P 2.6 **A TWO-MOMENT CLOUD MICROPHYSICS SCHEME WITH TWO PROCESS-SEPARATED MODES OF GRAUPEL**

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1 INTRODUCTION

A reliable description of cloud microphysical processes in cloud resolving regional atmospheric models is difficult. On the one hand, one has to consider the various types of hydrometeors and on the other hand to formulate all mutual interactions including transformation of one hydrometeor class to another. In most models cloud microphysics is represented by a one- or two-moment scheme discriminating five particle classes: cloud droplets, raindrops, cloud ice, snow and graupel.

"Graupel" usually comprises all large ice particles although many models take into account that graupel particles may be generated and grow in quite different ways. Putting all of them into one graupel category with fixed parameters, e.g. for mass-size relationship and fall velocity, as it is usually done in the models, is therefore inconsistent and a strong simplification. In some models an additional category is assumed, usually described as 'hail'. Its formation almost always proceeds via a transformation of large graupel to 'hail', with graupel originating from riming of ice crystals and snowflakes as well as from freezing raindrops. But the conversion from graupel to hail is often not well defined in these schemes and parameterising it adequately is challenging.

In order to be more consistent without having to describe the transition between graupel and hail, we suggest to use two graupel categories and distinguish clearly between graupel created by rimed ice particles (termed RIME graupel) and graupel created by freezing raindrops (frozen-raindrop-induced or FRI graupel for short).

2 IMPLEMENTATION OF A SECOND GRAUPEL CLASS

For our studies of convective cells we use the Lokalmodell (LM) by the German Weather Service, into which the two-moment bulk mircophysical scheme by Seifert and Beheng (2006) (SB) has been implemented.

In the standard SB-scheme graupel can be formed by two processes: (a) by riming of ice and snow particles and (b) by raindrops that freeze while ascending within the cloud. After formation the particles grow by deposition, collection of ice and snow, and by riming (see Seifert and Beheng, 2006, for a more detailed description). All the particles we get from these processes belong to the same category, namely graupel, which means that all have the same characteristics – the same mass-size-relationship, the same relation for the terminal velocity, the same size distribution, etc..

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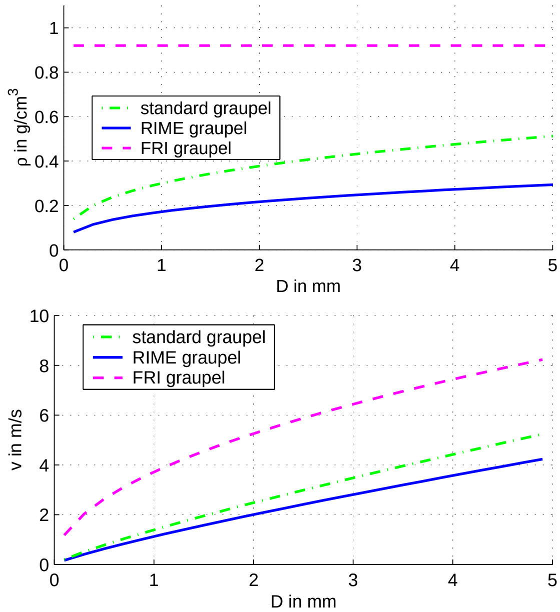

Fig. 1: *Density in g cm^{-3} (top) and terminal velocity in m s^{-1} (bottom) as a function of particle diameter in mm for different categories.*

As mentioned above, we aim at making the SB-graupel scheme more consistent without making it too complicated and thus we simply split the original graupel class according to the formation process into RIME graupel and FRI graupel. Both classes are clearly separated, i.e. there is no interaction or transformation at all between RIME and FRI graupel, which is a reasonable assumption since the garupel-graupel sticking efficiency is negligible. Aside from that, all processes are the same as in the original scheme.

