"REVIEWED"

AN EVALUATION OF HAIL SUPPRESSION CLOUD SEEDING EFFECTS ON FREQUENCIES OF WEATHER PHENOMENA IN SERBIA

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Abstract. An attempt is made to estimate the effect of hail suppression by silver iodide seeding in Serbia (eastern part of Yugoslavia), on hail-day frequency and the frequencies of other phenomena related to Cb clouds as observed at synoptic meteorological stations. The weather phenomena related to Cb clouds considered here include: hail, ice pellets, thunderstorms, gust winds, and amount of precipitation. The series of observations from 20 seeded and 20 non-seeded stations covers a 40-year period (1949-1988). The ratio of the average frequencies, in number of days in which these phenomena were observed during the seeding period, and the average frequencies observed during the non-seeding period, were calculated. Averaging was performed first over time for each station, and subsequently over 20 stations. A starting assumption on a positive correlation among frequencies of weather phenomena connected to Cb clouds was proven, as well as the correlation between the frequency of hail occurrences and the frequencies of the rest of the phenomena. The highest correlation coefficient $r = 0.72$ was found between frequencies of Cb clouds and the hail occurrences. The student's test for difference between the average hail frequency during the seeding operations and the average frequency before these operations in the same territory shows a reduction in the hail frequency which was statistically significant. That is not the case with differences of mean values of the frequencies of other phenomena for the same periods. Such a difference between the mean hail frequencies in the surrounding areas which had no hail suppression programs for the same periods was statistically negligible. These results suggest that the 20 years of seeding operations in Serbia have had a positive effect.

1. INTRODUCTION

The hail suppression system by silver iodide seeding in Serbia covers about 3.7 million hectares of agricultural surface. It represents one of the largest connected territories in the world protected by such a system. That territory has been seeded every year by several tens of tons of highly efficient silver iodide reagent.

Some investigations (Radinovic', 1989; Mesinger and Mesinger, 1992) have shown that such a compact territory seeded by a huge amount of reagent was reflected to the hail-day frequency, observed in the regular network of meteorological stations. This work is a follow-up of the same ideas, but we now consider the frequency of ice pellets and the change of amounts of precipitation during the hail suppression season. Furthermore, we attempt to find out the ratio between hail frequency changes and the frequency changes of the other meteorological phenomena connected to hailstorms which are not affected by silver iodide seeding (i.e., frequency of Cb clouds, thunderstorms, gust of winds).

For the apparent effectiveness of the seeding, and due to a great space and time variation of the frequencies of meteorological phenomena related to hailstorms, we used a specific way of smoothing. Thus, we calculated the ratio of average phenomena frequency in number of days in which given phenomena were observed per year during the seeding periods, and the average frequency during the non-seeding periods. Averaging was performed first over time for each station, and subsequently over 20 synoptic stations. In that way, each station affects the resulting average with the same weight, irrespective of the length of its seeding period.

2. METEOROLOGICAL STATIONS

After World War II, the Yugoslav network of meteorological stations was reconstructed, and the first year for which data from most of the stations were available was 1949. Thus, we have taken 1949 as the starting year of our datasets. The phenomena which are considered here are typically local and can occur at any time of the day or night. It is therefore probable that such phenomena were more correctly observed at stations having professional observers (synoptic stations) than the other types of meteorological stations (climatological, precipitation, etc.) without professional observers. For that reason, in our studies only observations from the synoptic stations which are registered by the World Meteorological Organization are used. Datasets from these stations are published in Meteorological Annuals. In the territory where the hail suppression operations were performed (target territory), there were 20 such stations. The same type and number of stations were taken in neighboring regions of Vojvodina, Bosnia, Herzegovina, and Montenegro, which had no hail suppression programs. These regions were considered as a control territory.

3. PERIOD OF OBSERVATIONS

Datasets used in this study covered the period 1949 to 1988. Some specific characteristics of this period are as follows: In the first half of this period (1949-1968), there were no hail suppression operations in Serbia nor in the neighboring regions. Then, in the third decade of this period (1969-1978), the hail suppression system in Serbia had been developing and expanding. In the last decade (1979-1988), the hail suppression system covered nearly all of Serbia except its northern province Vojvodina, and it was operating without essential changes in its methodology and technology.

Concerning the completeness of the datasets, it should be pointed out that of 40 stations in a 40-year period, or a total of 1600 station-years, only 31 station years were lacking; that is less than 2% of the total amount of data used, the exception being the frequency of Cb data which are not published. It was particularly difficult to get data frequency from original records archived in different regions.

4. HYPOTHESES ON FREQUENCY RELATIONS AMONG PHENOMENA CONNECTED TO Cb CLOUDS

In order to express our study more explicitly, we set up the three following hypotheses:

1) In a climatic homogeneous region, there is a statistically determined relation between the frequency of Cb clouds and the frequencies of the phenomena connected to Cb cloud occurrences.

2) If there is a statistically defined relation between the frequency of Cb clouds and the frequency of phenomena related to Cb clouds, then there is a statistical relation between the frequencies of these phenomena themselves.

3) If a frequency of certain phenomenon related to Cb clouds is changed by hail suppression seeding operations, then the statistical relations between that phenomenon and the rest of the phenomena related to Cb clouds will also be changed.

A confirmation of these hypotheses will be, at the same time, a confirmation of the hail suppression system effectiveness. That is a subject of consideration in the next section.

5. HAIL

There are several hypotheses trying to assert a possible positive effect of the hail suppression seeding by silver iodide. Here we shall set up two of them which may be checked by observations in the network of meteorological stations. These are:

1) Mean hail frequency occurrences observed in the regular network of meteorological stations in a period of hail suppression operations are significantly less than in a period before hail suppression operations in the same territory.

2) In a hail seeded territory, the mean hail frequency occurrences observed in the regular network of meteorological stations are significantly less than in a neighboring non-hail seeded territory for the same period.

In order to prove the validity of these hypotheses, we used the observations of number of days with hail occurrences for 20 synoptic stations in seeded (Table 1), and 20 synoptic stations in non-seeded (Table 2) territories for the period 1949-1988.

Mean and extreme values of these data, with their standard deviations for different periods, are shown in Tables 3 and 4.

Before data analysis, we shall make a few comments concerning the periods shown in Table 4. There were no seeding operations in Serbia nor in the neighboring control territory in the first half of the period, 1949-1968. In the third decade of the period, 1969-1978, the hail suppression system had been developing and spreading into Serbia and functioning with frequent interruptions. In the last decade, 1979-1988, the hail suppression system had been technically improved, functioning almost without interruptions and covering about 95% of Serbia (without the Vojvodina province).

Taking into account the above-mentioned facts and comparing Tables 3 and 4, the following indications suggest a positive effect of the hail suppression system in Serbia:

1) Hail frequency minimum was recorded in the decade 1979-1988, when hail suppression was

Table 1. Dataset on hail-day frequency observed at synoptic stations in seeded territory (Serbia without Vojvodina province)

