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RELIABLE VERIFICATION METHODS IN HAIL PREVENTION

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Abstract. Hail prevention effects are very difficult to verify in non-randomized experiments. Randomization techniques of historical precipitation data, as proposed by Gabriel, Hsu, 1980, are very useful and desirable but only rarely apply because they lack the homogeneous long period data sets. Physically meaningful parameters of simple cases such as global kinetic energy, maximum and mean size of hailstones, coverage of affected area, radar signatures of treated and untreated cells as time function, are proposed as variables to be examined. The preliminary results will show mainly the methodology. The small number of cases were characterized by decreasing energy and maximum size of hailstones in both the target and control area.

1. INTRODUCTION

The evaluation of any potential effects from hail prevention is still more controversial than the evaluation of precipitation enhancement programs. Is any verification possible if a project is a non-randomized one? Concerns in every case are related to the availability of reliable historical hail data covering the variables to be tested, and the maintenance of a chosen experimental design, especially the breadth of hail data during the whole period.

2. CHARACTERISTICS OF THE NON-RANDOMIZED HAIL PREVENTION PROJECT IN THE STUTTGART AREA

The target area includes some 2700 square kilometers around Stuttgart in southwest Germany. Controls include four adjacent areas (CA) and a far distant control area (CAF), each having about the same surface area as the seeding area (SA).

The operations periods have included the month of July in 1980 and the periods of 25 April through 15 October during the four-year period 1981 through 1984. The daily operations period was set for 0900 through 2100 local time. Operations criteria following the morning upper air sounding includes (1) total totals stability index, (2) stability-energy, (3) precipitable water, (4) convection and a convective 12-hourly trend index, and (5) specific radar criteria. These radar criteria include an echo-core intensity of at least 30 dbz and the tops of the echo at least 25,000 ft. msl, provided the core is above the freezing level. Nucleation is provided by pyrotechnic generated silver iodide dispensed from aircraft flying near cloud base.

3. BASIC REFLECTIONS ON VERIFICATION POSSIBILITIES

It will never be possible to demonstrate that an area without hail observed on the ground during a seeding period would have experienced hailfall during a no-seeding case. Nearly all verification efforts are linked to analogous methods in comparisons "with and without intervention". A reliable statistical verification of non-randomized projects must also be based on reliable historical data before, during and possibly following the experimentation period in order to avoid influences from "natural" variations or tendencies in the hail pattern.

The idea of re-randomization of historical data (Gabriel and Hsu, 1980) can be very useful. The main techniques of actual comparisons in rain modification are in the form of double ratios, target regression on controls, target regressions on first principal components of controls, two target-regressions (seeded and unseeded samples) and non-parametric rank power statistics. In the case of hail even the choice of a key variable is somewhat controversial. This is due to the fact that really meaningful variables such as global kinetic energy are lacking for long periods of record, a necessary item in the use of historical hail data. The global kinetic energy might be the result of smaller numbers of very large hailstones or very high concentrations of smaller hailstones. Further, the numerous variables representing agricultural or industrial damage are seldom objective indicators of total hailfall.

The choice of an adequate method for the necessary study of historical hail data (even when trying to apply test methods as proposed by Gabriel and Petrondas, 1983, using samples of two k consecutive seasons, dividing these into two periods of k seasons, considering the first as historical and the second as operational) suffers from the variability of observation stations in time and space. The latter is very sensitive to results related to the small mean areas of hail cells (some 2 sq. kilometers $\geqslant$45 dbz). A possible approach would be to combine the basically different verification methods.

Fortunately in southwest Germany a transformation of available hail diameter data (both mean and maximum sizes) was possible due to a kind of "calibration" by close-exposed hailpads during 1979 and 1980, immediately before the project became operational in the Stuttgart area. Beginning in 1953 every community has indicated on special reporting forms detailed hail observations. Hence, for about three decades before the experiment, hail data are available on frequency, coverage, duration, hail path, and the mean and maximum hailstone sizes. It is proposed to use these data sets for re-randomization, at least forward from 1969.

