GROUND SEEDING: A VERY POWERFUL TECHNOLOGY FOR THE FUTURE OF HAIL SUPPRESSION

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1. INTRODUCTION

For the past thirty years, ground seeding has been widely used for hail prevention, within various countries and under many conditions. Up to the present day, no really positive results are emerging at any place in the world concerning the efficiency of this seeding technique. For many scientists, "Grossversuch III" experiment (1957-1963), or "Mendoza" experiment (1959-1964) are always in mind when negative tests are recalled.

Three recent tests concerning direct seeding of hailstorms, the "N.H.R.E." (rockets), the "ALHAS" experiment (seedings from cloud base and cloud top), and the "Grossversuch IV" experiments (rockets), have not pointed out a more successful way to solve the hail prevention problem for economical applications to agriculture.

Therefore, thanks to these kinds of experimentation, the technologies for cloud seeding and for hail precipitation analyses were stimulated. A new three-year program has been fully supported by the Provencial Administration of Vicenza (Northern Italy), to test, under the U.C.E.A.'s control, the effects on hail precipitation of a new ground seeding technology, in which the nuclei production at ground level is without equivalent. The previous program was:

- full seeding over the Vicenza target area, but no seeding either over the Verona control area, or over the Trevisa control area (operating in 1978), as located in Fig. 1,
- seeding power and storm seeding factor on storm basis to be determined by an instrumented aircraft,
- hail impact energy densities recorded by dense hailcube networks, in both target area (107 hailcubes 720^2km) and control area (98 hailcubes, 850^2km).

The detailed experimental data have been published in numerous technical reports (e.g., Caponigro, 1983).

In this paper, the results of the seeding power measurements and of hail precipitation characteristics over the target and control areas during the three-year period are summarized.

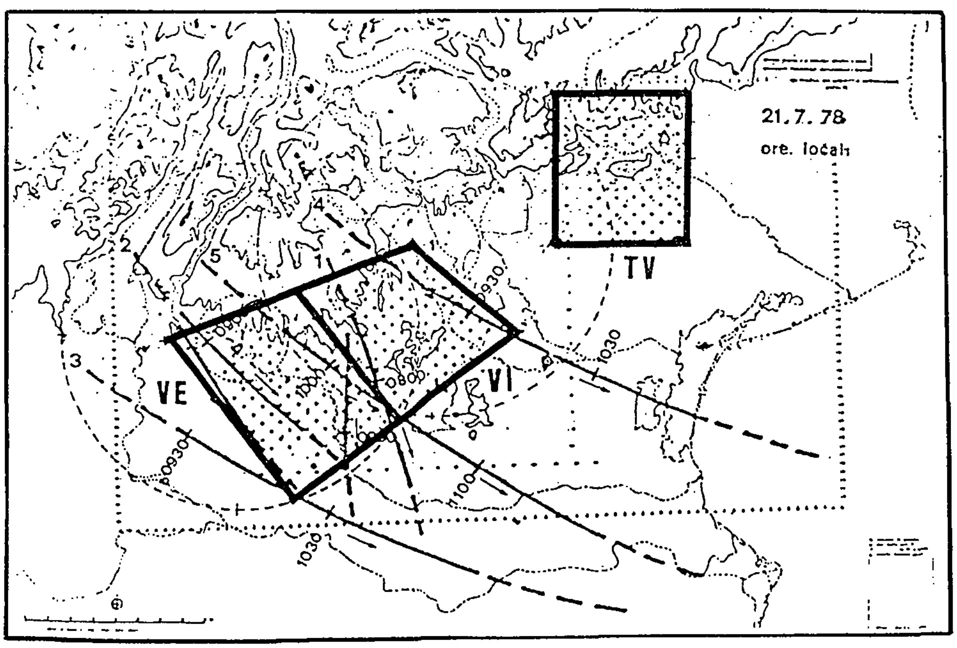

Figure 1. Hailcube networks on target area VI (Vicenza), control areas VE (Verona) and TV (Treviso). Superimposed, 5 storms trajectories, on July 21st, 1978.

2. A VERY POWERFUL SOURCE OF NUCLEI, ACTIVE AT -10°C, AT GROUND LEVEL.

The GMI 10/BTA is a new kid of AgI generator developed by SOREM (Buscaglione, 1977). It burns 100 gr of AgI per hour, from an AgI-Butylamine solution. Its average nuclei production (130 analysis is 2x10 active nuclei at -10° C per hour (Admirat, 1984). The network contains 15 GMI, each one mounted on a trailer and in radio-contact with the radar center. During the seeding, they move on pre-determined roads in front of storm trajectories. These generators burn from the hour that precedes the storm and are switched off after its passage. A seeding operation rarely exceeds 2 hours.

