NUMERICAL SIMULATION OF SQUALL LINE BY USING DETAILED MICROPHYSICS

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I. INTRODUCTION

The correct forecasting of the formation and propagation of the squall line is still an important issue. The solution of this problem need better understand both microphysical and dynamical processes occur in thunderstorms. The cold pools coexist with the squall lines are affected by the evaporation of water drops, melting by graupel particles (Tao et al., 1995; Dawson et al., 2010).

The formation of water drops due to the melting of snow flakes and graupel particles is crucial for the correct simulation of latent heat cooling. In most of the models it is supposed that the melted water immediately sheds off the surface of the partly melted solid hydrometeors. Several laboratory studies have shown that the shedding of meltwater occur only when the solid precipitation particles larger than about 1 cm (Rasmussen et al, 1984).

Rotunno et al. (1988) investigated long-lived squall lines and shown that the vertical wind shear, and the circulation around the developed cold pool is necessary to keep alive the storm (Weismann and Rotunno, 2004).

Studies about the sensitivity of evaporative cooling on the water drops size distribution and two-dimensional simulation of the squall line formation by using detailed microphysics will be presented.

II. DESCRIPITION OF THE MODEL

The model of microphysics base on that of published by Rasmussen et al, 2002. The overestimation of graupel formation – frequently occurs in the case of simulation of convective clouds – is avoid by tracking of riming of snow flakes. Also description of melting process was improved by taking into consideration of retention of melted water on the surface of snowflakes and graupel particles. The following parameters are the prognostic variables in the model:

- number concentration of water drops, pristine ice, snow flakes, rimed snow flakes and graupel particles in every bin.
- mixing ratios of water drops, pristine ice, snow flakes, mass of the rimed water on snow flakes, melted water on the snow flakes, graupel particles and melted water on the surface of the snow flakes.

The melting rate of the particles was affected by the heat conduction and by the released latent heat of diffusion as it is given in Pruppacher and Klett (2004). Besides these physical processes the heat given by the collected warmer water drops is also taken into consideration. It is supposed that while the characteristics (shape, density, terminal velocity) of the graupel particles are hardly affected by the melting, these parameters change significantly as the amount of the liquid water increases on the surface of the particles (Mitra et al, 1990).

The following microphysical processes were taken into account, for source of water drops: collision and coalescence of cloud droplets, melting of solid hydrometeors, breakup of droplets (spontaneous and collision induced), shedding of water from melting graupel and snow, which has larger diameter than 1 cm. The following processes were which sink of the water: self-collection, collision with ice, freezing, sedimentation and evaporation. The collision efficiencies of the different precipitation elements were calculated using kernel techniques.

Sensitivity test was made by using the kinematic model developed by Grabowski (1998) and Smolarkievicz (1984). The two-dimensional simulation of the squall line was made by the WRF. The mixing ratio and the number concentration of four different types of the hydrometeors (snowflakes, water drops, graupel particles and pristine ice) were calculated in 36 bins. The mass of the rimed water on the snow flakes and the mass of the melted water on snow flakes and on graupel particles were also prognostic variable.

III. RESULTS

The effects of microphysical processes on the formation of precipitation on squall line and the sensitivity of cold pool formation on the microphysical description were investigated by using a two-dimensional version of WRF with both detailed and bulk scheme (Rasmussen and Heymsfield, 1987; Thompson et al., 2004). 6-hour forecasts were made during the simulations. The horizontal grid comprises 601 grid points with 1000 m resolution, and vertical resolution was 250 m, and the height of the domain was 20 km height. The initial sounding comes from Weismann and Klemp (1982). A minor change was made because the moisture in the upper troposphere was not representative enough.

In the idealized simulations we investigated two different squall line formation processes: 1) formation of squall line due to wind shear, and 2) formation of squall line system due to temperature perturbation.

In the detailed microphysics the size distributions of the different species were divided into 36 bins. If the fraction of melted water on the solid hydrometeors exceeds 0.80 than the melted snowflakes and graupel particles were transferred to the water drop category.

