ONE EVIDENCE OF THE HAIL SUPPRESSION EFFICIENCY DERIVED FROM RADAR MEASUREMENTS

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Abstract. In Serbia (Yugoslavia) hail suppression programs have been operated continuously for the past twenty two years. Important details of how silver iodide stimulates freezing remain largely unknown. Assuming that seeding increases the concentration of the ice particles by a given factor, changes in the radar parameters of clouds can be expected. Two-minute radar parameter changes are considered. The differences between no seed and seed cases are analysed. During the seeding periods of cloud life a more rapid change in clouds parameters is clearly noted.

1. INTRODUCTION

In Yugoslavia operational nonrandomized hail suppression has been conducted since 1967. The most important activity is that in Serbia where the hail suppression system covers about four million hectares of agricultural surface. This is one of the largest areas in the world protected by such a system. Although this hail suppression project is considered operational, many of the activities have a pure research component (Ćurić, 1981 and 1985; Radinović, 1972).

An important aspect of the total hail suppression activity is the collection of data required for a further analysis. Two basically different types of data are collected: radar data and data collected at the rocket firing stations (substations manned by trained volunteer observers). These observers report days when hail occurred at their station, hail duration, intensity and hailstones size (ranged in nine classes).

The evaluation of hail control efficiency in Serbia has been based on two sources of data which have been obtained independently of the hail control system (Radinović, 1989). These are: 1) The size of the hail-swept agriculture area and percentage of the damaged crops; 2) Frequency of hail occurrences observed at the regular network of meteorological stations. Several statistical tests have been applied to above-mentioned data and they suggest that hailfall in the protected area is reduced by about 70%).

This paper presents an analysis of radar data from a operational hail project in Serbia designed to provide economical benefits. The possibilities that cloud seeding is associated with changes in the cloud top height, height of maximum radar reflectivity and temporal changes in radar reflectivity are investigated with the aid of simple techniques.

2. PROJECT DESIGN

The operational nonrandomised hail suppression project in Serbia is carried out by the regional Hydrometeorological Service. All protected areas are organized in so called hail suppression poligons. Each poligon has a radius of approximatly 30 km. The program is designed to operate 24 hours per day during the summer months (15th April to 15th October). All hailstorms drifting over the poligon are monitored by S band (10 cm wave length) radar located at the center of the poligon.

When a cloud meets specific criteria based on radar reflectivity, the significant temperatures and the ratio of the depth of cold and warm part of cloud, (Ćurić, 1981) the cloud is seeded. The seeding is conducted, from ground based rocket stations separated by about 5 km. Each m^3 of the seeded cloud volume is required to contain 10^5-10^6 artificial ice nuclei.

3. DESCRIPTION OF DATA

A large amount of ground measurements and observations, standard meteorological informations and radar data are collecting during the operational project. Most of the data are available on magnetic tape in the computer center of the Hydrometeorological Service of Serbia. Other data are stored in the annual reports, titled "The Hailstorm Data Series".

For every considered cell tracked and monitored by means of radar we have a large amount of data such as: an indication of cell motion its azimuth and distance, radar echo top heights, the heights of the maximum reflectivity zone, and changes in maximum reflectivity. The radars are operated day and night, and all data are collected each two or three minutes. Other operational data are also collected such as the number and type of rockets fired into each cloud.

4. METHOD OF EVALUATION

Radar records the integrated effects of all individual quantities such as reflectivity by rain drops, cloud droplets, ice particles, hailstones, snowflakes, and regions of large index of reflectivity. Assuming that seeding increases the concentration of the ice particles in the cloud by a given factor suggests imply the questions, what does this do to the various radar parameters? Absence of a fully satisfactory theory allow us to say that wide range of possible effects may be expected. Some of these include changes in cloud microphysics (glaciation), changes of cloud dynamics such as intensification of the updraft, shortening or lengthening of life time of cell, etc. (Foote et al., 1979; Federer and Waldvogel, 1978).