Years	No. of stations	No. of hail days	Mean No. of days	Moving 5-yr mean	Deviations	Years	No. of stations	No. of hail days	Mean No. of days	Moving 5-yr mean	Deviations
1949	16	11	0.69	-	-0.57	1969	20	22	1.10	1.39	-0.16
1950	17	11	0.65	-	-0.61	1970	18	29	1.61	1.33	0.35
1951	17	24	1.41	1.03	0.15	1971	20	32	1.60	1.37	0.34
1952	20	19	0.95	1.25	-0.31	1972	20	32	1.60	1.38	0.34
1953	20	29	1.45	1.45	0.19	1973	20	19	0.95	1.59	-0.31
1954	20	36	1.80	1.60	0.54	1974	20	23	1.15	1.48	-0.11
1955	20	33	1.65	1.88	0.39	1975	20	53	2.65	1.51	1.39
1956	19	43	2.15	1.81	0.89	1976	20	21	1.05	1.51	-0.21
1957	20	47	2.35	1.69	1.09	1977	20	35	1.75	1.50	0.49
1958	20	22	1.10	1.48	-0.16	1978	20	19	0.95	1.20	-0.31
1959	20	24	1.20	1.35	-0.06	1979	20	22	1.10	1.15	-0.16
1960	18	11	0.61	1.19	-0.65	1980	20	23	1.15	1.00	-0.11
1961	20	30	1.50	1.23	0.24	1981	20	16	0.80	1.00	-0.46
1962	20	31	1.55	1.18	0.29	1982	20	20	1.00	0.98	-0.26
1963	20	26	1.30	1.45	0.04	1983	20	19	0.95	0.98	-0.31
1964	20	19	0.95	1.35	-0.31	1984	20	20	1.00	0.94	-0.26
1965	20	39	1.95	1.42	0.69	1985	20	23	1.15	0.90	-0.11
1966	20	20	1.00	1.31	-0.26	1986	19	11	0.58	0.81	-0.68
1967	20	38	1.90	1.34	0.64	1987	19	16	0.84	-	-0.42
1968	19	14	0.74	1.27	-0.52	1988	19	9	0.47	-	-0.79

Table 2. Dataset on hail-day frequency observed at synoptic stations in non-seeded territory (Vojvodina, Bosnia, Herzegovina, and Montenegro)

Years	No. of stations	No. of hail days	Mean No. of days	Moving 5-yr mean	Deviations	Years	No. of stations	No. of hail days	Mean No. of days	Moving 5-yr mean	Deviations
1949	18	12	0.67	-	-0.59	1969	20	24	1.20	1.43	-0.06
1950	19	12	0.63	-	-0.63	1970	20	34	1.70	1.50	0.06
1951	20	22	1.10	0.84	-0.16	1971	20	31	1.55	1.44	0.29
1952	20	21	1.05	0.98	-0.21	1972	20	32	1.60	1.49	0.34
1953	19	14	0.74	0.99	-0.52	1973	20	23	1.15	1.42	-0.11
1954	20	28	1.40	1.13	0.14	1974	20	29	1.45	1.35	0.19
1955	20	13	0.65	1.27	-0.61	1975	20	27	1.35	1.34	0.09
1956	20	36	1.80	1.27	0.54	1976	20	24	1.20	1.47	-0.06
1957	20	35	1.75	1.18	0.49	1977	20	31	1.55	1.45	0.29
1958	20	15	0.75	1.33	-0.51	1978	19	36	1.80	1.35	0.54
1959	20	19	0.95	1.22	-0.31	1979	20	27	1.35	1.35	0.09
1960	20	28	1.40	1.16	0.14	1980	19	16	0.84	1.21	0.58
1961	20	25	1.25	1.57	-0.01	1981	20	24	1.20	1.12	-0.06
1962	20	29	1.45	1.66	0.19	1982	20	17	0.85	1.07	-0.41
1963	20	56	2.80	1.70	1.54	1983	20	27	1.35	1.00	0.09
1964	20	28	1.40	1.72	0.14	1984	20	22	1.10	1.00	-0.16
1965	20	32	1.60	1.68	0.34	1985	20	10	0.50	1.04	-0.76
1966	20	27	1.35	1.41	0.09	1986	19	23	1.21	0.93	-0.05
1967	20	25	1.25	1.37	-0.01	1987	20	21	1.05	-	-0.21
1968	20	29	1.45	1.39	0.19	1988	20	16	0.80	-	-0.46

TABLE 3

Minimum (Min), Maximum (Max), Mean (M), and Standard Deviation (σ) of Number of Hail Days Averaged Over Years and Station in Seeded Territory

Periods	Min	Max	M	σ
1949-58	0.65	2.35	1.42	0.58
1959-68	0.61	1.95	1.27	0.46
1969-78	0.95	2.65	1.44	0.95
1979-88	0.47	1.15	0.90	0.23
1949-68	0.61	2.35	1.34	0.51
1969-88	0.47	2.65	1.17	0.48
1949-88	0.47	2.65	1.26	0.52

TABLE 4

Minimum (Min), Maximum (Max), Mean (M), and Standard Deviation (σ) of Number of Hail Days Averaged Over Years and Station in Non-seeded Territory

Periods	Min	Max	M	σ
1949-58	0.63	1.80	1.05	0.45
1959-68	0.95	2.80	1.49	0.49
1969-78	1.15	1.80	1.46	0.23
1979-88	0.50	1.35	1.02	0.27
1949-68	0.63	2.80	1.27	0.51
1969-88	0.50	1.80	1.24	0.33
1949-88	0.50	2.80	1.26	0.43

covering nearly all of Serbia, and it was lower than in the non-seeded territory.

2) The standard deviation of hail frequency had the lowest value in the seeded territory in the last decade, while that was not the case in the non-seeded territory.

3) The smoothed values of the mean number of days per year and station, shown by a moving 5-year mean in the seeded territory, show a steady trend of hail frequency decrease from 1975 and beyond (Table 1). Such a trend in the non-seeded territory (Table 2) had been interrupted.

4) Difference between mean hail frequency numbers of days of seeded (s) (1969-1988) and non-seeded (ns) (1949-1968) periods in Serbia, according to the student's test gives:

$$Z_s\text{:}\ t_o = 1.09 \quad k = 40 \quad P(t_o \geq 1.09) \leq 0.1.$$

Such a difference in surrounding non-seeded territory gives:

$$Z_{ns}\text{:}\ t_o = 0.22 \quad k = 34 \quad P(t_o \geq 0.22) \leq 0.35.$$

These values show that the difference in mean hail frequency number of days between seeded and non-seeded periods in the seeded territory is statistically significant. On the other hand, the difference between mean values of the same periods in the non-seeded territory is negligible.

5) In the period 1949-1968, when hail suppression in Serbia was not operating, the mean hail frequency number of days in 14 years was above, and in 6 years below, the mean values in surrounding non-seeded territory. In the period when the hail suppression system was operating, that ratio was the opposite; i.e., in 14 years the ratio was below, and in 6 years it was above the corresponding values in non-seeded territory.

6. ICE PELLETS

The hail suppression system operating in Serbia has been based on the competition hypothesis. After this hypothesis, the seeding should increase the number of hail particles and thus reduce their size, consequently decreasing the frequency of hail (particles with a diameter of 5 mm and greater when recorded as hail), and increase the frequency of ice pellets (particles with a diameter of less than 5 mm).

In order to confirm or reject this hypothesis, the datasets on ice pellets observed in the seeded and non-seeded territories have been taken from the original reports kept at the Serbian and the Federal Hydrometeorological Institutes. These datasets are presented in Tables 5 and 6. In Tables 7 and 8, extreme and mean values of ice pellet frequencies in seeded and non-seeded territories are shown. From these tables, the following suggestions support the competition hypothesis of increased ice pellet frequency:

1) The smoothed values of the mean ice pellet days in the last decade of the period considered, when the hail supression system was completed, show much greater increase of the ice pellet frequency in seeded (Table 5) than in non-seeded (Table 6) territory.