With the one-dimensional model the sensitivity of the evaporative cooling on the water size distribution was investigated. The cooling due to evaporation of the water drops was calculated in a column of 1500 m height with base of 1 km^2. The relative humidity initially was 70% in the column. The size distribution of the water drops was given by gamma size distribution. The mixing ratio of the water drops was hold constant with the value of 3 g/kg. The mean radius of the drops changed in the interval of 50 µm to 500 µm. The Fig 1 shows the time integrated evaporation. Small difference was found between the cases of r_{mean} = 100 µm and r_{mean} = 200 μm. The large difference between the cases of r_{mean} = 50 μm and r_{mean} = 500 μm shows the importance of the correct simulation of the melting of solid precipitation elements. While the continuous shedding of melted water produces small water drops, the complete melting of graupel particles results in water drops larger than 100 μm.

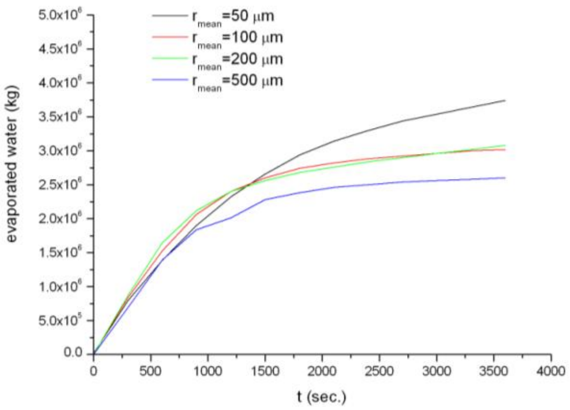

FIG. 1: Time integrated evaporation in a 1.5 km height column with base of 1 km^2. The mixing ratio of the water drops was constant with the value of 3 g/kg. The mean radius of the drops changed in the interval of 50 μm to 500 μm.

In two-dimensional simulations we examine the diabatic cooling due to the evaporation of the water drops. The results shown that the melting of solid hydrometeors plays an important role of the formation of cold pools.

In the cases of detailed microphysics no shedding of the melted water was supposed. The summary of the results is presented in the following Figures.

Fig. 2 shows the initial temperature profile, and the temperature perturbation shows up in bulges. The next figure (Fig. 3.) shows the rainwater content and the temperature profile at the 02:30:00 simulated time. The filled contours represent the mixing ratio of the rain water (the radius of the water drops is over 50 μm). The dashed lines represent the temperature at the same time.

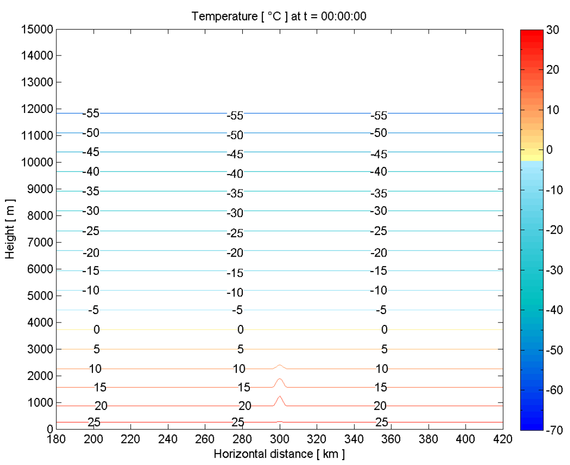

FIG. 2: Temperature profile [°C] at the initial time. The bulges represent the temperature perturbation.

