Sensitivity to Graupel Particle Properties in LMK Simulations With a Three-Category Ice Scheme

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Introduction

For DWD's mesoscale limited-area model LM, an additional optional microphysical parameterization scheme which takes into account also graupel has been developed (Reinhardt, 2005). This scheme is an extension of DWD's currently operational microphysics scheme (Doms et al., 2005) which is used in the global model GME (40 km mesh size) and in LM (7 km mesh size). It considers the mixing ratios of cloud water, cloud ice, rain, snow, and graupel as prognostic condensate categories. It is intended to be used in LMK ("LM-Kürzestfrist", see Doms and Förstner, 2004), the convection-resolving short-range version of LM.

Sensitivity to Graupel Particle Properties

Gilmore et al. (2004) carried out sensitivity tests with respect to the assumed properties of the graupel/hail category within a bulk (one-moment) microphysics parameterization. They used an idealized convective environment for their model setup (1 km mesh size, 30 m/s and 50 m/s wind speed with veering wind shear, supercell development, similar to Weisman and Klemp, 1984) and varied the intercept parameter $N_0^{\rm g}$ of the graupel particle size distribution ($f(D) = N_0^{\rm g}\exp(-\lambda D)$) and the graupel particle density $\rho_{\rm g}$. Decreasing $N_0^{\rm g}$ as well as increasing $\rho_{\rm g}$ each changes the bulk properties of the particle ensemble towards more hail-like properties, e.g. faster sedimentation and less rapid melting. In general, more precipitation accumulated at ground was found in the cases with the graupel/hail category weighted towards large hail.

The question arises whether underprediction of precipitation in convective events seen in a number of cases simulated with LMK may be caused by the lack of high-density hail-like ice particles in the microphysical parameterization scheme.

Sensitivities similar to those seen by Gilmore et al. (2004) could also be found with LMK in a similar idealized 3-d convective setup (2.8 km mesh size, unidirectional wind shear only, wind speed 25 m/s, symmetric storm splitting, similar to Weisman and Klemp, 1982). Surface precipitation (both mean and maximum) tends to be higher with the graupel category weighted towards hail-like properties, i.e. smaller intercept parameter and larger particle density, see Table 1. For $\rho_{\rm g} = 0.4\,{\rm g/cm^3}$ and $\rho_{\rm g} = 0.9\,{\rm g/cm^3}$, the velocity-size relationship is taken from Lin et al. (1983) and is considered in all microphysical process rates. A large sensitivity to $N_0^{\rm g}$ is found in the $\rho_{\rm g} \approx 0.2\,{\rm g/cm^3}$ and $\rho_{\rm g} = 0.4\,{\rm g/cm^3}$ cases: With $N_0^{\rm g}$ decreasing from $4\times10^6\,{\rm m^{-4}}$ to $4\times10^4\,{\rm m^{-4}}$ total surface precipitation increases by 144 % and 73 %, resp. Higher mass-weighted sedimentation velocity of the graupel particle ensemble (i.e. smaller $N_0^{\rm g}$) makes the particles less susceptible to horizontal advection (and subsequent evaporation outside the storm) and can therefore lead to more surface precipitation. As to be expected, with decreasing $N_0^{\rm g}$ and increasing $\rho_{\rm g}$ more unmelted graupel/hail can reach the ground. Much less surface precipitation (compared to all simulations including graupel) is found in the no-graupel (= standard LM microphysics) case confirming the need of a faster-than-snow falling ice species when simulating severe convection.