2) The difference between the mean number of ice pellet days per year and stations in the period when hail suppression was operating and when it was not operating using the student's test gives:

$$Z_s\text{:}\ t_o = 3.55 \quad k = 32 \quad P(t_o \geq 3.55) \leq 0.001.$$

Table 5. Dataset on ice pellets observed at synoptic stations in the seeded territory

Years	No. of stations	No. of pellets days	Mean No. of days	Moving 5-yr mean	Deviations	Years	No. of stations	No. of pellets days	Mean No. of days	Moving 5-yr mean	Deviations
1949	16	9	0.56	-	0.06	1969	20	0	0.00	0.32	-0.50
1950	17	8	0.47	-	-0.03	1970	18	2	0.11	0.36	-0.39
1951	17	3	0.18	0.48	-0.32	1971	20	16	0.80	0.42	0.30
1952	20	12	0.60	0.53	0.10	1972	20	13	0.65	0.58	0.15
1953	20	12	0.60	0.50	0.10	1973	20	11	0.55	0.72	0.05
1954	20	16	0.80	0.58	0.30	1974	20	16	0.80	0.67	0.30
1955	20	6	0.30	0.53	-0.20	1975	20	16	0.80	0.69	0.30
1956	19	11	0.58	0.50	0.08	1976	20	11	0.55	0.77	0.05
1957	20	7	0.35	0.37	-0.15	1977	20	15	0.75	0.73	0.25
1958	20	9	0.45	0.33	-0.05	1978	20	19	0.95	0.65	0.45
1959	20	3	0.15	0.24	-0.35	1979	20	12	0.60	0.71	0.10
1960	18	2	0.11	0.21	-0.39	1980	20	8	0.40	0.63	-0.10
1961	20	3	0.15	0.18	-0.35	1981	20	17	0.85	0.48	0.35
1962	20	4	0.20	0.19	-0.30	1982	20	7	0.35	0.46	-0.15
1963	20	6	0.30	0.23	-0.20	1983	20	4	0.20	0.52	-0.30
1964	20	4	0.20	0.25	-0.30	1984	20	10	0.50	0.52	0.00
1965	20	6	0.30	0.30	-0.20	1985	20	14	0.70	0.64	0.20
1966	20	5	0.25	0.29	-0.25	1986	19	16	0.84	0.85	0.34
1967	20	9	0.45	0.25	-0.05	1987	19	18	0.95	-	0.45
1968	19	5	0.26	0.21	-0.24	1988	19	24	1.26	-	0.76

Table 6. Dataset on ice pellets observed at synoptic stations in the seeded territory

Years	No. of stations	No. of pellets days	Mean No. of days	Moving 5-yr mean	Deviations	Years	No. of stations	No. of pellets days	Mean No. of days	Moving 5-yr mean	Deviations
1949	18	3	0.17	-	-0.29	1969	20	4	0.20	0.27	-0.26
1950	19	2	0.10	-	-0.36	1970	20	8	0.40	0.37	-0.06
1951	20	1	0.05	0.23	-0.41	1971	20	4	0.20	0.43	-0.26
1952	20	8	0.40	0.30	-0.06	1972	20	5	0.75	0.42	0.29
1953	19	8	0.42	0.44	-0.04	1973	20	12	0.60	0.40	0.14
1954	20	11	0.55	0.56	0.09	1974	20	3	0.15	0.46	-0.31
1955	20	16	0.80	0.60	0.34	1975	20	6	0.30	0.42	-0.16
1956	20	13	0.65	0.59	0.19	1976	20	10	0.50	0.48	0.04
1957	20	12	0.60	0.56	0.14	1977	20	11	0.55	0.63	0.09
1958	20	7	0.35	0.54	-0.11	1978	19	17	0.89	0.66	0.43
1959	20	8	0.40	0.50	-0.06	1979	20	18	0.90	0.58	0.44
1960	20	14	0.70	0.48	0.24	1980	19	9	0.47	0.54	0.01
1961	20	9	0.45	0.59	-0.01	1981	20	2	0.11	0.48	-0.35
1962	20	10	0.50	0.57	0.04	1982	20	7	0.35	0.35	-0.11
1963	20	18	0.90	0.58	0.44	1983	20	11	0.55	0.38	0.09
1964	20	6	0.30	0.60	-0.16	1984	20	5	0.25	0.45	-0.21
1965	20	15	0.75	0.55	0.29	1985	20	13	0.65	0.46	0.19
1966	20	11	0.55	0.43	0.09	1986	19	9	0.47	0.49	0.01
1967	20	5	0.25	0.41	-0.21	1987	20	8	0.40	-	-0.06
1968	20	6	0.30	0.34	-0.16	1988	20	14	0.70	-	0.24

TABLE 7

Minimum (Min), Maximum (Max), Mean (M), and Standard Deviation (σ) of Number of Ice Pellet Days Averaged Over Years and Station in Seeded Territory

Periods	Min	Max	M	σ
1949-58	0.18	0.80	0.49	0.18
1959-68	0.11	0.45	0.24	0.10
1969-78	0.00	0.95	0.60	0.31
1979-88	0.20	1.26	0.66	0.32
1949-68	0.11	0.80	0.36	0.19
1969-88	0.00	1.26	0.63	0.31
1949-88	0.00	1.26	0.50	0.29

TABLE 8

Minimum (Min), Maximum (Max), Mean (M), and Standard Deviation (σ) of Number of Ice Pellet Days Averaged Over Years and Station in Non-seeded Territory

Periods	Min	Max	M	σ
1949-58	0.05	0.80	0.41	0.25
1959-68	0.25	0.90	0.51	0.21
1969-78	0.15	0.89	0.45	0.24
1979-88	0.11	0.90	0.48	0.24
1949-68	0.05	0.90	0.46	0.23
1969-88	0.11	0.90	0.47	0.23
1949-88	0.00	0.90	0.46	0.22

These values show that the difference is statistically highly significant. Such a difference between the same periods in the non-seeded territory is:

$$Z_{ns}: \; t_o = 0.03 \quad k = 40 \quad P(t_o \geq 0.03) \leq 0.3,$$

showing that the difference is negligible.

3) The mean standard deviations of the ice pellet frequency in non-seeded territory are, for all decades, very similar. However, in the seeded territory, the standard deviations in the seeded period in relation to the non-seeded period are increased to over 60%.

4) Difference between mean ice pellet frequencies in seeded and non-seeded territories ($Z_T = Z_s - Z_{ns}$) in the non-seeded period (1949-1968) was positive in 8 and negative in 12 years. However, in the seeded period, the ratio was the opposite.

7. THUNDERSTORMS

In the region considered, as is well known, there are years with rainy reasons with frequent storms followed by thunderstorms and other phenomena related to Cb clouds. On the other hand, there are years with dry seasons and long lasting droughts when storms are rare. Such oscillations in the number of storms should be followed by similar oscillations in the frequency of all phenomena connected to Cb clouds. However, if some phenomena like hail and ice pellet frequencies can be reduced by seeding of Cb clouds, then the frequency oscillation of these phenomena will not follow the oscillations of other phenomena which are not affected by seeding. For that reason, a review of the thunderstorm frequency observed at synoptic stations in seeded and non-seeded territories is made. The datasets are given in Tables 9 and 10.

On the basis of these datasets, a statistical analysis of the thunderstorm frequency occurrences in seeded and non-seeded territories was made. The results obtained are presented in Tables 11 and 12.

These tables show a great similarity in the data in seeded and non-seeded territories. The total number of thunderstorm days observed at 20 synoptic stations in seeded territory for the 40-year period differs by only about 2% from the total number of thunderstorm days observed at the same number of stations in the same period in non-seeded territory. That difference is statistically negligible. This small difference can be found between the thunderstorm frequencies of the seeded and non-seeded periods in Serbia, which shows that the thunderstorm frequency is very favorable compared to the frequencies of hail and ice pellets which are influenced by the seeding.

8. Cb CLOUDS

In spite of the fact that hail forms in Cb clouds, a very high correlation between the frequencies of these two phenomena cannot be expected. First, the hail can be formed in small numbers of Cb clouds only because of some additional specific conditions that should be fulfilled. Secondly, when a Cb cloud is observed over the station, the hail from that cloud can fall somewhere in the vicinity and it will not be recorded.

Nevertheless, in a great number of cases, at random, it may be expected that a certain defined statistical ratio exists between the frequencies of Cb clouds and hail occurrences in a given region. Consequently, in a case of efficient hail suppression operations and hail frequency reduction, that ratio should be changed.

