"REVIEWED"

A CONFIRMATORY EVALUATION OF THE GROSSVERSUCH IV EXPERIMENT USING HAILPAD DATA (FRENCH NETWORK 1977 - 1981)

J-F. Mezeix
Groupement National d'Etudes des Fleaux Atmospheriques
Grenoble, France

P. Caillot
Informatique, Mathematiques et Sciences Sociales
Grenoble, France

1. INTRODUCTION

Grossversuch IV is a collaborative project, coordinated by the Institute for Atmospheric Physics of E.T.H. in Zurich. It includes the participation of universities and government agencies of France, Italy and Switzerland. Each participating group contributes its particular expertise toward a program designed to test whether a hail suppression method similar to the one proposed by scientists in the USSR, using their high altitude rockets, can successfully be applied in Central Europe, taking into account the climatic and logistic boundary conditions of the regions. The field program includes a 3cm radar with PPI and RHI for measuring the parameters needed for the seeding criteria, launchers for the Soviet Oblako rockets, a 10cm radar with PPI to measure precipitation quantiatively, and a ground network of hailpads with sufficient density to measure kinetic energy and massive hail in the test area. The area chosen lies between Lucerne and Langnau as shown in Figure 1.

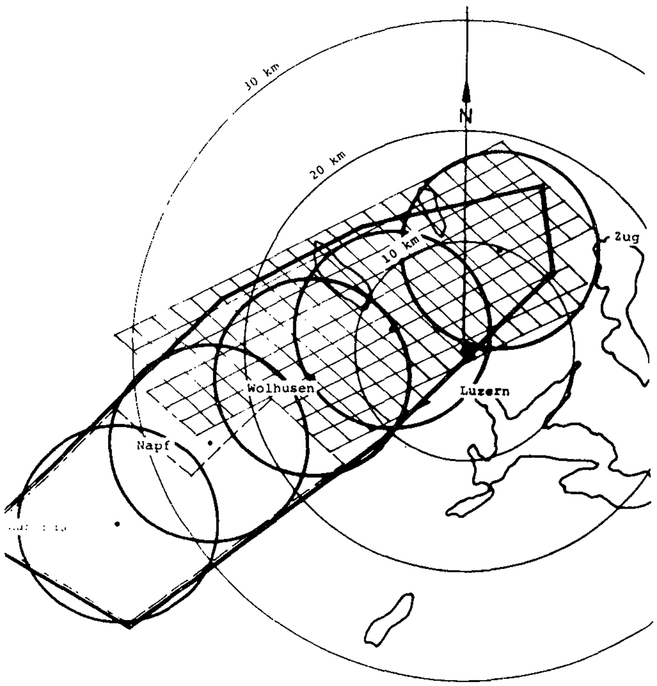

Fig. 1. Schematic map of the Swiss experimental area showing hailpad networks and rocket stations.

After 5 years of operations (1977-1981) we present here a confirmatory evaluation of the Grossversuch IV experiment, using hailpad data limited to the French network of the test zone. Three different countries (E.T.H. from Zurich, Switzerland, U.C.E.A. from Rome, Italy, and G.N. E.F.A. from Grenoble, France) have collaborated on this experiment in order on the one hand to strictly apply the Soviet hail prevention method in Switzerland and, on the other, to scientifically control the precipitation measurements.

Noting the design of Grossversuch IV as described by Federer et al. (1978), we recall that the program is seeking a possible global effect of the Soviet method on physical parameters of hailfall on the ground. To the hail kinetic energy E, the primary physical test variable, we add a series of secondary physical test variables, similarly measured by hailpads. These are global intensity variables (area of hailfalls, mass and number of hailstones), maximum punctual intensity variables (numbers, mass, kinetic energy and diameter per m^2) and mean global intensity variables (global variables/area of hailfall).

