A REVISED CLOUD MICROPHYSICAL PARAMETERIZATION FOR OPERATIONAL NUMERICAL WEATHER PREDICTION USING THE COSMO MODEL

Axel Seifert[1] and Susanne Crewell[2]
[1] German Weather Service, Offenbach, Germany
[2] University of Cologne, Cologne, Germany

1. INTRODUCTION

Quantitative precipitation forecasting (QPF) is one of the major applications of limited-area numerical weather prediction (NWP) models. With a limited-area NWP model, like the 7-km COSMO-EU at DWD, the detailed orography and the explicit simulation of mesoscale dynamical structures should lead to an increased forecasting skill compared to global models with coarser horizontal resolution.

Unfortunately, the last years have shown some problems with the precipitation forecasts of COSMO-EU. For example, an overestimation of orographic precipitation, a too frequent occurrence of very light precipitation (drizzle) and a general overestimation of the wintertime precipitation amounts.

Together with a model evaluation against cloud radar measurements which revealed that the model often predicted too low values of liquid and ice water content (Illingworth et al. 2007), these deficiencies point towards problems in the microphysical parameterization. Therefore a revised version of the COSMO-EU microphysics scheme has been developed and brought into operations.

2. MICROPHYSICS OF COSMO-EU

The grid-scale microphysics parameterization of COSMO-EU predicts the four hydrometeor species cloud droplets, raindrops, cloud ice and snowflakes using the mixing ratio of each hydrometeor type as prognostic variable and includes horizontal and vertical advection for all species. Rimed particles like graupel are not taken into account, since a convection scheme is used in the COSMO-EU at 7 km grid spacing. For most cloud microphysical processes the scheme follows the work of Rutledge and Hobbs (1983) and a detailed description is given in Doms and Schättler (2004). At DWD this scheme has been operational since 16 September 2003.

To improve the mesoscale precipitation structures predicted by COSMO-EU several modification have been made to the scheme:

Autoconversion/accretion

The Kessler-type autoconversion/accretion scheme has been replaced by the parameterization of Seifert and Beheng (2001) reading

$$\left.\frac{\partial L_r}{\partial t}\right|_{au} = \frac{k_{cc}}{20\,x^*}\frac{(\nu+2)(\nu+4)}{(\nu+1)^2} \times L_c^4\,N_c^{-2}\left[1+\frac{\Phi_{au}(\tau)}{(1-\tau)^2}\right]$$

with $L_{c/r}$ cloud/rain water content, N_c cloud droplet number concentration, ν shape parameter, $k_{cc} = 9.44\times10^9\ \mathrm{s}^{-1}\ \mathrm{kg}^{-2}\ \mathrm{m}^3$, $x^* = 2.6\times10^{-10}\ \mathrm{kg\ m}^{-3}$. The function $\Phi_{au}(\tau)$ describes the aging (broadening) of the cloud droplet distribution as a function of the dimensionless internal time scale

$$\tau = 1 - \frac{L_c}{L_c+L_r}$$

(for details see Seifert and Beheng 2001). In the one-moment scheme of COSMO-EU we simplify the scheme by assuming a constant cloud droplet number concentration of $N_c = 5\times10^8\ \mathrm{m}^{-3}$ and a constant shape parameter $\nu = 2$.

Corresponding author's address: Dr. Axel Seifert, Deutscher Wetterdienst, GB Forschung und Entwicklung, Kaiserleistr. 42, 63067 Offenbach, Germany. E-mail: axel.seifert@dwd.de

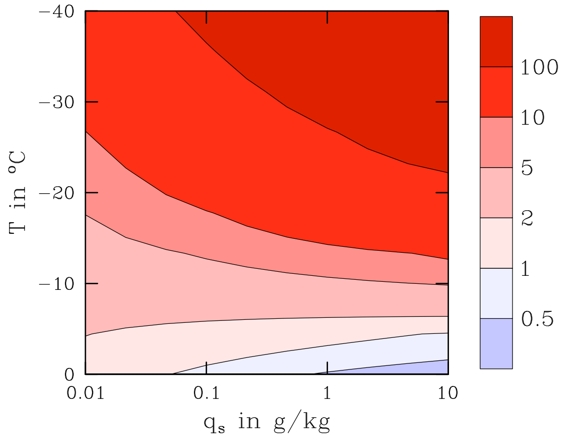


Figure 1: Snow intercept parameter $N_{0,s}$ normalized by $\mathcal{N}_{0,s} = 8\times10^5$ m^{-4} as a function of snow mixing ratio q_s and temperature T in °C.