Before analysis of Cb cloud frequency, we should mention that, in deriving these statistics,

Table 9. Dataset on thunderstorm frequency observed at synoptic stations in seeded territory in hail seasons

Years	No. of stations	No. of thun. days	Mean No. of days	Moving 5-yr mean	Deviations	Years	No. of stations	No. of thun. days	Mean No. of days	Moving 5-yr mean	Deviations
1949	16	505	32	-	-4	1969	20	636	32	37	-4
1950	17	499	29	-	-7	1970	20	712	36	38	0
1951	17	688	40	35	4	1971	20	705	35	37	-1
1952	19	651	34	36	-2	1972	20	940	37	38	11
1953	20	783	39	38	3	1973	20	749	37	42	1
1954	20	729	36	37	0	1974	20	692	35	43	-1
1955	20	850	42	39	6	1975	20	1137	57	48	21
1956	20	644	32	36	-4	1976	20	824	41	40	5
1957	20	874	44	38	8	1977	20	771	38	42	2
1958	20	543	27	36	-9	1978	20	616	31	37	-5
1959	20	873	44	36	8	1979	20	837	42	36	6
1960	17	591	35	34	-1	1980	20	666	33	35	-3
1961	20	589	29	38	-7	1981	20	716	36	37	0
1962	20	682	34	36	-2	1982	20	708	35	34	-1
1963	18	822	46	35	10	1983	20	741	37	33	1
1964	20	707	35	38	-1	1984	20	564	28	33	-8
1965	17	518	30	39	-6	1985	20	598	30	31	-6
1966	20	854	43	38	7	1986	20	740	37	30	1
1967	19	749	39	37	3	1987	20	499	25	-	-11
1968	20	831	42	38	6	1988	17	493	29	-	-7

Table 10. Dataset on thunderstrom frequency observed at synoptic stations in non-seeded territory in hail seasons

Years	No. of stations	No. of thun. days	Mean No. of days	Moving 5-yr mean	Deviations	Years	No. of stations	No. of thun. days	Mean No. of days	Moving 5-yr mean	Deviations
1949	18	550	30	-	-7	1969	20	726	36	38	-1
1950	18	555	31	-	-6	1970	19	713	38	39	1
1951	19	713	38	35	1	1971	20	700	35	37	-2
1952	20	800	40	36	3	1972	20	857	43	38	6
1953	20	727	36	38	-1	1973	20	695	35	39	-2
1954	20	736	37	37	0	1974	20	735	37	41	0
1955	20	774	39	36	2	1975	20	934	47	40	10
1956	19	591	31	35	-6	1976	20	828	41	39	4
1957	20	784	39	37	2	1977	20	798	40	41	3
1958	20	625	31	37	-6	1978	20	651	32	38	-5
1959	20	898	45	37	8	1979	20	877	44	37	7
1960	20	767	38	35	1	1980	20	637	32	36	-5
1961	20	592	30	40	-7	1981	20	702	35	37	-2
1962	20	650	32	40	-5	1982	20	775	39	35	2
1963	20	1094	55	39	18	1983	20	706	35	35	-2
1964	20	862	43	42	6	1984	20	683	34	36	-3
1965	20	731	36	44	-1	1985	20	636	32	33	-5
1966	20	877	44	41	7	1986	19	722	38	32	1
1967	20	804	40	40	3	1987	20	544	27	-	-10
1968	20	855	43	40	6	1988	20	583	29	-	-8

TABLE 11

Minimum (Min), Maximum (Max), Mean (M), and Standard Deviation (σ) of Number of Thunderstorm Days Averaged Over Years and Station in Seeded Territory

Periods	Min	Max	M	σ
1949-58	27	44	36	5.5
1959-68	29	46	38	6.0
1969-78	31	57	39	7.8
1979-88	25	42	33	5.2
1949-68	27	46	37	5.9
1969-88	25	57	36	7.1
1949-88	25	57	36	6.4

TABLE 12

Minimum (Min), Maximum (Max), Mean (M), and Standard Deviation (σ) of Number of Thunderstorm Days Averaged Over Years and Station in Non-seeded Territory

Periods	Min	Max	M	σ
1949-58	30	40	35	4.0
1959-68	30	55	41	6.1
1969-78	32	47	38	4.3
1979-88	27	44	34	5.2
1949-68	30	55	38	6.3
1969-88	27	47	36	5.0
1949-88	27	55	37	5.7

there were some difficulties. These kinds of data were not published, and it was necessary to go back to the original records. These records were archived in different hydrometeorological institutes and, at the time of preparation of this paper, some of these archives could not be used. Another difficulty relates to the observation hours. Namely, in Serbia the observations at synoptic stations have been performed hourly, while in surrounding republics those observations were performed every three hours. As a result, the frequency of Cb clouds in Serbia is about three times greater. That is seen in Tables 13 and 14.

The results of an analysis of Cb cloud frequencies, based on datasets shown above, are presented in Tables 15 and 16. From Tables 13 and 14, it is obvious that the number of Cb cloud days averaged over year and station oscillates in rather large limits. However, in Tables 15 and 16,

Table 13. Dataset on thunderstorm frequency observed at synoptic stations in seeded territory in hail seasons

Years	No. of stations	No. of Cb clouds	Mean No. of days	Moving 5-yr mean	Deviations	Years	No. of stations	No. of Cb clouds	Mean No. of days	Moving 5-yr mean	Deviations
1949	-	-	-	-	-	1969	18	594	33	36	-3
1950	-	-	-	-	-	1970	18	709	39	38	3
1951	-	-	-	-	-	1971	18	658	36	38	0
1952	-	-	-	-	-	1972	17	826	48	38	12
1953	-	-	-	-	-	1973	18	630	35	41	-1
1954	-	-	-	-	-	1974	18	553	31	42	-5
1955	-	-	-	-	-	1975	18	972	54	39	18
1956	-	-	-	-	-	1976	18	730	40	39	4
1957	-	-	-	-	-	1977	18	665	37	41	1
1958	-	-	-	-	-	1978	18	566	31	37	-5
1959	11	464	42	-	6	1979	18	813	45	35	9
1960	11	373	34	-	-2	1980	18	546	30	35	-6
1961	12	358	30	37	-6	1981	18	620	34	37	-2
1962	12	388	32	36	-4	1982	18	661	37	33	1
1963	17	799	47	35	11	1983	16	600	38	33	2
1964	15	524	35	37	-1	1984	17	464	27	34	-9
1965	18	543	30	38	-6	1985	18	525	29	33	-7
1966	17	703	41	36	5	1986	17	702	41	31	5
1967	13	491	38	35	2	1987	18	500	28	-	-8
1968	17	594	35	37	-1	1988	18	508	28	-	-8

TABLE 14

Dataset on Thunderstorm Frequency Observed at Synoptic Stations in the Non-seeded Territory in Hail Season

Years	No. of Stations	No. of Cb Clouds	Mean No. of Days	Moving 5-yr Mean	Deviations
1949	15	115	8	--	-4
1950	18	115	6	--	-6
1951	17	145	8	9	-4
1952	20	232	12	9	0
1953	20	195	10	11	-2
1954	19	214	11	12	-1
1955	20	235	12	12	0
1956	19	243	13	12	1
1957	20	310	16	13	4
1958	20	149	17	12	-5
1959	20	294	15	11	3
1960	20	188	9	10	-3
1961	20	193	10	13	-2
1962	20	183	9	13	-3
1963	20	466	23	14	11
1964	20	317	16	14	4
1965	11	119	11	16	-1
1966	11	147	13	15	1
1967	11	206	19	--	7
1968	11	169	15	--	3

it may be seen that mean decade values, as well as the standard deviations for the same decades, are very close.

