WEATHER MODIFICATION EXPERIMENTS IN BAVARIA

HANS GERHARD MÜLLER
DEUTSCHE VERSUCHSANSTALT FÜR LUFT- UND RAUMFAHRT,
MÜNCHEN-RIEM

1. Introduction

The region of the Bavarian Plains, situated at the northern slope of the Alps is frequently affected by hail damage. Therefore, the Bayerischer Landtag (Bavarian State Parliament) decided to start an experiment using silver iodide released from rockets, as well as from ground generators, to obtain more information about possibilities of suppressing hail by seeding hail clouds. Silver iodide seeding possibly may cause hail suppression by adding artificial ice nuclei to an air mass in which natural ice nuclei are very few in number, as is known for tropical air masses in Central Europe. If it were possible to generate a large number of small ice particles instead of a small number of big hailstones, damage could be reduced considerably. But there is still some doubt whether the usual seeding action will get a sufficient number of artificial ice nuclei into sensitive parts of the thunderstorm cloud at the right time.

The region of Rosenheim was chosen for the experimental area due to the special interest in this field shown by the Rosenheim local authorities as well as the farmers' association. The main part of the Rosenheim district consists of plains with only small hills and a number of minor lakes. The southern part is on the northern slope of the Alps and extends to the border of Austria (Tyrol). The Rosenheim district covers an area of approximately 320 square miles, extending 21 miles from north to south along the Inn River, and 15 miles west to east. Lake Chiemsee forms part of the eastern border.

The intention was to suppress hail as much as possible in the target area (Rosenheim district). Therefore, at first it was necessary to investigate how often hail damage has been observed and the main features of its occurrence. This investigation was based on official weather reports and the reports of the official hail Insurance Organization.

In our region, hail is an infrequent event and restricted in area. For this reason, the official weather reports give characteristic values for the number of hail observations at the place of each weather station itself but not good information about the number of hail strikes in the whole region. In this respect, the hail insurance reports for the damaged area are more informative.

As can be seen from the weather data as well as from the hail insurance reports,

most severe hailstorms are characterized by strips 10 to 20 miles wide and up to several hundred miles long. Their main extension is nearly parallel to the chain of the Alps and also parallel to the prevailing wind direction. The 40 large hailstorms occurring during the years before experiments began were investigated. This study showed that the menace of hail damage is at maximum when warm tropical maritime air masses crossing the Alps and causing strong "Foehn" effects are replaced by cooler polar air. The cold front itself normally is masked by the subsiding air motion before the front. Therefore, the front as it approaches our region is not characterized by squall lines, but by an increasing number of local thunderstorms developing into widespread showers with time. The danger of hail damage is at its maximum during the first phase of this development. Hail occurs only rarely when the cold front already has passed.

Figures 1 and 2 indicate the shape of hail damage areas in the normal situation

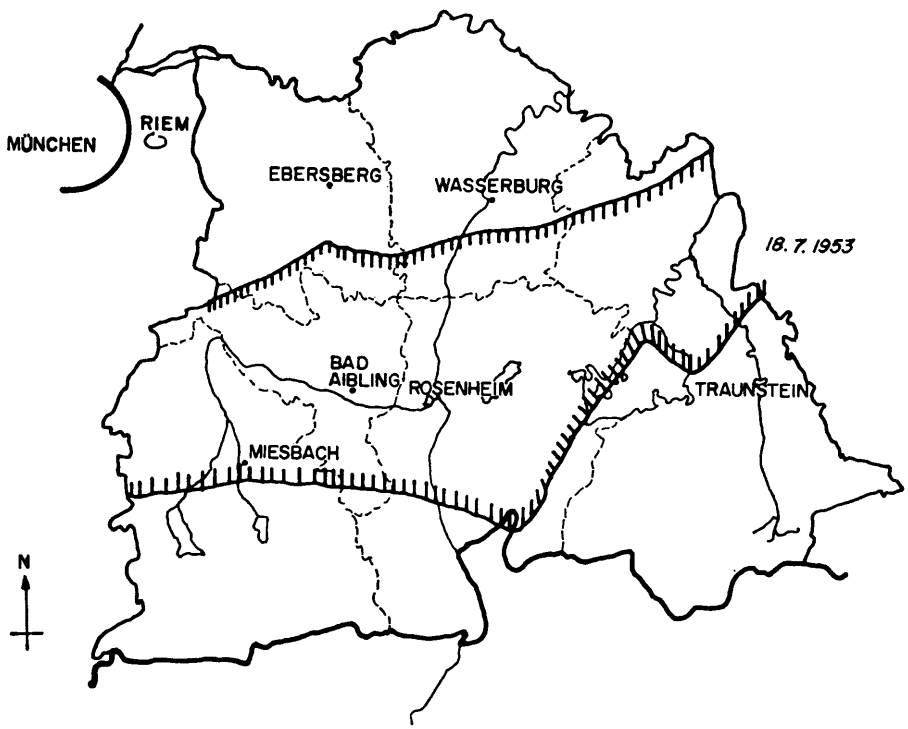

FIGURE 1

Hail damage area July 18, 1953 (preseeding period).

of a major hailstorm. The maps show the Rosenheim district surrounded by the districts of Ebersberg, Aibling, Miesbach, and Wasserburg (control area A) in the west and north and the Traunstein district east of Rosenheim.

