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THE INFLUENCE OF CLOUD DROP SIZE DISTRIBUTION ON SIMULATED SEEDING EFFECTS OF HAIL-BEARING CLOUD

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Abstract. Two versions of a microphysical model were applied to investigate the silver iodide/cloud environment interaction. One version uses the monodisperse size distribution for cloud droplets, while the Marshall-Palmer distribution was applied to raindrop fraction. The second version uses the Khrgian-Mazin size distribution for the entire drop spectra. The AgI residence time and the graupel production were calculated at the top of the seeding zone defined between isotherm levels of -8°C and -12°C, when the AgI agent is injected at the level of -8°C. AgI agent residence time and graupel production were found to be greater in the KM version in comparison to the MMP version. Graupel production was found to be highly dependent on drop size distribution and mean radius of drop spectrum.

1. INTRODUCTION

Hail causes considerable demage to crops and property. Many hypotheses have been proposed for suppressing hail. The most common has been creating enhanced competition among hailstones and their embryos for available moisture. This hypothesis is known as "beneficial competition" (Sulakvelidze 1967). Under this concept,the total amount of supercooled water available for hailstone growth is considered fixed. If the number of hailstones could be increased, then the share of the supercooled water that each would receive would be reduced and hailstone sizes would be reduced accordingly. Smaller hailstones would fall more slowly and lose a larger fraction of their ice mass by melting, thereby decreasing the total hail mass. A hail suppression project based on the Soviet method has been in operation in Serbia for twenty-eight years. The concept and the effectiveness of the hail suppression in Serbia have been described in more detail by Ćurić (1990), Ćurić and Janc (1995), Radinović (1989) and Mesinger and Mesinger (1992).

Computer models which simulate cloud and precipitation development can provide useful information about the type of effects to be expected from cloud seeding. They can highlight a number of possible seeding strategies, and seeding materials which are likely to have the greatest success, as presented, for instance, by Ćurić and Janc (1993,1995) and Farley et al. (1994).

Ćurić and Janc (1990,1993) developed a microphysical model based on results of Lamb et al. (1981) and applied it in the temperature interval between -8°C and -12°C which is considered to be the seeding zone in the operational hail suppression programme in Serbia. Ćurić and Janc (1990) investigated the natural and artificial graupel production by varying the temperature, pressure and initial number concentrations of contact and deposition nuclei for different cloud conditions. They showed that Brownian and inertial collection rates due to cloud droplets are the most effective contact nucleation mechanisms in producing graupel particles for seeded cases and for cases that lack raindrops. If both contact and deposition nucleation mechanisms work simulataneously, the contact nucleation mechanism seems to be more effective for graupel production.

The research reported here focused upon one aspect to analyze the influence of the assumed drop size distributions on the graupel production and the seeding agent residence time inside the seeding zone for the AgI agents used in the operational hail suppression project in Serbia.

2. MICROPHYSICAL MODEL

A new version of the microphysical model of Ćurić and Janc (1993) was applied to simulate the interaction of AgI particles with the cloud environment. Contrary to Ćurić and Janc (1990) it also considers diffusiophoresis and thermophoretic contact nucleations, while the immersion freezing term is omitted because its role seems to be small. The model has the conventional approach with respect to drop size distribution. Hence,the monodisperse size distribution was used for cloud droplets with the radius of 10μm according to Hsie et al. (1980), while the Marshall-Palmer size distribution with the fixed intercept parameter of $8\times10^{6}\,\mathrm{m}^{-4}$ was used for raindrops, radius ≥50 μm (hereafter called MMP case). The MMP case produces an unnatural gap into size range of both the cloud droplet and the raindrop spectra. In order to avoid the inconsistency of cloud droplet and raindrop size distribution treatment the Khrgian-Mazin size distribution for the entire drop spectrum was applied (hereafter called KM case).