The diameter-mass as well as the velocity-mass relation of the different particles are parameterized by power laws. The main difference between RIME, FRI and the 'old' standard graupel is, that different parameters have been chosen for these relations. Consequently, the particles differ in density and terminal fall velocity. As shown in Fig. 1, a constant density of 0.9 g cm^{-3} has been assigned to FRI graupel assuming that it consists mainly of frozen drops. The 0.9 g cm^{-3} has to be seen as an upper bound; for real cases a lower value might be more suitable. The density of RIME graupel is much lower and slowly increasing with diameter. The density of the old standard graupel lies between the new categories. Similar differences result for terminal velocity (Fig. 1).

3 MODEL SETUP

LM-simulations were performed for three different idealized cases assuming thermodynamic and wind profiles according to Weisman and Klemp (1982):

Case 1: low CAPE, low wind shear

Case 2: moderate CAPE, strong wind shear

Case 3: high CAPE, low wind shear.

The size of the model domain was 100 km×180 km with a horizontal resolution of 1 km. The upper boundary was at 18 km with 50 vertical levels. Convection was triggerd by a warm air bubble.

For all of the cases simulations with maritime CCN and continental CCN conditions were performed using the old graupel scheme as well as the new one, giving finally a total of 12 model runs. For all simulations the same IN conditions were assumed.

4 EFFECTS ON THE GRAUPEL PARTICLES

Because graupel is now split into two categories it can develop two different size distributions which may combine to an overall bi-modal graupel spectrum. As an example, Fig. 2 shows the mass-size distributions for the run with the old and with the new scheme at the same gridpoint at a certain time. In the given example, the distribution of FRI graupel is significantly shifted to larger particles compared to both standard and RIME graupel. This bi-modality corresponds to results by Seifert et. al (2006) showing that – applying a bin microphysical model – freezing of large raindrops leads to a graupel mode with large particles whereas RIME graupel particles form a mode with smaller ones. Note that at other gridpoints and at other times the spectra may look different.

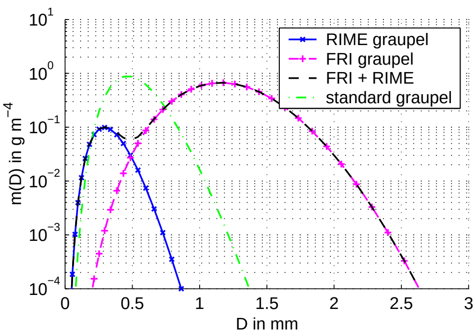

Fig. 2: *Mass-size spectra for graupel particles for maritime case 1 at y=50 km, x=57 km, z=8 km and t=30 min. FRI and RIME graupel develop spectra with two distinct modes and combine to a bi-modal spectrum.*

Nevertheless, the differences in mean particle size shown in Fig. 2 are typical, as can be seen in Fig. 3. The mean mass of FRI graupel particles is significantly higher than that of all others. They grow for about one hour and then get slowly smaller again. The particle mass of the RIME graupel class is much smaller, especially at the beginning. RIME graupel grows almost continuously and the difference to FRI graupel is getting smaller. The particle mass of graupel in the run with the old (standard) scheme corresponds very well to the overall mean particle mass of graupel in the new scheme (RIME+FRI), which is quite reasonable. Inspite of that, an average raindrop is significantly larger with the new scheme than with the old scheme (see also Fig. 3). This is also consistent with the results by Seifert et al. (2006) showing, that compared to a bin-microphysical model, the raindrops of the standard SB-scheme are too small.

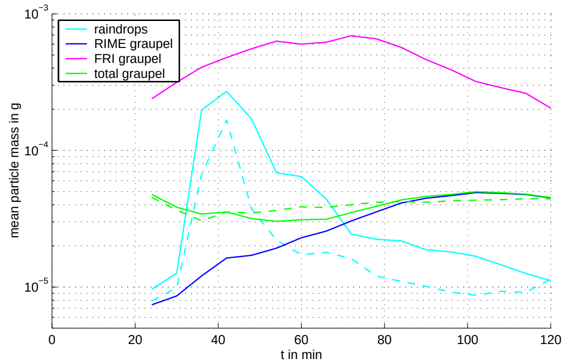

Fig. 3: *Temporal evolution of mean particle size calculated from domain averaged number and mass density. Dashed lines: results with the old scheme.*