The nul hypothesis to be tested is as follows: The seeding of hailstorms following the Soviet rocket seeding technique, during the experimental unit (12:00 PM - 9:00 PM) does not change the characteristics of the distributions of kinetic energy of hail produced by a phc (potential hailcell) between the natural cases (NS) and the seeded cases (S), determined by a scheme of randomization (50% - 50%). To this test we add the comparison of distributions of the secondary test variables. All the potential hailcells are defined in very precise time limits: t_o the time when the Soviet criterion for detection of hail-bearing cells and seeding filled for the first time and t_f, the time when it is filled for the last time inside the test zone. The test variables are considered in the interval t_o + 5 mn to t_f + 20 mn in order to take into account the lapse of time necessary for the action of silver iodide. It is likewise possible to avoid an intra-day correlation of the cells by accumulating the values of the test variables of the cells per day.

In this first evaluation, we consider neither the discriminate radar function between rain and hail (because this function is not valid and because the hailpads are good discriminate functions) nor the seeding coverage nor the predictors. But we add a supplementary evaluation in the intervals of the respective times t_0 + 10 mn to t_f + 20 mn and t_0 + 15 mn to t_f + 20°mn in the case where silver iodide effects would possibly be detected on the ground from 10 mn to 15 mn after dispersion in the cloud.

The confirmatory statistic evaluation presented here is partial, limited to the French network of hailpads and would not prejudge results of exploratory analyses. Beyond the control of the Soviet method, we are not yet able to know whether the Soviet schema of hail formation in the accumulation zone and the beneficial competition embryo concept (Sulakvelidze et al., 1967) are valid or not in the Napf region of Switzerland.

2. THE DATA USED

The quality of hail measures appears to be a condition of the test quality of the experiment. Therefore, we have tried to perfect a reliable recording device for hail, and a procedure of maintenance, processing an analysis which are as precise as possible (Vento, 1976; Mezeix and Admirat, 1978; Admirat et al., 1980).

2.1 Experimental device

The experimental data come from a dense and regular network of 211 hailpads with a regular lozenge-shaped mesh area of 3.8 km² covering about 800 km² in the northeastern part of the test zone in Switzerland (Figure 2). In 1977, the hailpad, sensitive to the impacts of hail (0.1 m²) was a sheet of aluminum 0.2 mm thick, rebaked and glued onto emalene foam. Since 1978 it has been replaced by roofmate (polystyrene).

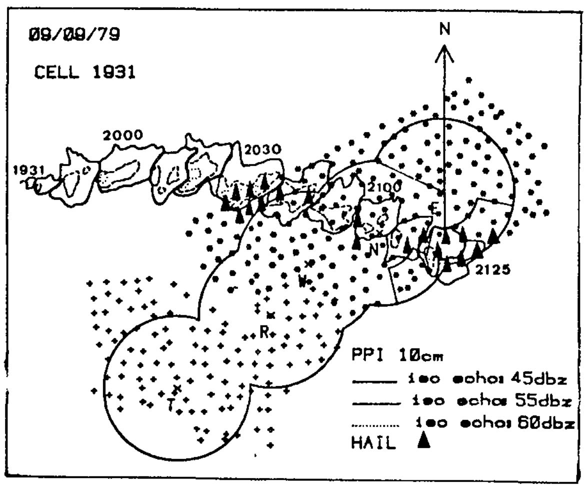

Figure 2. French and Italian hailpad networks covering the test zone. Radar reflectivity contours of hailcell 1931 (PPI 5°) associated with impacted hailpads.

The practical use of roofmate imposes a preparation and a series of controls: coating with white paint to avoid decomposition of the surface, calibration of each batch of roofmate pads, post-fall inking to increase the sharpness of the impacts to assist with the analyses, and finally the conservation and photographing of the pads.

The measurement of impacts leads to a determination of the number and diameter of hailstones greater than 5 mm regrouped by diameter interval class of 4 mm. Punctual intensity variables by m² are calculated: total number, total mass, total kinetic energy and diameter of hailstones.

$$N_T = \sum_{i=1}^{m} n_i \ ; \ M_T = 4.7\ 10^{-7} \sum_{i=1}^{m} n_i \ d_i^3 \ ;$$

$$E_T = 4.58\ 10^{-6} \sum_{i=1}^{m} n_i \ d_i \ ; d_m \ . \quad (1)$$

where n_i is the number of hailstones in the diameter interval Δd_i with mean diameter d_i (mm) with m intervals.

