values is the confirmatory test. The main results are

TABLE 10. Results of the $C(\alpha)$-test. Effect of seeding on frequency of cells, kinetic energy (E_G) for cells with hail, and kinetic energy for all experimental cells (zero and nonzero cases).

Randomization	No. cells		Frequency		Nonzero*				Zero and nonzero			
	Zero	Nonzero	Effect	P	$\bar{E}_G$	$\tilde{\rho}$	Z_2	P	$\bar{E}_G$	$\tilde{\rho}$	Z_3	P
Seed	36	47	+9%	0.60	1282	1.55	1.27	0.20	717	1.69	1.43	0.15
No-seed	60	62			826				424			

* 90% confidence limits for ρ, 0.95, 3.30.

TABLE 11. Test of seeding effect with the secondary response variables of 47 seed (S) and 62 no-seed (N) cells. The P-values are given for two-tailed tests.

Secondary response variable	Random-ization	Lognormal distribution d_{max}	Lognormal distribution 5% level	Test: Mann–Whitney U	Test: Mann–Whitney P	Test: t t	Test: t P	$\tilde{\rho}$	90% confidence limits for ρ	
log M_G	S N	0.08 0.08	yes yes	0.76	0.44	0.61	0.54	0.75	0.35	1.66
log N_G	S N	0.09 0.09	yes yes	0.87	0.39	0.71	0.48	0.73	0.35	1.55
log S_G	S N	0.15 0.17	no no	1.00	0.32	—	—	1.32	—	—
log D_{max}	S N	0.12 0.06	yes yes	0.24	0.81	0.47	0.64	1.04	0.92	1.19
log E_{Tmax}	S N	0.10 0.09	yes yes	1.08	0.28	1.05	0.30	0.65	0.32	1.29
log M_{Tmax}	S N	0.11 0.11	yes yes	1.14	0.25	1.21	0.23	0.62	0.33	1.22
log N_{Tmax}	S N	0.11 0.12	yes no	1.53	0.13	—	—	0.59	—	—

1) Cloud seeding by the Soviet method used operationally in central Switzerland did not lead to a significant reduction of the frequency number of hail cells ($P = 0.60$; χ^2 with Yate's correction).

2) The confirmatory evaluation for cells with hail shows no significant trend either to increase or to decrease the values of the test variable (hail kinetic energy). This result is obtained with a t-test: P-value of 0.59. (The use of the Mann–Whitney test without any hypothesis on the distribution function of data leads to the same result.) The t-test is associated with very wide confidence intervals, probably due to the small number of hail-producing cells considered (62 no-seed and 47 seed). At the 10% significance level the effect could vary between a 66% decrease and a 75% increase.

3) The very positive results announced in the Soviet

TABLE 12. Test of seeding effect with the daily cumulated values of the secondary response variables for 26 seed (S) and 31 no-seed (N) days. The P-values are given for two-tailed tests.

Secondary response variable	Random-ization	Lognormal distribution d_{max}	Lognormal distribution 5% level	Test: Mann–Whitney U	Test: Mann–Whitney P	Test: t t	Test: t P	$\tilde{\rho}$	90% confidence limits for ρ	
log M_G	S N	0.07 0.06	yes yes	1.06	0.29	1.09	0.28	0.58	0.25	1.33
log N_g	S N	0.07 0.06	yes yes	1.15	0.25	1.24	0.22	0.56	0.23	1.22
log S_G	S N	0.11 0.10	yes yes	0.22	0.82	0.46	0.65	1.15	0.70	1.89
log D_{max}	S N	0.14 0.08	yes yes	0.10	0.92	0.09	0.93	1.01	0.86	1.22
log E_{Tmax}	S N	0.11 0.08	yes yes	1.12	0.26	1.38	0.17	0.55	0.27	1.12
log M_{Tmax}	S N	0.12 0.08	yes yes	1.20	0.23	1.58	0.11	0.53	0.28	1.04
log N_{Tmax}	S N	0.11 0.09	yes yes	1.75	0.08	2.01	0.04	0.49	0.29	0.89

TABLE 13. Results of the $C(\alpha)$-test with secondary response variables for cells with hail (47 seed and 62 no-seed) and for all experimental cells (83 seed and 122 no-seed).

Secondary response variable	Γ-distribution		Frequency		Nonzero cases		Zero and nonzero cases	
	d_{max}	5% level	Effect	P	$\tilde{p}$	P	$\tilde{p}$	P
M_G	0.11	no	9%	0.60	1.49	0.23	1.63	0.17
N_G	0.09	yes			1.36	0.33	1.48	0.24
S_G	0.17	no			1.65	0.023	1.80	0.029
D_{max}	0.09	yes			1.05	0.50	1.15	0.39
E_{Tmax}	0.07	yes			0.94	0.84	1.03	0.86
M_{Tmax}	0.06	yes			0.86	0.58	0.93	0.92
N_{Tmax}	0.07	yes			0.73	0.23	0.79	0.85

Union do not seem to be confirmed. A 70% decrease of hail kinetic energy ($\alpha = 0.05$, $\beta = 0.2$) cannot be supported here.

4) One confirmatory evaluation based on radar and another on hailpad data agree in detecting no significant effect on the kinetic energy of hail. This agreement is an important point to acknowledge. However, they differ with respect to estimated values of the geometric means [$\exp(\widehat{\Delta\gamma}) = 2.5$ by radar and $\tilde{p} = 0.77$ by hailpads].

5) The $C(\alpha)$-test does not show any effect of seeding on all experimental cells (zero and nonzero combined).

6) We can add evaluations with seven secondary response variables to these results. Statistical tests, applied either to global intensity or to maximum point intensity variables, show no significant effect in increasing or decreasing the value of hailstone number, mass or diameter, and area of hailfall—except one case with cumulative values of N_{Tmax}. Note, however, that the seed/no-seed ratios of geometric means of the hailed area S_G and the diameter D_{max} for cells with hail are greater than 1.0 (1.32 and 1.04, respectively), whereas for the other five variables (M_G, N_G, M_{Tmax}, N_{Tmax}, E_{Tmax}) the ratios are less than 1.0.

5. Further exploratory analysis with hailpad data

This analysis should help to determine a possible effect of storm seeding in particular cases (according to storm type or meteorological situation) or under special conditions (other test variables, other types of test). Examination of a possible physical effect is involved rather than testing the overall effectiveness of the method used in an operational manner. We therefore move from the operational feasibility aspects of the technique to a more physical objective.

Exploratory analyses often take a more detailed nature following the experiment, resulting from the acquired knowledge and the problems encountered; they provide additional information for understanding the experiment. However, we cannot forget that statisticians do not agree on the importance of exploratory analysis in the elicitation of results (Bradley, 1980; Court, 1980; Gabriel, 1980).

Three exploratory investigations are considered in the following. One is concerned with testing the distribution of the various response variables over four new time intervals between (t_0 + 5 min) and (t_f + 20 min). Indeed, the initial choice of 5 min after t_0 and of 20 min after t_f could appear arbitrary. Changing the time interval permits one to test the temporal stability of the results. The second evaluation is concerned with the use of a meteorological predictor in testing the effect on kinetic energy. In an analogy with the use of a predictor in the test based on radar data, we introduce a meteorological predictor of hail kinetic energy able to improve the results. The third investigation is concerned with a test based on mean intensity variables considering two variables simultaneously (E_G and S_G, M_G and S_G, N_G and S_G), both representative of hail phenomena (Mezeix and Chassany, 1983).

a. *Comparison of test variables over various time intervals*

Two complementary objectives of these comparisons are to test the stability of the response of the storm to seeding and to determine the best time interval during which silver iodide acts.

In order to investigate the possibility that the reaction of the silver iodide may be delayed for more than 5 min, separating the time of cloud seeding from the possible effect on the ground, Mann–Whitney tests were carried out with the measurements of the hailstorm response variables over two new time intervals: (t_0 + 10 min) to (t_f + 20 min) using 52 no-seed and 41 seed cells and (t_0 + 15 min) to (t_f + 20 min) using 37 no-seed and 32 seed cells with hail. The results for all variables are listed in Table 14. The hypothesis H_0 (no difference in the seed versus no-seed distributions of the primary and secondary test variables in the two new time intervals) cannot be rejected for any of the response variables, whatever time interval is considered. The level of significance P is always $\geq$0.22. Note that the value of $\tilde{p}$ draws closer to 1.0 and the level of significance increases as the time interval is reduced (except for D_{max}).

TABLE 14. Two-tailed P-values of the Mann–Whitney test and the ratios of geometric means $\tilde{p}$ (seed (S)/no-seed (N) with primary ($\log E_G$) and secondary response variables considered for several different time intervals.

Primary or secondary response variable	Number of cells									
	41 S/62 N		41 S/52 N		32 S/37 N		47 S/60 N		47 S/59 N	
	Time interval									
	(t_0 + 5 min) to (t_f + 20 min)		(t_0 + 10 min) to (t_f + 20 min)		(t_0 + 15 min) to (t_f + 20 min)		(t_0 + 5 min) to (t_f + 15 min)		(t_0 + 5 min) to (t_f + 10 min)	
	$\tilde{p}$	P	$\tilde{p}$	P	$\tilde{p}$	P	$\tilde{p}$	P	$\tilde{p}$	P
$\log E_G$	0.77	0.49	0.84	0.63	0.95	0.79	0.68	0.36	0.66	0.39
$\log M_G$	0.75	0.44	0.82	0.57	0.91	0.64	0.67	0.32	0.65	0.30
$\log N_G$	0.73	0.39	0.77	0.48	0.85	0.56	0.65	0.28	0.64	0.26
$\log S_G$	1.32	0.32	1.23	0.41	1.17	0.67	1.27	0.42	1.28	0.34
$\log D_{\max}$	1.04	0.81	1.05	0.62	1.05	0.73	1.03	0.87	1.02	0.94
$\log E_{T\max}$	0.65	0.28	0.74	0.49	0.82	0.69	0.58	0.19	0.57	0.17
$\log M_{T\max}$	0.62	0.25	0.71	0.41	0.77	0.59	0.56	0.17	0.55	0.15
$\log N_{T\max}$	0.59	0.13	0.65	0.22	0.70	0.30	0.53	0.08	0.52	0.07

Further tests with new time intervals assume that the final duration of reaction of the silver iodide is limited to 15 or 10 min after t_f. For the eight maximum point- and global-intensity variables, the hypothesis of equal distribution means cannot be rejected by the Mann–Whitney test. Furthermore, a trend towards an increase in the hailed area and a decrease in E_G, M_G and N_G (see also Table 14) is still observed.

A modification of the time interval when the silver iodide could act does not result in changes in the conclusion; it shows no significant statistical effect of seeding on the various response variables. We cannot determine a time interval that would improve the fit to the seeding.

b. *Test with hail kinetic energy using a meteorological predictor*

The purpose of a predictor in a hail modification experiment is to reduce variability and decrease the sample size necessary for an equally significant statistical result (Flueck and Mielke, 1977). The predictor is constrained to be independent from any eventual seeding effect.

A hail kinetic energy predictor has been established by Mezeix et al. (1980) on a sample of 58 no-seed days using a stepwise multiple-linear regression with 22 meteorological variables. The best regression function limited to five variables is given by

$$\log E_G = 0.0802T_{\max} - 0.057\ \underset{850}{\bar{H}\mathrm{sol}} + 0.0045E_{C\max} + 0.25\ \mathrm{Sh}850/500 - 0.15\Delta\theta'_w + 6.32 \quad (20)$$

with a correlation coefficient of $r = 0.57$; $T_{\max}$ is the maximum temperature at the radar site (see Fig. 2), $\underset{850}{\bar{H}\mathrm{sol}}$ the mean relative humidity in the layer ground/850 mb, $E_{C\max}$ the maximum calculated kinetic energy of a one-dimensional cloud model, Sh850/500 the mean wind shear 850/500 mb, $\Delta\theta'_w$ the variation in 12 h of the potential pseudoadiabatic temperature of a wet bulb thermometer.

Equation (20) shows the leading effect of ground temperature ($T_{\max}$), atmospheric instability ($E_{C\max}$), wind shear and frontal systems (the negative values of $\Delta\theta'_w < -3$ correspond to cold fronts) in the development of storms. On the other hand, mean relative humidity in the lower layers has a negative sign which appears paradoxical.

