Comments on "Main Results of Grossversuch IV"

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The results of the Grossversuch IV experiment, such as they are, presented by Federer et al. (1986) give the Soviet method of hail prevention by rockets almost no chance of efficiency, at least when this method is used in Switzerland. Although the authors have found some signs of a seeding effect, they attribute them to mere chance. Nevertheless, I would like to show that a simple analysis of the distribution of the daily hailfall kinetic energy suggests that a seeding effect is most probable.

The Soviet scientists state that if seeding reduces the hail damage in the most common situations, it may be partially unsuccessful in the worst ones (Burtsev, 1985). This variable response of the seeding must increase the concentration of damage on very few days, so that the daily energy distribution of hailfall for the seed and no-seed samples may be different. We may check this hypothesis with the data presented by Federer et al. (1986).

The double cumulative curve (DCC) (Crow, 1982) is a convenient illustration of the distribution of hail on various days: the cumulative percentage of hail energy, ordered from the largest to the smallest value, is plotted against the cumulative percentage of hail days. For the Grossversuch experiment, using the data presented in Table A1 by Federer et al. (1986), DCCs can be drawn with the values of the global hailpad kinetic energy E_G for the seed hail days and for the no-seed hail days (Table 1, Fig. 1).

It can be seen that the concentration of hail is greater for the seed sample; for example, 85% of the total E_G is produced by 5 days in the seed sample versus 11 days in the no-seed sample. This result is consistent with a lower effect of the seeding for the worst days.

Crow (1982) presents a formula for testing the significance of the difference between two DCCs. In order to use this formula, it is first necessary to test whether each of the samples is consistent with an exponential distribution. In fact, the Kolmogorov-Smirnov test for the exponential distribution (Lilliefors, 1969) does not reject the hypothesis of exponentiality at the 0.20 significance level. We may then use the method described by Crow (1982); with his notations, we have

$$\max K(q) = 0.089 \quad \text{at} \quad q = 0.166$$

$$\text{Variance of difference of two DCCs} = 0.071\ K(q)$$

$$\text{Standard deviation} = 0.079.$$

The difference observed in Fig. 1 is 0.160, which is 2.02 times the standard deviation and, hence, is significant at the 5% level. It may be argued that the days when hail was forecast but did not occur must be included in the distributions. If they are, the difference between the two curves decreases to 0.135, but since the samples are larger (32 and 43 instead of 26 and 31), the significance level still reaches the 5% level.

We may conclude that the two samples of hail days, which resulted from the randomization process, are different. Two alternatives are offered:

1) The difference between the two samples is due to the randomization, and not to the seeding. We then must be very suspicious of any randomization process

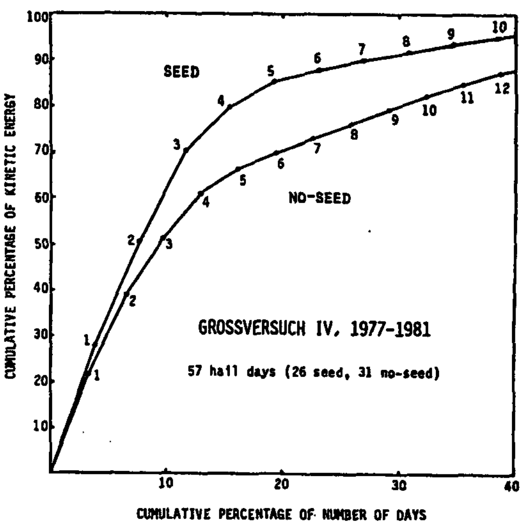

FIG. 1. Cumulative percentages of hail energy per day versus the percentages of the number of hail days. Numbers are the ranks n_i of the daily energy.

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TABLE 1. Percentages and cumulative percentages of daily kinetic energy E_G; n_i is the rank of the day, ordered from the highest to the lowest value of E_G. [From Table A1 in Federer et al. (1986).]