The global intensity variables of each hailfall are obtained by adding the P respective punctual values and by multiplying them by the theoretical area s of the mesh unit (3.8 km²). With 3.78 km² and a standard deviation of 0.5 km², the real average value of the surface of Thiessen's polygones associated with each hailpad is quasi-identical to the theoretical value (3.8 km²).

$$E_G = s \sum_{i=1}^{P} E_{Ti} \ ; \ S_G = Ps \ ;$$

$$M_G = s \sum_{i=1}^{P} M_{Ti} \text{ et } N_G = s \sum_{i=1}^{P} N_{Ti} \ , \quad (2)$$

represent the global values of kinetic energy, mass and number of hailstones integrated in the entire hailfall. We also calculate the mean global intensity variables per unit area N_{Gmoy}, M_{Gmoy}, E_{Gmoy}, and the maximum punctual variables per m² N_{Tmax}, E_{Tmax}, M_{Tmax}, D_{max}.

An estimating method of measurement errors on kinetic energy and area of hailfall from a model of hailpattern integrating punctual errors (Doras, 1982) allows us to establish that the estimation of the true surface S_R and of the true kinetic energy E_R by S_G is without bias and that the standard error decreases according to relations 3 and 4.

$$\sigma S_R/\bar{S}_R = 1.3\ S_G^{-0.71} \qquad (S_G \text{ in km}^2) \qquad (3)$$

$$E_R/\bar{E}_R = 3.18\ E_G^{-0.505} \qquad (E_G \text{ in MJ}) \qquad (4)$$

2.2 The data

Let us consider the production of hail assigned to the phc unit. By a quick and regular maintenance of the hailpad network, we have been able to obtain data characteristics of this cell unit. It is an improvement on daily recordings.

2.2.1 Practical procedure for the determination of hailed zones.

After the determination by the 3cm radar of the values of t_0 and t_f, time of first and last seeding criterion on the test zone of each cell, the 10cm PPI radar reflectivity contours

(Waldvogel et al.) 45 dBZ, 55 dBZ, 60 dBZ, 65 dBZ and 70 dBZ (according to the cases) are digitized and drawn on a schema of the test zone just as is the mass center of each iso-echo contour with the corresponding time. A very exact account, hailpad by hailpad of the hailed zone, is then realized by superimposing the PPI data of the cell with the hailpattern data (Figure 1.). When no hailpad has received hail, we consider the cell as a zero case.

As a first approximation, the most probable time of a hailfall on a hailpad (average time over the duration of the fall), corresponds to the time of the mass center of the echo 55 dBZ above the hailpad. In some cases where there is no echo 55 dBZ, we take the mass center of the echo 45 dBZ. With this procedure, all the hailpads are credited with an average fall-time. The various hail variables can then be calculated in any time interval.

2.2.2 Summary of the cells

During 5 years, among the 216 cells (94 S and and 122 NS) of the experimental unit on the alarm days within the test zone, we select all the cells totally or partially situated on the French network, i.e. 114 cells.

Following the preceding time procedure, we determine the number of cells with hail and without hail in the time intervals t_o + 5 mn, t_o + 10 mn and t_o + 15 mn to t_f + 20 mn (Table 1).

Table 1. Summary of 114 S and NS cells on the French network in three time intervals.

Time interval	Number of cells (114)			
	$S_{\text{with hail}}$	NS	$S_{\text{zero cases}}$	NS
[t_o + 5 mn t_f + 20 mn]	20	37	21	36
[t_o + 10 mn t_f + 20 mn]	18	34	23	39
[t_o + 15 mn t_f + 20 mn]	15	28	26	45

We note 57 cases (with hail from 37 NS cells and 20 S cells) and 57 zero cases (36 NS cells and 21 S cells) in the design interval t_o + 5 mn, t_f + 20 mn. By reducing the limits of the time interval in which the seeding of storms could have an effect, we reduce the hail production of each cell and increase the number of zero cases.