Size distribution of snow

Based on measurements of Field et al. (2005) a new parameterization of the intercept parameter $N_{0,s}$ of the exponential snow size distribution

$$f(D) = N_{0,s}\exp(-\lambda D),$$

is introduced. In the revised scheme the intercept parameter is parameterized as a function of temperature T and snow mixing ratio q_s by:

$$N_{0,s} = \frac{27}{2}a(3,T)\left(\frac{q_s}{\alpha}\right)^{4-3b(3,T)}$$

with $\alpha = 0.069$. The functions $a(3,T)$ and $b(3,T)$ are given by Table 2 of Field et al. (2005). This parameterization is used instead of the constant $\mathcal{N}_{0,s} = 8\times10^5$ m^{-4} which was used in the old version of the scheme. Especially at cold temperatures this leads to a much higher intercept parameter (see Fig. 1), this corresponds to smaller snowflakes at high levels which fall out much slower.

Sticking efficiency of ice and snow

For the autoconversion of cloud ice and the aggregation of cloud ice by snow a temperature dependent sticking efficiency has been introduced similar to Lin et al. (1983):

$$e_i(T) = \max(0.2, \min(\exp(0.09(T-T_0)), 1.0))$$

with $T_0 = 273.15$ K.

Geometry and fall speeds of snow

The geometry of snow has been changed to more dendrite-like habit with a mass-diameter relation of $m = \alpha\ D^2$ with $\alpha = 0.069$ and a terminal fall velocity of $v = 15\ D^{1/2}$ with D in m, m in kg and v in m/s.

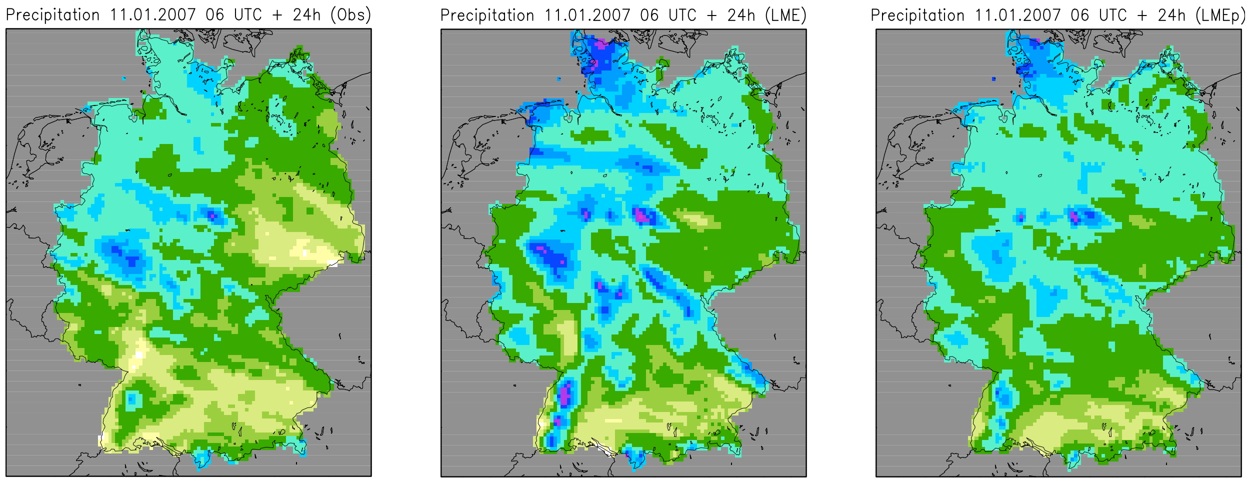
Overall these changes lead to a slower formation of rain and snow as well as a reduced sedimentation velocity of snow. The terminal fall velocity of snow of $v = 15\ D^{1/2}$ is somewhat lower than usually assumed based on observations or laboratory measurements. This ’tuning’ can be justified by the fact that a 7-km model cannot yet fully resolve the updraft structures of mesoscale orography, as e.g. shown by Garvert et al. (2005) who compare simulations with 4 km and 1.3 km resolution with observations.