The relationship (20) applied to the sample of 31 no-seed and 26 seed hail days can be used in computing the deviation ϵ between the measured and estimated hail kinetic energy in both cases according to Biondini et al. (1977):

$$\epsilon_{\text{no-seed}} = \log E_{G1}\ \text{measured} - \log E_{G1}\ \text{estimated}, \quad (21)$$

$$\epsilon_{\text{seed}} = \log E_{G2}\ \text{measured} - \log E_{G2}\ \text{estimated}. \quad (22)$$

The nonzero value of the mean deviation in the no-seed sample (Table 15) may be explained by the sample being different from the one used to establish the relationship. A t-test comparing the distributions of deviations rejects the equal-means hypothesis at a very high statistically significant level ($P = 0.015$). The values of ϵ_s are smaller, which means that for equal estimated values, the measured values are smaller for the seed cases than for the no-seed cases. Thus, at a very high level of statistical significance, the use of a meteorological predictor of the test variable indicates a decrease in hail kinetic energy for seeded cells. This very interesting result is partly explained by the reduction of the variance with the predictor. However, the credibility granted to this exploratory result remains questionable.

TABLE 15. T-test on ϵ-values with a meteorological predictor: $\log E_G$ (measured) minus $\log E_G$ (estimated) for 26 seed and 31 no-seed days.

	Mean	t	P
ϵ_{seed}	-0.37 ± 2.22	2.47	0.015
$\epsilon_{no\text{-}seed}$	1.05 ± 1.65		

c. Tests with two response variables

Kinetic energy was considered first as representative of the observations on the storm process. Then we considered several secondary response variables. None of these variables alone characterize hailfall in the same way. Multidimensional analyses (Mezeix and Chassany, 1983) have shown that hail patterns may be interpreted first by a size effect (representing 90% of the variance) and then by a second minor, but nevertheless significant, factor (7% of the variance) related to the shape and spreading of the hail patterns. The three global intensity variables, energy, mass and number, are the most closely related to the first factor and thus representative of the size effect. The hailed area is more representative of the second factor. It appears possible to define each hail pattern in the set of hail patterns by means of two entities: 1) the size (well represented by E_G, M_G or N_G) and 2) the hailed area (S_G). However, although S_G is measured in Grossversuch IV, it is not controlled, i.e., we are unable to eliminate any possible effect on the area in order to consider only the possible effects on the kinetic energy, hailstone number or mass. We therefore propose to consider pairs of response variables by using E_G and the area S_G, M_G and S_G, N_G and S_G, respectively. The newly resulting variables $\bar{E}_G$ (E_G/S_G), $\bar{M}_G$ (M_G/S_G) and $\bar{N}_G$ (N_G/S_G) are three mean intensity variables.

1) COMPARISON OF EXPERIMENTAL RELATIONSHIPS BETWEEN NO-SEED AND SEED CASES

The calculation of regression equations between parameters made it possible to show the organization of the hail phenomenon with multidimensional expansion characteristics (Mezeix and Doras, 1981). With the sample of 62 no-seed and 47 seed cells, we established best-fit relationships (in the form $\log Y = b \log X + a$) between S_G and E_G (Fig. 11), S_G and M_G, and S_G and N_G which can be compared:

Seed	Equation	r
no	$\log S_{G1} = 0.40 \log E_{G1} + 0.351$	0.84
yes	$\log S_{G2} = 0.37 \log E_{G2} + 0.58$	0.81
no	$\log S_{G1} = 0.41 \log M_{G1} + 1.09$	0.84
yes	$\log S_{G2} = 0.38 \log M_{G2} + 1.26$	0.80
no	$\log S_{G1} = 0.43 \log N_{G1} - 0.50$	0.83
yes	$\log S_{G2} = 0.40 \log N_{G2} - 0.23$	0.80

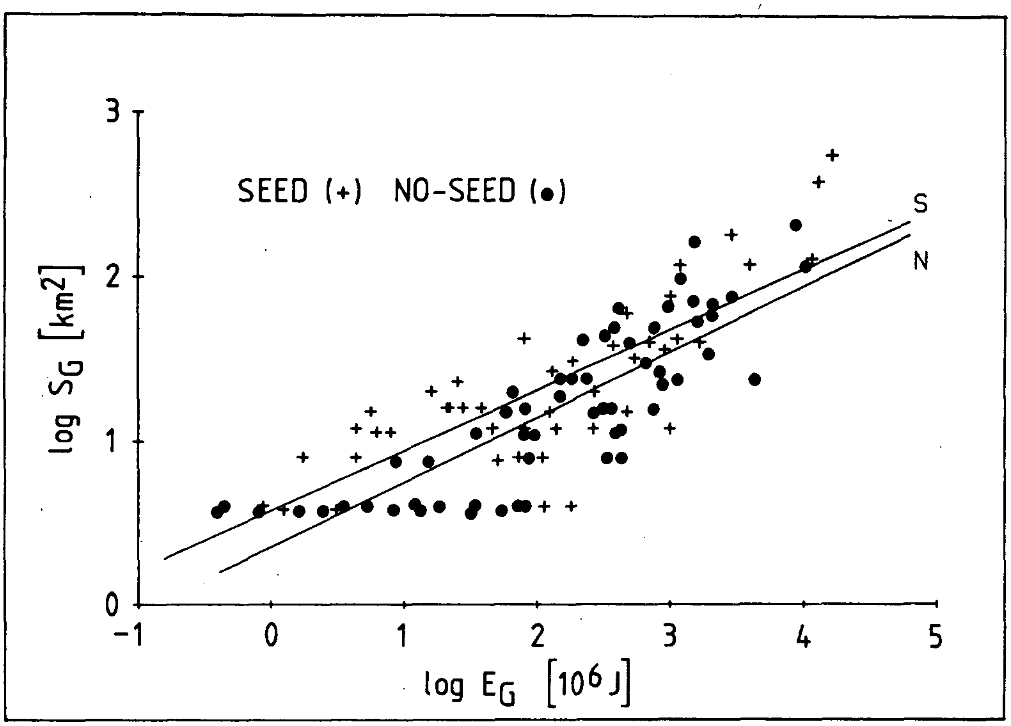

FIG. 11. Regression lines between global kinetic energy ($\log E_G$) and area ($\log S_G$) for 62 no-seed and 47 seed cells in the time interval (t_0 + 5 min) to (t_f + 20 min).

The b_i coefficients are very close due to a certain interdependence of the variables E_G, M_G and N_G. A one-tailed test designed for the comparison of empirical regression lines (Aivazian, 1978) showed a significant difference in the Y-intercept (a) for the three relationships (Table 16).

These results are difficult to interpret since each relationship involves two independent variables in terms of measurement. The seed cases combine both a larger area effect and a smaller hail production effect (E_G, M_G, N_G). If we assume that storm seeding cannot modify the hailed surface area, then the total number of hailstones, the hailstone mass and hail kinetic energy are significantly lower in the seeded hailfalls for an equal surface area. But the hypothesis of an increase of the area by seeding cannot be excluded.

TABLE 16. One-tailed test on seed and no-seed regression coefficients of a linear fit between two response variables (47 seed and 62 no-seed cells with hail).

Relationship	$t(b_2 = b_1)$	P	$t(a_2 = a_1)$	P
$\log S_G/\log E_G$	0.58	0.28	3.21	0.001
$\log S_G/\log M_G$	0.54	0.30	3.20	0.001
$\log S_G/\log N_G$	0.44	0.33	3.10	0.001

2) COMPARISON WITH HAIL VARIABLES $\bar{E}_G$, $\bar{M}_G$ AND $\bar{N}_G$

The mean kinetic energy $\bar{E}_G$ (E_G/S_G), the mean mass $\bar{M}_G$ (M_G/S_G), and the mean global number $\bar{N}_G$ (N_G/S_G) per square meter represent three response variables, each a function of two others. In the interval (t_0 + 5 min) to (t_f + 20 min), the level of significance of the two-tailed t-test (P = 0.04) and a value of $\tilde{\rho}$ = 0.55 with a 90% confidence interval excluding 1.0 [0.34, 0.89] lead to the rejection of the hypothesis H_0 that the distribution means are equal for $\bar{N}_G$. (See Table 17.) The Mann–Whitney test gives a similar result with a P-value of 0.05 for $\bar{N}_G$. This means that the average number of hailstones per square meter for the seed cases is statistically significantly less than for the no-seed cases. This could result from a larger hailed area and/or a smaller global number. It is, however, difficult to distinguish between these two effects.

At this stage of exploratory analysis, the tests combining two hail variables appear to show a difference in the mean global number of hailstones, indicating a probable cumulative effect related to increasing area and decreasing global number. Considering the trend of the seeded cells towards higher values of hailed area and lower values of E_G, the hypothesis of a seeding effect that increases the number of embryos and thereby decreases their size and energy, resulting in a greater dispersion by horizontal winds, cannot be excluded. Such an assumption requires modeling in order to determine its validity and importance. Although it is not presently possible to give a physical interpretation of these results in relation to a possible microphysical modification or to envisage their application to agriculture, hope does reappear that research in hail suppression is not completely closed.

d. Conclusions

Initial exploratory evaluations demonstrate three points.

1) Changes in the assumed duration of the silver iodide reaction do not alter the results of the so-called confirmatory test with kinetic energy or with secondary response variables. This confirms the validity of the time interval chosen and also the stability of the results.

2) The use of a meteorological predictor established with independent data reveals a significant reduction in the kinetic energy of the hail. The decrease of variance improves the power of the test.

3) The mean hailstone number per square meter is statistically significantly lower for the seed cases. This is an important result since this mean intensity variable incorporates variables related to both the size effect (N_G) and a second factor explaining the hailfall area (S_G). In the future the hailed-area variable, which has always been considered constant in the modification hypothesis, should be included as a response variable.

TABLE 17. Test of seeding effect on three variables of mean intensity, each a function of two other test variables, for 47 seed and 62 no-seed cells with hail.

Response variable	Lognormal distribution 5% level	Test: Mann–Whitney U	Mann–Whitney P	t: t	t: P	$\tilde{\rho}$	90% confidence limits for ρ	
$\log\bar{E}_G$	yes	1.50	0.13	1.66	0.10	0.58	0.33	1.00
$\log\bar{M}_G$	yes	1.72	0.09	1.81	0.07	0.57	0.33	0.95
$\log\bar{N}_G$	yes	1.93	0.05	2.04	0.04	0.55	0.34	0.89

Other so-called exploratory evaluations will follow to confirm or invalidate these important physical effects of hailstorm seeding.

6. Representative draw analysis and additional exploratory results

The present section encompasses various exploratory results based on radar data and on the comparison of hailpad- and radar-derived data. The "representative draw analysis" presented in section 6a examines whether or not those variables which cannot be affected by the seeding procedure coincide for the seed and no-seed group within statistical variability. If clear differences of relevant variables had occurred by chance, this would complicate the interpretation of any differences in response variables. Another aspect of verifying assumptions made in earlier sections is the examination of the hail energy distributions (section 6b). The estimated seeding effect as measured by radar (section 3) and hailpads (section 4) differs to a remarkable extent. This fact raises the question of how closely the two ways of measuring the energy are related (section 6c). The later sections (6d–h) describe further estimates and randomization tests of the seeding effect on the energies.

a. Representative draw analysis

If the randomization scheme in Grossversuch IV worked well, it would have produced a representative draw and any "natural bias" between seed and no-seed samples should have been avoided. A "natural bias" means a large difference in a variable which cannot be influenced by seeding but which has itself an effect on the response variable. This could affect the outcome of the experiment in either of two directions: 1) it could produce an apparent treatment effect although there is none or 2) it could compensate and thereby mask real treatment effects. Some important variables are listed in Table 18. The first group contains variables which describe a cell up to (t_0 + 5 min), which is assumed to be the time when the first seeding effect may occur. Only the first cell of a hail day is considered, since the following cells of the same day could be affected by the first cell seeding. The variables R and D are excluded from the following discussion because of possible seeding effects. The variables in the second group describe the daily synoptic situation. With the exception of M^I, F^I and F^IM^I, they are determined from radiosonde data made at noon in Payerne, about 100 km southwest of the radar site; M^I, F^I and F^IM^I were obtained by studying weather maps (frontal or air-mass situation) and PPI films (information about radar echo movements). If seeding strongly affects the dynamics of a storm, M^I and F^IM^I could be influenced by seeding. To investigate this point, cells outside the experimental area have also been studied. No difference between cells inside and outside the experimental area could be established with respect to the movement parameter M^I. Therefore, it can be assumed that these variables are also unaffected by seeding.

