Reply

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Dessens (1987) raises several important aspects of the complex problem of hail suppression. His aim is to produce a compromise between two incompatible findings: the results of Grossversuch IV versus the Soviet claims. This effort is welcomed; however, the methods and ideas proposed by Dessens cannot withstand a thorough analysis, as too many vague assumptions have to be made. For the long-term benefit of understanding the mechanism of hail formation, per se, and to illuminate the still inconsistent situation of hail prevention, it seems to be worthwhile to discuss some points in detail.

1. Double cumulative curve and test

A large amount of effort and preparation was invested in the planning of Grossversuch IV. An attempt was made to define the final test before any data have been evaluated, so that any possible bias from the test itself on the outcome of the main result could be avoided. In addition, a search was made for the most powerful evaluation method using predictor and discriminant functions, the most appropriate test, an exactly measurable test variable, etc. The whole procedure was published well in advance of the evaluation phase of Grossversuch IV (see Federer et al., 1978–79). The confirmatory evaluation of the Grossversuch IV experiment using two completely independently measured sets of data (hailpad and radar) is well known: there is no statistically significant difference between the seeded and unseeded hail cells [Federer et al. (1986)].

Among the many additional exploratory tests made and also published in Federer et al. (1986), there are some (8 out of 110) which indicate a seeding effect ($P \leq 0.05$). It is interesting to note that two have a favorable seeding effect, whereas six have an unfavorable seeding effect. It is well known that statistically significant results can appear due to the multiplicity effect, i.e., some out of a number of tests turn out to be significant by pure chance. The largest number of exploratory tests, however, do not have any seeding effect at all. These facts should be kept in mind when considering the additional exploratory test proposed by Dessens (1987).

In his test, Dessens uses the method published by Crow (1982), which he applies to daily hailfall kinetic energies measured by hailpads during Grossversuch IV. Dessens states that "a seeding effect is most probable." It seems that the procedure described by Dessens (1987) was performed correctly, which means the double cumulative curves (DCC) from seeded and unseeded hail days are significantly different at the 5% level. We doubt, however, that this result demonstrates a significant difference in the size distributions of the two samples. There are several reasons which make the reliability of Dessens' analysis uncertain:

(a) The assumption of an exponential distribution is not correct. Hail energies follow a lognormal distribution rather than an exponential distribution (Federer et al., 1986). Why not perform the test by assuming a lognormal distribution?

(b) The shape of a DCC is highly dependent on the largest case. Omitting the largest seed day (25 May 1977) and attributing it to the unseeded sample reduces the maximum difference between the two DCCs by about a factor of 2. No significant difference is found at all. How can we trust a test procedure which reacts so drastically to the shift of one single case?

A common way to reduce the influence of large outlying values is the logarithmic transformation of the data. The Kolmogorov-Smirnov test can be used to compare the seed and no-seed distributions of the logarithmic energy values. Doing this with the data from Dessens' Table 1, one finds a P-value larger than 0.2, i.e., the test result does not show any significant difference between the two samples.

(c) Dessens forgot the zero cases. His seeding effect model stipulates a reduction of hail energy due to seed-

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ing for the small cases. Under this hypothesis one would reasonably expect that the seeding is successful at least for very small cases. The number of zero values should become larger when seeding occurs. Only six zero values, however, appear in the seed sample, compared to 12 zero values which are found in the no-seed sample.

2. Variability of hailfalls

Another point discussed by Dessens (1987) is the natural variability of the kinetic energy of hailfalls. He suggests that there is a big difference in the hail climatology between Switzerland and the areas of hail prevention in the Soviet Union, insofar as the Grossversuch IV area would be characterized by more major hail days than the areas in the Soviet Union. No values about the natural variability of hail mass or hail kinetic energy of hailfalls measured by hailpads are available from areas in the Soviet Union. Therefore, we compare the hail climatology of the Grossversuch IV area with those of other countries having such information. Measurements from unseeded hail cells are considered only to exclude any influence of a possible seeding effect.