5 EFFECTS ON CLOUD STRUCTURE AND PRECIPITATION

In all cases of this sensitivity study the most obvious effect of the new scheme is a strong increase in the total volume of precipitation (see Tab. 1), which results mainly from an increase in the area with a considerable amount of precipitation (see Fig. 5). The effect is stronger for continental CCN conditions than for maritime CCN conditions. Compared to that, the effect on maximum values of accumulated precipitation and precipitation rate is small.

Further characteristic differences between the runs with the old and with the new scheme will be shown by the example of case 1 with continental CCN.

Fig. 4 shows cross-sections of specific masses of raindrops and graupel at y=50 km after a simulation time of 60 min. The corresponding wind field and rain rate are also represented. The most striking feature (and characteristic of all the cases) is that with two graupel categories we get a wider area of precipitation combined with a broader downdraft. We can also see that FRI graupel is concentrated at the center of the cloud leading to a higher total mass of graupel at lower levels than for the simulation with only one graupel category (see also Fig. 6). The differences in cloud microphysics have an impact on cloud dynamics and this in turn further changes the microphysical properties.

Table 1: *Total volume of precipitation and maximum values of accumulated precipitation and precipitation rate after a simulation time of 120 min for model runs with the standard (1-cat. graupel) and with the new (2-cat. graupel) scheme, under maritime (mar) and continental (con) CCN conditions.*

Case	total volume of precip. (10^3 m^3)		maximum acc. precip. (mm)		maximum precip. rate (mm h^{-1})	
	2-cat. graupel	1-cat. graupel	2-cat. graupel	1-cat. graupel	2-cat. graupel	1-cat. graupel
1 con	288	74	7.7	3.9	53.6	38.8
1 mar	1354	790	24.9	19.2	90.1	90.1
2 con	2220	760	3.9	2.1	45.1	31.2
2 mar	7449	4276	12.7	9.4	145.0	81.5
3 con	3129	1083	17.9	12.1	49.6	36.5
3 mar	10770	6387	62.4	56.8	156.9	156.8

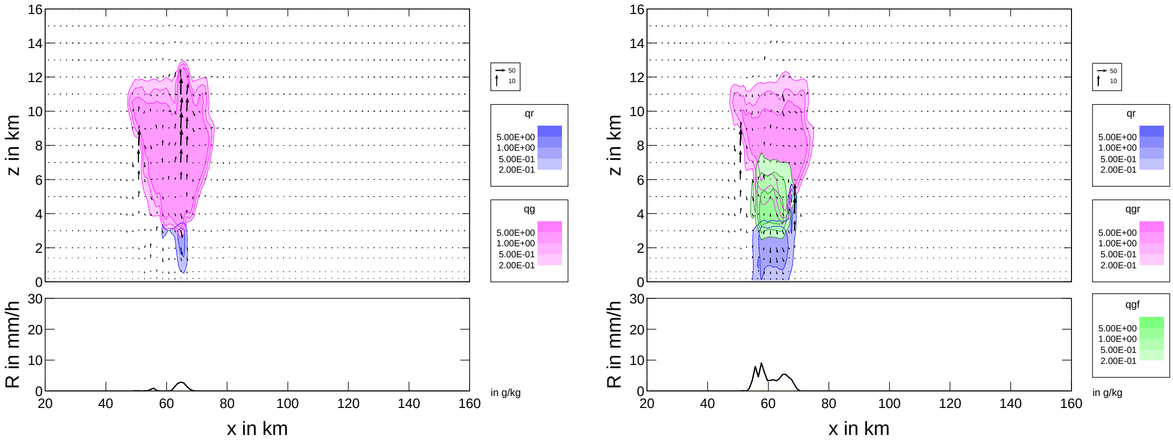

Fig. 4: *(x,z)-cross-sections of specific masses of rain and graupel in g/kg as well as wind field and rain rate for continental case 1.* **Left:** *old scheme; blue=rain drops, magenta=graupel.* **Right:** *new scheme: blue=raindrops, magenta=RIME graupel, green=FRI graupel.*