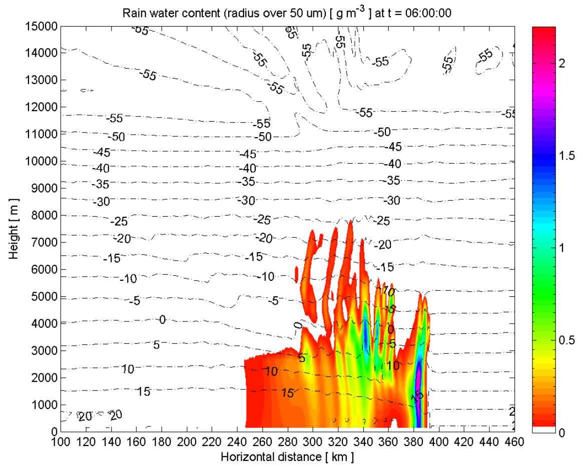

FIG. 3: Rain water (radius larger than 50 μm) content [g m^{-3}] at t = 06:00:00 simulated time, using detailed microphysics. The dashed lines designate the temperature in °C.

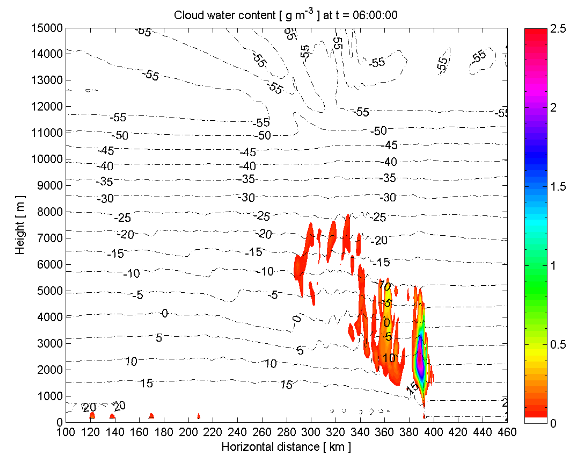

FIG. 4: Cloud water (radius less than 50 μm) content [g m^{-3}] at t = 06:00:00 simulated time, using detailed microphysics. The dashed lines designate the temperature in °C.

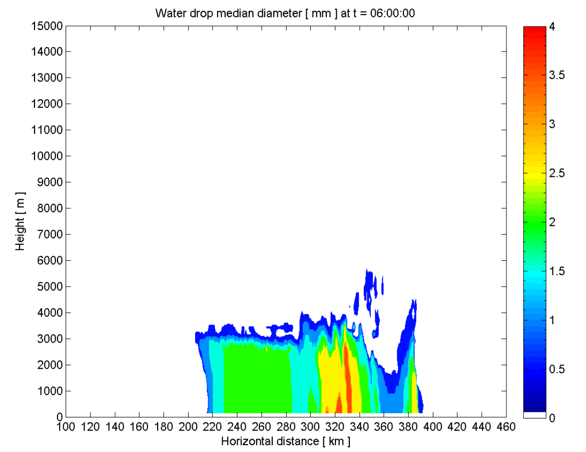

FIG. 5: Median volume diameter of water drops [mm] at t = 06:00:00 simulated time, using detailed microphysics. The dashed lines designate the temperature in °C.

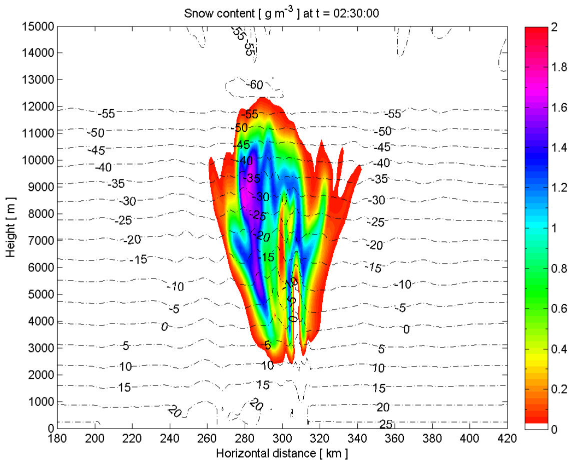

FIG. 6: Snow flake content [g m^{-3}] at t = 06:00:00 simulated time, using detailed microphysics. The dashed lines designate the temperature in °C.