3. FIRST CONFIRMATORY RESULTS

The evaluation of a weather modification experiment is a difficult problem. The main difficulties stem from the variability of the storm phenomena (Changnon, 1971; Mezeix and Doras, 1981), from the difficulty of forecasting and establishing the reliable predictors of quantitative physical parameters of precipitation (in particular the numerical storm models do not yet allow forecasting of seeding results) and from the multidimensionality of hailstorms characterized by meteorological, thermodynamic and microphysical variables (Der Megreditchian et al., 1980; Rouet et al., 1980; Mezeix and Rouet, 1981). We can add to this that the effects possibly produced by the cloud seeding are less than the natural variability. We are thus confronted with the search for a weak signal within an important and random background noise. Thus, statistical evaluation is necessary. As regards Grossversuch IV, we must remember that we have chosen a statistical evaluation procedure in the comparison of physical parameters of precipitation between natural and seeded storms within the same zone, determined by a randomization (50% - 50%).

Two types of tests are presented here following the nature of the hypothesis made on the law of probability of the considered variables: t test whenever the expression of the probability density function is known (log normal), the non-parametric test of Mann Whitney whenever the probability density function is unknown. The absence of information on the law of probability leads to only a slight loss of the power of the tests. For example, the non-parametric test of Mann Whitney is 10% less powerful than the best of parametric tests (Dennis, 1980). As we shall see with the significance level of the results obtained, we now consider these two tests.

With this confirmatory analysis, we closely follow the statisticians' recommendations on the treatment of weather modification experiments (Weather Modification Advisory Board, 1979). However, we emphasize the discussion is not over between statisticians on the importance which should be accorded to the exploratory analyses in the confirmation of the results (Bradley, 1980; Court, 1980; Gabriel, 1980).

3.1 Test of the seeding effect on the frequency of zero cases

For each of the intervals of time t_o + 5 mn, t_o + 10 mn, and t_o + 15 mn to t_f + 20 mn, a contingency table (2x2) is extracted from Table 1. The x^2 test is used three times (respectively x^2 = 0.04; x^2 = 0.076 and x^2 = 0.035) and does not allow the rejection of the hypothesis of the homogeneity of the samples. The proportion of zero cases is the same amongst the natural cells and the seeded ones.

To demonstrate an effect at the 5% level in the three time intervals, it would have been necessary for 7 S cells with hail to be transformed into 7 supplementary S zero cases.

3.2 If $\bar{x}_1 = \overline{\log E_{G1}}$ and $\bar{x}_2 = \overline{\log E_{G2}}$ are the two means of the kinetic energy of the two samples NS and S, an unbiased estimator of D, the difference in the true mean values, is calculated by $\hat{D} = \bar{x}_2 - \bar{x}_1$ and the median-unbiased estimate by $\tilde{\rho} = 10^{\hat{D}}$. We can define 90% or 95% confidence limits for $\tilde{\rho}$, the ratio of the two real geometric mean by the power ten functions of

$$\bar{x}_2 - \bar{x}_1 \pm t_{n1+n2-2,\alpha}\ s_d \sqrt{\frac{1}{\bar{n}_1} + \frac{1}{\bar{n}_2}}$$

The interest of the calculation of $\tilde{\rho}$ is in a practical reading of the ratio of the two geometric means and in the use of the P percentage of augmentation or reduction of the variables linked to ρ by P = ρ -1.

3.2.1 Comparison of the variables in the interval (t_0 + 5 mn, t_f + 20 mn)

At the 5% level (Kolmogorov Smirnov's test) all the test variables except the area are log normal (Figure 2). The equality of the variances of the two samples cannot be rejected for any variable. The significance levels of t test and of Mann Whitney's tests are > 0.05 and quite identical (Table 2). We cannot therefore reject the H_0 hypothesis of the equality of the mean of the test variables (10% level).

The values of $\tilde{\rho}$ are superior to 1 for the global variables and for the maximum diameter and inferior to 1 for the other variables. But this tendency, either to rise or to decrease according to the variables is not significant.

For kinetic energy, at the 10% significant level, the ratio ρ is between 0.33 and 3.82, between a 282% increase of the energy and a 67% decrease. The small number of cases induces very large intervals between which an effect could exist.

For the areas of hailfall (between a decrease of 19% and an increase of 278%) and for the mean global number of hailstorms (between a decrease of 71% and an increase of 11%) the value of P is the smallest, indicating a nonsignificant tendency of the areas to rise and of the mean global number of the hailstones to decrease. This may be an effect of the faster displacement speed of the cells in the seeded cases.