The rarity of hail per any given square meter per season is cause for extreme caution with any interpretation. Area coverage data as obtained with some recognized error by radar appear necessary. For this reason, a climatological-statistical inventory of hail cells has been initiated with the video recording and analysis of PPI data form the 5cm radar system.

4. PROPOSED VARIABLES TO BE TESTED

4.1 One of these variables is the total hail energy (global kinetic energy E_G) deduced from a number n_i of measured hail diameters d_i within the interval d_i of each of the m observed intervals. The point kinetic energy E_T also depends on the density of the air (mainly the altitude of the area).

$$E_T = 4.5o \cdot 1o^{-6} \sum_{i=1}^{m} n_i d_i^4 \; [J / m^2]$$

Considering the number of hail-affected pads (p) and the area s $(km^2) \rightarrow E_G$

$$E_G = s_i \sum_{j=1}^{p} E_{T_j} \; [1o^6 \; . \; J] .$$

Doras (1982) proposed increments for spatial energy as:

$$E_{x,y} = E_M \, e^{\left(\frac{-x^2}{a^2} \frac{-y^2}{b^2}\right)} \; [1o^6 J]$$

with E_M = maximum kinetic hail energy, x,y = horizontal coordinates a,b, = empirical coefficient s. We obtained as "reduced" kinetic energy $[10^6 J/m^2]$ per k km^2 of SA and CA as noted in Table 1.

Table 1.

Reduced kinetic hail energy $[10^6/m^2]$ on seeded and unseeded days in 1980-1984 (Stuttgart area)

	Cases	SA	CA
a. seeded days:	53	0.42	0.48
b. unseeded days:	22	1.34	0.77
a/b		0.31	0.62

The comparisons a/b for both SA, CA and (since 1983) of CAF are noted.

4.2 The comparison of hail affected areas (coverage) the mean of $\bar{E}_F$ between SA and CA for both periods (prior to project initiation, 1969-1978) and for the operational period is further proposed as

$$\int_{SA_{1981-89}} \bar{E}_F - \int_{CA_{1981-89}} \bar{E}_F \cong 0^{+)} \text{ and } \int_{SA_{1969-78}} \bar{E}_F - \int_{CA_{1969-78}} \bar{E}_F \cong 0^{+)} .$$

+) in the case of no-seeding effect.

4.3 The mean of all data ("point-values") of mean hailstone diameters the mean of $\bar{d}_i$ between SA, CA and CAF for both periods (ϑ 2°) is compared:

$$\bar{d}_{SA_{1981-89}} - \bar{d}_{CA_{1981-89}} \cong 0^{+)} \text{ and } \bar{d}_{SA_{1969-78}} - \bar{d}_{CA_{1969-78}} \cong 0^{+)}$$

+) in the case of no-seeding effect.

4.4 A comparison of the power of treated and untreated hail cells at the beginning of seeding, time t_0 and at a given time t_i following the seeding, will be tested for significance.

$$\frac{\sum P^+_{zt_i} - \sum P^+_{zt_o}}{\sum P_{zt_i} - \sum P_{zt_o}} = 1.oo, \text{ if there is no seeding effect.}$$

This hypothesis will be verified with P_Z^+ are the chosen treated hail cells and P_Z was the chosen untreated hail cells.

4.5 A comparison of the "coverage" will be verified using the difference between treated and untreated cells at the beginning of seeding (t_0) and at a given time following seeding (t_i).

$$\frac{\bar{C}^+_z t_i - \bar{C}^+_z t_o}{\bar{C}_z t_i - \bar{C}_z t_o} = 1.oo \text{ , if there is no seeding effect}$$

with $\bar{C}_Z^+$ treated hail cells coverage, $\bar{C}_Z$ untreated hail cells coverage to be chosen with t_0, t_i defined as above.