3. RESULTS

Results for surface precipitation

The revised version of the microphysical scheme of COSMO-EU has been tested in an operational setup including full data assimilation over several weeks from 20 Dec 2006 to 8 Feb 2007. Using consistent data assimilation is especially important, since the change of the model physics alters all microphysical variables. Not using separate data assimilation would lead to inconsistent initial conditions and therefore to spurious results by introducing a large model spin-up.

Figure 2 shows two examples of the 24-hour accumulated precipitation for 11 January 2007 and 22 December 2006. For 11 Jan COSMO-EU overestimates the orographic precipitation in the mountainous regions of Germany. This effect is reduced with the new version of the cloud microphysics scheme (LMEp). The COSMO-EU forecast of 22 Dec 06 shows widespread light precipitation in Brandenburg and Sachsen (East Germany) which was not observed. The model using the new microphysics (LMEp) does not show this problem.

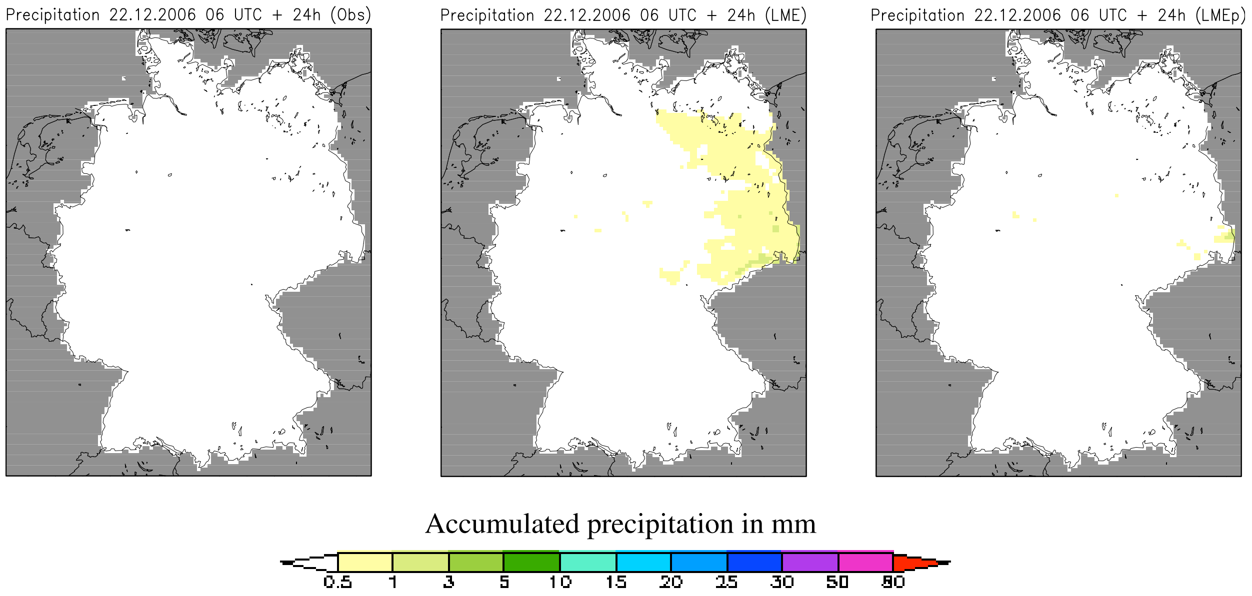


1) Accumulated precipitation 06-06 UTC from 00 UTC forecasts of 11 Jan 2007

a) Observations

b) Old microphysics

c) Revised microphysics



2) Accumulated precipitation 06-06 UTC from 00 UTC forecasts of 22 Dec 2006

d) Observations

e) Old microphysics

f) Revised microphysics

Figure 2: Accumulated precipitation 06-06 UTC from 00 UTC forecasts of 11 Jan 07 and 22 Dec 06 (LME: old microphysics, LMEp: revised microphysics) and surface observations (Obs).