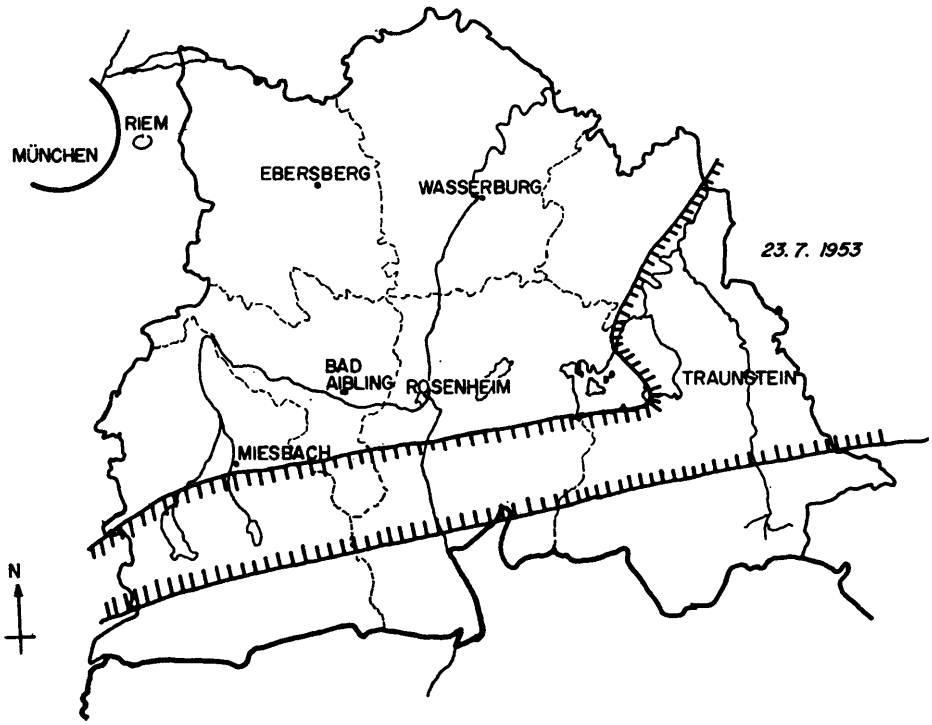

FIGURE 2

Hail damage area July 23, 1953 (preseeding period).

2. Organization of the experiment

Under these premises, the experiment was organized as follows. Seventy six rocket posts were installed along the Inn river and manned on a voluntary basis. They are stationed in a triple chain, two series west of the Inn and one on the eastern border with a mean distance of one to two miles from post to post. Some posts are situated where local thunderstorms are especially frequent (see figure 3). Each post has up to ten rockets at its disposal. They are stored according to state regulations for storing explosives. The two men at each post have taken a course in handling explosives and a special examination. The rockets each contain 800 gms of cheddite and 16 gms of AgI. They can attain a maximum height of about 4500 ft above the ground. Since the freezing level in summer over Bavaria is about 10,000 to 12,000 ft, the seeding agent must be transported to its working height by the updraft normally connected with thunderstorms and must be dissipated by turbulence. It is quite possible that the wind distribution between the height of the exploding rocket and the place where seeding must be done to be effective may be unfavorable. This risk cannot be excluded. The rocket posts are alerted normally by radio and in special cases by telephone.

In each case, the time difference between alert and rocket firing is kept as short as possible. Since hailstorms are most frequent in the afternoon, alerts were usually given with a special radio broadcast for farmers at noon. This way of forecasting was very effective during the last years of the experiment, although in the first years some failures occurred. The rocket posts are allowed to fire after the alert is given at any time they feel that seeding may be useful. Also, they are