Knight et al. (1979) published DCCs (cumulative percent of hail–cumulative percent of number of hail days) for northeast Colorado, Alberta, Kenya and South Africa. Figure 1 shows these DCCs together with the curve for the Grossversuch IV data. To facilitate the comparison, hail mass instead of hail kinetic energy has been taken as has been done by Knight et al. (1979). It can be clearly seen that the curve (Grossversuch IV) is very close to the Alberta curve. The one from Northeast Colorado is also very close up to a cumulative percent of hail mass of 80%. The largest difference is found between the curves from GV IV and Kenya,

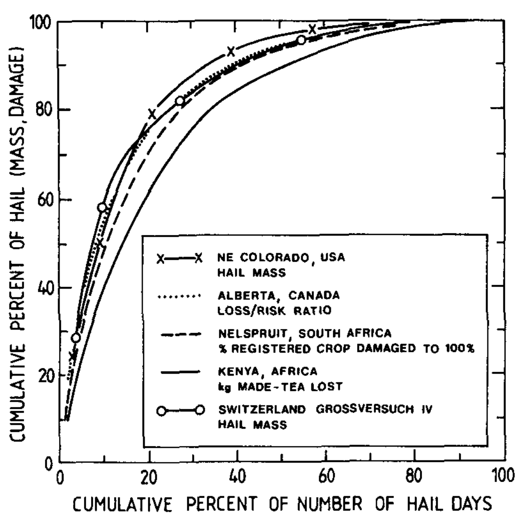

FIG. 1. Comparison of the double cumulative curves (cumulative percent of hail–cumulative percent of number of hail days) of northeast Colorado, Alberta, Kenya and South Africa with Switzerland.

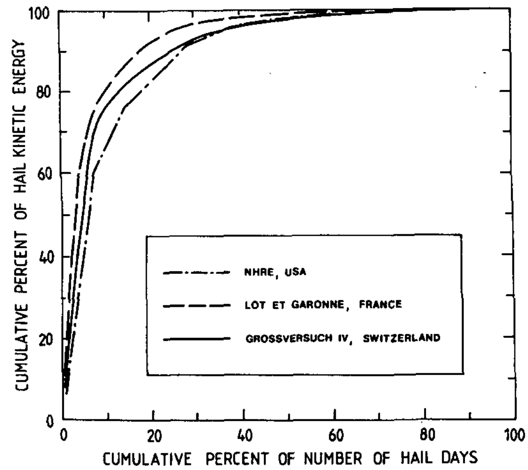

FIG. 2. Cumulative percent of hail kinetic energy measured on hailpad network versus the cumulative percent of the number of hail days for three different regions.

which could be due to the method (kg made–tea lost) used to derive a DCC (Kenya). Another comparison from different countries is given in Fig. 2. It shows DCCs with natural daily hail kinetic energy measured with three hailpad networks: NHRE, 14 natural cases; Grossversuch, 96 natural cases including preexperimental data; Lot et Garonne, 53 natural cases (Husson et al., 1984). As for hail mass, the kinetic energy shows a very similar climatological repartition between the three countries.

The comparison of the curves in both figures shows that, although there are large climatological differences between the different areas, there is an astonishing agreement between the different hail climatologies. Considering the agreement between the curves, it seems highly speculative to assume that the different areas of hail prevention in the Soviet Union with different climatologies should all show a drastically different behavior in corresponding DCCs, as suggested by Dessens (1987). But even if this would be the case, what would such a curve look like? It would have very few large cases with large damage and very many small cases with little or no damage. This would be reflected in a curve with a very steep initial slope. The "best" curve in this respect is the one from Grossversuch IV. Therefore, also from a climatological point of view, the hypothesis of Dessens (1987) is not confirmed.

3. Stratification of hail cells

Dessens (1987) also discusses the stratification of hail days. He correctly points out that this is a difficult undertaking. Before applying such a stratification on hail days or, as is more meaningful, on hail cells, we would like to give some general comments about such a procedure. There are two possibilities for seeded statistical units: One is the assumption that the seeding procedure has no effect at all. The alternative is that some reaction takes place after seeding. In the first case there is no problem to make a stratification of the cells in small and large ones. In the second case, however, it is an impossible task, because some large, seeded hail cells are large due to the seeding (unfavorable effect), and therefore would belong to the group with small hail cells. Other large, seeded hail cells did not react to the treatment and therefore really are large ones. The third possibility is that the seeding effect was a favorable one, and then the originally large hail cell has to be found in the ensemble with small cells. It is clear that similar possibilities can be developed for small, seeded hail cells. At the present time it is not possible to separate hail cells which behave in the complex manner just described.