Because of the complexity of the possible effects we have turned to some quantitative parameters for assistance. Radar parameter of 90 hail cells have been investigated. Those cells with seeded (T_s) and nonseeded (T_{ns}) duration periods of 30 minutes are selected. Obviously, longer lasting cells are considered. Within seeded periods may be some unseeded subperiods, if their durations are shorter Than 5 minutes. If unseeded periods follow a seeded period, the intermediate period, T_i, is taken into consideration (see fig.1). This period is taken to be 10 minutes. In general, the total unseeded period for one cell is the sum of preseeded and postseeded periods, as it is indicated in fig.1.

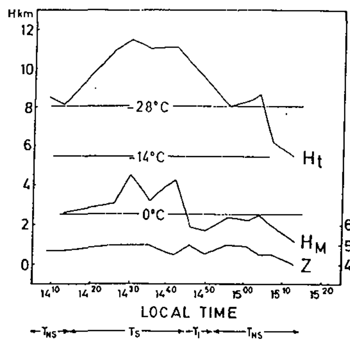

Fig.1 Time plot of radar cloud height (H_t), maximum radar reflectivity (Z) and height of maximum radar reflectivity (H_m). The horizontal lines show the levels of several temperatures of the 30 May 1987.

Fine-timescale radar observations allow us to obtain quite good temporal evolution of data. Between two successive measurements the linear change of data is assumed (fig.2).

The following expression is used for calculation of the coefficient k as a measure of the change tendency for the considered radar parameter y

$$k_{iy} = \frac{1}{2} \frac{(Y_{i+1} - Y_i)^2}{(Y_i - \bar{Y})^2} \qquad (1)$$

where is i the time interval, $\bar{Y}$ the mean values of the considered radar parameter over the all time period (in our case this period is 30 minutes). Since we consider a time interval of 2 minutes for one cell,

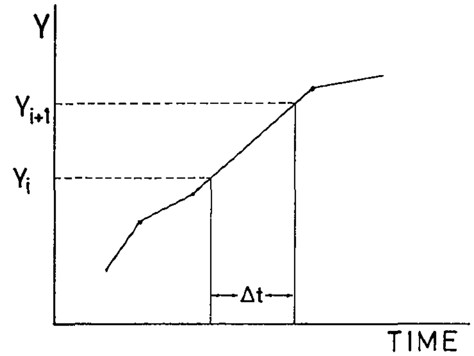

Fig.2 Shematic representation of the temporal change of radar parameter Y.

15 values of coefficient k are calculated for the seeded and 15 values for the unseeded period. This coefficient is considered as a predictor for the previously mentioned radar parameters.

5. DESCRIPTIONS OF THE PREDICTORS

The purpose of this section is to find one quantity that predicts the behavior or considered radar parameters in seeded and unseeded periods for all 90 cells. The difference between these quantities must have information about mean seeding effects on clouds. The frequency distribution of the considered radar parameters for all cells as a function of coefficient k is analysed.

a) <u>The Height of the Maximum Reflectivity</u>

The frequency of the coefficient for heights of maximum reflectivity, taking all cells together, is shown in Fig.3. The distribution indicates that in the largest number of cases the coefficient k is located between 0.01 to 0.5. The logarithmic scale for k is taken due to the wide range variability of k.

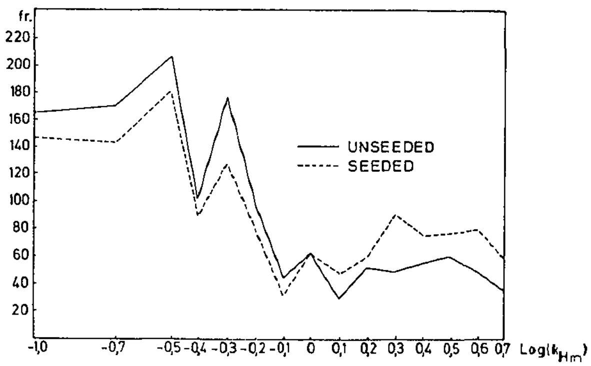

Fig.3 Frequences of coefficient for the maximum reflectivity height as function of log k_{Hm} for all cells during seeded (dashed line) and unseeded period of cloud life.