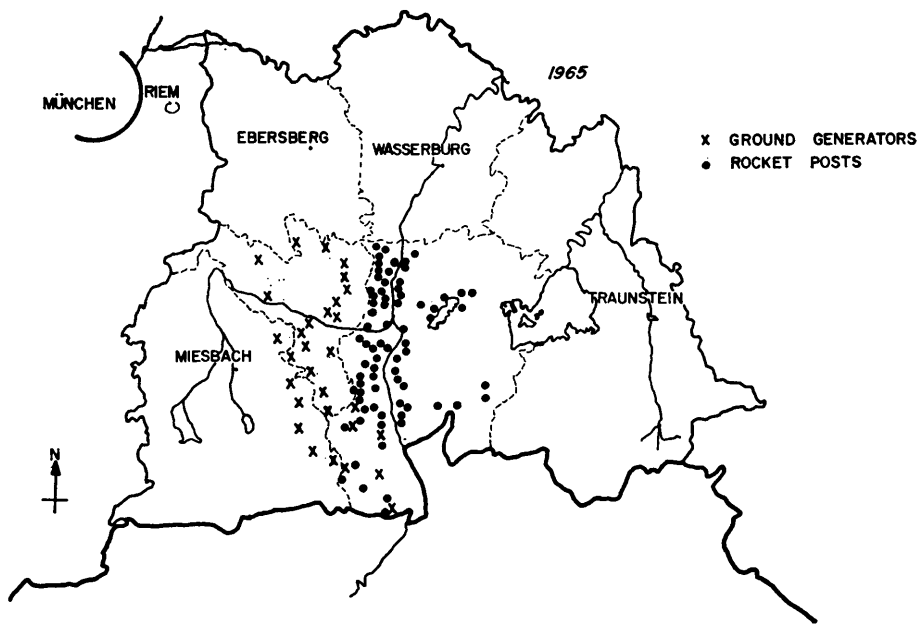

FIGURE 3

Rocket posts and ground generators in Bavaria, 1965.

allowed to fire rockets on Sundays and holidays when alert cannot be given and the post feels seeding would be helpful to the thunderstorm situation. Certainly, a large responsibility is given to the rocket posts. Special training was given each year to help them know more about the properties and development of thunderstorms. Frequent inspections showed that, generally, the understanding was on a very high level and only a small portion of the material was expended due to misunderstanding or misuse. In the latter case, the man in charge was replaced. Since the exact time of rocket firing depends on the judgement of the post, the number of rockets used varied over a wide range from only a few rockets up to 284 within a few hours. Generally, the number of rockets used was in appropriate proportion to the thunderstorm menace. The rocket posts report as to each day of activity in order to aid the evaluation and to get used rockets replaced.

In addition to the rocket network, a network of silver iodide ground generators

was installed. Thirty propane gas generators (eighteen in the first experimental year) dispersing 1 gm of AgI per minute dissolved with NaI in acetone were distributed in a double chain west of the target area. The upwind situation was chosen to give the seeding agent produced near the ground more time to reach its working height by updraft and turbulent mixing with the surrounding air. The ground generator posts are alerted in the same way as the rocket posts but, for the ground generators, the time of operation is announced by broadcast so that, normally, all generators are in action during the same time.

It was not possible to carry out this experiment on a random basis. Certainly randomization gives a better basis for statistical evaluation. But, the cooperation with the rocket, as well as ground generator posts, is based on a strictly voluntary basis and none of the participants in the experiment were paid for hours worked and for loss in their own working time. This voluntary work can be done only if the helpers feel that they are working in their own interest. So, it is not possible to request that, on a randomized "no seeding" day, they observe a thunderstorm without being allowed to become active. This restriction may be harmful to the evaluation; nevertheless, it is inevitable.

For the evaluation of these experiments, all available weather information is gathered, not only for the Rosenheim district but also for the adjacent areas. These are the districts of Ebersberg, Aibling, Miesbach, and Wasserburg, situated to the west and north of Rosenheim, covering an area of 940 square miles (control area A) and the district of Traunstein, situated east of Rosenheim, covering 460 square miles. The observations from synoptic and climatological stations of the whole region, and the observations from the mountain weather station of Wendelstein in the northern part of the Miesbach district, as well as those from Zugspitze and Hohenpeissenberg in the western surroundings, off the map are available. At the Munich-Riem airport a complete set of weather observations is available including two radiosondes and four rawinsondes ascents per day. A 200 kw weather radar set (three cm wavelength, RHI and PPI scope) regularly takes pictures of the precipitation areas.

Also, the agents of the hail insurance corporation give regular reports on all damage occurring in the six districts. In addition to this, a network of about 600 voluntary observers was established. They are dispersed over the six districts reporting all observed thunderstorm or hailstorm activity. Furthermore, on alert days, they report whether or not hailstorms or thunderstorms occurred at their location.

Since preliminary results of the evaluation showed that possible effects of seeding may extend far beyond the borders of the seeded experimental area as well as into the selected comparison areas, the districts of Laufen (200 sq mi) and Altötting (200 sq mi) northeast of Rosenheim, off the map given here, were selected as an additional control area (control area B). Due to lack of funds and manpower, it was not possible to establish a special observer's network in the area. All data given in this report covering control area B are based on the reports of the hail insurance agents only. The data are evaluated in three ways.