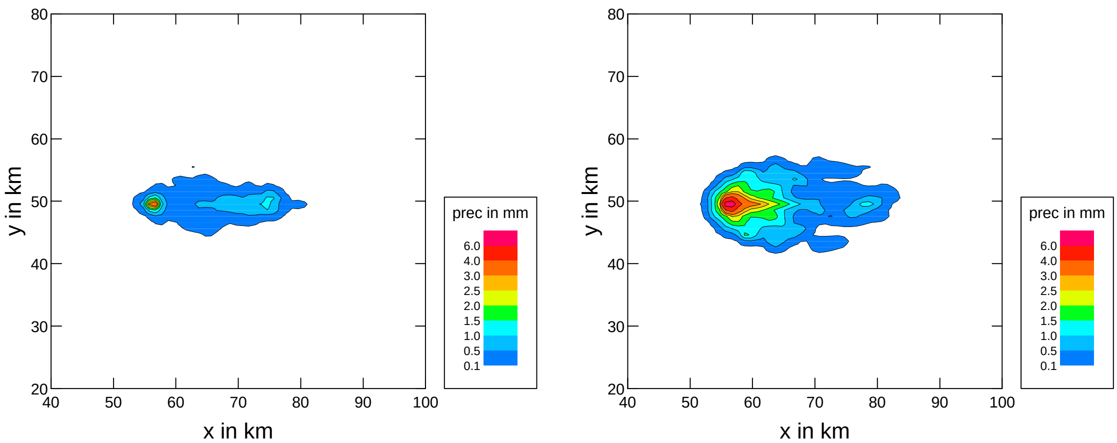

Fig. 5: *Accumulated precipitation after t=120 min for continental case 1.* **Left:** *old scheme (one graupel class).* **Right:** *new scheme (two graupel classes).*

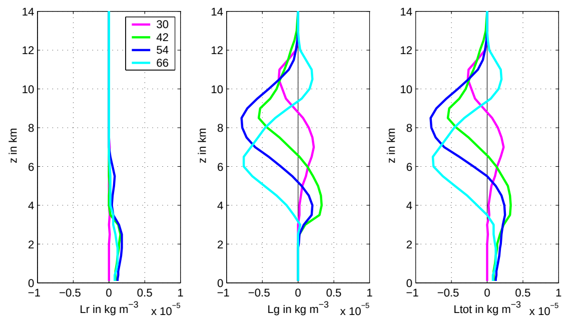

Fig. 6: *Differences in the mean profiles of water content (new scheme - old scheme) after a simulation time of 30, 42, 54 and 66 min for continetal case 1.* **Left:** *rain drops.* **Center:** *total graupel.* **Right:** *sum over all particle types.*

As Fig. 6 shows, one important result of introducing the new scheme is that mass is vertically redistributed, i.e. shifted to lower levels, resulting in more rain at levels below 4 km and finally more precipitation at the ground. A common problem with the simulation of convective systems is that too much mass seems to be blown to the top and finally out of the cloud. Therefore, this shift is regarded as being beneficial.

6 SUMMARY AND CONCLUSIONS

In the 2-moment scheme by Seifert and Beheng (2006) graupel has been split up into two particle classes: FRI graupel and RIME graupel. This allows

- a clear distinction between graupel formed by rimed ice particles with a lower density and graupel formed via the freezing of raindrops with a higher density
- the evolution of two distinct graupel size distributions which may combine to a bi-modal spectrum.

Case studies with the regional model LM showed that the separation into two graupel categories leads to

- larger raindrops
- a vertical redistribution of mass
- enhanced precipitation at the ground.

All these effects seem to be beneficial. Further studies will have to demonstrate whether these sensitivities on the new graupel scheme also occur in real cases.

References

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