3.2.2 Comparison of the variables in the intervals (t_0 + 10 mn, t_f + 20 mn) and (t_0 + 15 mn, t_f + 20 mn)

Nor can we detect an effect of seeding on the physical parameters of hail in the other time intervals (Table 3). We note the tendency of the global parameters to increase and, in particular of the area and of the hail kinetic energy, to be reinforced. However, the values are below any reasonable significance level.

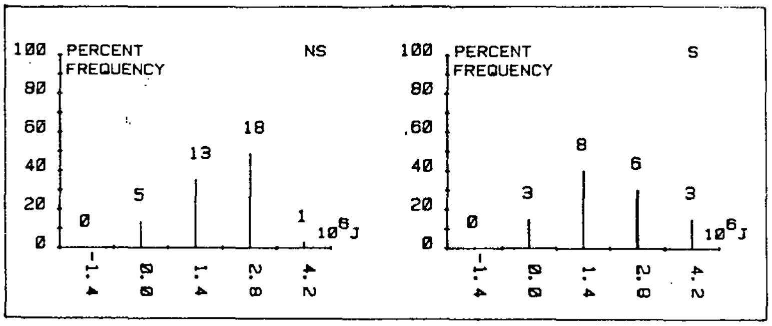

Figure 2. Distribution of NS and S hail kinetic energy (37 NS and 20 S cases - Grossversuch IV 1977-1981)

Table 2. Test of the H_0 hypothesis with the various test variables, considering the cell unit in the t_0+5 mn t_f + 20 mn time interval (Grossversuch IV 1977-1981).

response variable	normality 5 % level	t test t	t test p	Mann Whithney test U	Mann Whithney test P	$\tilde{\rho}$	90 % confidence limits for ρ	
Log E_G	yes	0.15	0.88	0.01	0.99	1.12	0.33	3.82
Log S_G	no	--	--	1.23	0.22	1.76	0.81	3.78
Log M_G	yes	0.09	0.93	0.05	0.96	1.07	0.34	3.38
Log N_G	yes	0.00	1	1.15	0.89	1.00	0.33	3.07
Log D_{max}	yes	1.29	0.20	1.25	0.21	1.16	0.96	1.40
Log N_{Tmax}	yes	0.87	0.39	1.01	0.31	0.63	0.25	1.55
Log E_{Tmax}	yes	0.44	0.66	0.46	0.64	0.77	0.27	2.14
Log M_{Tmax}	yes	0.59	0.56	0.53	0.60	0.71	0.27	1.89
Log E_{Gmoy}	yes	0.99	0.33	0.84	0.40	0.64	0.30	1.37
Log M_{Gmoy}	yes	1.15	0.26	1.12	0.26	0.61	0.29	1.26
Log N_{Gmoy}	yes	1.41	0.16	1.39	0.16	0.57	0.29	1.11

Table 3. Significance level P of the t test and estimatation of the ratio of the $\tilde{\rho}$ geometric means in the time intervals.

test variable	[t_0 + 10 mn t_f + 20 mn] P	[t_0 + 10 mn t_f + 20 mn] $\tilde{\rho}$	[t_0 + 15 mn t_f + 20 mn] P	[t_0 + 15 mn t_f + 20 mn] $\tilde{\rho}$
Log E_G	0.65	1.41	0.50	1.75
Log S_G	0.12 *	1.77	0.06	2.00
Log M_G	0.69	1.34	0.52	1.67
Log N_G	0.76	1.24	0.55	1.57
Log D_{max}	0.18	1.17	0.22	1.16
Log N_{Tmax}	0.68	0.79	0.35	0.90
Log E_{Tmax}	0.99	0.99	0.84	1.15
Log M_{Tmax}	0.88	0.91	0.42	1.05
Log E_{Gmoy}	0.65	0.30	0.81	0.88
Log M_{Gmoy}	0.56	0.76	0.73	0.84
Log N_{Gmoy}	0.42	0.70	0.60	0.78

3.2.3 Comparison of the daily variables cumulated in the interval $t_o + 5$ mn, $t_f + 20$ mn

In the initial design (Federer et al., 1978) we assumed no intraday correlation between hail cells. In case of alternative hypothesis, we cumulate per day the values of the parameters of the test variables always in the interval $t_o + 5$ mn, $t_f + 20$ mn and obtain 23 NS days and 14 S days.