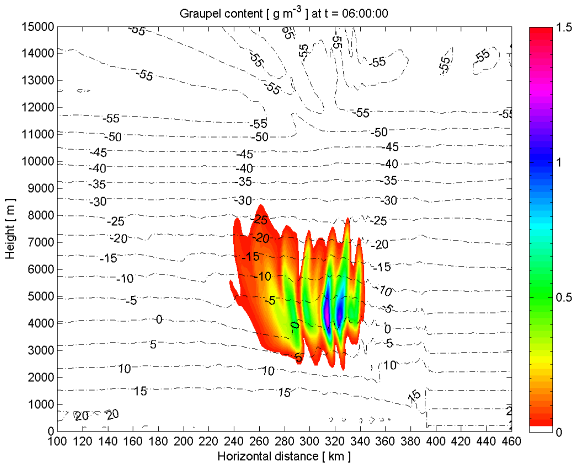

FIG. 7: Graupel particles content [g m^{-3}] at t = 06:00:00 simulated time, using detailed microphysics. The dashed lines designate the temperature in °C.

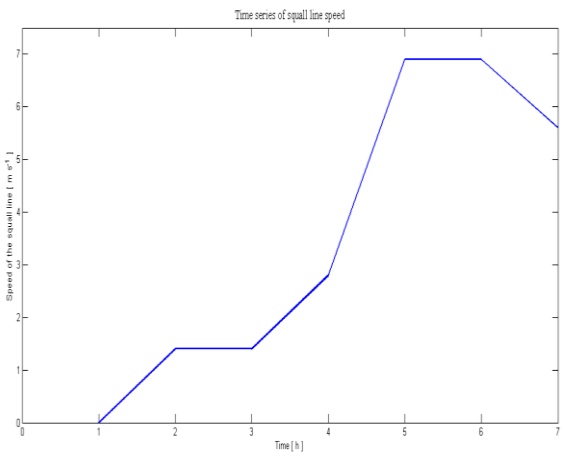

FIG. 8: Time dependence of the squall line speed [m s^{-1}] using detailed microphysics.

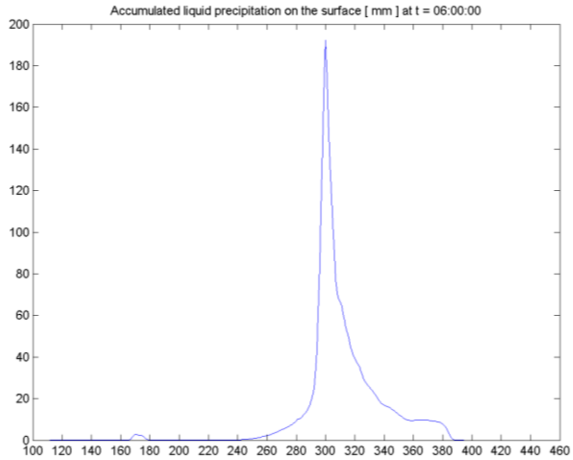

FIG. 9: Accumulated liquid precipitation at t = 06:00:00 simulated time, using detailed microphysics.

The formation of the cold pool may readily observe during the simulation period. The cloud water and rain water content are presented on Fig. 3 and 4. The maximum of mean diameter of the water drops was 3.6 mm in the convective region, and it reached only 2 mm in the stratiform region (Fig. 5). Both graupel particles and snow flakes was completely melted above the level of 5 °C (Fig 6 and 7). Fig. 8 shows the speed of squall line propagation. The maximum value was near 7 m s^{-1}, 4 and 5 hours after the start of the simulation. Most of the precipitation falls at the stratiform region of the squall line (Fig. 9).

IV. CONCLUSIONS

In this paper a detailed microphysics technique is applied to simulate how the melting of the snow flakes and graupel particles affect with the formation of the cold pool.
Numerical experiments were made with a one- dimensional kinematic model to investigate the impacts of the water size distribution on the evaporative cooling. The calculations show the importance of the correct simulation of the melting of solid precipitation elements. The bin scheme results in realistic cold pool formation.

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