The differences between the mean values of the variables for the seed and no-seed groups were investigated by a χ^2-test for the indicator variables and by the Wilcoxon–Mann–Whitney (WMW) rank sum test for the other parameters. In cases where the WMW test yielded a two-tailed P-value ≤ 0.2, a randomization test of location was performed and the result of this test was then taken as the final P-value. This procedure avoided the need for the expensive and time consuming randomization test for all variables. It can be seen from Table 18 that for 5 variables (M^I, H_B, H_0, ENGY, SI) out of 26 the differences are significant at the 5% level. The remaining 21 variables do not show any statistically significant difference between the seed and no-seed ensemble. The significant differences occur in the group of the 13 daily variables and therefore suggest some difference between the seed and no-seed days in terms of environmental parameters. The differences in ENGY and SI suggest a greater instability on the seed days and therefore larger values of R and f on seed days could be possible. The significantly higher 0°C level (H_0) on seed days implies that these days were considerably warmer, which also could lead to reinforced convective activity.

The observed imbalances led to a more detailed investigation of the differences of the daily variables for the seed and no-seed groups. The main question is the extent of the influence of the observed differences on the main test result. For this purpose, a linear regression between the variable D ($=R - f$) and each of the daily variables (except the indicator variables) was computed, using all 122 no-seed cells for the period 1977–81. Two sets of regressions were calculated using first $D = R - f_1$ and second $D = R - f_2$. (See section 3 and Table 1 for the meaning of f_1 and f_2, respectively.) Considering $D = R - f_1$, Table 19 shows that 3 (T_B, WV, BI) out of the 10 regressions should be investigated in more detail because the correlation coefficients turned out to be significantly different from zero. However, the results of Table 18 show no significant difference between the seed and no-seed ensembles for these three daily variables and therefore the possible influence of this bias is irrelevant. The second set of regressions with the variable $D = R - f_2$ shows an even clearer picture: no correlation coefficient points toward any possible influence. Thus it can be concluded that the statistically significant differences of the daily variables between the seed and no-seed ensembles found in Table 18 have a negligible influence on the relevant variable D. This result justifies the use of predictor functions already proposed and discussed in the design and simplifies the interpretation of the main result of Grossversuch IV given in section 3.

TABLE 18. Basic statistics and test results of variables not influenced by seeding (with the exception of R and D) from 33 seed (S) and 43 no-seed (N) cells and days, respectively, (1977–81).

Variable	Median		Mean		Standard deviation		2-tailed P-values*		
	S	N	S	N	S	N	WMW	Rand.	χ^2
				First cell of day					
$\ln(A_{46}+1)$	2.02	1.72	2.03	1.79	1.38	1.05	0.29		
d	0.43	0.37	0.69	0.56	0.87	0.66	0.77		
D**	−3.07	−1.85	−2.81	−1.67	3.01	2.94	0.13	0.098	
E_0	0.26	0.30	1.28	0.99	2.22	1.49	0.51		
f_1	5.84	5.06	6.06	5.05	2.34	2.58	0.052	0.074	
f_2	2.80	3.15	3.31	3.26	2.84	2.38	0.31		
G_0	5.00	4.66	4.30	5.03	5.00	5.61	0.67		
G_2	1.78	2.75	2.20	3.29	5.01	5.91	0.40		
H_V	9.00	9.00	9.36	9.12	1.69	1.94	0.62		
L	32.90	33.55	31.21	32.00	12.71	13.43	0.70		
R**	1.37	2.34	3.25	3.38	3.60	3.24	0.59		
t^I	—	—	0.52	0.42	0.51	0.50			0.55
T_V	−41.00	−41.00	−40.80	−40.70	10.51	12.45	0.99		
Z^I_{51}	—	—	0.76	0.79	0.44	0.41			0.95
Δt_{46}	5.00	7.00	9.33	10.47	12.15	14.25	0.82		
				Daily variables					
BI	97.2	97.3	97.14	97.10	1.75	1.06	0.54		
ENGY	691	465	735	516	468	412	0.028	0.033	
F^I	—	—	0.58	0.35	0.50	0.48			0.082
F^IM^I	—	—	0.55	0.30	0.51	0.46			0.057
H_B	2.41	2.09	2.29	2.02	0.51	0.45	0.007	0.011	
H_0	3.49	3.24	3.42	3.17	0.46	0.48	0.018	0.028	
KI	27.5	29.0	28.38	29.20	3.53	4.35	0.22		
M^I	—	—	0.91	0.65	0.29	0.48			0.019
Sh	1.54	1.67	2.13	2.24	2.24	2.87	0.79		
SI	−2.49	−1.61	−2.47	−1.59	1.47	1.61	0.034	0.014	
T_B	7.60	7.70	7.85	7.64	2.66	3.21	0.83		
TTI	48.80	49.70	48.89	49.14	2.93	2.45	0.50		
WV	9.24	8.94	9.29	8.91	1.51	1.77	0.28		

* WMW = Wilcoxon-Mann-Whitney rank sum test; Rand = Randomization test of location (difference of means) with 5000 rerandomizations; χ^2 = Chi-square test, corrected after Yates.

** These two variables may be affected by seeding and will not be used in the representative draw analysis.

TABLE 19. The correlation coefficients for the correlations between daily variables and the variables $D = R - f_1$ and $D = R - f_2$, respectively. Here 122 no-seed cells (1977–81) have been used.

Daily variable	Correlation coefficient	
	$D = R - f_1$	$D = R - f_2$
BI	0.18*	0.11
ENGY	−0.11	−0.12
H_B	0.10	0.08
H_0	−0.12	−0.02
KI	−0.09	−0.03
Sh	0.03	0.15
SI	0.17	0.15
T_B	−0.20*	−0.12
TTI	−0.01	−0.07
WV	−0.19*	−0.12

* Significantly different from zero at the 5% level.

b. Assessing the distribution of the hail energies

The tests presented in section 4, notably the t- and $C(\alpha)$-tests, are based on the assumption that the kinetic energies follow a lognormal or gamma distribution, respectively. Both of these distributions are widely used to model rainfall. Mielke and Johnson (1973) introduced the three-parameter kappa-distribution for rainfall data. Crow et al. (1979) found that the three types of distributions could be fitted to their 33 nonzero daily hailfall values to give nonsignificant χ^2-tests. Morgan et al. (1980) examined hailfall data of seven networks that have been observed in various countries and different time periods. They only give a variation of empirical cumulative distribution functions for hail mass values of individual pads, which are not comparable to the total energy (or mass) values discussed here. The present data probably form the largest set of hail energy values ever obtained. The 165 nonzero radar energies and the 109 nonzero hailpad energies allow us to determine the distribution fairly well.

The lognormal model can be assessed easily by applying the standard fitting and testing procedures to the logarithmized energies. The density of the two-parameter gamma distribution is

$$[\sigma\Gamma(\alpha)]^{-1}(x/\sigma)^{\alpha-1}\exp(-x/\sigma), \tag{23}$$

where $\alpha > 0$ and $\sigma > 0$ are called the shape and scale parameter, respectively, and Γ denotes the gamma function. Maximum likelihood estimates for α and σ are given by the equations

$$\ln(\alpha) - \frac{\Gamma'(\hat{\alpha})}{\Gamma(\hat{\alpha})} = \ln(\bar{x}) - \overline{\ln(x)}, \tag{24}$$

$$\hat{\sigma} = \bar{x}/\hat{\alpha}. \tag{25}$$

(See, for example, Neyman and Scott, 1967.) The kappa 3 distribution has the density

$$\frac{\alpha\theta}{\beta}\left(\frac{x}{\beta}\right)^{\theta-1}\left[\alpha + \left(\frac{x}{\theta}\right)^{\alpha\theta}\right]^{-1-1/\alpha}, \quad x > 0, \tag{26}$$

where β is a scale parameter, and α and θ determine the shape. If θ is fixed and equals one, the resulting family is called the kappa 2 distribution. Maximum likelihood estimates may be obtained by applying a general minimization routine (such as ZXMIN of the subroutine library IMSL). For more details, consult Mielke and Johnson (1973).

In order to test the goodness of fit, two χ^2-tests were performed for each distribution. The class limits for the first test are the quantiles (or percentage points) corresponding to 2, 5, 10, 50, 90, 95 and 98%. Since the tails are examined quite carefully by this choice, the test is designed to detect long tails (kurtosis) and skewness; the latter would also lead to high χ^2-terms in the two middle classes. The second test uses the percentage values 5, 10, 20, 30, . . . , 90 and 95% and is more sensitive to local deviations in the body of the distribution.

The estimated parameters and the test results are given in Table 20. Figure 12 shows *Q–Q*-plots (Chambers et al., 1983). (Note that both axes have been plotted in log scale.) The test results show an acceptable fit only for the hailpad energy with the kappa 3 distribution. For the radar energies, the lognormal and the kappa 3 distribution fit better than the other two. The gamma distribution clearly fits the worst in both cases.

A glance at the *Q–Q*-plots and a more detailed analysis of the contributions to the χ^2-statistic show that all distributions have longer tails than the data. If the tails are not examined by the test—more precisely, if the extreme classes are determined by the 10th and 90th percentage points—the lognormal distribution provides an acceptable fit (nonsignificant χ^2-value). Also, if seed and no-seed cells are examined separately, the lognormal distribution fits better. This is partly due to the decrease in sample size. The kappa 3 distribution fits the worse in these cases.

In summary, the lognormal distribution seems to give an acceptable fit, except for the fact that the most extreme observations seem to have "moved in." The kappa 3 distribution does not achieve a clearly better fit overall, in spite of the increased flexibility of this family due to the additional parameter. The kappa 2 distribution fits worse than the lognormal. The gamma distribution is clearly inadequate.

We conclude that *t*-tests for logarithmized values are more adequate than $C(\alpha)$-tests for comparing nonzero hail kinetic energies and that robust versions of the *t*-test are not called for since outliers (with respect to the extremely variable distribution) are not observed; they may have been suppressed by the measurement procedure. However, when using the prediction approach, such a conclusion should be based on an examination of the conditional distributions, i.e., the residuals.

c. Correlation between radar- and hailpad-measured hail kinetic energies

This section gives an overview of how well the hailpad and radar measurements of hail kinetic energy are correlated. Waldvogel et al. (1978) found an excellent agreement for hail cells with energy values larger than 1 GJ, whereas Waldvogel and Schmid (1983) obtained an overall correlation coefficient of 0.5 when comparing the log energies and taking into account smaller cells also. The correlation coefficient was 0.9 when the radar measured below the melting level.

The scatterplot in Fig. 13 presents the hail energies of Grossversuch IV cells. Only the nonzero cases (for both radar and hailpad) have been considered. The figure confirms the above mentioned findings. The agreement is good for the large cells ($E_G > 1$ GJ), whereas the differences become large for the smaller cells. The overall correlation coefficient is 0.54, which is in good agreement with the Waldvogel and Schmid (1983) study. When taking the energy values instead of the logarithms, the overall correlation coefficient increases to 0.82. Recent work continues to study the problem of how to correct the radar energies by considering the melting of hailstones and the vertical profiles of radar reflectivity (Schmid and Waldvogel, 1983; Andermatt, 1984). If and how much the agreement is improved by these corrections has not yet been established.

d. The seeding coverage

The Soviet method prescribes that a rocket be launched every five minutes to a specified point in the cell as long as the seeding criterion is fulfilled. This prescription may not always be observed strictly because of one or more of the following reasons: 1) the cell was not seeded because another cell was under treatment at the same time; 2) there were technical

TABLE 20. Parameter estimates and goodness-of-fit tests of several model distributions applied to kinetic energy data (S = seed, N = no-seed). Numbers in parentheses are P-values.