The base of comparison should be non-seeded days in a manner as follows:

a) seeding days, with coverage of stratified seeded cells (c_s) and unseeded cells (c_{us}):

$$\frac{c_s}{c_{us}} = A$$

b) no-seeding days: chosen group of unseeded cells (c_{us}) and unseeded cells: (as above) (c'_{us}):

$$\frac{c_{us}}{c'_{us}} = B$$

"B" is expected to be close to 1.00. Variations from 1.00 are due to non-representative sampling or "noise".

$A \ll B$ is expected if a seeding effect is positive, and $A \gg B$ if a seeding effect is negative.

5. PRELIMINARY RESULTS

It is important to identify the conditions before the start of any project. In the case of the 1969-1978 period (as deduced from the community hail reports after "calibration", one should deduce the mean (m) hailstone diameters maximum (M) hailstone diameters, and the mean time duration of echo cores. These values are shown in Tables 2 and 3.

Table 2

Mean ($\overline{m}$) and maximum ($\overline{M}$) diameters (mm) corresponding kinetic energy ($\overline{E}$ in 10^{-3} J, $\overline{E}_M$ in J.)

	$\overline{m}$	$\overline{M}$	$\overline{E}$	$\overline{E}_M$
SA	10.50	20.20	54.70	748.80
CA_i	10.00	19.30	45.00	622.80

Table 3

Mean duration of echo cores ≥45 dBz

	Occasions with seeding (1984) in (minutes)	Occasions Without seeding (1983, 1984) in (minutes)
SA	9	12
CA_W	19	
CA_N	19	20
CA_E	13	
CA_S	19	
ALL CA's	17	20
SA-CAi	-8	-8

The mean duration of echoes ≥45 dbz decreased slightly.

The mean simultaneous duration of an echo core ≥45 dbz within SA was only 60% of the duration of all CA_i on days with seeding and 75% on days without seeding.

In the case of seeded cells, the area covering a core echo intensity of ≥ 45 dbz decreased by 17% when seeded cells are compared with non-seeded cells within the adjacent control areas (CA_i) this decrease in seeded core echo intensity is approximately 86% some 10 minutes following seeding.

Hail diameters and numbers of hailstones were compiled from a hailpad network installed at the end of 1982 in the far distant control area (CAF) of the Kaiserstuhl, some 100 km southwestward of the seeding areas (SA). The results are presented in Table 4.

Table 4.

Mean ($\overline{m}$) and maximum ($\overline{M}$) hail diameters in mm, number (n_2) of individual hailstones per 0.1 m^2, percentage of oval hailstones (%), mean kinetic energy $\overline{E}$ in 10^{-3}J, maximum kinetic energy of the largest hailstone E_M in joules, and the total kinetic energy per hailpad in 10^{-3}J (averages of 1980-1984 data).

	$\overline{m}$	$\overline{M}$	n	%
SA	6.94	11.06	2069	10.6
CA_W	6.34	8.28	2447	10.2
CA_N	5.66	7.60	1899	7.4
CA_E	6.22	10.60	2174	15.8
CA_S	7.25	11.63	1831	14.0
CAF	7.30	10.30	1125	24.12
SA	7.18	9.52	1639	15.00

	$\overline{E}$	E_M	E
SA	10.80	80.74	21.99
CA_W	9.70	28.26	27.90
CA_N	5.03	19.59	8.10
CA_E	6.98	65.48	14.90
CA_S	14.07	119.91	21.48
CAF	14.98	75.06	24.12(only '83,'84)
SA	12.10	37.67	20.40(also '83,'84)

It can be concluded that the experimental area received during the first five seasons about 20% of the mean kinetic hailstone energy of the average of the previous 10 seasons. The mean kinetic energy of the control area decreased from 45 (10^{-3} J) to 8.95 (10^{-3} J), also 20% of the historic value. Additionally, the mean maximum hailstone size decreased from 20.2 mm to 11.06 mm (54.7%) within the SA, and from 19.3 mm to 9.53 mm (49.4%) when comparing the 1969-1978 period with the 1980-1984 period.

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