On the storm scale, this network can be considered as a single flat source, that has a surface area of 1800 km and can be characterized by a seeding power of

$$Q_V = \frac{15x2x10^{16}}{1800} = 1.6x10^{14} \text{ nuclei/hour.km}^2$$

(at -10° C). The same calculation for the "Grossversuch III" network and for the "Mendoza" network respectively gives

$$Q_V = 2.6\ x_2 10^{II} \text{ and } Q_M = 8.2 \times 10^{12} \text{nuclei/}$$

hour.km (at -10° C). The seeding power from "Vicenza" network is respectively 640 times and 20 times higher than the "Grossversuch III" or the "Mendoza" program. Other comparisons (Admirat and Buscaglione, 1982) showed that the "Vicenza" network is the most powerful source of active nuclei at -10° C, ever used in the field of hail prevention.

3. A HIGH "STORM SEEDING FACTOR" BELOW STORM

The ice forming power in the air over the target and the control areas has been analyzed by means of a two-liter cloud chamber, cooled to -10° C, installed in an instrumented twin-engine aircraft.

In anticyclonic atmospheric conditions (without ground seeding), and the distribution of the values of the natural ice forming power of air at 1500 meters a.s.l., shows (Figure 2) that 84% are between 0 and 3 ice crystals per litre, at -10° C. The average value of 131 analyses during the three-year period is 1.7 c/l. This rather high value probably indicates some influence of residual AgI nuclei over the experimental zone.

The atmospheric conditions are particularly favorable to the atmospheric diffusion from the Po Valley (alt. 30m) to the foothills of Alps (alt. 1000 to 1500 m) by means of daily breezes. Some ground seeding was carried out in order to measure the diffusion-deactivation factor of the AgI plume over a few kilometers downwind (less than one hour).

In the cases when a quasi-steady state is established, the analyses show an increase by two orders of magnitude in the ice forming power of air near the nuclei source (less than 2 km), and only by one order of magnitude at 10-15 km downwind. These results are in good agreement with those obtained in France (Soulage and Admirat, 1968).

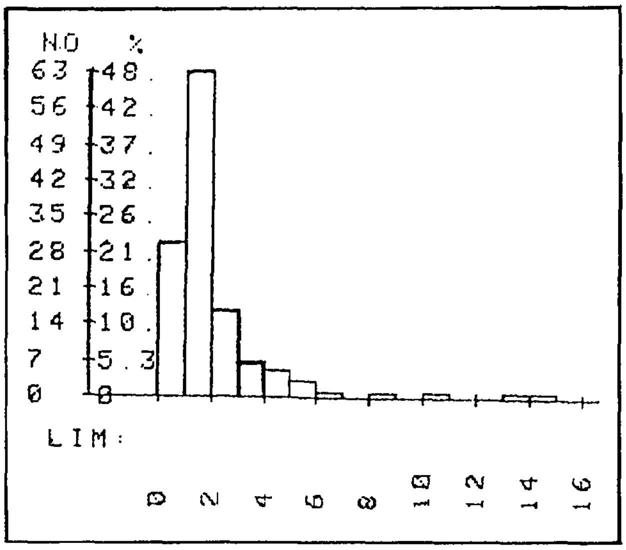

Figure 2: Statistical distribution of 131 values of the ice forming power of air, at -10° C, and at 1500 m a.s.l. over the target area.

In stormy weather conditions, the analyses were performed in the updraft just below the cloud base when the storm was crossing the target area. The results of 31 analyses range from 30 to 200 c/l, at -10° C. Therefore, we conclude:

- such nuclei concentrations, at this temperature, prove that most of AgI nuclei are active as seeding nuclei at cloud condensation level following atmospheric diffusion, transfer and deactivation
- a storm seeding factor (S.S.F.), defined as the ratio of artificial to natural nuclei, can be quantified in this case between 100 and 500 at 10°C. For various past ground seeding experiments in other areas the S.S.F. only ranges between 1 and 10 (Admirat and Buscaglione, 1982). As expected, the "Vicenza" network has the most important seeding power of all the ground based technologies.

4. REDUCTIONS IN ENERGY DENSITIES AND MASS OF HAIL ON TARGET AREA

During the three-year period 1977 through 1979 (April 15 - October 15), detailed data have been collected from 26 hailstorm cases.

The methodology for calculating kinetic energy densities from dents on a styrofoam-aluminum sheet was the same as in use during the "Grossversuch IV" test (Admirat and al., 1980). In Table 1, only average values of E_0, E_T and M_T are summarized. The corresponding values are lower in the target area than in the control area, except for the total hail mass in 1978. These measured reductions in kinetic energy densities are also observed from economical data over the two periods 1970-76 and 1977-79, as shown in Table 2.