			E_{GR}		E_G	
	E_{GR}	E_G	S	N	S	N
Total number of cells	216	205	94	122	83	122
Number of nonzeros	165	109	72	93	47	62
			Lognormal distribution			
moments of $\ln(E)$						
mean	4.20	4.73	4.62	3.87	4.58	4.84
standard deviation	3.02	2.50	2.93	3.07	2.60	2.44
skewness	0.051 (.787)	−0.300 (.196)	−0.022 (.936)	0.133 (.595)	−0.006 (.986)	−0.557 (.067)
kurtosis	−0.804 (.032)	−0.554 (.227)	−0.547 (.328)	−0.927 (.061)	−0.689 (.312)	−0.280 (.641)
			Goodness-of-fit tests			
$\chi^{2(1)}$	25.5 ($<10^{-4}$)	13.0 (.011)	7.26 (.123)	15.1 (.005)	6.19 (.185)	7.06 (.133)
$\chi^{2(2)}$	19.2 (.014)	8.71 (.368)	4.11 (.847)	19.2 (.014)	2.36 (.968)	8.97 (.345)
			Kolmogorov–Smirnow			
	0.052	0.070	0.056	0.067	0.067	0.105
			Gamma distribution			
estimated parameters						
$\hat{\alpha}$ ± standard error ($\hat{\alpha}$)	0.223 ± .019	0.312 ± .033	0.234 ± .03	0.219 ± .025	0.272 ± .044	0.358 ± .051
$\hat{\sigma}$ ± standard error ($\hat{\sigma}$)	7639 ± 1417	3284 ± 665	9394 ± 2591	6052 ± 1507	4713 ± 1522	2311 ± 593
			Goodness-of-fit tests			
$\chi^{2(1)}$	62.4 ($<10^{-4}$)	18.4 (.001)	30.2 ($<10^{-4}$)	33.0 ($<10^{-4}$)	18.2 (.001)	8.30 (.081)
$\chi^{2(2)}$	62.5 ($<10^{-4}$)	18.3 (.019)	29.0 (.0003)	42.8 ($<10^{-4}$)	18.3 (.019)	13.2 (.106)
			Kolmogorov–Smirnow			
	0.174	0.113	0.209	0.189	0.159	0.101
			Kappa 2 distribution			
estimated parameters						
α	0.457	0.591	0.485	0.449	0.557	0.637
β	34.2	83.9	57.8	23.4	63.8	106
			Goodness-of-fit tests			
$\chi^{2(1)}$	25.3 ($<10^{-4}$)	15.1 (.005)	10.75 (.030)	19.4 (.0007)	4.83 (.306)	10.1 (.038)
$\chi^{2(2)}$	28.6 (.0004)	14.2 (.076)	13.28 (.103)	21.8 (.0052)	2.57 (.958)	14.3 (.075)
			Kolmogorov–Smirnow			
	0.060	0.078	0.07	0.071	0.076	0.107
			Kappa 3 distribution			
estimated parameters						
α	0.548	2.00	0.908	0.151	0.89	3.09
β	38.9	238	94.5	14.4	90.6	406
θ	0.865	0.476	0.632	2.63	0.712	0.427
			Goodness-of-fit tests			
$\chi^{2(1)}$	22.1 (.0001)	5.86 (.119)	11.0 (.012)	21.9 (.0001)	6.19 (.103)	3.09 (.377)
$\chi^{2(2)}$	25.7 (.0006)	7.97 (.335)	6.47 (.486)	24.9 (.0008)	1.94 (.963)	3.97 (.784)
			Kolmogorov–Smirnow			
	0.058	0.056	0.050	0.074	0.076	0.064

problems with the rockets (e.g., misfiring, no burning of the seeding agent); 3) there were logistical problems (e.g., radar difficulties, communication interruptions with the launching crews, mishandling, no launching permission from air traffic control); 4) an addition of minor delays occurred in each step of the operation. Most of these errors can be identified. Careful scrutiny of the logbooks allows us to determine, for each cell, the "seeding coverage," defined as the ratio of rockets launched successfully according to the prescription to the number required by the prescription. The design states that the cell with a seeding coverage of less than one-third would be eliminated from the analysis. As mentioned in section 3b, it became clear that the seed-

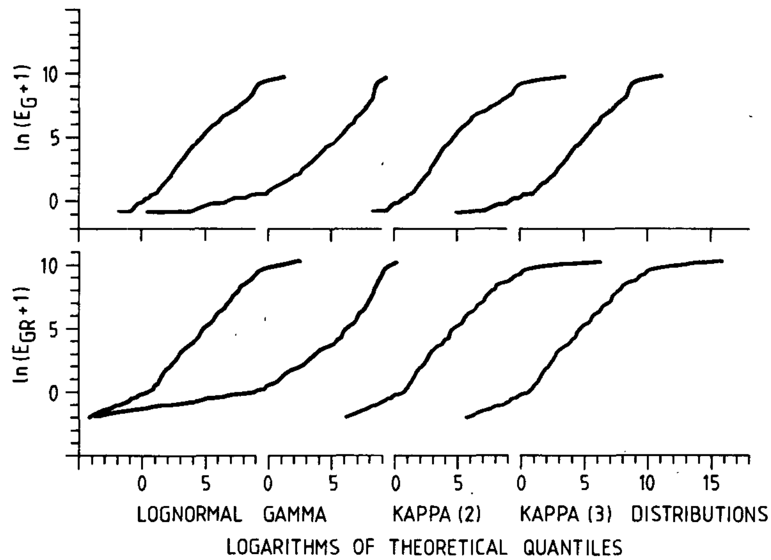

FIG. 12. Q–Q plots of the lognormal, gamma, kappa 2 and kappa 3 distributions.

ing coverage is related to the size of the cell. Because a small seeding coverage happens much easier if the lifetime of a cell is short, such a criterion would eliminate more small than large seeded cells (Fig. 14), thus leading to an artificial increase of the average energy for seeded cells. Therefore, a test with the remaining cells would not answer the question of the effectiveness of the hail prevention method. (For completeness, we mention that with the insufficiently seeded cells eliminated, we obtained $\widehat{\Delta\gamma} = 1.44$ and $P = 0.071$.)

e. Randomization test with hailpad data

In sections 3 and 4, the radar-derived energy values were used for a highly sophisticated randomization test, whereas the hailpad data were analyzed by χ^2- and

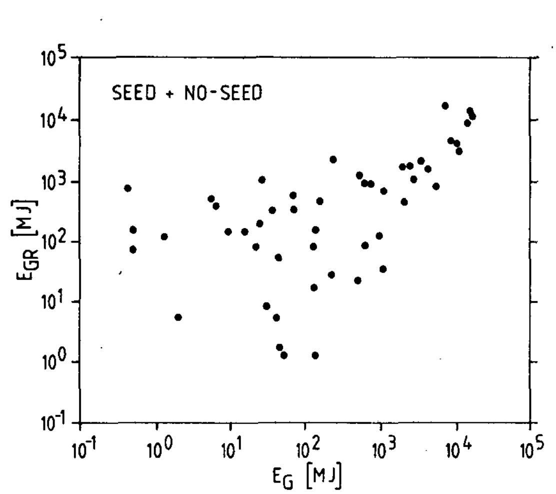

FIG. 13. The hailpad and radar energies for 49 hailcells (nonzero cases for both radar and hailpad).

t-tests. It may be of interest to submit the hailpad data to the alternative procedure described in section 3d. In search of a predictor function, we resort to the same radar-derived and daily synoptical predictors. There are no hailpad data which would be suitable as predictors. While a predictor function for daily energy values based on synoptical parameters is discussed in section 5a, the C_p-search procedure for the cell energies ended up with

$$f_{3T} = 5.01 + 0.786\ \ln(A_{45}{}^{+} + 0.1) - 1.04F^{I}M^{I} + 0.262H_V - 2.68Z_{51}^{I} - 1.09H_0 \quad (27)$$

for cells originating in the test area and

$$f_{3R} = -3.33 - 2.69T^{I} - 0.166T_V + 0.67\ \ln(E_0 + 0.01) \quad (28)$$

for penetrating cells. The reduction in variance was $1 - \mathrm{var}(D)/\mathrm{var}(R) = 23\%$.

The estimated $\Delta\gamma$ was $\widehat{\Delta\gamma} = -0.0227$, corresponding to a decrease of hailpad energy by 2%. The two-sided P-value turned out to be 0.95. The results for a randomization test using the raw data, without prediction, were $\widehat{\Delta\gamma} = -0.186$, $\exp(\widehat{\Delta\gamma}) = 0.83$, $P = 0.66$. These results reaffirm the conclusion that no seeding effect can be demonstrated.

f. Disregarding the discriminant function in the test with radar data

The design for the confirmatory testing procedure (section 3) included the step of eliminating cells that were predicted to produce rain only. As reported in section 3, the discriminant function was fixed on the basis of preexperimental data and behaved poorly,

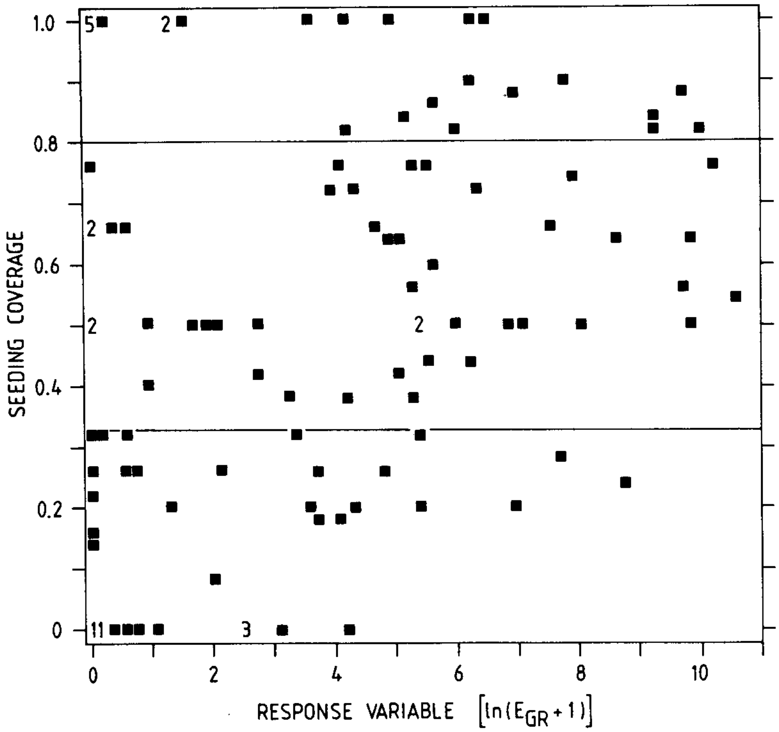

FIG. 14. The seeding coverage as a function of the response variable R_{GR} (113 cells, 1977–82).

eliminating 44% of the actual (nonzero) hail cells (Table 4). We therefore repeated the test of section 3c with all 216 cells, regardless of their discriminant function value. The results are as follows: The estimated effect was $\widehat{\Delta\gamma} = -0.417$, corresponding to a *reduction* of hail energy by seeding by $[1 - \exp(-0.417)]100\% = 34\%$ with a rough (classical) confidence interval ranging from 71% reduction to 74% increase. The two-sided P-value was 0.22. The dependence on T_B was estimated by a coefficient of $\widehat{\Delta\beta} = 0.301$ and its P-value was 0.09.

It is interesting to note that reintroducing the cells which were predicted to produce only rain changes the estimated effect of seeding to a remarkable extent. Although it probably has to be attributed to chance, we intend to further investigate this point in the future.

g. Analysis with nontransformed parameters

Transformed parameters (logarithm of the global hail kinetic energy) have been used in the confirmatory analysis since the data become more symmetrical. To avoid problems regarding the physical meaning and usefulness of this transformation the difference between seed and no-seed cells is investigated in this section by taking the original energy values, measured by radar and hailpads, without any transformation.

The response variable is now the global kinetic energy E per experimental cell. No predictor functions, concomitant variable or other statistical refinements will be used. It is clear that because no predictor function is used (predicting hailfall is still an unsolved task), the variability of the data is very large. Therefore it is important to take a powerful test which best suits data obtained from hailfall measurements. The distribution of hailfall kinetic energy is very skewed: small hailfalls are found very often and big events are rare. Neyman and Scott (1967) believed that the best parametric statistical test in this respect is an optimal $C(\alpha)$-test which they themselves used frequently for analyses with rainfall data (e.g., Neyman et al., 1969; and Neyman and Osborn, 1971). The $C(\alpha)$-test assumes that the values of hail kinetic energy are closely approximated by a gamma distribution. Therefore, the best fitting gamma distribution is first computed for each dataset, and these functions are then used for the statistical tests and comparisons. A further assumption of the procedure is that the alternative to no effect of cloud seeding is a multiplicative effect with a constant multiplication factor—the more severe the storm, the larger the effect. The distribution should be affected in scale but not in shape. In section 4c the $C(\alpha)$-test is already used to test the distribution of the hailpad data, and some mathematical explanations about the test are given there. The test is significant when the two-tailed probability P is ≤ 0.05.