The Khrgian-Mazin size distribution of drops may be written (Ćurić and Vuković 1991) as

$$f(R) = AR^{2}\exp(-BR) \qquad (1)$$

where

$$A = 1.46\frac{L}{\rho_w R_M^{6}}; B = \frac{3}{R_M}. \qquad (2)$$

Here L is the liquid water content; R_M is the mean radius for drop spectra, ρ_w is the liquid water density, while R is the drop radius. The R_M takes the values of 10 and 20μm respectively in our model runs.

The prognostic equations of microphysical model were those described by Ćurić and Janc (1990, 1993). The activation curves for contact and deposition nuclei are described by Hsie et al. (1980). The continuity equation for the agent mixing ratio, X_S, adapted for zero-dimensional convective cloud model was written as

$$X_S^{t+\Delta t} = X_S^t - \mu X_S^t \Delta t \div (S_{BFC}^t + S_{BR}^t + S_{IR}^t + S_D^t)\Delta t. \qquad (3)$$

All terms on the right-hand side of (3) refer to the previous time step where Δt designates the time step, taken to be 1s, of the microphysical model. The second term on the right-and side of (3) describes the effects of turbulent diffusion in the seeding zone. The entrainment rate μ was fixed at the value of $10^{-3}s^{-1}$ in shallow layer (500-600 m). The rest of the terms in small brackets are the sink terms caused by 1) Brownian collection rate due to cloud droplets and phoretic processes, 2) inertial collection rate due to cloud droplets, 3) Brownian and inertial collection rates due to raindrops and 4) deposition respectively.

The seeding zone was considered to be between isotherm levels of -8°C and -12°C. Within the zone, the lapse rate of temperature was taken to be 7 K/km. The pressure at the bottom level of the seeding zone was taken to be p=570 hPa, the mean climatological value for the period of the application of the operational hail suppression project in Serbia.The depth of the seeding zone in all calculations is d=571m. The liquid water content was assumed to be fixed within the zone ($5\times10^{-3}kgkg^{-1}$). The values of the reference vertical velocity (w_r) were held fixed inside the seeding zone ($10\text{-}20\,ms^{-1}$) and they were independent of additional graupel production. On the other hand, the resulting vertical velocity depends on the artificial graupel production as described by Ćurić and Janc (1993).

3. SIZE DISTRIBUTION EFFECTS

The primary aim of this work was to investigate, for great variety of atmospheric conditions, the possible influence of variation in drop size distribution on the graupel production (N) and the seeding agent residence time (t_R), which were considered to be the most important factors for successful hail supression activities in Serbia (Ćurić and Janc, 1993). The graupel production refers to that at the top of the seeding zone, while the seeding agent residence time was the time needed for seeded parcel to move upwards from the bottom to the top of the seeding zone. According to the hail suppression concept in Serbia (Ćurić and Janc 1995), the seeding operation was terminated if the graupel cocentration of $100\,m^{-3}$ formed inside the seeding zone. Herein, the effects of the cloud drop size distribution in the seeding zone was investigated for four types of the seeding agents used in the operational hail suppression project in Serbia (TG-10, TG-5, SAKO-6, PP-6) whose main characteristics are published by Ćurić and Janc (1995). Their main characteristics were that they provide the same chemical composition but differ from each other only by a particle mass and mixing ratio.

Table 1. summarizes the initial number concentrations of cloud droplets and raindrops for both model versions (KM and MMP). They were

Table 1.: The initial number concentrations of cloud droplets, N_C (in m^{-3}), and raindrops, N_R (in m^{-3}) for the KM and MMP model versions and the values of the mean radius of drop spectrum (10 and 20μm), respectively.

R_M	$N_C(m^{-3})$		$N_R(m^{-3})$	
	KM	MMP	KM	MMP
10 μm	0.391×10^{9}	0.866×10^{9}	0.147×10^{5}	0.560×10^{3}
20 μm	0.479×10^{8}	0.659×10^{9}	0.991×10^{6}	0.275×10^{4}

determined in the following manner: the cloud and rain water mixing ratios were calculated using Eqs. (1) and (2) and then corresponding concentrations for both model versions under the same cloud/rain water mixing ratio. The arbitrary size limit (diameter of 100μm) between two parts of the drop spectrum (Hsie et al. 1980) was assumed. The varied values of R_M changes the rain (cloud) water mixing ratio (see Eq. 1). It should be noted that the KM model version produces more small raindrops or it generates more large cloud droplets compared to the MMP one. This was especially evident for R_M=20 μm.