The surface area damaged by hail impact is reduced by 57% in the target area and only 35% in the control area.

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Table 1: Average values over target (Vicenza) and control (Verona) areas of:
E_T = point density of the total kinetic energy
E_o = point density of the vertical component of kinetic energy
M_T = point density of the total hail mass

Year		1977	1978	1979
E_T $J.m^{-2}$	Target area	57	98	326
	Control area	71	106	326
E_o $J.m^{-2}$	Target area	45	74	147
	Control area	60	85	208
M_T $Kg.m^{-2}$	Target area	0.56	0.78	1.35
	Control area	0.68	0.68	1.71

Table 2: Damaged surface area (km^2) from economical data and relative reduction in target and control areas.

Period	1970-76	1977-79	Reduction
Target area	6153	2633	- 57 %
Control area	5256	3418	- 35 %

5. MODIFICATIONS OF THE HAIL-SIZE SPECTRUM IN TARGET AREA

In Table 3, the average numbers of stones per m^2, the number of cases, and the relative frequencies have been classified according to the hailstone sizes. These values show the largest stones occur in the control area, while the number density of the smallest ones is approximately equivalent in both areas. In 1978 this happened only in a few cases.

The average values of λ and n_0 of the Marshall-Palmer distribution are shown in Table 4. While λ and n_0, can be considered as constant during the three-year period within the target area, they change substantially in the control area. So we have λ, n_0 (target area)$>\lambda$, n_0 (control area) only in 1978 and 1979.

Therefore, these differences are in good agreement with a theoretical modification of a hail-size spectrum by seeding.

Table 4: λ and n_0 values of hail-size spectrum in target and control areas.

Year	1977	1978	1979
λ (target area)	0.081	0.083	0.081
λ (control area)	0.098	0.036	0.067
log n_o (target)	3.715	3.646	3.822
log n_o (control)	3.854	2.909	3.558

Table 3. Intercomparson of average hail size spectra, in target (Vicenza) and control (Verona) areas.

Year	Diameter (mm)		[6-9]	[10-13]	[14-17]	[18-21]	[22-25]	[26-29]	[30-33]	[34-37]	[38-41]	[42-45]
1977	Target area	(1)	1971	445	147	237						
		(2)	50	30	12	2						
		(3)	53	32	13	2						
	Control area	(1)	2043	315	168	112	37					
		(2)	43	30	16	6	4					
		(3)	43	30	16	6	4					
1978	Target area	(1)	2168	351	139	75	42	41				
		(2)	108	162	57	31	10	3				
		(3)	29	44	15	9	3	< 1				
	Control area (Verona)	(1)	1564	314	110	84	54	75	66	41	50	25
		(2)	132	38	57	22	16	8	3	3	3	1
		(3)	46	13	20	8	6	3	1	1	1	< 1
	Control area (Treviso)	(1)	1801	553	204	169	101	62	30	25		
		(2)	105	84	35	29	19	10	5	1		
		(3)	36	29	12	10	7	3	2	< 1		
1979	Target area	(1)	1924	717	352	135	100	41				
		(2)	38	31	20	16	5	3				
		(3)	35	28	17	14	4	2				
	Control area	(1)	2492	672	347	150	23	23	37	50		
		(2)	41	36	23	17	6	6	4	1		
		(3)	30	26	17	12	4	4	3	< 1		

(1) Avg.stone number m^{-2} (2) case number (3) %

6. DISCUSSION AND CONCLUSION

As an evidence the "Vicenza" network is a very powerful program for storm seeding. It does away with former networks such as "Grossversuch III" or "Mendoza". Because of their low seeding power, these could not be effective in the hail modification process.

We shall now compare the volume and the concentration of seeded air by direct and indirect techniques. In five minutes, a rocket releases between 10 and 3x10 nuclei per m , active at -10 C. The diffusion volume is approximately 0.15 km . By ground seeding, the ice nuclei concentrations range between 0.5x10 to 2x 10 per m active at -10 C. The volume is approximately 5 km (updraft diameter 3 km, updraft velocity 4 m. s). This comparison is certainly imprecise, but it quantifies the main difference between the two seeding methods.

The second point deals with the modification of hail precipitation in the target area, as revealed by (1) annual values of kinetic energy densities, (2) hail size spectra, and (3) economical data. These observations are not sufficient to conclude that a close relationship between seeding and hail reduction exists (as in most of the actual cloud seeding operations).

A second test would be warmly appreciated in order to help reduce that part of the climatological chance and to confirm these positive results since it is the first time that quantitative results coincide at three different stages of the hail process. A confirmatory test would be welcome so that we could determine if storm seeding from the ground is definitely an old-fashioned technique or if it is a good one for the future of hail suppression.

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