Beside the two variables E_G and E_{GR}, which have been used in the confirmatory test, four new variables will be introduced for comparison. They are E_I and

TABLE 21. Comparison of the seed and no-seed cells using the kinetic hail energy in MJ for different variables E measured by hailpad and radar. The number of cells, percentage of zero cases, the average kinetic energy, the ratio seed/no-seed of the kinetic energy, the P-value of the $C(\alpha)$-test and the confidence boundaries are given; S = seed, N = no-seed.

Period	Response variables		Number of cells		Percentage of zero cases (all cells)		Average kinetic energy per cell (MJ)		Ratio	Two-tailed P-value	90% confidence boundaries (%)*	
			S	N	S	N	$\bar{S}$	$\bar{N}$	$\bar{S}/\bar{N}$	$C(\alpha)$-test	Lower	Upper
1977–81	Pad	E_I	61	70	47.5	51.4	480.7	382.1	1.26	0.58	−32	+189
	Pad	E_F	44	73	54.5	47.9	703.0	335.7	2.09	0.22	+23	+946
	Pad	E_G	91	122	48.8	49.2	662.1	420.1	1.58	0.24	−5	+230
	Radar	E_{56}	94	122	23.4	23.7	3417.4	2023.8	1.69	0.09	+10	+204
	Radar	E_{61}	94	122	57.4	61.5	1329.2	802.4	1.66	0.24	−13	+255
	Radar	E_{GR}	94	122	23.4	23.7	1682.6	1008.6	1.67	0.14	+4	+226
1977–82	Pad	E_F	57	80	54.4	51.3	1350.7	308.6	4.38	0.016	+148	+1586
	Radar	E_{56}	113	140	23.0	27.1	3735.4	1772.6	2.11	0.013	+33	+248
	Radar	E_{61}	113	140	58.4	64.3	1555.6	670.0	2.22	0.058	+12	+327
	Radar	E_{GR}	113	140	23.0	27.1	1908.8	881.1	2.17	0.019	+31	+286

* The effect is calculated for nonzero cases only.

E_F, the global kinetic energy values derived from the Italian or the French hailpad network, and E_{56} and E_{61}, the radar-derived kinetic energies of a hail cell using the cutting method (Waldvogel et al., 1978) instead of the gradual method (E_{GR}). All six variables are tested for the period 1977–81 but only four of them (E_F, E_{56}, E_{61}, E_{GR}) could be analyzed for the 6-year period 1977–82 because the Italian network[3] was no longer in operation in 1982. In the present evaluation, the number of seed cells for E_G is 91 instead of the 83 used in section 4. The eight seed cells without seeding (see Table 6) are taken into account so the results can be better compared with the radar-derived variables for which we have used all experimental cells.

Table 21 shows the results of the two tests applied on the different response variables E. For each variable and period, the number, the percentage of zero cases and the average kinetic energy of the seed and no-seed cells, the ratio (seed/no-seed), the P-value of the $C(\alpha)$-test and the 90% boundaries are given.

For the period 1977–81, none of the variables E shows a significant effect, but all of them give a ratio higher than 1.0, meaning that on seed days, on the average, more hail kinetic energy was measured by both radar and hailpads. E_G and E_{GR}, as used in the confirmatory test, show good agreement in the ratio ($\sim$1.6), in the P-values and in the confidence boundaries, although E_G involved many more zero cases. The obvious disagreement between E_{GR} and E_G in the average kinetic energy is due to the fact that E_{GR} is measured until (t_f + 20 min); at that time, the cell can already be outside of the hailpad networks which have measured E_G. This point will be examined further. Comparing only the two variables E_I and E_F, derived from the southwestern and the northeastern network, respectively, one can see that the ratio for the southwestern (Italian) network is lower (1.26) than the French counterpart (2.09). This point should also be investigated further. The number of cells with zero kinetic energy is rather large in both subnetworks. The three radar variables E_{56}, E_{61} and E_{GR} show the same ratio and comparable P-values and confidence intervals.

For the period 1977–82, all four variables show an increased seed/no-seed ratio and P-values that indicate a significant—or an almost significant—effect. To illustrate what changed the ratio between the seed and no-seed ensembles so drastically, two back-to-back stem and leaf diagrams for E_F and E_{GR} have been drawn in Fig. 15. They represent the distributions of the kinetic energy for the period 1977–81; the cases for 1982 are also given separately. The kinetic energy is given for each case only for storms $\geq$ 1 GJ, whereas for storms < 1 GJ the numbers of cases for $E = 0$ and $0 < E < 1.0$ GJ are indicated. Because the contribution of the cells below 1 GJ to the total energy is quite small, it is not necessary to know the exact values for this presentation. Figure 15 clearly shows that two additional strong seeded cells (15 July 1982/cell 1452 and 16 July 1982/cell 1814) in the prolonged experiment influenced the result of the confirmatory period strongly. No no-seed cell above 1 GJ was measured in 1982, hence the seed/no-seed ratio increased considerably and still in the "wrong" direction.

In summary, for the confirmatory 5-year period 1977–81, no significant difference, especially a reduction in hail kinetic energy on seed days, has been established. The observed ratios are higher than 1.0,

[3] In 1982, the Italian group was operating the French hailpad network.

E_F (GJ)

no-seed 1982	no-seed 1977–81	stem	seed 1977–81	seed 1982
* 6	35	0	24	7
** 1	33	0	14	3
	54	1	12	6
	90	2	5	
		3		
		4	0	
		5		
		6		
		7	5	
		8		
	4	9		
		10		
		11		
		12		
		13	2	
		14		
		15		
		16		
		17		
		18		0
		19		(82-7-16)
		20		
		21		
		22		
		23		
		24		
		25		
		26		2
		27		(82-7-15)

E_{GR} (GJ)

no-seed 1982	no-seed 1977–81	stem	seed 1977–81	seed 1982
* 9	29	0	22	4
** 9	75	0	57	11
	94421	1	13	1
	2	2	248	0
	33	3	1	
	5	4		
	300	5	9	
	52	6	7	
		7		
		8		
	0	9		
		10	38	
		11		
		12		
		13		
	8	14		
		15		
		16	2	3
	8	17	7	(82-7-16)
		18		
		19	8	
		20		
		21		
		22	1	
		23		
	7	24		
		25		
		26		
		27	8	
		28		
		37		6
		38		(82-7-15)

* Number of cells E = 0
** Number of cells 0 < E < 1.0

FIG. 15. Back-to-back stem and leaf diagram of the response variable E_F and E_{GR} for the period 1977–81 and separately, for comparison, on the left and right side of the main diagram (1977–81), the cases for 1982. The kinetic energy is given only for storms ≥ 1 GJ, whereas for storms < 1 GJ the number of cases with $E = 0$ and $0 < E < 1.0$ GJ is indicated. The stem values are in GJ and the leaves are multiples of 0.1 GJ. [E.g., The heaviest hail cell, measured by radar (E_{GR}), received 37.6 GJ in hail kinetic energy.]

pointing in the direction of a "wrong" effect (increase in hail). For the period 1977–82, a significant increase for E_F, E_{56} and E_{GR} has been found. Two heavier cases in 1982 greatly influenced the significance of the result. The conclusion is the same as in the confirmatory analysis: operational seeding according to the Soviet method described in the design does not reduce the hail kinetic energy; on the contrary. the tendency is toward an increase on seed days and this is true for radar-derived as well as hailpad-derived energy values.

h. Another estimate of the seeding effect

According to section 6b, a useful description of the energy values is in terms of a mixture of a fraction p of observations following a lognormal distribution and a fraction $(1 - p)$ of zero cases. The three parameters of this model, p, μ and σ^2, are best estimated by the empirical fraction $\hat{p}$ of nonzero values and the mean $\hat{\mu}$ and empirical variance s^2 of their logarithms. The expectation of this distribution (in raw scale) is $p \times \exp(\mu + \sigma^2/2)$ and can be estimated in the obvious way. This ratio of estimated expectations for seed and no-seed cells is

$$\hat{\rho} = \frac{\hat{p}_S}{\hat{p}_N} e^{(\hat{\mu}_S - \hat{\mu}_N)} e^{(\hat{\sigma}_S^2 - \hat{\sigma}_N^2)/2}$$

$$= \begin{cases} 1.01 \times 2.13 \times 0.65 = 1.40 & \text{for radar energies} \\ 1.01 \times 0.77 \times 1.47 = 1.14 & \text{for hailpad energies.} \end{cases} \quad (29)$$

Note that the second factor for hailpad energies is equal to the effect as estimated in section 4. The third factor reflects the fact that the estimated variance of the logarithmized energies is different for seed and no-seed cells. Since the Levene test shows that the ratio of the variances is not significant and is of opposite direction for radar and hailpad energies, this difference should be attributed to chance. Incidentally, it diminishes the discrepancy between the seeding effects estimated by hailpad and radar energies.

TABLE 22. Summary of statistical tests on seeding effects in Grossversuch IV.

Analysis type	Expt. subunit	Data	Response variable	Test	Predictor	$\tilde{\rho}$	P-value	Reference*
confirm. according to design	cell excl. $d < .4$	radar	$\ln(E_{GR} + 1)$	random	from prelim. data	2.53	0.16	Table 5
alternative	cell	radar	$\ln(E_{GR} + 1)$	random	from GVIV data	1.46	0.22	Table 5
confirm.	cell excl. $E_G = 0$	hailpad	$\log(E_G)$	t WMW	none	0.77	0.59 0.49	Table 8 section 4
explo.†	day	hailpad	$\log(E_G)$	t WMW	none	0.59	0.32 0.35	Table 9 section 4
explo.	cell excl. $E_G = 0$	hailpad	E_G	$C(\alpha)$	none	1.55	0.20	Table 10
explo.	cell	hailpad	E_G	$C(\alpha)$	none	1.69	0.15	Table 10
explo.	cell, day	hailpad	secondary variables	t, WMW $C(\alpha)$	none	0.49 1.80		Tables 11–14
explo.	day	hailpad	$\log(E_G)$	t	meteor. variables	0.24	0.015	Table 15
explo.	cell	hailpad	$\log(\overline{E_G})$ $\log(\overline{M_G})$ $\log(\overline{N_G})$	t	none	0.58 0.57 0.55	0.10 0.07 0.04	Table 17
explo.	cell	radar	E_{GR}	$C(\alpha)$	none	1.67	0.14	Table 21
explo.	cell	hailpad French Italian	E_G	$C(\alpha)$	none	 2.09 1.26	 0.22 0.58	Table 21
explo.	cell 1977–82	radar	E_{GR}	$C(\alpha)$	none	2.17	0.019	Table 21
explo.	cell 1977–82	hailpad French	E_G	$C(\alpha)$	none	 4.38	 0.016	Table 21
explo.	cell	radar	$\ln(E_{GR} + 1)$	random	none	2.15	0.12	section 6
explo.	cell	radar	$\ln(E_{GR} + 1)$	random	from prelim. data	0.66	0.22	section 6
explo.	cell	hailpad	$\ln(E_G + 1)$	random	none	0.83	0.66	section 6
explo.	cell	hailpad	$\ln(E_G + 1)$	random	from GVIV data	0.98	0.95	section 6
target-control area design	day	radar	E_{GR} double ratio	random	control area values	1.50	0.67	Klein (1982)
range effects	cell in range 10–25 km 25–40 km 40–55 km	radar	$\ln(E_{GR} + 1)$	WMW	none	 <1 >1 <1	 0.69 0.002 0.81	Andermatt (1984)
explo. rain	day	rain gages	rain amount	$C(\alpha)$	none	0.98	0.92	Schiesser (1985)
gradient study	single contour	radar	horiz. reflect. gradient	t	none	0.98	0.42	Schmid et al. (1984)

* References to tables and sections refer to this report.

† Explo. denotes exploratory.

7. Discussion and conclusions

The randomized hail suppression experiment Grossversuch IV was designed to test the Soviet cloud-seeding method, which is based on the concept of beneficial competition of hailstone embryos. The conduct of the 5-year (1977–81) experiment was an exact copy of the Soviet hail-suppression operation, using Soviet rockets and launchers and the same seeding criterion. Hail was measured by a dense hailpad network and by a carefully calibrated 10-cm radar. A day-by-day randomization scheme was chosen, and a cell was defined as the experimental subunit. Hail kinetic energy was selected as the primary response variable. The design of the confirmatory evaluation was published at the beginning of the experiment (Federer et al., 1978/79).