The comparison of the distributions by the t test and the MW test, does not allow the determination of a difference in mean values (Table 4). Again, we find results similar to those of the cells, with a very strong tendency for the area of the fall to increase (significance level 0.07). For the area, the effect (at the 5% level) would be included between a 5% decrease and a 250% increase, and for the hail kinetic energy between a 65% decrease and a 370% increase.

Table 4. Test of the H_o hypothesis with various daily test variables (23 NS days, 14 S days) in the time interval $t_o + 5$ mn, $t_f + 20$ mn (Grossversuch IV 1977-1981).

response variable	normality 5 % level.	t test t	t test p	Mann Whithney test U	Mann Whithney test p	δ
Log E_G	yes	0.35	0.73	0.34	0.73	1.25
Log S_G	yes	1.85	0.07	1.39	0.16	1.81
Log M_G	yes	0.29	0.77	0.25	0.80	1.19
Log N_G	yes	0.19	0.85	0.16	0.87	1.12
Log D_{max}	yes	1.36	0.18	1.30	0.19	1.19
Log N_{Tmax}	yes	0.88	0.39	0.88	0.38	0.67
Log E_{Tmax}	yes	0.32	0.75	1.13	0.90	0.84
Log M_{Tmax}	yes	0.73	0.47	0.36	0.71	0.7
Log E_{Gmoy}	yes	0.87	0.39	0.38	0.70	0.69
Log M_{Gmoy}	yes	1.05	0.3	0.78	0.43	0.66
Log N_{Gmoy}	yes	1.37	0.18	1.03	0.30	0.61

4. CONCLUSION

Thus summarized, the principal confirmatory results of the global evaluation of the Grossversuch IV experiment using hailpad data limited to the French network, appear to be the following:

1. The seeding of storms with USSR rockets has no effect on the frequency on the number of hailfalls.

2. A global effect of the seeding does not appear in a significant statistical way (level 10%) to increase or to decrease the values of hail kinetic energy and respectively the number, mass, area and diameter, despite a nonsignificant tendency for these values to increase. However, the small number of storm cases considered in the test and the natural variability of the storm phenomenon lead to confidence intervals so large, that the true underlying effect could have ranged from a substantial increase to a substantial decrease without detection by these statistical tests. For example, for hail kinetic energy at the 10% level can vary between 0.33 and 3.92 (0.64 and 9.41 for the NHRE) and for the area of hailfall between 0.81 and 3.78 (0.54 and 1.94 for the NHRE).

If we consider the hail production of the cells in the time intervals $t_o + 5$ mn to $t_f + 20$ mn and $t_o + 10$ mn to $t_f + 20$ mn or $t_o + 15$ mn to $t_f + 20$ mn, or cumulated per day, the results are identical on the absence of significant modification of the various test variables.

The very positive results announced by the Soviets (Burtsev, 1976, 1980) do not seem to be found here. Nevertheless, we shall complete these first results with data recorded by the Italian team before reaching a definitive conclusion on the Soviet method. By adding more cases, the significance levels may be higher.

Exploratory evaluations are now being conducted in order to research the possible effects of silver iodide in precise storm cases, allowing us to show a microphysical action on the cloud. In particular, several stratifications are under study. These are seeding coverage, types of storms, and meteorological conditions.

The difficulty of showing an effect in the context of a control experiment, which brought together important scientific and technical means, has the advantage of indicating from a practical point of view the probable impossibility of modifying storms, using limited and fairly unreliable techniques. This seems to be a first and very important practical result.

Following the apparent negative results of the NHRE (Crow et al., 1979), of Alberta (Goyer, 1980) and of Grossversuch IV, we can ask the question of whether the microphysical method of modifying hailstorms is not more and more an impasse supported by modification concepts which may not be completely established (Hitschfeld 1977).