For the seeded period (dashed line) there is a clearly expressed increase in frequency of occurrence of higher values of coefficient k (values of log k_{Hm} between 0 - 0.7). This increase may be induced by latent heat released during the formation of new ice particles in cloud. It is interesting to note that such difference in frequences for seeded and unseeded periods is in accordance with the embryo competition theory. However, in the absence of a fully satisfactory theory this may be considered only as one indicator of seeding effects.

b) The Cloud Top Height

Seeding of convective clouds can modify cloud top height through microphysical and dynamical effects. This increase in cloud height is induced by artificial glaciation of supercooled cloud water as noted by many authors (Federer et al., 1985; Dennis et al., 1975; e.t.c.).

In Fig.4 the frequency of k_{Ht} for cloud top heights is shown. The behavior of this distribution is the same as the coefficient of the maximum reflectivity. The main features which emerge from this curves behavior is the increase of frequencies for higher values of k_{Ht} (values of log k_{Ht} between 0.2-0.7) for seeded period.

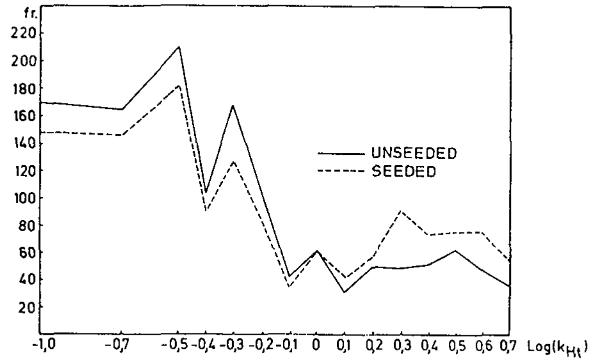

Fig.4 The same as fig.3 but for cloud top height.

c) The Maximum Radar Reflectivity

The frequency of the coefficient for maximum radar reflectivity is shown in fig.5. These curves have similar behavior as those for two previously analysed radar

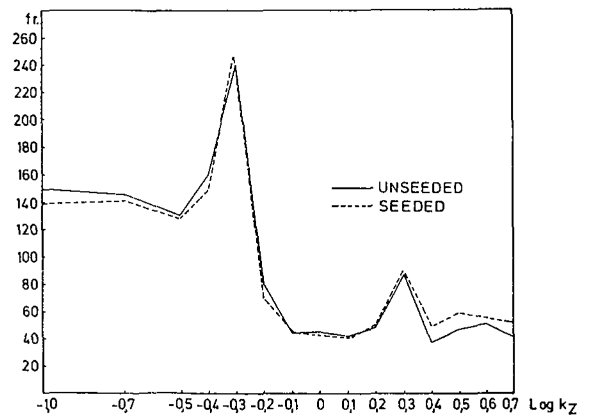

Fig.5 The same as fig.3 but for maximum radar reflectivity Z.

parameters. The maximum frequencies are moved toward the higher values of k_Z (values of log k_Z between 0.3-0.7). It is apparent for the seeded cases there is a smaller increase of frequencies with higher values of k_Z than for other radar parameters.

6.CONCLUSION

It is interesting to note that the effects presented here may only be considered as one indicator of the seeding. The data strongly suggest that seeding has a clearly expressed influence on frequency distribution change. The increase in number of cases with higher values of coefficient k is remarkable. This indicator of hail suppression efficiency can be identified within the characteristics of C_b clouds during the seeding and non-seeding period of cloud life. Although no current hail suppression hypothesis exists that involves an increase or a decrease in the short-term variability of storm characteristics, the data presented here suggest that it exists in a large number of considered cloud cells.

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