9. GUST WINDS

Gust wind is one of the phenomena related to Cb clouds. Gust wind is considered to be wind which speed reaches or exceeds Beaufort force number 8 (17.2 - 20.7 m s^{-1}). Such a wind speed is recorded any time it appears, and the numbers of days with gust winds are published in the Meteorological Annuals. That wind speed is recognized by most insurance companies for storm damage reimbursement.

Starting from an assumption that a hail season with greater frequency of storms and hail days will have a greater frequency of gust winds, statistics on frequency of days with gust winds in the period

TABLE 15

Minimum (Min), Maximum (Max), Mean (M), and Standard Deviation (σ) of Number of Cb Cloud Days Averaged Over Years and Station in Seeded Territory in Hail Season

Periods	Min	Max	M	σ
1959-68	30	47	36	5.3
1969-78	31	54	38	7.8
1979-88	28	45	34	6.3
1969-88	28	54	36	7.1
1959-88	28	54	36	6.5

TABLE 16

Minimum (Min), Maximum (Max), Mean (M), and Standard Deviation (σ) of Number of Cb Cloud Days Averaged Over Years and Station in Non-seeded Territory in Hail Season

Periods	Min	Max	M	σ
1949-58	6	16	10	3.2
1959-68	9	23	14	4.5
1949-68	6	23	12	4.1

Table 17. Dataset of gust winds observed at synoptic stations in seeded territory in hail seasons

Years	No. of stations	No. of days	Mean No. of days	Moving 5-yr mean	Deviations	Years	No. of stations	No. of days	Mean No. of days	Moving 5-yr mean	Deviations
1949	16	34	2.1	-	-1.0	1969	18	52	2.6	2.9	-0.4
1950	17	18	1.0	-	-2.0	1970	19	81	4.3	3.0	1.2
1951	17	17	1.0	1.4	-2.0	1971	20	71	3.6	3.3	0.6
1952	19	46	2.4	1.2	-0.6	1972	20	51	2.6	3.8	-0.4
1953	20	6	0.3	1.3	-2.8	1973	20	65	3.2	3.8	0.2
1954	20	23	1.2	1.5	1.8	1974	19	101	5.3	3.5	2.2
1955	19	29	1.5	1.4	-1.6	1975	20	89	4.4	4.0	1.4
1956	20	44	2.2	1.7	-0.8	1976	20	35	1.8	4.4	-1.2
1957	20	31	1.6	1.8	-1.4	1977	20	107	5.4	4.0	2.4
1958	20	39	2.0	1.9	-1.0	1978	19	98	4.9	3.8	2.0
1959	20	35	1.8	1.7	-1.2	1979	20	73	3.6	4.5	0.6
1960	19	35	1.9	1.6	-1.2	1980	20	82	4.1	4.4	1.2
1961	20	24	1.1	1.5	-2.0	1981	20	87	4.4	4.3	1.4
1962	20	23	1.0	1.9	-2.0	1982	20	100	5.0	4.8	2.0
1963	18	34	1.9	2.2	-1.2	1983	20	93	4.6	5.4	1.6
1964	20	71	3.6	2.4	-0.6	1984	20	118	5.9	5.2	2.8
1965	17	69	3.2	2.7	-0.2	1985	20	139	7.0	5.3	4.0
1966	19	43	2.3	2.7	-0.8	1986	20	66	3.3	5.3	-0.2
1967	19	43	2.3	2.5	-0.8	1987	20	115	5.8	-	2.8
1968	19	41	1.9	2.7	-1.2	1988	19	84	4.4	-	1.4

Table 18. Dataset of gust winds observed at synoptic stations in non-seeded territory in hail seasons

Years	No. of stations	No. of days	Mean No. of days	Moving 5-yr mean	Deviations	Years	No. of stations	No. of days	Mean No. of days	Moving 5-yr mean	Deviations
1949	18	22	1.2	-	-4.4	1969	20	95	4.8	6.0	-0.8
1950	20	23	1.2	-	-4.4	1970	20	136	6.8	60	1.2
1951	20	13	0.6	1.2	-5.0	1971	20	133	6.6	60	1.0
1952	20	31	1.6	1.7	-4.0	1972	20	105	5.2	69	-0.4
1953	20	32	1.6	2.3	-4.0	1973	20	135	6.8	7.3	1.2
1954	20	66	3.3	2.9	-2.3	1974	20	183	9.2	6.7	2.6
1955	20	84	4.2	3.2	-1.4	1975	20	176	8.8	7.3	3.2
1956	19	68	3.6	3.8	-2.0	1976	20	73	3.6	7.7	-2.0
1957	20	70	3.5	4.0	-2.1	1977	20	159	8.0	7.4	2.4
1958	20	90	4.5	4.6	-1.1	1978	19	169	8.9	6.4	3.3
1959	20	88	4.4	4.6	-1.2	1979	20	152	7.6	6.7	2.0
1960	20	142	7.1	5.1	0.5	1980	20	71	3.6	6.0	-2.0
1961	20	92	3.6	5.0	-2.0	1981	19	101	5.3	5.7	-0.3
1962	20	116	5.8	5.5	0.2	1982	19	91	4.8	5.8	-0.8
1963	20	105	5.2	5.6	-0.4	1983	20	140	7.0	6.5	1.4
1964	20	116	5.8	5.8	0.2	1984	20	168	8.4	7.0	2.8
1965	20	148	7.4	5.8	1.8	1985	20	138	6.9	8.3	1.3
1966	20	101	5.0	6.0	-0.6	1986	20	154	7.7	8.8	2.1
1967	20	110	5.5	5.8	-0.1	1987	19	220	11.6	-	6.0
1968	20	129	6.4	5.7	0.8	1988	20	189	9.4	-	3.8

TABLE 19

Minimum (Min), Maximum (Max), Mean (M), and Standard Deviation (σ) of Number of Thunderstorm Days Averaged Over Years and Station in Seeded Territory

Periods	Min	Max	M	σ
1949-58	0.3	2.4	1.5	0.66
1959-68	1.0	3.6	2.1	0.81
1969-78	1.8	5.4	3.8	1.23
1979-88	3.3	7.0	4.8	1.12
1949-68	0.3	3.6	1.8	1.13
1969-88	1.8	7.0	4.3	1.23
1949-88	0.3	7.0	3.1	1.65

TABLE 20

Minimum (Min), Maximum (Max), Mean (M), and Standard Deviation (σ) of Number of Thunderstorm Days Averaged Over Years and Station in Non-seeded Territory

Periods	Min	Max	M	σ
1949-58	0.6	4.5	2.5	1.35
1959-68	3.6	7.4	5.6	1.16
1969-78	3.6	9.2	6.9	1.86
1979-88	3.6	11.6	7.2	2.32
1949-68	0.6	7.4	4.1	2.03
1969-88	3.6	11.6	7.0	2.10
1949-88	0.6	11.6	5.6	2.48

April-September have been derived. The values obtained for the seeded and non-seeded territories are given in Tables 17 and 18.

In the gust wind analysis, it was noticed that a few stations in these datasets had much higher frequencies than others. Those stations are situated in the areas of strong local winds or located at a higher altitude. Local winds at these stations, even in the warmer half of a year, can reach a speed of the gust wind and, in that way, influence greatly the gust wind frequency. As a result, the average gust wind frequencies in different periods are very different. That is very clear from Tables 19 and 20. The most remarkable characteristic in these tables is an increase of the mean wind speed from the first to the last decade. The mean wind speed in the last decade is about 3 times greater than in the first one. From other tables, it is obvious that such an increase of the gust wind frequency has not been a result of such an increase in the number of storms. It was therefore related to an increase in the strong local winds caused by corresponding synoptic situations.

Another characteristic is that the mean frequency of the gust winds in the non-seeded territory is about twice as great as in the seeded territory. Reasons for that are the high frequencies at a few stations located in an area of frequent and strong local winds Koshawa and Bora (i.e., Vrsac, Mostar, Titograd).