5. ACKNOWLEDGEMENTS

The participation of the G.N.E.F.A. group in the Grossversuch IV experiment was made possible firstly to Bruno Federer of the E.T.H. in Zurich, the promoter of the operation and the person responsible for its realization, as well as to A. Waldvogel; secondly, to P. Admirat who got the project underway in France and who began the collaboration of the G.N.E.F.A. with the Swiss team; thirdly, Professor S. Rossini and D. Vento and the Italian team of the U.C.E.A. in Rome. A fruitful collaboration was then established between the three teams and was continued from the beginning of the operation. We wish our colleagues will accept our very sincere gratitude.

The recording and processing work and the treatment of the numerous data from several years of experimentation, all preliminary necessary and indispensable conditions to a scientific test, are due to the G.N.E.F.A. team who for seven years accomplished this difficult task in great part abroad. We give them our sincere compliments and thanks.

In part, the Grossversuch research was supported in France by the Ministry of Agriculture, the National des Calamites Agricoles, the Assurances Mutuelles Agricoles, the Assemblee Pleniere des Societes d'Assurances, the Establissement Public de la Region Rhone-Alpes and by local organizations.

REFERENCES

Admirat, P., D. Vento, J. F. Mezeis, J.P. Rouet, et A. Aparo, 1980: Atmos Ocean, 18 (1), 27-42.

Bradley, R. A. 1980: Statistical Analysis of Weather Modification Experiments. E. J. Wegman and D.J. De Priest, Eds., M. Deckker, New York.

Burtsev, I., 1976: Proc. 2nd Scientific Conf. on Weather Modification. Boulder, Colorado W.M.O. 443-213-227.

Burtsev, I., 1980: Third W.M.O. Scientific Conf. on Weather Modification, Clermont-Ferrand, 547-554.

Changnon, S.A., 1971: J. Appl. Meteor., 10, 270-274.

Court, A., 1980: Statistical Design of Weather Modification Experiments. E.J. Wegman and D.J. De Priest, Eds., M. Deckker, New York.

Crow, E.L., A.B. Long, J.E. Dye, A.J. Heymsfield, and P.W. Mielke, 1979: J. Appl. Meteor., Vol. 18 1538-1558.

Dennis, A.S., 1980: Academic Press, 267 pp

Der Megreditchian, G., O. Dubrule, R.P. Rouet, P. Admirat, 1980: Third W.M.O. Scientific Conf. on Weather Modification, Clermont-Ferrand, 763-770.

Doras, N., 1982: Rapport Technique G.N.E.F.A., n°42, Valence.

Federer, B., A. Waldvogel, W. Schmid, F. Hampel, E Rosini, D. Vento, P. Admirat, and J.F. Mezeix, 1978: Pageoph, Vol., 117, 548-571.

Gabriel, K.R. 1980: Statistical Analysis of Weather Modification Experiments. E.J. Wegman and D.J. De Priest, Eds., M. Deckker, New York.

Goyer, G.G. and J.H. Renick, 1980: Third W.M.O. Scientific Conf. on Weather Modification, Clermont-Ferrand, 557-563.

Hitschfeld, W.F., 1977: Hail: A Review of Hail Science and Hail Suppression, G. B. Foote and C. A. Knigh, Eds., Meteor. Monogr. n° 38 Amer. Meteor. Soc., 193.

Mezeix, J.F., and P. Admirat, 1978: Atmos. Ocean 16 (1), 61-68.

__________, and N. Doras, 1981 a: J. Appl. Meteor. Soc., Vol. 20, n°4, 377-385.

__________, and J.P. Rouet, 1981 b: Amer. Meteor. Soc., Vol. 20, n°4 377-385.

Morgan, G., and N. Towery, 1975: J. Appl. Meteor. 14, 763-770.

Sulakvelidze, G.K., M.S.H. Bibilashvili and V.F. Lapcheva, 1967: Israel Program for Scientific Translations, Jerusalem, 208 pp.

Rouet, J.P. and G. Der Megreditchian, 1980: W.M.O. Scientific Conf. on Weather Modification, Clermont-Ferrand, 771-777.

Vento, D., 1976: J. Appl. Meteor., Vol. 18, 1521-1525.

Waldvogel, A., B. Federer, W. Schmid, and J. F. Mezeix, 1978. J. Appl. Meteor., 17, 1680-1693.

Weather Modification Advisory Board, 1978: Rep. U.S. Govt., Washington, D.C.