A list of the main results of the experiment is presented in this paper and summarized in Table 22. The confirmatory test based on radar measurements (see section 3) and the χ^2- and t-test based on hailpad data that are also considered to be confirmatory (see section 4) all furnish the same result: no statistically significant seeding effect on hail kinetic energy. The same result is found by most of the exploratory tests. Some of them, however, give P-values below the 5% level:

(i) the test on hailpad data using a meteorological predictor (favorable seeding effect);

(ii) the $C(\alpha)$-tests including data of the additional year, 1982 (unfavorable seeding effect);

(iii) the test on $\log(\overline{N_G})$ with hailpad data (favorable seeding effect),

(iv) the test on $\ln(E_{GR} + 1)$ using cells within a distance of 25–40 km from the radar site (unfavorable seeding effect).

It is not possible at the present time to assess the value of these significant results. They may easily be attributed to the multiplicity effect (which means that some out of a number of tests turn out significant by pure chance), but seeding influences are also a possible explanation. Further analyses will be necessary to clarify these results.

Generally, the data show the following trend: taking the logarithms of hail kinetic energy, one finds a tendency for smaller hailpad-measured seeded values (compared to the unseeded values) whereas the contrary is found from the radar data. Therefore, the most favorable possible seeding effect is different for the two datasets. A reduction of more than 30% in hail kinetic energy is rejected at the test level of 5% when using the confirmatory (or the alternative) test with radar data. (See Table 5.) The test with the hailpad data gives a more favorable limit; only a reduction of more than 66% in hail kinetic energy is rejected at a level of 10%. (See Table 8.) The corresponding limits in the opposite direction are an increase of 159% (alternative test with radar data) and 75% (hailpad data), respectively.

The discrepancy between the radar and hailpad data disappears when using the energy values instead of their logarithms. The most favorable possible seeding effect is of the order of 0% for both data sets [$C(\alpha)$-test applied to E_G and E_{GR}; see Table 22]. Thus, any reduction in kinetic energy is rejected at a nominal level of 10% using this kind of evaluation.

In summary, the Soviet hail-suppression method was not as effective in central Switzerland as claimed by the Soviet scientists. On the contrary, a majority of the evaluations suggest some trend to larger seeded-hail energy and larger seeded-hail area values, a result which is strikingly similar to the outcome of the NHRE experiment (Knight et al., 1979). Note that the confidence intervals of the statistical tests used in Grossversuch IV are generally narrower than in NHRE, which is due to the larger data sample. It is evident, however, that the statistical outcome of a randomized, multi-year weather-modification experiment is not convincing without physical support. Therefore, a major effort was undertaken to examine the existence of the so-called "big drop zone" (BDZ), which is a necessary condition for the effectiveness of the beneficial competition concept. In 1982 and 1983, the T-28 armoured airplane was flown through medium and small hail cells in search of large supercooled raindrops. Only an extremely few were found (Smith et al., 1984); thus the basic assumption of the Soviet hail-suppression method was not fulfilled. The question remains open for very large hail cells. The hailstones coming from such cells often have frozen drop embryos (Federer and Waldvogel, 1978) whose origin is still unclear at the present stage of our knowledge.

What should be done in the future? First, the authors hope that the results presented in this paper encourage further investigations on Grossversuch IV. Second, future cloud-seeding experiments should investigate seeding effects at the time and location of the distributed seeding material by means of in-situ measurements and remote sensing technology. Such field programs were recently successful in detecting significantly larger ice particle amounts in seeded clouds (Sax et al., 1979; Isaac et al., 1982). Extension of such experiments to hail clouds should help (a) to close the missing links in our knowledge between cloud formation and hailfall at the ground, and (b) to work out new and more successful hail suppression concepts.

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APPENDIX

TABLE A1. Cell Information—Selected Data

Symbol	Definition	Symbol	Definition
Date	Day, month, year	t_f	Time criterion last met within the experimental area
N/S	Randomization: N = no-seed, S = seed	t_{fs}	Time of first seeding
F/T	Storm type: F = frontal, T = thermal	t_{ls}	Time of last seeding
S/M	S = stationary cell, M = moving cell	N_R	Number of rockets fired per cell (4 PGIM = 1 Oblako = 1 rocket)
T_B	Temperature cloud base (CCL) (°C)		
ID	Identification number of the cell	sc	Seeding coverage
R/T	Criterion first met; T = within, R = outside the experimental area	E_G*	Global hailpad kinetic energy (MJ)
		R	Response variable [$R = \ln(E_{GR} + 1)$]
H_v	Height of cloud top at t_0 (km)	d	Discriminant function
t_0	Time criterion first met within the experimental area	f	Predictor function

Date	N/S	F/T	S/M	T_B	ID	R/T	H_V	t_0	t_f	t_{fs}	t_{ls}	N_R	sc	E_G	R	d	f
								SEED CELLS									
25 May 1977	S	F	M	6.6	1850	R	11.8	1852	2100	1901	2039	10	0.24	16671.70	8.82	0.81	8.22
30 May 1977	S	F	M	2.2	1422	T	7.4	1420	1435	1425	1437	3	0.66	0.00	4.63	0.28	5.35
					1437	T	7.4	1437	1452	1443	1450	2	0.66	73.68	0.40	0.50	6.43
					1503	T	7.1	1501	1510	1511	1512	2	0.50	0.00	2.05	0.28	5.98
					1611	T	6.0	1537	1625	1546	1610	5	0.15	0.00	0.00	−0.17	3.44
					1632	T	6.7	1639	1645	1648	1648	1	0.00	0.00	2.52	0.06	6.23
					1652	T	8.8	1621	1731	1630	1723	3	0.21	1005.27	0.00	−0.41	3.35
10 June 1977	S	F	M	7.5	1315	T	9.8	1258	1403	1308	1405	6	0.19	25.49	3.63	−0.17	4.21
18 June 1977	S	T	M	3.8	1305	T	8.0	1305	1309	0	0	0	0.00	0.00	0.00	0.60	5.20
					1311	T	10.3	1322	1353	1329	1348	3	0.42	484.36	5.03	1.02	5.81
					1327	T	10.0	1331	1335	1334	1339	2	1.00	0.00	1.58	0.57	6.45
					1342	T	8.2	1333	1450	1338	1448	13	0.63	13233.06	9.78	−0.17	1.55
4 July 1977	S	T	M	12.2	1921	T	10.0	1922	1926	0	0	0	0.00	0.00	0.00	0.37	2.56
5 July 1977	S	F	M	10.8	1731	T	9.6	1726	1739	1724	1734	3	0.33	46.19	0.00	−0.17	4.40
8 July 1977	S	F	S	8.9	1354	T	9.5	1323	1356	1348	1348	1	0.14	4.40	0.00	−0.17	1.73
					1353	T	9.0	1353	1420	1404	1419	3	0.43	4.40	5.57	0.75	5.01
					1507	T	10.5	1507	1530	1507	1510	2	0.20	269.52	7.00	1.20	7.27
					1508	T	9.7	1458	1523	1501	1501	1	0.20	0.00	1.27	−0.17	1.86
					1523	T	11.0	1527	1540	1534	1534	1	0.17	181.87	4.03	0.30	6.19
					1538	T	10.5	1544	1549	0	0	0	0.00	0.00	2.50	0.62	5.36
					1611	T	9.0	1617	1657	1621	1657	5	0.63	0.00	5.09	0.13	5.38
					1639	T	9.0	1639	1654	1645	1645	1	0.17	0.00	3.77	0.52	5.54
					1823	T	9.0	1828	1849	1844	1844	1	0.25	0.00	4.86	0.97	7.23
7 Aug 1977	S	F	M	5.1	1320	T	8.0	1319	1319	0	0	0	0.00	0.00	0.00	0.10	5.77
					1323	R	9.5	1348	1428	1355	1427	5	0.50	38.49	8.02	0.62	2.12
17 Aug 1977	S	T	M	8.8	1650	R	13.8	1708	1725	1714	1722	3	0.75	1029.68	10.45	2.77	8.67
18 May 1978	S	F	M	9.8	1350	T	9.0	1351	1358	1401	1401	1	0.00	0.00	0.00	−0.11	3.95
					1406	T	8.3	1410	1450	1419	1447	3	0.66	0.00	0.00	−0.10	4.42
22 May 1978	S	F	M	9.3	1621	T	8.6	1632	1640	1639	1640	2	0.50	0.00	0.00	0.13	5.29
					1639	R	9.0	1640	1648	1647	1647	1	0.00	0.00	0.00	0.10	0.39
8 June 1978	S	F	M	11.8	1236	R	8.3	1254	1309	1257	1309	4	1.00	131.82	6.24	0.86	7.78