The number of days with hail damage in each township of the target district is compared with the respective number in the control areas and with the respective number in a comparable preseeding period. The control areas are (1) the districts of Ebersberg, Aibling, Miesbach, and Wasserburg (control area A) situated generally upwind from Rosenheim, (2) Traunstein in the downwind direction, and (3) the districts of Laufen and Altötting (control area B) to the east and northeast of Traunstein, also in downwind direction.

Control area B is used only for general comparison, not for special weather situations since the density of the observing network was much smaller there than in other districts.

Since the seeding period extended from 1958 to 1965, the period from 1950 to 1957 was used as a control period. The economic agricultural and climatic conditions are comparable for the periods.

3. Results

On the basis of all available information, maps were drawn showing the distribution of seeding activity as well as the observed hail damage and its change with time and the distribution of rainfall. Up to now, forty maps for particular days have been drawn. Three examples of such maps are shown in figures 4 to 6.

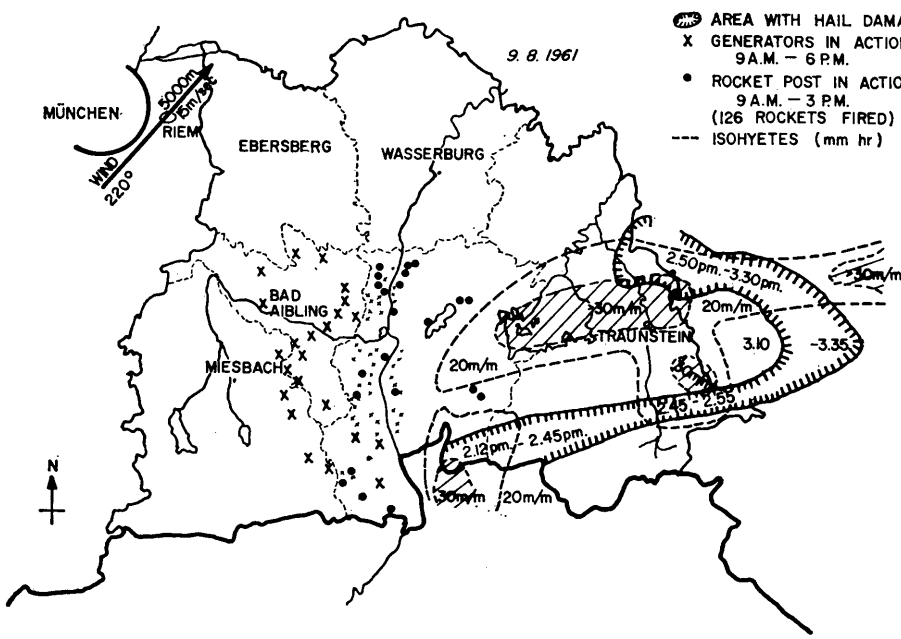

FIGURE 4

Seeding activity, hail occurrence, and precipitation August 9, 1961.

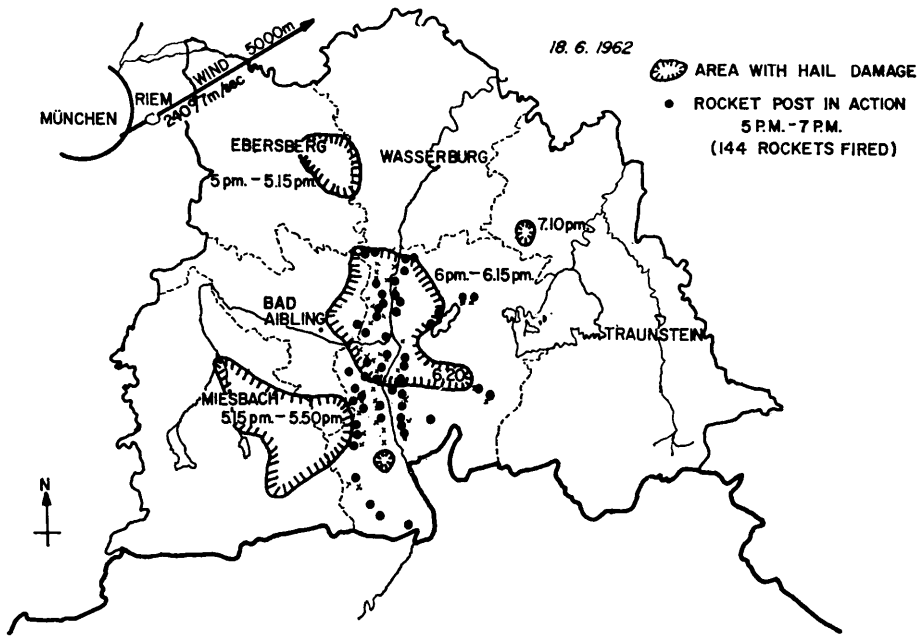

FIGURE 5

Seeding activity and hail occurrence June 18, 1962.

