AIR POLLUTION AEROSOLS INDUCE LARGER HAIL

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I. INTRODUCTION

The conceptual model of aerosols invigorating convective storms and producing large hail was proposed by Rosenfeld (2006). Formation of large hail with diameter exceeding several centimeters is observed over land in areas of highly polluted air (Andreae et al., 2004). Large hail is not observed in microphysically maritime deep convective clouds. Formation of large hail is often assigned to effects of atmospheric instability leading to vertical velocities in clouds exceeding 30-40 m/s and allowing hail to grow within clouds for a long period of time (Rosenfeld et al., 2006) It often assumed that large hail particles form as a result of recirculation within clouds when embryos of hail fall in zones of low or negative vertical velocities and then ascend being involved in strong updraft by turbulent flows. Nevertheless, the physics of the process of large hail formation remains not clear enough. Formation of large hail was observed in smoky clouds during SMOCC campaign, while no hail was found in green-ocean clouds formed under nearly similar thermodynamic conditions. We suppose that aerosol effects play a crucial role in formation of large hail. It is obvious that large hail forms as by intense riming in the presence of large supercooled water content. It was found in observations (Rosenfeld and Woodley, 2000; Andreae et al., 2004) and numerical studies (e.g., Khain et al. 2001, 2004, 2005) that aerosols lead to formation of high concentration of supercooled small droplets ascending to high levels. These observations show that small cloud droplets in vigorous updrafts do not freeze until the level of homogeneous freezing of -38ºC. The latter allows a relatively small number concentration of graupel to grow quickly into hailstones by riming. The role of aerosols in the formation of large hail was investigated in the course of the ANTISTORM project using an advanced version of the spectral microphysics Hebrew University cloud model (HUCM). Two case studies have been simulated: a hailstorm on 28 July 2006 near Stuttgart (Germany) and in smoky and green-ocean clouds observed in the Amazon.

II. MODEL DESIGN

The HUCM has been described in detail by Khain et al (2004, 2005). It is a 2-D nonhydrostatic model with spectral (bin) microphysics (SBM). This microphysics is based on solving an equation system for seven size distribution functions (water drops, 3 types of ice crystals, snow, graupel and hail). The model includes the aerosol particles budget. Aerosols are described by a special size distribution function. The model takes into account the main microphysical processes including nucleation of water droplets and ice crystals, their growth by diffusion, water-water, water-ice and ice-ice collisions, freezing and melting, differential sedimentation of cloud particles.

To describe large hail formation number of mass bins used for representation of size distribution functions was increased from 33 to 43. The maximum size corresponds to particles with melted diameter of about 4 centimeter.

Hail forms in the model in several ways: a) It was assumed that hail forms as a result of collision of large frozen drops with small supercooled droplets; b) in new model version it was assumed that hail can form as intense riming of graupel with diameter exceeding 1000 µm if LWC of supercooled droplets exceeds 3 gm^{-3}. Density of hail was assumed to be 0.9 gm^{-3}. In case LWC of supercooled droplets is below 3 gm^{-3} formation of graupel was assumed with density of 0.4 gm^{-3}. The threshold value is chosen to stress that intense riming takes place in clouds with high supercooled LWC.

III. DESIGN OF CASE STUDY AND MODEL SIMULATIONS

The hailstorm event that took place around Stuttgart (Germany) 28 July 2006 was chosen for simulations. This hailstorm was accompanied by falling hail of several centimeters in diameter. Sounding corresponding to this case is shown in Figure 1.

Sounding data

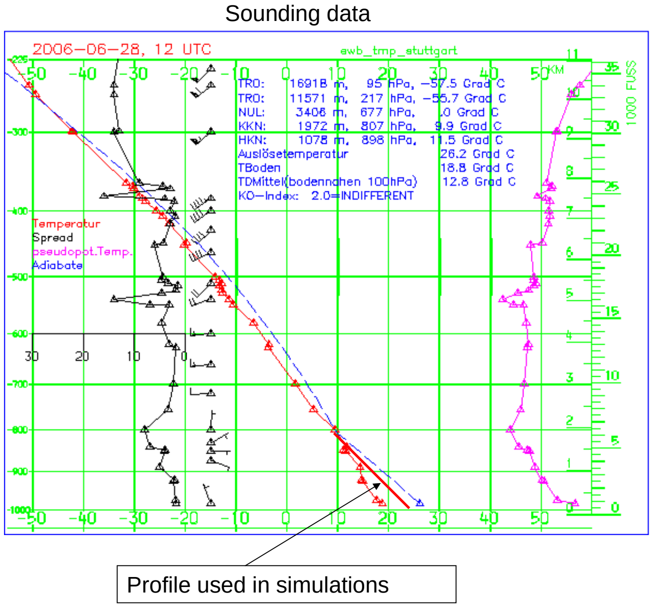

Figure 1. Sounding observed within the area of hailstorm

The red line with triangles in Fig. 1 indicated measured sounding. Note that this sounding is stable and can be result of effects of cooling in the boundary layer as result of melting and evaporation. In the surrounding meteorological stations temperature near the surface exceeded 25C. Respectively, we used profile of temperature in the boundary layer shown by solid red line. This sounding allowed reproduction of deep convective clouds with vertical velocities exceeding 30 m/s.