According to data contained in the Meteorological Annuals, it is not possible to separate the gust winds caused by storms from those caused by strong local pressure gradients.

In order to eliminate the local wind influence to the frequency of gust winds caused by storms, five synoptic stations situated in the local wind areas and at an altitude greater than 500 m above sea level on seeded, and the same number of stations on non-seeded territories were omitted. The gust wind frequencies obtained after this reduction of number of stations are presented in Tables 21 and 22.

An analysis of the gust wind frequencies in this second variance has been shown in Tables 23 and 24. From these tables, it is seen that the gust wind frequencies are more balanced with much smaller annual variations. However, it should be pointed out that the frequencies in seeded and non-seeded territories are rather divergent. A trend of frequency increase is noticeable, too, but it is much less pronounced, particularly in the seeded territory.

10. AMOUNT OF PRECIPITATION

In Cb cloud seeding, with a goal to suppress the hailfall, we are acting on microphysics of the cloud. After some authors (i.e., Gagin and Neumann, 1974; Ben-Zvi, 1989; Aleksic, 1989), seeding for hail suppression tends to stimulate precipitation. Taking into account the size of the hail control territory in Serbia and the amount of silver iodide seeding materials used in a hail season, we made an attempt to estimate whether or not this seeding may have affected the amount of precipitation observed. For this purpose, we calculated the amount of precipitation for the hail season (April-September) recorded at 20 synoptic stations in the seeded and, at the same number of stations in the non-seeded territories in the period 1949-1988. These datasets are presented in Tables 25 and 26.

Extreme and mean values as well as the quotient of precipitation amount during the hail season for different periods are presented in Tables 27 and 28.

This analysis has shown that the amounts of precipitation in the seeded and non-seeded territories are comparable. The seasons of higher,

Table 21. Dataset of gust winds frequency in seeded territory, after omitting of stations located in the strong local wind areas.

Years	No. of stations	No. of days	Mean No. of days	Moving 5-yr mean	Deviations	Years	No. of stations	No. of days	Mean No. of days	Moving 5-yr mean	Deviations
1949	12	24	2.0	-	0.4	1969	14	26	1.8	1.6	0.2
1950	12	9	0.8	-	-0.8	1970	13	21	1.6	1.5	0.0
1951	12	13	1.1	1.2	-0.5	1971	15	38	2.5	1.7	0.9
1952	14	26	1.8	1.0	-0.2	1972	15	18	1.2	1.9	-0.4
1953	15	5	0.3	1.2	-1.3	1973	15	19	1.3	2.1	-0.3
1954	15	17	1.1	1.4	-0.5	1974	14	40	2.8	1.6	1.2
1955	14	25	1.8	1.3	0.2	1975	15	41	2.7	2.3	1.1
1956	15	32	2.1	1.6	0.5	1976	15	14	0.9	2.7	-0.7
1957	15	20	1.3	1.7	-0.3	1977	15	55	3.7	2.5	2.1
1958	15	26	1.7	1.5	0.1	1978	15	48	3.2	2.2	1.6
1959	15	21	1.4	1.2	-0.2	1979	15	21	1.9	2.4	0.3
1960	13	10	0.8	1.1	-0.8	1980	15	16	1.1	2.1	-0.5
1961	15	12	0.8	0.9	-0.8	1981	15	29	1.9	1.9	0.3
1962	15	11	0.7	0.7	-0.9	1982	15	34	2.3	1.9	0.7
1963	13	10	0.8	1.1	-0.8	1983	15	32	2.1	2.1	0.5
1964	13	8	0.6	1.2	-1.0	1984	14	32	2.3	2.0	0.7
1965	13	33	2.5	1.4	0.9	1985	13	26	2.0	2.0	0.4
1966	14	21	1.5	1.3	-0.1	1986	14	17	1.2	2.0	-0.4
1967	14	19	1.4	1.6	-0.2	1987	14	35	2.5	-	0.9
1968	14	8	0.6	1.4	-1.0	1988	14	28	2.0	-	0.4

Table 22. Dataset of gust winds frequency in non-seeded territory, after omitting of stations located in the strong local wind areas.

Years	No. of stations	No. of days	Mean No. of days	Moving 5-yr mean	Deviations	Years	No. of stations	No. of days	Mean No. of days	Moving 5-yr mean	Deviations
1949	13	15	1.2	-	-0.9	1969	15	49	3.3	2.6	1.2
1950	15	12	0.8	-	-1.3	1970	13	30	2.3	2.6	0.2
1951	15	7	0.5	0.8	-1.6	1971	15	40	2.7	2.6	0.6
1952	15	13	0.9	0.9	-1.2	1972	14	27	1.9	2.3	-0.2
1953	15	9	0.6	1.0	-1.5	1973	13	37	3.8	2.4	1.7
1954	15	26	1.7	1.1	-0.4	1974	13	26	2.0	2.2	-0.1
1955	15	20	1.3	1.1	-0.8	1975	13	35	2.7	2.4	0.6
1956	14	16	1.1	1.3	-1.0	1976	14	20	1.4	2.4	-0.7
1957	15	14	0.9	1.4	-1.2	1977	13	43	3.3	2.3	1.2
1958	15	24	1.6	1.4	-0.5	1978	11	27	2.4	2.0	0.3
1959	15	29	1.9	1.6	-0.2	1979	12	21	1.8	2.3	-0.3
1960	15	26	1.7	1.9	-0.4	1980	14	16	1.1	2.2	-1.0
1961	15	27	1.8	1.9	-0.3	1981	13	36	2.8	2.2	0.7
1962	13	30	2.3	2.1	0.2	1982	14	38	2.7	2.7	0.6
1963	15	32	2.1	2.2	0.0	1983	12	32	2.7	3.2	0.6
1964	15	44	2.9	2.4	0.8	1984	11	46	4.2	3.0	2.1
1965	12	21	1.8	2.3	-0.3	1985	15	54	3.6	3.0	1.5
1966	15	45	3.0	2.5	0.9	1986	14	23	1.6	2.7	-0.5
1967	14	26	1.8	2.6	-0.3	1987	10	30	3.0	-	0.9
1968	14	42	3.0	2.7	0.9	1988	10	12	1.2	-	-0.9

TABLE 23

Minimum (Min), Maximum (Max), Mean (M), and Standard Deviation (σ) of Number of Gust Wind Days in the Seeded Territory After Omitting Stations Located in the Strong Local Wind Areas

Periods	Min	Max	M	σ
1949-58	0.3	2.1	1.4	0.58
1959-68	0.6	2.5	1.1	0.60
1969-78	0.9	3.7	2.2	0.94
1979-88	1.1	2.5	1.9	0.64
1949-68	0.3	2.5	1.2	0.85
1969-88	0.9	3.7	2.0	0.73
1949-88	0.3	3.7	1.6	0.74

TABLE 24

Minimum (Min), Maximum (Max), Mean (M), and Standard Deviation (σ) of Number of Gust Wind Days in the Non-seeded Territory After Omitting Stations Located in the Strong Local Wind Areas

Periods	Min	Max	M	σ
1949-58	0.5	1.7	1.1	0.40
1959-68	1.7	3.0	2.2	0.54
1969-78	1.4	3.8	2.7	0.73
1979-88	1.1	4.2	2.5	0.90
1949-68	0.5	3.0	1.6	0.74
1969-88	1.1	4.2	2.6	0.81
1949-88	0.5	4.2	2.1	0.92

as well as the seasons of lower, amounts of precipitation in seeded territory are coincident with those in the non-seeded territory. Also, the correlation between amounts of precipitation in these two territories is rather high. For the first half of the period, 1949-1968, it amounts to $r = 0.90$; and for the second half, 1969-1988, $r = 0.68$; while for the whole period, 1949-1988, it amounts to $r = 0.74$.