	Seed days, $n = 32$, $\Sigma E_G = 60254.42$ MJ				No-seed days, $n = 43$, $\Sigma E_G = 51249.99$ MJ		
n_i	Date	E_G (%)	$\sum_1^{n_i} E_G$ (%)	n_i	Date	E_G (%)	$\sum_1^{n_i} E_G$ (%)
1	25 May 1977	27.7	27.7	1	1 Jun 1978	21.7	21.7
2	18 Jun 1977	22.8	50.5	2	31 Jul 1978	17.1	38.8
3	14 Jul 1978	19.7	70.2	3	18 Jul 1978	12.4	51.2
4	10 Jun 1979	9.5	79.7	4	7 Aug 1979	9.8	61.0
5	30 May 1979	5.8	85.5	5	15 Jun 1980	5.2	66.2
6	8 Aug 1981	2.2	87.7	6	24 Jun 1977	3.6	69.8
7	6 Aug 1978	2.0	89.7	7	5 Sep 1978	3.2	73.0
8	30 May 1977	1.8	91.5	8	31 May 1978	3.1	76.1
9	17 Aug 1977	1.7	93.2	9	5 Jun 1979	3.0	79.1
10	6 Aug 1981	1.5	94.7	10	12 Jul 1979	3.0	82.1
11	9 Jul 1981	1.3	96.0	11	19 Jun 1978	2.6	84.7
12	3 Jun 1981	1.2	97.2	12	18 Aug 1977	2.4	87.1
13	8 Jul 1977	0.8	98.0	13	10 Jul 1981	1.8	88.9
14	6 Aug 1979	0.7	98.7	14	19 Jun 1977	1.6	90.5
15	30 Jun 1978	0.3	99.0	15	6 Jun 1980	1.5	92.0
16	31 May 1981	0.2	99.2	16	15 May 1981	1.5	93.5
17	8 Jun 1978	0.2	99.4	17	12 Jun 1979	1.3	94.8
18	16 Jun 1981	0.2	99.6	18	29 Jul 1980	0.9	95.7
19	11 Jul 1978	0.1	99.7	19	9 Sep 1979	0.8	96.5
20	5 Jul 1977	0.1	99.8	20	17 May 1978	0.7	97.2
21	7 Aug 1977	0.06		21	2 Jun 1979	0.6	97.8
22	18 Aug 1980	0.06	99.9	22	3 Jun 1978	0.5	98.3
23	10 Jun 1977	0.04		23	3 Aug 1979	0.3	98.6
24	15 Aug 1980	0.04		24	21 May 1980	0.3	98.9
25	26 Jul 1980	0.03		25	21 Jun 1977	0.3	99.2
26	26 May 1980	0.003	100.0	26	30 May 1981	0.3	99.5
27 to 32	6 days, no hail			27	22 Aug 1977	0.2	99.7
				28	24 Jun 1981	0.1	99.8
				29	31 Aug 1981	0.07	99.9
				30	25 Jun 1981	0.06	
				31	25 Jun 1978	0.03	100.0
				32 to 43	12 days, no hail		

in past or future hail prevention experiments. However, the probability of such a large difference under the null hypothesis is only 0.05.

2) The difference results from the seeding, and not from the randomization. This means that the seeding increases the concentration of hail, by increasing hail in some circumstances and/or decreasing it in others.

If we suppose that the distribution of the seed-days sample before the seeding was identical to the distribution of the no-seed sample, then the seeding must have variable response according to the hail day severity. Examples of seeding responses, computed from the data of Table 1, are given in Table 2.

In the three examples, the change due to the seeding which is necessary to explain the difference between the two samples, is large enough. Everyone may consider the most probable type of seeding response according to his opinion on hail prevention. For example, the Soviet claims are consistent with type (a) seeding response.

When the cell is considered as the experimental unit instead of the day, the analysis presented leads to the same results with a significance level better than 1%, either with or without the zero cases. However, we may

TABLE 2. Cumulative percentages of daily kinetic energy for the seed sample; actual distribution after seeding, and most probable distribution before seeding. Three examples of variable seeding response leading to the observed difference are given.

Seed days n_i	ΣE_G (%) after seeding	ΣE_G (%) before seeding	Relative change (%) due to seeding (a)	(b)	(c)
1–5	85.5	70.0	−50	0	+77
6–26	14.5	30.0	−80	−60	−30
1–26	100.0	100.0	−59	−17	+45

wonder whether the cells should be considered as independent, as required for the DCC variance calculation.

In conclusion, the analysis of the distribution of hail for the seed days and for the no-seed days strongly suggests that there is an effect of the seeding on the kinetic energy of the hailfall, and that this effect depends on the hail-day severity. Finally, we can propose the following scenario, which may reconcile the results of Grossversuch IV with the Soviet claims: in the regions of U.S.S.R. where the seeding is highly efficient, major hail days are perhaps exceptional, so that the mean effect of seeding is large. In Switzerland, major hail days are not rare, and the mean effect is lower. Would it be possible to continue this discussion by considering the seeding efficiency in Grossversuch IV after a stratification of hail days?

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