On August 9, 1961 (figure 4), there was a deep depression between the coast of western Norway and Scotland. Humid maritime air was transported into Bavaria by strong southwestern flow along a trough extending far to the south. Heavy showers occurred in the morning. At 0900 rocket posts and generators were alerted, and 24 generators were activated and 23 rocket posts fired 126 rockets. From 1340 until 1700 heavy thunderstorms occurred. The area of hail damage, the shape of a horseshoe, is shown in the map in figure 4. It should be noted that the inner region of the horseshoe had the largest amount of precipitation (33 to 36 mm), but had no hail.

On June 18, 1962, regions of cyclonic character were surrounded by a high pressure region between Poland and Spain. In those regions showers and thunderstorms occurred. Cool air penetrating to a great height over an overheated surface caused thunderstorms with hail from 1500 until 2200. Hail was reported by twenty six observers, and five townships suffered damage. The hail damage areas are shown in figure 5. Thirty five rocket posts fired 144 rockets.

On August 29, 1964, a cyclone centered in southern Scandinavia moving from west to east. A cold front connected with this cyclone passed over southern Germany and entered Bavaria in the afternoon. Before this front arrived insolation had caused strong turbulence, so that thunderstorms with heavy precipitation occurred. Twenty two observers reported hail. Twenty five ground

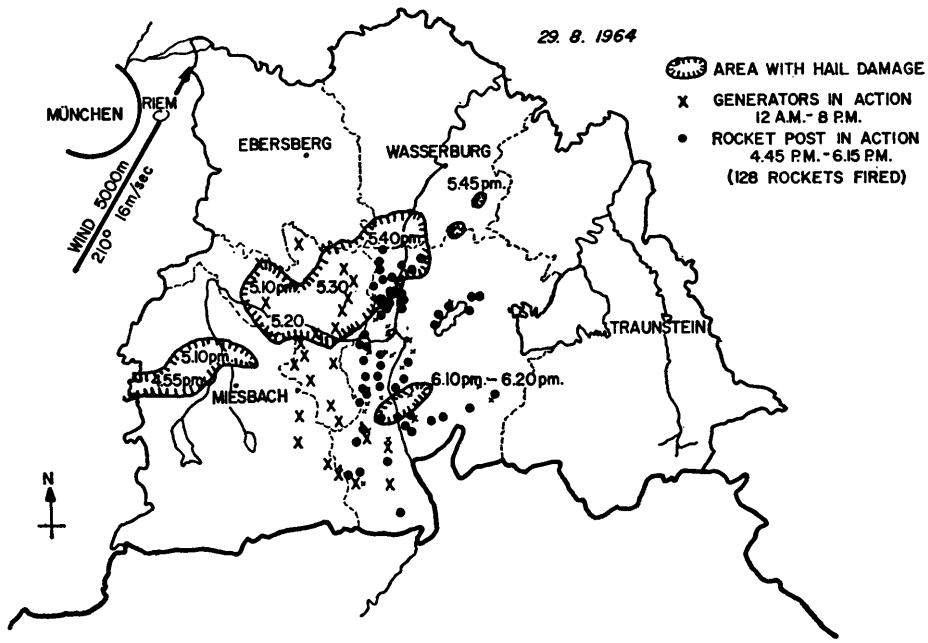

FIGURE 6

Seeding activity and hail occurrence August 29, 1964.

generators were in operation and fifty seven rocket posts fired 128 rockets (figure 6).

For the second method of evaluation, all available weather data for the experimental and control areas and periods were put on punchcards together with data characterizing the experimental activity such as the number of rockets fired and generators activated. This provided a chance to sort out all of the observed results according to wind direction, speed and shear, thermodynamic stability, different air masses, barometric tendency, curvature of isobars, and so forth. This part of the evaluation has not yet been completed.

Finally, the number of townships damaged by hail multiplied by the number of days with damage was summed and recorded for each year and each district separately as shown in table I. From this list one can compare the sum of the hail damage days in the target area (Rosenheim) during the experimental period from 1958 to 1965 with that in the preseeding period from 1950 to 1957. During the eight year seeding period, damage occurred on 72 per cent of the seeded days, and on 100 per cent during the preseeding period. Looking at the same table for the windward situated control area of Ebersberg, Aibling, Miesbach, Wasserburg, one finds also that in control area A the number of hail damage days during the experimental period from 1958 to 1965 was only 71 per cent compared to 100 per cent during the period from 1950 to 1957. Thus, one could conclude

that the eight year period from 1958 to 1965 had less hail damage generally than the period from 1950 to 1957 and therefore no effect of seeding appears to exist.