The total effect of the microphysical processes inside the seeding zone contributes to different values of the graupel number concentration (m^{-3}) at the top boundary. The agent residence time for both KM and MMP versions is shown in Figs. 1 and 2 for two cloud environments of R_M=10 and 20μm, respectively. The graupel production is presented in Figs. 3 and 4 for the same conditions as in Figs. 1 and 2.

The KM version has greater rain production so that the agent residence time and the graupel production were always greater than for the MMP one (Figs. 1-4). As can be seen from Figs. 1 and 2, the agent residence time shows an exponential type dependence on reference vertical velocity. For w_r=20 ms^{-1}, the curves for different agent types approach each other. The cloud atmosphere with R_M=20μm leads to more intense graupel production,which in turn, increases the agent residence time and the discrepances among curves for different agents (compare Figs. 1 and 2).

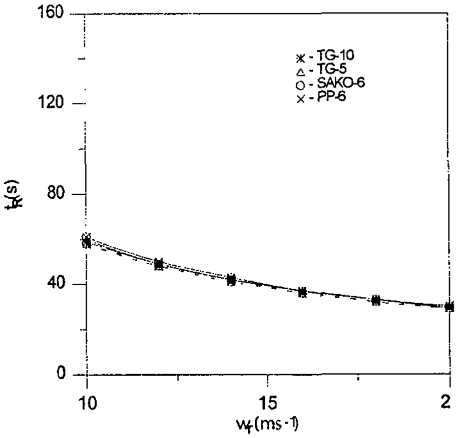

Fig. 1.: The agent residence time, t_R(s), vs reference vertical velocity for the agents used and the cloud atmosphere with R_M=10μm. Solid and dashed lines designate the KM and the MMP cases, respectively.

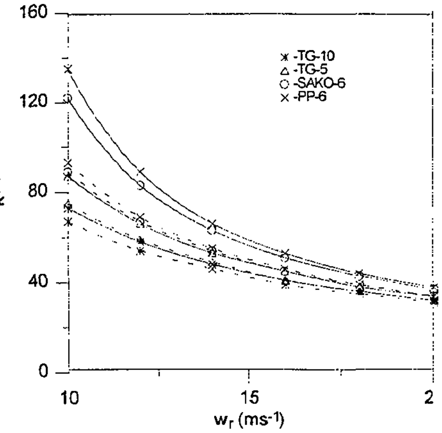

Fig. 2.: As in Fig. 1 but for R_M =20μm.

Our calculations show that the SAKO-6 and PP-6 agents are more effective in producing cloud ice and then graupel (Figs. 3 and 4). The greatest graupel production (15.2 m^{-3}) and the longest residence time (135s) are observed for the PP-6 agent if R_M=20μm and w_r=10 ms^{-1} for the KM version (Figs. 2 and 4). The graupel production was greater for the KM version than for the MMP one if R_M=10μm (Fig. 3). Further, the KM version gives nearly double MMP graupel production for R_M=20μm (Fig. 4). We also concluded that the graupel production does not

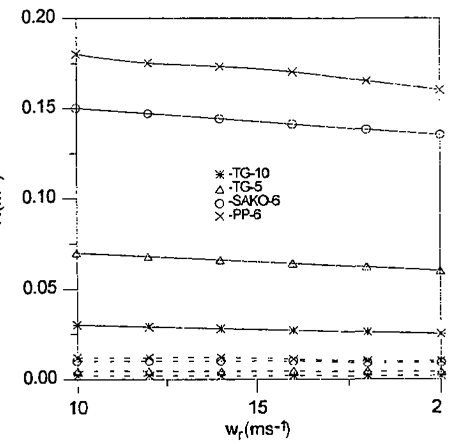

Fig. 3.: Graupel production, N (m^{-3}), vs reference vertical velocity for the agent used and the cloud atmosphere as in Fig. 1. Solid and dashed lines mean the same as in Fig. 1.

depend significantly on the reference vertical velocity. The model calculations (not presented here) clearly show that the mechanism via the gravitational coagulation between cloud ice formed by deposition nucleation and raindrops mainly contributes to the pronounced differences in graupel production for two model versions. It seems reasonable because the KM size distribution always generates greater concentrations of small raindrops than the MMP case under the same conditions (see Table 1).