30 June 1978	*S*	*T*	*M*	6.1	1459	*T*	7.3	1503	1543	1509	1543	8	0.71	1.25	3.97	0.53	5.84
					1546	*T*	7.7	1551	1621	1602	1624	3	0.38	1.25	5.32	0.45	5.53
					1654	*T*	7.0	1658	1701	1705	1705	1	0.00	0.00	0.60	0.58	4.68
					1655	*T*	7.8	1705	1827	1711	1826	5	0.38	189.27	3.24	0.49	3.95
11 July 1978	*S*	*F*	*M*	7.4	1303	*R*	8.7	1310	1328	1332	1332	1	0.00	0.00	4.17	0.39	7.24
					1304	*T*	8.6	1312	1332	1317	1334	3	0.66	0.00	0.63	0.16	6.30
					1413	*R*	10.0	1430	1531	1451	1517	7	0.28	80.86	7.70	1.54	8.46
14 July 1978	*S*	*T*	*M*	10.0	1542	*R*	12.4	1635	1710	1644	1707	8	0.50	11721.41	9.89	1.77	5.82
					1559	*R*	11.5	1710	1728	1719	1734	6	0.50	124.81	6.85	2.27	7.33
3 Aug 1978	*S*	*T*	*M*	11.4	1215	*T*	5.8	1215	1237	1225	1229	2	0.40	0.00	1.08	0.28	3.33
6 Aug 1978	*S*	*F*	*M*	9.4	1759	*R*	11.3	1839	1918	1840	1915	17	0.81	1212.26	9.24	2.27	8.32
30 May 1979	*S*	*T*	*M*	7.0	1558	*T*	10.8	1627	1717	1625	1719	14	0.82	2939.75	10.00	3.11	8.04
					1618	*T*	9.2	1629	1643	1634	1647	4	1.00	552.74	4.23	0.37	4.42
10 June 1979	*S*	*T*	*M*	7.2	1302	*T*	8.9	1307	1355	1305	1354	14	0.90	1682.07	7.77	0.43	6.73
					1337	*T*	11.3	1343	1426	1344	1419	12	0.83	4018.94	9.29	0.81	6.67
					1709	*T*	8.9	1713	1718	1718	1718	1	1.00	0.00	0.00	0.02	4.25
6 Aug 1979	*S*	*T*	*M*	7.6	1526	*T*	9.0	1524	1542	1530	1550	4	0.20	50.85	4.32	0.01	3.90
					1901	*T*	9.7	1908	2019	1911	2020	23	0.73	381.01	7.94	0.11	6.84
					1920	*T*	8.0	1917	1952	1920	1947	6	0.71	6.27	4.26	−0.17	4.01
					2006	*T*	7.6	2005	2025	2009	2015	3	0.63	7.98	4.90	0.19	4.83
14 Sep 1979	*S*	*F*	*M*	10.8	1355	*T*	8.5	1403	1423	1407	1428	8	0.75	−0.08	5.33	0.22	8.05
					1437	*T*	9.3	1442	1452	1445	1448	2	0.75	−0.08	5.47	0.35	8.55
					1731	*R*	10.1	1823	1900	1827	1859	7	0.50	−0.08	5.44	1.68	5.57
26 May 1980	*S*	*T*	*S*	3.4	1542	*T*	8.1	1559	1608	1602	1607	2	0.75	1.76	0.00	0.48	3.30
26 July 1980	*S*	*F*	*M*	5.7	1917	*T*	10.8	1927	1956	1932	1955	9	0.83	0.88	5.11	0.60	8.68
					1933	*R*	13.3	2020	2100	2028	2046	3	0.33	16.27	5.45	3.76	9.40
					2047	*T*	10.0	2050	2100	2105	2105	1	0.00	0.00	2.48	0.44	8.57
15 Aug 1980	*S*	*F*	*M*	9.5	1733	*R*	9.2	1746	1911	1751	1902	20	0.71	21.99	6.30	2.87	11.12
					1901	*T*	8.8	1900	1919	1916	1916	1	0.25	0.00	3.77	−0.06	5.27
19 Aug 1980	*S*	*T*	*M*	7.8	1753	*R*	8.3	1804	1817	1810	1814	2	0.66	0.00	0.00	0.18	1.81
					1817	*T*	8.3	1817	1822	1820	1822	2	1.00	3.09	0.00	0.36	3.29
					1822	*T*	8.3	1829	1858	1825	1851	8	0.50	5.64	1.92	0.27	4.37
					1930	*T*	8.3	1937	2000	1943	1943	1	0.20	27.71	5.42	0.52	5.92
					2037	*T*	8.3	2039	2047	0	0	0	0.00	0.00	1.04	0.25	4.61
16 May 1981	*S*	*F*	*M*	4.5	1413	*T*	6.9	1422	1422	0	0	0	0.00	0.00	0.00	0.27	6.13
31 May 1981	*S*	*T*	*M*	4.8	2107	*T*	9.2	2113	2120	2120	2135	3	0.50	0.00	0.00	0.41	3.84
					2129	*T*	10.3	2131	2200	2136	2205	7	0.42	141.28	2.81	0.49	4.53
3 June 1981	*S*	*F*	*M*	4.7	1904	*T*	11.0	1909	1913	1915	1918	2	0.00	21.11	0.78	1.05	9.21
					1950	*T*	11.2	1955	1958	1956	1956	1	1.00	0.00	6.44	0.74	8.64
					2003	*T*	11.1	2008	2012	2011	2011	1	1.00	0.00	0.00	0.27	6.89
					2020	*T*	9.2	2023	2104	2026	2104	12	0.89	711.56	6.23	0.82	8.85
16 June 1981	*S*	*F*	*M*	10.1	1409	*T*	8.8	1414	1424	1427	1427	1	0.00	113.48	3.15	0.31	7.60
9 July 1981	*S*	*T*	*S*	6.8	1620	*T*	11.1	1624	1630	1651	1651	1	0.00	0.00	0.31	0.45	4.70
					1629	*T*	9.6	1639	1641	0	0	0	0.00	0.00	0.00	0.25	2.83
					1643	*T*	11.4	1651	1730	1651	1731	7	0.81	276.00	6.05	0.44	5.12
					1713	*T*	10.9	1723	1742	1716	1745	7	1.00	1.76	3.61	0.44	4.46
					1723	*T*	11.0	1729	1807	1749	1808	6	0.44	482.19	6.27	0.43	4.83
					1936	*R*	12.8	2016	2036	2027	2036	3	0.50	0.00	5.39	1.47	6.01
6 Aug 1981	*S*	*F*	*M*	7.3	1946	*T*	11.2	1950	2001	1951	2005	6	1.00	0.00	1.37	0.69	9.39
					1953	*T*	11.0	1956	2002	1959	1959	2	0.50	0.00	2.74	0.93	9.70
					2006	*T*	11.2	2008	2046	2012	2044	17	0.88	923.17	9.69	0.54	11.96
					1936	*R*	10.2	2016	2055	2020	2052	5	0.25	0.00	2.20	1.26	8.73

TABLE A1. (*Continued*)

Date	N/S	F/T	S/M	T_B	ID	R/T	H_V	t_0	t_f	t_{fs}	t_{ls}	N_R	sc	E_G	R	d	f
					2028	T	10.0	2024	2027	2027	2031	2	1.00	0.00	0.00	−0.17	5.03
					2038	T	8.4	2034	2041	2038	2041	2	1.00	0.00	0.21	−0.17	6.53
					2043	T	10.0	2042	2052	2045	2052	2	0.50	0.00	7.13	0.28	8.46
8 Aug 1981	S	T	M	8.3	1450	T	9.7	1454	1505	1459	1502	3	1.00	0.00	0.00	0.54	6.31
					1505	T	12.6	1533	1558	1535	1600	7	0.50	110.97	6.00	1.47	7.14
					1710	T	9.5	1731	1810	1739	1809	7	0.63	1143.54	8.68	1.98	7.96
					1735	T	8.5	1738	1742	0	0	0	0.00	0.00	0.00	0.39	5.00
					1750	T	8.2	1753	1808	1757	1757	1	0.33	0.00	3.41	0.46	5.32
					1802	T	8.2	1804	1843	1818	1842	4	0.38	0.00	4.15	0.50	7.29
					1815	T	11.0	1822	1855	1827	1849	4	0.57	81.37	5.30	0.70	7.32
16 Aug 1981	S	F	M	12.3	1742	T	8.2	1805	1812	1813	1815	2	0.25	0.00	0.79	0.75	7.61
9 June 1982	S	T	S	6.6	1405	T	9.2	1405	1420	1424	1424	1	0.00	−0.08	0.00	0.19	5.05
					1515	T	9.0	1515	1518	1521	1521	1	0.00	−0.08	0.00	0.27	4.37
					1614	T	9.2	1616	1619	1622	1627	2	0.00	−0.08	0.00	−0.16	2.85
					1624	T	9.3	1622	1651	1626	1646	3	0.50	−0.08	1.68	0.15	3.83
					1700	T	9.1	1704	1718	1712	1712	1	0.33	−0.08	0.60	0.37	4.82
					1924	R	10.5	1941	1951	1944	1950	2	1.00	−0.08	4.91	0.44	2.89
					2004	T	9.5	2005	2059	2008	2059	15	0.82	−0.08	4.18	0.41	4.13
					2123	T	9.6	2125	2140	2130	2145	4	0.33	−0.08	0.12	0.17	3.71
					2146	T	9.8	2152	2159	2157	2157	1	0.25	−0.08	0.00	0.03	3.67
10 June 1982	S	T	S	6.6	1442	T	8.0	1441	1558	1445	1553	19	0.66	−0.08	7.60	0.01	2.98
					1514	T	9.9	1516	1615	1602	1615	3	0.08	−0.08	2.09	0.20	4.72
					1546	T	11.0	1548	1604	1551	1604	6	1.00	−0.08	1.34	0.17	4.64
					1616	T	10.0	1617	1646	1619	1647	8	0.75	−0.08	4.07	0.52	5.04
					1700	T	9.2	1717	1736	1725	1734	3	0.25	−0.08	0.55	0.52	4.57
15 July 1982	S	F	M	9.6	1452	T	9.3	1453	1616	1502	1613	18	0.53	−0.08	10.54	0.32	7.03
16 July 1982	S	F	M	7.3	1814	R	13.2	1851	2015	1903	2010	23	0.56	−0.08	9.70	3.79	12.35
					2002	T	12.3	2004	2018	2010	2010	1	0.50	−0.08	1.01	0.55	8.63
					1912	R	13.1	2005	2027	2008	2020	3	0.60	−0.08	5.60	1.74	6.91
					1953	R	14.0	2022	2042	2027	2042	5	0.88	−0.08	7.01	3.78	7.90
								NO-SEED CELLS									
19 June 1977	N	T	M	7.7	1735	R	9.3	1743	1836	0	0	0	0.00	854.96	7.21	0.14	2.10
21 June 1977	N	T	S	6.1	1454	T	9.2	1456	1502	0	0	0	0.00	0.00	1.04	0.35	2.68
					1512	T	10.2	1513	1520	0	0	0	0.00	0.00	0.00	0.65	3.42
					1520	T	7.0	1522	1532	0	0	0	0.00	88.19	0.00	0.02	1.29
					1528	T	7.5	1533	1554	0	0	0	0.00	54.32	4.42	0.23	5.79
24 June 1977	N	T	S	6.3	1443	T	8.8	1441	1504	0	0	0	0.00	152.29	0.40	0.28	3.79
					1501	T	8.7	1502	1535	0	0	0	0.00	0.00	2.71	0.45	3.55
					1649	T	10.9	1649	1701	0	0	0	0.00	0.00	1.97	0.41	2.74
					1654	T	8.1	1656	1736	0	0	0	0.00	1623.45	7.53	0.00	3.53
					1715	T	9.0	1733	1745	0	0	0	0.00	59.34	8.17	1.21	7.71
					1801	T	7.2	1757	1831	0	0	0	0.00	0.00	2.23	−0.17	3.14
14 July 1977	N	F	M	10.9	1655	R	8.5	1706	1708	0	0	0	0.00	0.00	0.00	0.36	1.56
16 Aug 1977	N	T	M	8.3	2036	T	10.3	2038	2042	0	0	0	0.00	0.00	0.00	0.02	4.24
					2049	T	11.0	2052	2100	0	0	0	0.00	0.00	3.77	0.10	5.43

18 Aug 1977	*N*	*T*	*M*	8.1	1324	*T*	8.6	1326	1428	0	0	0	0.00	1218.72	6.23	0.50	6.23
22 Aug 1977	*N*	*T*	*M*	7.2	1502	*T*	5.3	1503	1503	0	0	0	0.00	0.00	0.00	0.36	1.85
					1521	*T*	5.4	1525	1559	0	0	0	0.00	97.36	0.00	−0.55	−0.44
					1549	*T*	5.7	1553	1553	0	0	0	0.00	0.00	0.00	0.48	4.86
17 May 1978	*N*	*F*	*M*	7.9	1819	*T*	5.6	1813	1855	0	0	0	0.00	373.17	2.04	−0.17	3.63
31 May 1978	*N*	*T*	*S*	3.8	1227	*T*	10.2	1223	1350	0	0	0	0.00	776.13	8.56	0.02	2.75
					1351	*T*	10.5	1345	1437	0	0	0	0.00	81.90	6.45	−0.17	0.70
					1428	*T*	10.8	1431	1505	0	0	0	0.00	676.10	6.96	0.47	5.39
					1535	*T*	8.7	1552	1601	0	0	0	0.00	81.06	3.11	0.64	3.78
					1732	*T*	8.8	1726	1745	0	0	0	0.00	0.00	0.00	−0.17	1.05
1 June 1978	*N*	*T*	*S*	4.6	1758	*T*	9.2	1758	1825	0	0	0	0.00	410.95	0.00	0.31	3.09
					1830	*T*	9.2	1833	1847	0	0	0	0.00	13.37	2.70	0.61	3.34
					1833	*T*	10.9	1836	1933	0	0	0	0.00	10722.29	9.10	0.18	4.29
3 June 1978	*N*	*F*	*S*	4.8	1253	*T*	11.3	1253	1301	0	0	0	0.00	0.00	1.10	0.77	6.33
					1310	*T*	11.0	1312	1320	0	0	0	0.00	0.00	1.11	0.13	4.07
					1332	*T*	11.7	1341	1342	0	0	0	0.00	240.63	1.70	0.49	6.03
6 June 1978	*N*	*T*	*M*	6.8	1633	*T*	11.0	1633	1643	0	0	0	0.00	0.00	3.78	0.19	5.57
7 June 1978	*N*	*F*	*M*	8.2	1920	*R*	10.7	1932	1955	0	0	0	0.00	0.00	4.83	0.22	3.17
19 June 1978	*N*	*T*	*M*	6.0	1144	*R*	5.2	1200	1215	0	0	0	0.00	0.00	2.10	0.58	4.53
					1249	*T*	5.2	1250	1328	0	0	0	0.00	980.15	3.26	0.76	4.92
					1319	*T*	5.2	1324	1324	0	0	0	0.00	347.93	0.00	0.45	3.52
25 June 1978	*N*	*T*	*M*	0.7	1356	*T*	6.0	1349	1349	0	0	0	0.00	0.84	0.00	−0.17	−0.05
					1509	*T*	6.3	1508	1518	0	0	0	0.00	15.46	0.00	0.15	1.65
18 July 1978	*N*	*F*	*M*	8.5	1206	*T*	9.0	1206	1220	0	0	0	0.00	1964.11	9.79	0.38	6.00
					1216	*R*	11.4	1230	1240	0	0	0	0.00	4387.41	10.12	0.95	8.13
					1244	*T*	9.8	1247	1252	0	0	0	0.00	0.00	3.91	0.19	5.82
31 July 1978	*N*	*F*	*M*	10.1	1816	*R*	12.7	1914	2034	0	0	0	0.00	8750.49	9.60	3.59	10.55
16 Aug 1978	*N*	*F*	*M*	12.4	1208	*T*	8.1	1223	1240	0	0	0	0.00	0.00	6.79	2.03	12.93
5 Sep 1978	*N*	*T*	*S*	10.5	1642	*T*	7.5	1653	1806	0	0	0	0.00	1143.38	5.83	0.37	5.31
					1744	*T*	8.7	1746	1804	0	0	0	0.00	441.18	4.11	0.62	5.85
					1814	*T*	9.1	1831	1906	0	0	0	0.00	33.43	5.68	0.77	5.44
					1858	*T*	9.3	1905	1919	0	0	0	0.00	0.00	0.13	0.09	3.41
					1903	*T*	9.4	1914	1933	0	0	0	0.00	0.00	3.54	0.21	3.77
					1917	*T*	8.4	1920	1945	0	0	0	0.00	8.78	5.92	0.50	6.10
					1925	*T*	8.5	1928	1942	0	0	0	0.00	0.42	3.28	0.51	4.93
2 June 1979	*N*	*T*	*S*	11.7	1320	*T*	11.5	1322	1337	0	0	0	0.00	0.00	3.74	0.66	6.01
					1450	*T*	9.9	1553	1603	0	0	0	0.00	83.22	6.84	2.01	7.46
					1607	*T*	8.2	1616	1720	0	0	0	0.00	225.66	8.09	0.32	5.26
					1625	*T*	8.4	1624	1642	0	0	0	0.00	8.36	2.95	0.10	5.15
					1728	*T*	8.5	1729	1739	0	0	0	0.00	0.00	0.24	0.45	3.43
					1731	*T*	9.0	1735	1752	0	0	0	0.00	0.00	3.51	0.52	5.01
4 June 1979	*N*	*T*	*S*	8.7	1250	*T*	12.0	1312	1340	0	0	0	0.00	0.00	0.32	0.60	5.59
5 June 1979	*N*	*T*	*S*	10.0	1436	*T*	8.3	1439	1554	0	0	0	0.00	12.32	6.32	0.30	3.48
					1446	*T*	9.5	1452	1459	0	0	0	0.00	3.52	0.00	0.21	2.91
					1709	*T*	9.5	1713	1822	0	0	0	0.00	1529.63	8.52	0.20	4.30
					1719	*T*	8.2	1725	1745	0	0	0	0.00	0.00	2.28	0.27	4.77
					1813	*T*	9.0	1823	1823	0	0	0	0.00	0.00	0.65	0.10	3.54
					1832	*T*	10.0	1835	1850	0	0	0	0.00	0.00	1.99	0.50	4.52
					1725	*T*	9.0	1744	1750	0	0	0	0.00	0.00	0.67	0.57	5.05
11 June 1979	*N*	*F*	*M*	10.4	1417	*T*	9.5	1423	1426	0	0	0	0.00	0.00	0.67	0.25	7.03
					1510	*T*	8.4	1509	1509	0	0	0	0.00	0.00	0.00	0.37	5.54
					1754	*T*	8.2	1758	1804	0	0	0	0.00	0.00	0.00	0.38	6.90