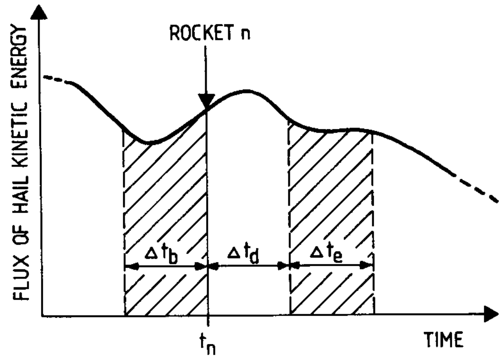

FIG. 4. The time evolution of the flux of the hail kinetic energy of a seeded hail cell. Time intervals are Δt_b, before seeding; Δt_d, delay time; Δt_e, effect of seeding.

4. Seeding coverage

A further important aspect of a weather modification experiment is the quality of seeding. It could well be that large, seeded hail cells got large because the seeding was bad, whereas small, seeded hail cells were small because of a good seeding operation. It has been considered that a stratification of seeded hail cells or any other statistical unit is an impossible task at present. To clarify at least some aspects of the quality of seeding and the development of seeded hail cells, an investigation has been made to see whether large cells have a lower seeding coverage compared to the small ones.

The detailed description of this analysis is given by Schiesser and Waldvogel (1985). The main result is as follows: large hail cells have better seeding coverage than small cells. At first glance, this looks like a contradictory result; however, when considering the operational and logistical problems of a seeding operation it becomes clear that a large and thus long-lasting cell (see Waldvogel and Schmid, 1982) can be treated more easily. This is illustrated in Fig. 3, where the seeding coverage is plotted against the duration of the hail cell.

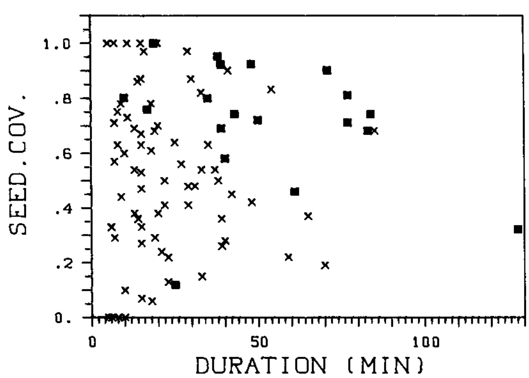

FIG. 3. Scatter diagram seeding coverage against duration of the hail cell. Closed squares; 19 larger storms having kinetic energies (E_{GR}) > 1 GJ.

A total number of 99 seeded hail cells have been studied: 19 out of the 99 are large cells having kinetic energies larger than 1 GJ. The large cells are represented with a black dot in Fig. 3. Looking at this figure, one immediately sees that on the average, the large cells have a better seeding coverage than the small ones: about 85% of the large cells (16 out of 19) have a seeding coverage larger than 50%, and for about 70% (13 out of 19) the coverage is even larger than 70%. The average seeding coverage for the 19 large cells is 0.69 and for all the 99 seeded hail cells it is 0.58.

Considering that the 19 long-lasting hail cells contribute to 96% of the total kinetic energy of all the seeded hail cells, and further considering that these cells had a good seeding coverage (~70%), it is difficult to explain the outcome of the Grossversuch IV experiment with the excuse that there was a bad seeding coverage.

Another, and an even more detailed approach to evaluate the seeding quality is by considering single-seeding events (rockets). Such an evaluation has been published by Waldvogel and Schiesser (1985). The main idea of this study is the comparison of the kinetic energies of the hail cell measured during two time intervals Δt_b and Δt_e. The interval Δt_b (10 min) represents the time immediately before the seeding, while Δt_e is the time interval (10 min) during which the reaction of the seeding can be measured. It is clear that there is a third time interval Δt_d (delay) during which the seeding material is dispersed and the microphysical reactions of hail suppression take place. A schematic picture of this idea is shown in Fig. 4.