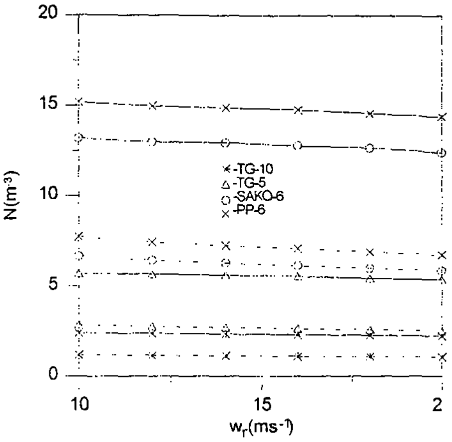

Fig. 4: As in Fig. 3 but for R_M *=20μm..*

4. CONCLUSIONS

The KM model version generates smaller number concentrations of cloud droplets compared to the MMP version. The resulting effect of the increased raindrop production for the KM version always results in greater graupel production and seeding agent residence time compared to the MMP case.

Following the model concept it may be concluded that the mechanisms with respect to rain water fraction is only responsible for graupel production. The size distribution functions have pronounced effect on the graupel production. The smallest values of the graupel production and the seeding agent residence time are calculated for the TG-10 agent, while the greatest is for the PP-6 one. This is influenced mainly by the different agent particle masses (sizes). In accordance to the beneficial competition hypothesis model results suggest that the PP-6 agent is the most effective at suppressing hail. It is further suggested, the radar reflectivity criterion alone is insufficient for decision making about hail suppression, the drop size distribution must also be known in the seeding zone just before the agent injection due to the optimal rocket consumption.

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5. REFERENCES

Ćurić,M.,and D. Janc,1990:Numerical study of the cloud seeding effects.*Meteorol. Atmos. Phys.*, 42,145-164.

Ćurić, M., and Z. Vuković, 1991: The influence of thunderstorm thunderstorm-generated acoustic waves on coagulation. Part I: Mathematical formulation. *Z. Meteorol.*, 41,164-169.

Ćurić,M.,and D. Janc,1993: Dependence of the simulated seeding effects of Cb cloud on the types of the AgI agents. *Meteorol. Atmos. Phys.*, 52,91-100.

Ćurić,M.,and D. Janc,1995: On the consumption of AgI seeding agent: Dependence on the liquid water content in the seeding zone. *J. Wea. Mod.*,27,17-20.

Farley, R.D., Nguyen, P., and H. D. Orville, 1994: Numerical simulation of cloud seeding using a three-dimensional cloud model. *J. Wea. Mod.*,26,113-124.

Hsie, E-Y., Farley, R.D., and H.D. Orville,1980: Numerical simulation of ice-phase convective cloud seeding. *J. Appl. Meteor.*,950-977.

Lamb,D.,Hallett,J.,Sax,R.I.,1981: Mechanistic limitations to the release of latent heat during the natural and artificial glaciation of deep convective clouds. *Quart. J. Roy. Met. Soc.*,107,935-954.

Mesinger,F., and N. Mesinger, 1992: Has hail suppression in Eastern Yugoslavia led to a reduction in the frequency of hail?,*J. Appl. Meteor.*,34,104-111.

Radinović, Dj.,1989: Effectiveness of hail control in Serbia.*J. Wea. Mod.*,21,75-84.

Sulakvelidze, G.K.,1967: Showers and hail. (in Russian). Leningrad, *Gidrometeoizdat*, 412pp.

Young,K.C.,1977: A numerical examination of some hail suppression concepts. *Meteor. Monogr.*,No. 38, 195-214.