TABLE I

PRODUCT OF THE NUMBER OF TOWNSHIPS WITH HAIL DAMAGE AND THE NUMBER OF DAYS WITH HAIL DAMAGE DURING THE SEASON

Year	E	A	M	W	Sum CA	R	T	L	Aö	Sum CB
Control period										
1950	52	11	13	54	130	13	29	12	13	25
1951	30	6	2	2	40	12	20	16	9	25
1952	1	1	1	2	5	18	11	23	1	24
1953	6	14	14	7	41	39	42	31	18	49
1954	12	7	1	2	22	12	27	20	7	27
1955	2	2	—	7	11	8	16	11	28	39
1956	20	25	16	16	77	42	47	31	8	39
1957	14	26	4	2	46	17	26	27	11	38
Total	137	92	51	92	372	161	218	171	95	266
Experimental period										
1958	23	7	9	29	68	23	21	17	4	21
1959	21	14	2	5	42	21	26	33	17	50
1960	9	8	1	8	26	26	20	22	7	29
1961	6	3	—	3	12	5	14	16	4	17
1962	10	3	5	—	18	10	8	6	1	7
1963	12	4	5	12	33	8	13	22	16	38
1964	10	17	5	3	35	17	10	5	17	22
1965	13	11	1	3	28	6	7	13	7	20
Total	104	67	28	63	262	116	119	131	72	204
Comparison %	76	73	55	69	71	72	55	77	76	77

Two remarks must be made here.

(1) In the districts of Ebersberg and Wasserburg, the year 1950 was an especially bad year for hail damage so that the Ebersberg district was about 413 per cent of the average of the 15 following years; in Wasserburg it was 780 per cent. On the other hand, in the Rosenheim area that year ranked very low in hail damage (ninth among all of the years from 1950 to 1965). Omitting this year would lower the average hail damage in the control area for the control period. In this case the percentage of hail damage days for the experimental period (compared with the control period = 100) would be 98 per cent for the districts of Ebersberg, Aibling, Meisbach, and Wasserburg, 29 per cent for Rosenheim, and 40 per cent for Traunstein.

(2) For reasons given above a number of the ground generators were installed in the Aibling and Miesbach regions. It may be possible that, depending on wind aloft conditions, a part of the seeding agent became active above the control area instead of the target area. In this case, the effect of seeding would be

obscured. The control area should have been chosen at a greater distance from the target area. But it would be a disadvantage because it is impossible to find a control area at a greater distance with otherwise sufficiently similar orographic and climatic conditions. In any case, the Traunstein district shows a remarkably