TABLE A1. (*Continued*)

Date	N/S	F/T	S/M	T_B	ID	R/T	H_V	t_0	t_f	t_{fs}	t_{ls}	N_R	sc	E_G	R	d	f
12 June 1979	N	F	M	8.6	1710	R	13.8	1745	1812	0	0	0	0.00	338.36	4.26	0.97	5.06
					1803	T	9.0	1810	1825	0	0	0	0.00	0.00	2.02	0.25	7.53
					1745	T	10.9	1751	1826	0	0	0	0.00	331.62	3.61	0.55	7.20
					1830	T	9.6	1836	1845	0	0	0	0.00	0.00	3.51	0.65	7.87
24 June 1979	N	F	M	8.3	1930	T	7.4	1956	2001	0	0	0	0.00	0.00	5.27	0.89	7.95
					1931	T	7.8	1959	2004	0	0	0	0.00	0.00	0.80	0.89	8.55
12 July 1979	N	F	M	12.9	2044	T	8.5	2048	2100	0	0	0	0.00	1538.29	8.57	1.00	11.14
					2045	R	9.8	2054	2100	0	0	0	0.00	0.00	4.29	0.34	3.54
31 July 1979	N	T	M	11.4	1610	T	8.4	1612	1623	0	0	0	0.00	0.00	4.94	0.80	6.04
					1612	T	8.4	1621	1632	0	0	0	0.00	0.00	6.36	0.54	6.52
3 Aug 1979	N	T	M	13.2	1351	R	8.6	1358	1433	0	0	0	0.00	185.67	7.24	0.65	5.59
7 Aug 1979	N	T	M	5.8	1727	R	10.8	1746	1830	0	0	0	0.00	18.47	8.41	1.16	6.63
					1757	T	9.8	1755	1810	0	0	0	0.00	1.67	5.14	0.01	4.14
					1804	T	9.4	1808	1855	0	0	0	0.00	2921.01	8.73	0.20	4.87
					1851	T	10.2	1900	2022	0	0	0	0.00	2071.25	8.78	1.29	8.18
					1902	T	10.2	1914	1914	0	0	0	0.00	0.00	0.00	−0.14	3.21
9 Sep 1979	N	T	M	8.0	1931	R	12.4	2031	2100	0	0	0	0.00	391.30	6.86	1.95	5.36
21 May 1980	N	T	S	−0.2	1223	T	8.2	1210	1210	0	0	0	0.00	0.00	0.00	−0.17	0.44
					1628	T	7.2	1627	1647	0	0	0	0.00	1.67	3.82	0.19	1.91
					1651	T	9.2	1648	1717	0	0	0	0.00	0.00	0.00	−0.17	1.18
					1657	T	7.8	1656	1700	0	0	0	0.00	0.00	3.76	0.37	4.13
					1741	T	8.7	1748	1752	0	0	0	0.00	0.00	0.00	0.41	2.82
					1842	T	9.3	1855	1929	0	0	0	0.00	152.31	4.92	0.15	1.38
6 June 1980	N	T	M	7.3	1151	R	9.3	1200	1201	0	0	0	0.00	0.00	0.68	0.69	4.73
					1203	T	8.2	1203	1206	0	0	0	0.00	66.86	2.63	0.40	4.75
					1243	R	9.2	1253	1305	0	0	0	0.00	274.51	3.84	0.06	2.35
					1300	T	9.5	1313	1318	0	0	0	0.00	0.00	0.50	0.69	4.38
					1306	T	8.6	1315	1321	0	0	0	0.00	0.44	0.00	0.09	4.48
					1351	T	10.4	1358	1409	0	0	0	0.00	440.71	0.00	0.21	5.34
15 June 1980	N	T	M	6.2	1420	T	8.9	1424	1438	0	0	0	0.00	2146.38	5.41	0.61	5.31
					1426	T	8.0	1430	1441	0	0	0	0.00	510.69	1.84	0.63	4.70
29 July 1980	N	F	M	13.1	1351	T	9.8	1358	1417	0	0	0	0.00	0.00	5.55	0.21	8.84
					1427	T	10.0	1432	1524	0	0	0	0.00	443.61	7.68	0.18	10.25
					1531	T	9.0	1535	1548	0	0	0	0.00	0.00	0.00	0.70	8.52
					1555	T	9.8	1606	1626	0	0	0	0.00	8.36	3.44	0.64	9.07
15 May 1981	N	T	S	5.5	1630	T	9.1	1638	1647	0	0	0	0.00	758.33	0.34	0.37	3.28
21 May 1981	N	F	M	2.3	1647	T	11.9	1728	1745	0	0	0	0.00	0.00	0.00	0.86	6.32
30 May 1981	N	T	S	5.9	1629	T	9.0	1632	1642	0	0	0	0.00	140.05	2.34	0.20	5.63
24 June 1981	N	T	S	5.6	2053	T	8.0	2056	2101	0	0	0	0.00	72.58	0.00	0.43	3.98
25 June 1981	N	F	M	2.5	1509	T	8.0	1517	1517	0	0	0	0.00	34.31	0.00	0.43	5.75
10 July 1981	N	F	S	5.9	1530	T	9.8	1540	1619	0	0	0	0.00	5.28	3.74	0.38	4.71
					1653	T	10.2	1651	1704	0	0	0	0.00	0.00	0.64	0.10	4.19
					1739	T	8.8	1736	1811	0	0	0	0.00	898.05	6.40	−0.17	2.98
					1809	T	7.8	1806	1817	0	0	0	0.00	2.51	0.00	−0.17	3.62
					1850	T	6.0	1844	1902	0	0	0	0.00	0.00	0.50	−0.17	1.97
					1859	T	8.2	1858	1921	0	0	0	0.00	0.00	3.17	0.15	4.24
					2026	T	10.7	2031	2053	0	0	0	0.00	0.00	1.82	0.19	4.03
					2123	T	7.5	2129	2135	0	0	0	0.00	0.00	0.77	0.12	4.62

					2108	*T*	10.7	2113	2118	0	0	0	0.00	0.00	0.00	0.52	4.59
11 July 1981	*N*	*T*	*S*	12.5	1414	*T*	7.2	1424	1426	0	0	0	0.00	0.00	0.00	0.09	3.97
					1435	*T*	7.6	1436	1502	0	0	0	0.00	0.00	1.36	0.46	4.36
					1653	*T*	7.6	1658	1658	0	0	0	0.00	0.00	0.00	−0.31	2.34
					1715	*T*	8.2	1719	1739	0	0	0	0.00	0.00	0.54	0.25	4.83
22 July 1981	*N*	*T*	*M*	7.4	1932	*T*	7.6	1947	1955	0	0	0	0.00	0.00	0.65	0.30	3.58
31 Aug 1981	*N*	*T*	*M*	6.6	2103	*T*	7.5	2102	2104	0	0	0	0.00	0.00	0.51	0.19	4.27
					2118	*R*	8.6	2135	2200	0	0	0	0.00	35.18	7.06	0.12	2.58
2 June 1982	*N*	*T*	*M*	6.3	1551	*T*	12.0	1614	1632	0	0	0	0.00	−0.08	0.00	0.94	5.52
					1638	*T*	12.0	1638	1645	0	0	0	0.00	−0.08	0.00	0.31	4.79
					1659	*T*	11.2	1702	1714	0	0	0	0.00	−0.08	0.00	0.07	3.53
5 June 1982	*N*	*T*	*S*	6.4	1323	*T*	11.5	1331	1409	0	0	0	0.00	−0.08	4.16	0.69	5.76
					1428	*T*	11.8	1428	1535	0	0	0	0.00	−0.08	4.89	0.61	4.87
					1539	*T*	10.0	1541	1553	0	0	0	0.00	−0.08	0.54	−0.01	3.13
					1540	*T*	9.2	1542	1615	0	0	0	0.00	−0.08	0.00	−0.01	3.33
					2150	*T*	9.8	2152	2200	0	0	0	0.00	−0.08	3.79	0.31	4.26
7 June 1982	*N*	*T*	*S*	6.0	1501	*T*	8.2	1501	1501	0	0	0	0.00	−0.08	0.00	0.38	4.17
					1604	*T*	8.5	1609	1622	0	0	0	0.00	−0.08	0.87	0.36	6.25
					1721	*T*	9.3	1721	1729	0	0	0	0.00	−0.08	1.25	0.52	4.09
					1801	*T*	8.0	1818	1856	0	0	0	0.00	−0.08	4.16	0.69	5.07
					1912	*T*	9.0	1919	1919	0	0	0	0.00	−0.08	0.00	−0.28	2.82
					1928	*T*	9.1	1929	1937	0	0	0	0.00	−0.08	0.00	0.20	3.60
					1931	*T*	11.2	1931	1931	0	0	0	0.00	−0.08	0.00	0.33	4.46
					1948	*T*	10.4	1950	1952	0	0	0	0.00	−0.08	0.09	0.46	3.53
					2023	*T*	8.3	2028	2045	0	0	0	0.00	−0.08	1.36	0.38	5.60
					2056	*T*	9.4	2058	2100	0	0	0	0.00	−0.08	0.00	0.31	3.33

* −0.08 = cell out of network or network not in operation.

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