We compare two simulations with aerosol concentrations of 100 cm^{-3} (low aerosol concentration) and 2500 cm^{-3} (high aerosol concentration).

IV. RESULTS

The dirty cloud had large number off small supercooled cloud droplets. The simulation indicated the existence of large supercooled cloud water content that reached 4 g m^{-3} above 6 km. The latter allowed intense riming of graupel and formation of hail in dirty cloud at higher levels than in the cloud developed in clean air.

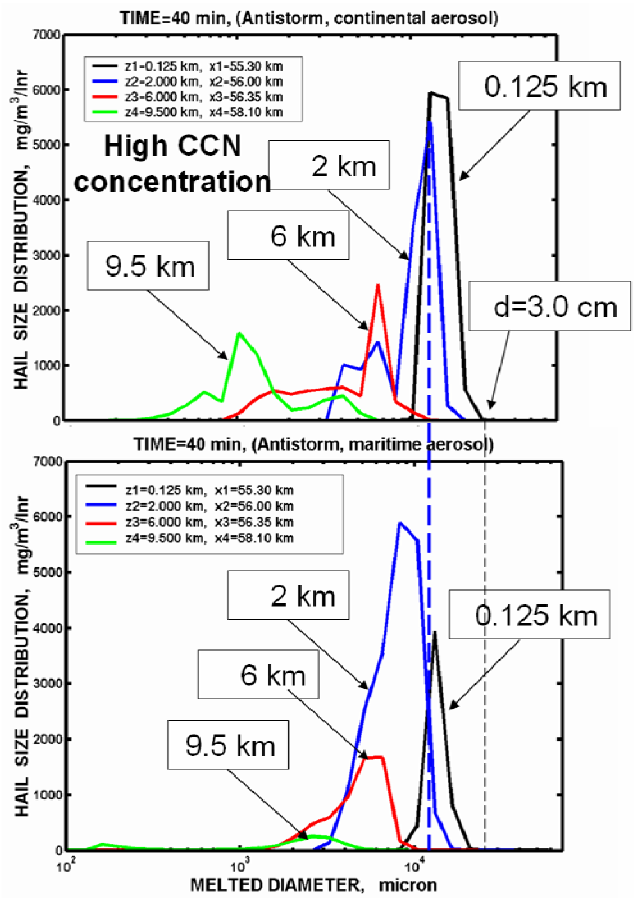

Figure 2. Mass distributions of hail at different heights in clouds developed in dirty (upper panel) and clean air (lower panel) at t=40 min.

The ice microphysical structure of clean and dirty clouds are dramatically different, especially, in the the field of hail. The hail in cloud formed in dirty air starts at higher levels and falls through the whole cloud collecting cloud droplets. As a result, it becomes larger and falls to the surface, while in the storm developed in clean air mass of hail falling on the surface is much smaller.

Figure 2 presents an example of mass distribution of hail at different heights in clouds developed in clean and dirty air at t=40 min. One can see the following important differences in the mass distributions. In dirty (high aerosol concentration) air hail forms at high levels (9.5 km) , where mass of hail in cloud developed in clean air is negligible. As a result, hail at the surface is much larger in the polluted storm with maximum diameter of 3 cm. In clean air maximum diameter was about 1.3 cm, so the difference in masses of maximum hail is about 10 times.

Besides, the total mass of hail falling on the surface in from the dirty cloud (storm) was also by order of magnitude larger than incase of clean air storm.

The evaluations show that the kinetic energy of hail falling on the surface from the dirty cloud was 30-50 times higher than that in the clean air case.

Supplemental simulations of green-ocean and smoky clouds in Brazil indicate similar tendency of formation of much larger hail content in smoky clouds. In green-ocean cloud hail content is negligible. The difference between the hailstorms in Germany and in Brazil is that hail falls on the surface in Germany, while it melts in Brazil not reaching the surface. The difference is caused by the differences in the freezing levels in these cases: the freezing level was 4.5 km in Brazil and 2.7 km in Germany.

Comparison of simulations with 33 bins (old version) and 43 bins (new model version) indicates significant difference in hail in cloud forming in polluted air, and no difference in clouds developing in the clean air. The main difference in the polluted cases was the maximum size of hail, which was limited by size of 0.5 cm in the 33 bin version. Correspondingly, the hail largely melted during its fall in the 33 –bin version, while hail reached the surface in the 43 bin case.

V. CONCLUSIONS

Results of simulations indicate that aerosols foster formation of large hail in deep convective clouds. The kinetic energy of the hail falling in cloud formed in the dirty air can be 30-50 times higher than that in clouds forming in clean air. So the damage caused by hail is highly dependent on the presence of aerosols in the atmosphere. Thus, numerical simulations with spectral bin microphysics model support the hypotheses about aerosol effects on large hail, proposed in ANTISTORM.

VI. AKNOWLEDGMENTS

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