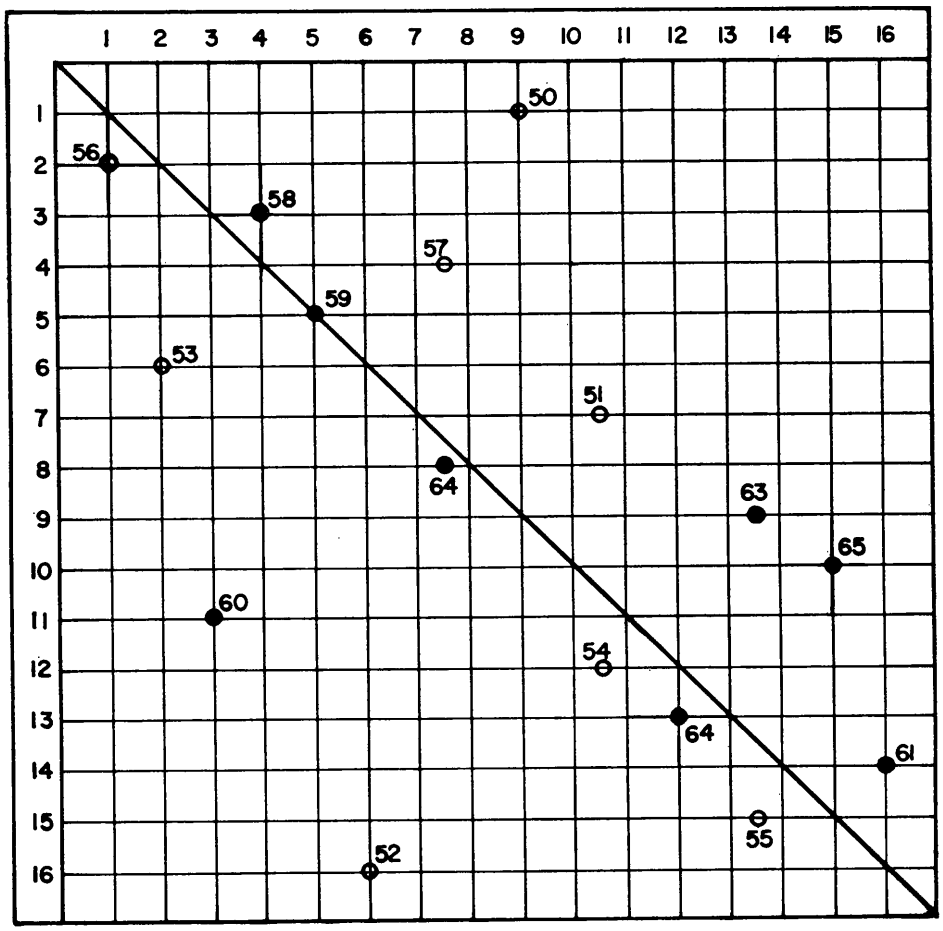

FIGURE 7

Annual hail damage days ranks in the Rosenheim region (abscissa) compared with control area A (ordinate).
Open circles: control period 1950–57.
Solid dots: experimental period 1958–65.

small number of hail damage days, reduced to 55 per cent (omitting 1950, which is 40 per cent) of the damage days during the control period 1950 to 1957. To see if this might be an effect of seeding or if there is a decrease of hail occurrence in regions situated east of Rosenheim, one may compare with the data given for the

districts of Laufen and Altötting (control area B), in table I. Compared to the control period 1950 to 1957, the number of damage days is lowered to 77 and 76 per cent, respectively. Laufen and Altötting are situated east and northeast of Traunstein.

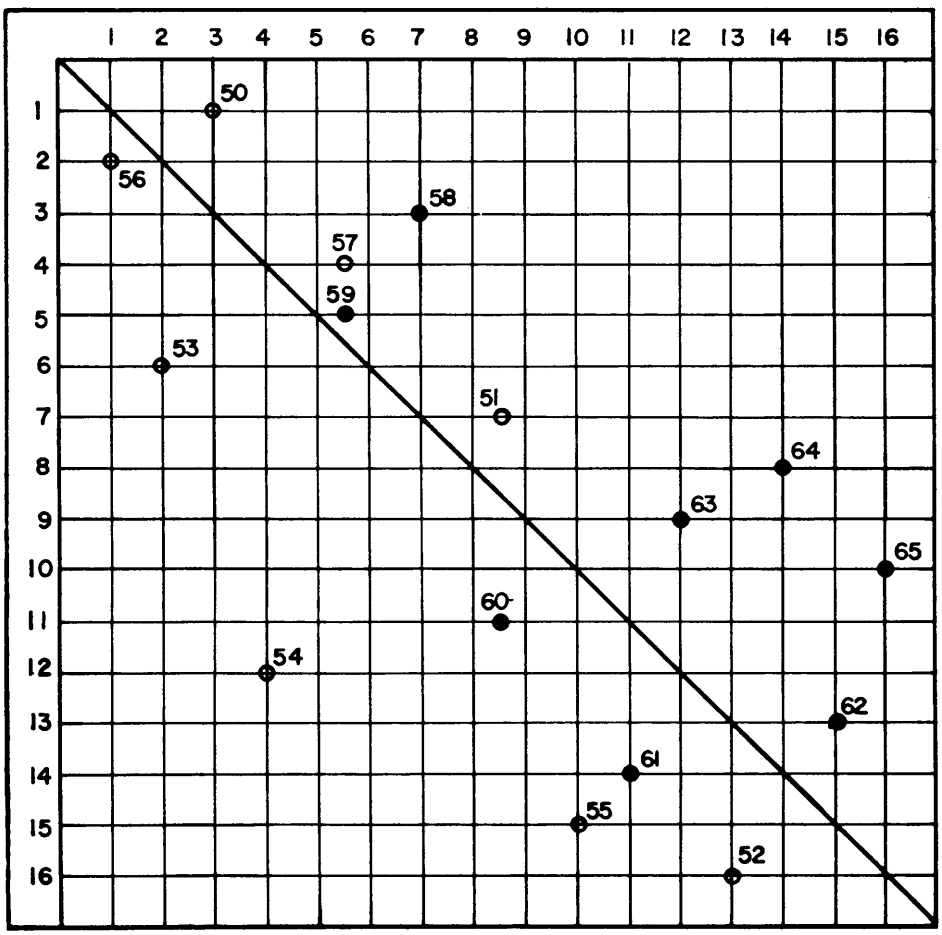

FIGURE 8

Annual hail damage days ranks in the Traunstein region (abscissa) compared with control area A (ordinate).
Open circles: control period 1950–57.
Solid dots: experimental period 1958–65.