The justification of this evaluation is the hypothesis of the seeding operation which states: whatever development or treatment a hail cell has undergone before a distinct seeding event, the hail production will be reduced after a given delay time during which the seeding material of the rocket n could act. It is clear that a successful seeding operation should have a smaller energy value E_e measured during Δt_e when compared

	negative differences (N)		positive differences (P)	
5	98765	0	1346	4
7	6665541	1	0789	4
20	99887666655544321111	2	11789	5
10	9986553210	3	11234446666777777778899	23
24	999998888766644433331110	4	001122333444667779	18
19	9999988666554333322	5	1112567888999	13
21	655533333222221111000	6	00011112223333445555566777	26
		7	00	2
1	2	8		
107				95
	$\overline{\ln(\lvert D61\rvert + 1.0)} = 4.22$		$\overline{\ln(D61 + 1.0)} = 4.54$	
	ratio N/P = 0.93			
	P = 0.18			

FIG. 5. Stem and leaf diagram of the logarithms of negative and positive differences of kinetic energy (using E_{61}) for 202 seeding events and the time intervals $\Delta t_b = \Delta t_d = \Delta t_e = 10$ min.

with the one E_b measured during Δt_b. And it is also clear that the difference D, defined as

$$D = E_e - E_b \qquad (1)$$

should be negative in such a case. The data of 202 seeding events for the 19 large hail cells previously mentioned are given in Fig. 5 in a stem and leaf diagram, showing the logarithms of negative and positive differences as defined in Eq. (1). A randomization test of location, testing the hypothesis that no difference would be found between the two averages showed a non-significant two-tailed P-value of 0.18. Other time intervals for the delay time Δt_d and for the seeding effect (Δt_e) have been tested in the same way, but none of the calculations showed any significant difference.

5. Conclusions and discussion

Several points of the comment by Dessens (1987) about the main results of Grossversuch IV have been investigated. Conclusions are as follows:

- It is true that there is a statistically significant difference between seeded and unseeded hail days when using the DCC method. The result of Dessens (1987) is highly unstable, however, which means the change of one single case alters the outcome. When taking into consideration the zero cases, which is a more reasonable evaluation procedure, the outcome is also different. Further, this is just one among many possible exploratory analyses, and therefore the result could well be due to the multiplicity effect.
- The idea of a different hail climatology in the Soviet Union seems highly speculative. Astonishingly similar behavior has been found for different climatologies all over the world.
- Seeding of large cells is better than small ones. Therefore, it is difficult to understand why small cells should show a favorable effect which cannot be found for the large cells. Even if this would be the case, the method is very questionable because large cells (19 out of 99) contribute 96% of the total hail kinetic energy. Therefore, what is the value of a method which can eventually decrease damage by only 4% of the total hail damage?
- An investigation of single seeding events (rockets) has shown that there is no statistically significant difference between kinetic energies measured before the seeding event and after the reagent should have shown its effect, and therefore should be measurable. This result is found when all rockets fired into the hailstorms are considered, as well as when only those events are analyzed which represented a perfect seeding coverage; i.e., the rocket was at the right time at the right place and operated correctly.
- The microphysical and dynamical investigations with the T-28 airplane in Grossversuch IV thunderstorms (Waldvogel et al., 1987) question the main idea of the hail prevention method: graupel particles but no supercooled raindrops have been found in the radar-identified big drop zones.
- There is a large number of different confirmatory and exploratory tests (over 100) which have been applied to the data of the Grossversuch IV experiment, and there are investigations about the seeding coverage of hail cells and about the effect of single perfect seeding events plus microphysical in situ measurements with the T-28 aircraft. The tenor of all these results and measurements is clear. *There is no statistically significant difference between seeded and unseeded hail cells, and from a microphysical point of view it would be surprising if there were.* If this result is valid for Swiss hailstorms only or if it has a more general significance cannot be answered at the present time.

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