Less sensitivity is found in two simulations of real (convective) weather situations: A pre-frontal squall-line case (July 18, 2004) and a case with less organized, more isolated convection in a situation with weak large-scale gradients (August 07, 2004), see Tab. 2. In contrast to the idealized warm-bubble setup, in the August 07 case area-mean precipitation tends to decrease when moving from light-graupel to hail-like particle properties in the graupel/hail category, while in the July 18 case one might see the same but very much damped tendency as in the idealized setup. As in the idealized setup, in both real cases maximum precipitation is lower in the no-graupel simulation than in any of the simulations including graupel. In the August 07 case simulated precipitation becomes less widespread (i.e. areas receiving precipitation becoming smaller without maxima being reduced) when moving from the no-graupel over the low-density-graupel to the high-density-graupel/hail case which might be due to the effect of ice precipitation becoming less subject to horizontal advection when sedimenting faster (no figure shown). In the July 18 case, this feature is not seen. That the sensitivity to the assumed properties of the graupel category is smaller in simulations of real convective cases compared to the idealized setup may be attributed (i) to more (negative) feedbacks being active in longer integration time and on a larger domain, (ii) to graupel being overall less important in simulations of real weather events (since there are always also more stratiform and snow-dominated areas) compared to the idealized simulations where much more graupel than snow is simulated, and (iii) to significant decrease of depositional growth when graupel is assumed to be more hail-like opposed to riming being less affected. Tab. 2 shows also that in simulations weighted towards large hail (all $N_0^{\rm g}$=$4\times10^4\,{\rm m^{-4}}$ simulations; the more the higher $\rho_{\rm g}$) explicit simulation of hail occurence at the ground is possible.

N_0^{g}	ρ_{g}	TotP	TotG	MaxP	MaxG
4×10^4	≈ 0.2	36.17	0.1069	23.03	0.0001
4×10^5	≈ 0.2	27.55	0.0000	16.91	0.0000
4×10^6	≈ 0.2	14.80	0.0000	10.91	0.0000
4×10^4	0.4	35.51	0.1883	22.79	0.5017
4×10^5	0.4	32.02	0.0000	19.07	0.0000
4×10^6	0.4	25.79	0.0000	16.05	0.0000
4×10^4	0.9	32.82	3.4673	25.56	5.8234
4×10^5	0.9	35.01	0.0000	21.27	0.0000
no graupel	–	4.13	–	4.26	–

Table 1: Comparison of surface precipitation for simulations with different assumed intercept parameter N_0^{g} (in m^{-4}) and graupel particle density ρ_{g} (in $\mathrm{g/cm}^3$). Accumulated mass on ground (total precipitation (TotP) and graupel (TotG) in Tg and maximum total precipitation (MaxP) and maximum graupel precipitation (MaxG) in mm. All after 2 hours.

		Aug 07, 2004				Jul 18, 2004			
N_0^{g}	ρ_{g}	MeanP	MeanG	MaxP	MaxG	MeanP	MeanG	MaxP	MaxG
4×10^4	≈ 0.2	0.3627	0.0004	64.05	0.46	4.384	0.222	91.37	1.65
4×10^5	≈ 0.2	0.4461	0.0000	57.64	0.00	4.318	0.0	94.46	0.0
4×10^6	≈ 0.2	0.4548	0.0000	47.71	0.00	4.183	0.0	81.20	0.0
4×10^4	0.4	0.3136	0.0002	49.55	1.07	4.369	2.098	98.34	3.15
4×10^5	0.4	0.4023	0.0000	58.61	0.00	4.341	0.0	83.31	0.0
4×10^6	0.4	0.4846	0.0000	57.92	0.00	4.341	0.0	83.71	0.0
4×10^4	0.9	0.3109	0.0061	73.71	10.15	4.276	20.906	98.39	9.60
4×10^5	0.9	0.3129	0.0000	56.61	0.05	4.334	0.047	86.73	0.0
no graupel	–	0.4190	–	41.96	–	4.154	–	79.41	–

Table 2: As Tab. 1, but for simulated 23-hour precipitation sum of LMK forecasts started at August 07, 2004 00 UTC and at July 18, 2004 00 UTC. MeanP and MeanG stand for mean total precipitation and mean graupel precipitation (in mm), resp. Numbers are valid for a subdomain of total model domain.

Conclusion and Outlook

Underprediction of convective precipitation cannot be cured by changing the graupel particle properties from those of low-density graupel to those of more hail-like particles (at least in the 3-d simulations of real cases).
However, it is under consideration to change the bulk properties of the graupel category in such way that more hail-like particles instead of low-density graupel particles are represented. This would allow for an explicit simulation of surface hail occurence. Then it would be more consistent to take into account also wet growth of the hailstones which is neglected currently. On the other hand, medium- and low-density graupel would then be represented less accurately. A compromise might be to make N_0^{g} dependent on the graupel/hail mixing ratio, i.e. let N_0^{g} decrease when q_{g} increases.

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