Since the variability of hail occurrence is great, it may be practical to use ranks to correlate the hail damage observations from the seeded and nonseeded periods. Rank 1 means the year with the largest number of hail damage days, rank 16 means the year with the lowest.

Figures 7 to 9 show the ranks of hail damage days for the years from 1950 to 1957 (open circles) and from 1958 to 1965 (solid dots) for areas of Rosenheim (on the abscissa of figure 7), Traunstein (on abscissa of figure 8), and Laufen and Altötting (on abscissa of figure 9), each compared to the respective number of

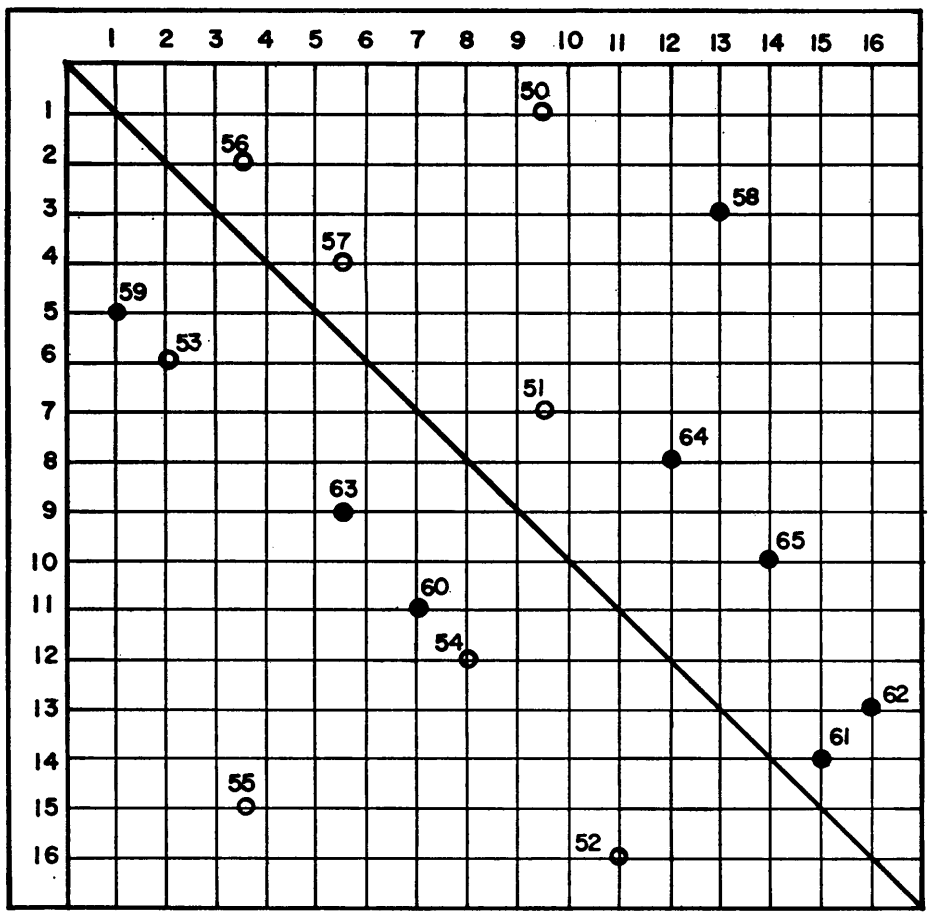

FIGURE 9

Annual hail damage days ranks in the Laufen and Altötting region (control area B) compared with control area A.
Open circles: control period 1950–57.
Solid dots: experimental period 1958–65.

hail damage days in control area A (as ordinate). For the upper right part of the figures, the rank of the Rosenheim, Traunstein, and Laufen and Altötting districts, respectively, is higher than the rank of control area A. Table II gives the distribution of the ranks.

TABLE II

NUMBER OF YEARS WITH RANKS OF HAIL DAMAGE DAYS HIGHER (LOWER) IN THE AREA MENTIONED THAN IN CONTROL AREA A

Area	Rosenheim	Traunstein	Laufen Altötting
Control period 1950–57	3 (5)	3 (5)	4 (4)
Experimental period 1958–65	4, 5 (3, 5)	6 (2)	5 (3)

4. Conclusions

It is felt that an eight year period is far from providing significant data about a weather phenomenon as infrequent as hail. On the other hand, the target area is felt to be too small compared with the variability of the weather situation. Under the given circumstances it would probably be more useful to choose a target area with an area four times as large as the Rosenheim district. More information about the experiment may be expected from a thorough examination of each special weather situation. This examination would also be useful in the problem of whether the seeding activity had an effect on the amount of precipitation. This question has not been considered yet since the hail menace was the primary concern of this experiment.