Further, the quotient (q) of the amounts of precipitation between the mean values for different periods and the average value for the whole period considered in the seeded and non-seeded territories is very similar. However, a difference between the quotients of the first and second half of the period considered, i.e., between the seeded and non-seeded periods in the seeded territory, is a little bit greater than in non-seeded territory. That difference amounts to an increase of 3 - 4%, which might be prescribed to the effect of the hail suppression operations.

Table 25. Dataset of precipitation amount recorded at synoptic stations during the hail season in the seeded territory

Years	No. of stations	Total amount	Mean amount	Moving 5-yr mean	Deviations	Years	No. of stations	Total amount	Mean amount	Moving 5-yr mean	Deviations
1949	16	5586	349	-	-28	1969	20	7494	375	393	-2
1950	17	3516	207	-	-170	1970	19	8531	449	416	72
1951	17	6432	378	302	1	1971	20	7904	395	429	18
1952	20	4331	216	314	-161	1972	20	10059	503	437	126
1953	20	7221	361	373	-16	1973	20	8446	422	443	45
1954	20	8180	409	364	31	1974	20	8317	416	458	39
1955	20	10057	503	425	127	1975	20	9572	479	438	102
1956	19	6249	329	407	-48	1976	20	9390	470	444	93
1957	20	10440	522	420	145	1977	20	8020	401	447	24
1958	20	5394	270	300	-107	1978	20	9113	456	432	79
1959	20	9532	477	391	100	1979	20	8579	429	416	52
1960	18	6365	354	343	-23	1980	20	8122	406	397	29
1961	20	6652	333	349	-44	1981	20	7763	388	386	11
1962	20	5605	280	332	-97	1982	20	6076	304	365	27
1963	20	5983	299	327	-78	1983	20	7989	399	350	22
1964	20	7874	394	331	17	1984	20	6609	330	345	-47
1965	17	5591	329	352	-48	1985	20	6582	329	356	-48
1966	20	7064	353	364	-24	1986	20	7306	365	333	-12
1967	20	7740	387	361	10	1987	20	7119	356	-	-21
1968	20	7181	359	385	-18	1988	17	4849	285	-	-92

Table 26. Dataset of precipitation amount recorded at synoptic stations during the hail season in the non-seeded territory

Years	No. of stations	Total amount	Mean amount	Moving 5-yr mean	Deviations	Years	No. of stations	Total amount	Mean amount	Moving 5-yr mean	Deviations
1949	18	7490	416	-	-33	1969	20	10481	524	466	75
1950	20	5314	266	-	-193	1970	20	9534	477	495	48
1951	20	8741	437	380	-12	1971	20	7191	360	484	-89
1952	20	6316	316	392	-133	1972	20	12379	619	486	170
1953	20	9320	466	445	17	1973	20	8816	441	494	-8
1954	20	9685	474	435	25	1974	20	10673	534	534	85
1955	20	10644	532	469	83	1975	20	10317	516	410	67
1956	20	7704	385	449	-64	1976	20	11225	561	543	112
1957	20	9806	490	467	41	1977	20	10052	503	536	54
1958	20	7298	365	438	-84	1978	19	12009	600	515	151
1959	20	11235	562	434	113	1979	20	10033	502	495	53
1960	20	7715	386	399	-63	1980	20	8185	409	469	-40
1961	20	7328	366	412	-83	1981	20	9256	463	429	14
1962	20	6362	316	396	-133	1982	20	7461	373	431	-76
1963	20	8617	431	405	-18	1983	20	7997	400	425	-49
1964	20	9620	481	424	32	1984	20	10211	510	417	61
1965	20	9018	451	456	2	1985	20	7576	379	423	-70
1966	20	8808	440	468	-9	1986	20	8470	424	425	-25
1967	20	9529	476	477	27	1987	20	8079	404	-	-45
1968	20	9888	494	486	45	1988	20	8164	408	-	-41

11. RELATION BETWEEN HAIL AND ICE PELLET FREQUENCIES

A comparison of mean annual number of hail and ice pellet days in non-seeded territory (Tables 2 and 6) shows that there is a certain parallelism in a multi-year series of these phenomena. Years of great hail frequencies coincide with years of great ice pellet frequency and vice versa. That illustrates the following facts:

1) A year with the greatest annual frequency of number of hail days (1963) has the greatest annual frequency of number of ice pellet days.

2) The sign of deviations of mean annual frequency of hail and ice pellet number of days was the same in 29, and opposite in 11 of the 40 years.

In the seeded territory, these relations were completely reverse. If we look at the seeded period

TABLE 27

Minimum (Min), Maximum (Max), Mean (M), and Quotient (q) of Amount of Precipitation (mm) per Hail Season and Station in the Seeded Territory

Periods	Min	Max	M	σ
1949-58	207	522	354	0.94
1959-68	280	477	356	0.94
1969-78	375	508	437	1.16
1979-88	285	429	359	0.95
1949-68	207	522	355	0.94
1969-88	285	503	398	1.06
1949-88	207	522	377	1.00

TABLE 28

Minimum (Min), Maximum (Max), Mean (M), and Quotient (q) of the Amount of Precipitation (mm) per Hail Season and Station in the Non-seeded Territory

Periods	Min	Max	M	σ
1949-58	266	532	415	0.92
1959-68	366	562	440	0.98
1969-78	360	619	514	1.14
1979-88	373	510	427	0.96
1949-68	266	562	427	0.96
1969-88	360	619	470	1.05
1949-88	266	619	449	1.00

only, 1969-1988, then in Tables 1 and 5 we may see:

1) A year with the lowest annual frequency of the number of hail days (1988) had the greatest annual frequency of the ice pellet number of days;

2) The sign of deviations of the mean annual frequency of hail and ice pellet days was the same in 8, and opposite in 12, of 20 years.

It may be seen from smoothed values of the mean annual frequency of number of hail and ice pellet days in the non-seeded territory (Tables 2 and 6) that in the last decade there is no trend of rising or falling of hail frequency, while a slight increase in the frequency of ice pellets was noticeable. However, the smoothed values in seeded territory (Tables 1 and 5) for the same period show a marked decreasing trend of hail frequency and an increase in ice pellet frequency.

A correlation coefficient between the annual frequencies of hail and ice pellets in the seeded territory and in the non-seeded period was positive ($r = 0.20$). However, in the seeded period in the same territory, the correlation coefficient was negative ($r = -0.16$), while for the whole 40-year period it was close to zero.

In the non-seeded territory, the correlation coefficient between annual frequencies of hail and ice pellet number of days was always positive. For the period 1949-1968, it was rather high ($r = 0.60$), while for the period 1969-1988, it was $r = 0.39$.

12. RELATION BETWEEN HAIL AND THUNDERSTORM FREQUENCIES

Mean annual frequency of the number of hail and thunderstorm days given in Tables 1, 2, 9, and 10 shows that there is a parallelism in the multi-year course of these two phenomena. Years with the greatest frequency, and years of the lowest frequency of thunderstorm occurrences coincide with the greatest and lowest frequency of hail occurrences. Then, the deviations of mean values of these phenomena have the same sign in 26 of the 40 years. These characteristics are identical for both territories -- seeded and non-seeded. Further, the smoothed values of the mean annual frequencies of the thunderstorm and hail in the last decade of the period considered show a trend of decreasing. However, that trend of decreasing has been much more pronounced in hail than in thunderstorm frequency.

A correlation coefficient between the hail and thunderstorm frequencies is positive. In the non-seeded period, 1949-1968, it was $r = 0.20$. After introducing hail suppression operations, 1969-1988, the correlation coefficient was significantly increased, reaching $r = 0.61$. This increase was caused by two factors. First, in the last decade both frequencies had a decreasing trend and their deviations had the same sign. Secondly, the marked decrease of hail frequency in the last decade caused greater absolute values of deviations than the rest of the years.

The correlation coefficients between the hail and thunderstorm frequencies in the first and second half of the 40-year period in the non-seeded territory were very close. However, in the seeded territory, they were rather different. Thus, for the first half of the period 1949-1968, in the seeded territory the correlation coefficient between the hail and thunderstorm frequencies was $r = 0.55$, and for the second half, 1969-1988, it was $r = 0.41$.

13. RELATION BETWEEN HAIL AND Cb CLOUD FREQUENCIES

From an incomplete dataset on Cb cloud frequency, some relations to hail frequency can be derived. Thus, a comparison of the hail and Cb cloud frequencies in the period 1949-1968, in the non-seeded territory shows that years of the greatest and lowest frequencies coincide. Furthermore, in about two-thirds of the years in the period considered, the deviation of the mean values had the same sign. Correlation coefficient between mean annual frequency of hail and Cb cloud number of days for the period 1949-1968 at the control territory was $r = 0.72$. The ratio between total number of hail and Cb cloud days shows that, in every 10 Cb clouds, one hailfall appears.

The statistics on Cb clouds observed in the seeded territory have been derived for the period 1959-1988. The important characteristics, which may be seen in Table 15, are that mean decade frequencies observed in the seeded territory are very equalized. The Cb cloud frequency in the last decade was somewhat less than in the previous two decades. However, the smoothed mean annual frequency does not show a decreasing trend, but a marked equalization. On the contrary, the hail frequency in that period had a marked trend of frequency decrease. Due to such a non-uniformity, the correlation coefficient between annual hail and Cb cloud frequencies was decreased to $r = 0.66$.

In the target territory in the non-seeded period (1959-1968), in each 28 Cb clouds observed, one hailfall was recorded. In the last decade (1979-1988), when the hail suppression system was operating well, that ratio changed, and in every 37 Cb clouds observed, one hailfall was recorded.

14. RELATION BETWEEN HAIL AND GUST WIND FREQUENCIES

A comparison of Tables 1 and 17 shows that in annual frequency courses of hail and gust winds (first variant) in the target and control territories, there are no noticeable similarities between them. Years with maximum and minimum frequencies are not coincided. For the reason of a pronounced trend of the gust wind frequency increase, from the beginning to the end of the period considered, the deviations in the first half of the period were predominantly negative and, in the second part of the period, positive.

Correlation coefficient between annual hail and gust wind frequency in the first half of the period (1949-1968) was $r = 0.31$; and in the second half, it was close to zero.

These correlation coefficients show that the hail and gust wind frequencies are independent or, to some extent, opposite. That means that in the gust wind frequencies, the strong local winds, as well as the upper station winds, are predominant in relation to number of gust winds caused by storms. And, as is well known, the strong local and upper winds are not favorable for Cb cloud development.

The connection between annual hail and gust wind frequencies in the control territory is in direct proportion. In the first half of the period, the correlation coefficient is $r = 0.46$, and in the second half it is $r = 0.21$, while for the whole period it amounts to $r = 0.24$.

In order to eliminate the local and upper wind influences on the total gust wind frequency, we omitted five synoptic stations in the seeded and non-seeded territory, located in Bora and Koshawa wind areas, as well as the synoptic stations located at an altitude greater than 500 m above sea level (second variant). If we now compare the annual hail and gust wind frequencies (Tables 1 and 21) in the target territory, we notice certain similarity in their annual courses.

In the target territory, the correlation coefficients between hail and gust wind frequencies after the second variant are: In the first half of the period, $r = 0.26$; in the second half of the period, $r = 0.12$; and for the whole period, $r = 0.35$. In the control territory, the correlation coefficients after the second variant are: In the first half of the period, $r = 0.37$; in the second half and for the whole period, $r = 0.07$.

15. RELATION BETWEEN HAIL FREQUENCY AND AMOUNT OF PRECIPITATION

A comparison of Tables 1, 2, 25, and 26 shows that years having greater amounts of precipitation in the hail season (April-September) have greater number of hail days and vice versa. In the control territory, the number of positive and negative deviations of hail frequency and amounts of precipitation are equal in the first half, as well as in the second half, of the 40-year period.

However, in the target territory, in the first half of the period (1949-1968) when the hail suppression system was not operating, the precipitation amounts were less than in the period when the system was operating. As a consequence, the number of negative deviations was twice as great in the first half as in the second half of the period.

The hail frequency had a complely reverse course. In the first half of the period, the frequencies were greater than in the second half when the hail suppression system was operating. Therefore, in the second half of the 40-year period, 15 of the 20 years had a negative deviation. Such a reverse course in the hail frequency and the amount of precipitation, in spite of their generally directly proportional ratio, may be prescribed to the effect of hail suppression activities.

The correlation coefficient between the hail frequency and amount of precipitation in the target territory for the first half of the period when the hail suppression system was not operating amounts to $r = 0.47$. For the second half of the period when the hail suppression system was operating, the correlation coefficient was $r = 0.57$.

In the control territory, the correlation coefficient between the hail frequency and the amount of precipitation for the first half of the period was $r = 0.07$. For the second half of the period, it was $r = 0.60$. This relatively high correlation coefficient is the result of negative deviations of both precipitation amount and hail frequency in eight years in the last decade.

16. CONCLUSIONS

The starting assumption in this paper was that hail suppression seeding reflects on the frequency of the phenomena related to Cb clouds, which may be observed in the regular network of meteorological stations. The first hypothesis stating that, "In a climatic homogeneous region, there is a defined statistical relation between Cb cloud frequency and the frequencies of phenomena related to these clouds," has been confirmed. Datasets on Cb clouds and hail frequencies observed in the regular network of meteorological stations at the non-seeded territory showed a correlation coefficient of r = 0.72.

The second hypothesis was "If there is a statistical relation between Cb cloud frequency and the frequencies of phenomena related to these clouds (that was confirmed through the first hypothesis), then there is a statistical relation among these phenomena themselves." This hypothesis has been confirmed by the correlations between hail frequency and the frequencies of the rest of the phenomena related to the Cb clouds (the ice pellets, thunderstorm, gust wind, and amount of precipitation). Thus, between hail and ice pellet frequencies, correlation coefficients in non-seeded territory amount to r = 0.39; between hail and thunderstorm frequencies, r = 0.46; between hail and gust winds as well as amounts of precipitation, r = 0.24.

The third hypothesis stating, "If the frequency of one phenomenon related to the Cb cloud is changed by seeding that cloud, then the statistical relation between that and the rest of the phenomena related to Cb clouds will be changed," has also been confirmed by a significant change in the correlation coefficients between hail frequency and the frequencies of the rest of phenomena in the seeded and non-seeded periods. Thus, the correlation coefficient between hail and ice pellet frequencies in the non-seeded period was r = 0.20, while in the seeded period it changed the sign and became r = -0.16. Furthermore, the correlation coefficient between hail and thunderstorm frequencies in the non-seeded period was r = 0.20; in the seeded period, it was increased to r = 0.61. There were also great changes of correlation coefficient between hail frequency and the frequencies of the gust winds and amounts of precipitation.

It may be concluded that there are statistical relations among the phenomena related to Cb clouds. By Cb cloud seeding, these statistical relations are changed in comparison to those existing in non-disturbed natural conditions. These changes of defined statistical relations between the phenomena related to Cb clouds, which are caused by hail suppression seeding, can be observed in the regular network of meteorological stations. These changes may be used as an estimation of the effectiveness of hail suppression operations.

Acknowledgments. This work has been supported by the Republic Hydrometeorological Institute of Serbia and by the Science Association of Serbia, Belgrade.

Appreciation is extended to Mrs. Verica Vesic, Mr. Zoran Babic, and other colleagues who helped in collecting datasets. Also the author wishes to thank Mrs. Ljubica Radoja for typing the manuscript, Mrs. Joie L. Robinson, and other reviewers for editorial assistance.

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