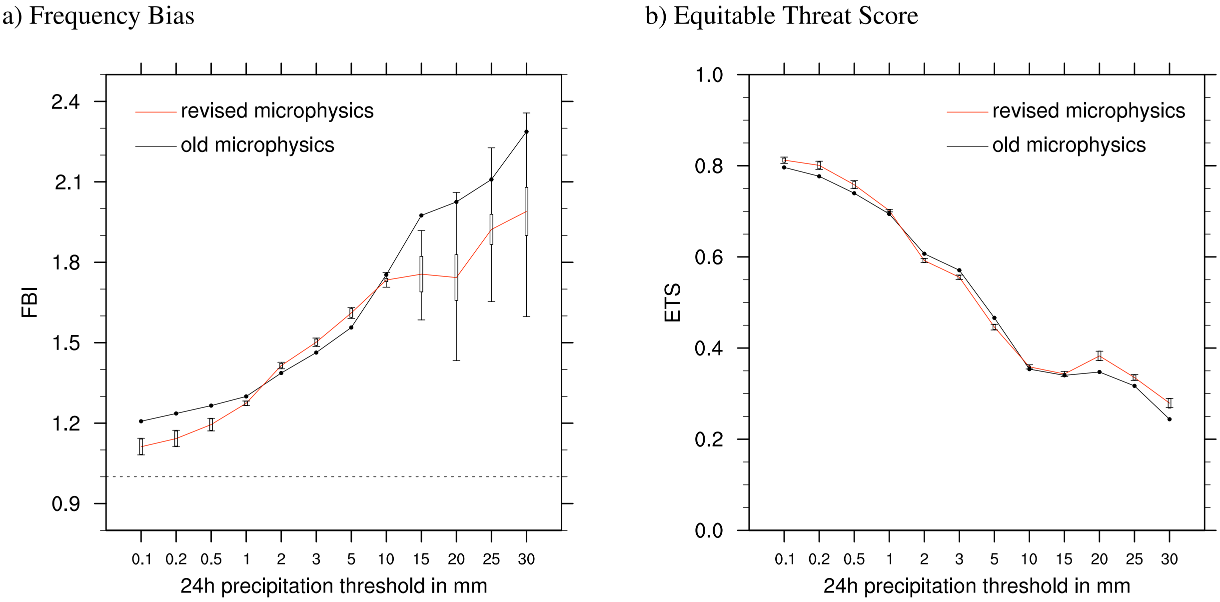


Figure 3: Frequency bias (left) and equitable threat score (right) for 24h precipitation accumulations for various thresholds. Error bars indicate statistical significance at 5 % level of a difference between the two model versions using a bootstrap hypothesis test (outer bars: resampling over model and days, inner bars/boxes: resampling over models only).

Table 1: QPF scores of the 6 week forecasting experiments of COSMO-EU with old vs revised microphysical scheme for 3 different precipitation thresholds (FBI frequency bias, POD probability of detection, FAR false alarm rate, TSS true skill statistics, ETS equitable thread score).

	$>$ 0.5 mm / 24 h		$>$ 2.0 mm / 24 h		$>$ 20 mm / 24 h	
Score	old	revised	old	revised	old	revised
FBI	1.265	1.195	1.387	1.415	2.025	1.743
POD	0.963	0.950	0.907	0.906	0.794	0.771
FAR	0.239	0.204	0.346	0.360	0.608	0.558
TSS	0.597	0.655	0.661	0.645	0.776	0.756
ETS	0.740	0.758	0.607	0.592	0.348	0.384

In the test period of 6 weeks the new version shows an improvement in many QPF scores (see Table 1). Especially the scores for weak precipitation ($>$ 0.5 mm / 24 h) and heavy precipitation ($>$ 20 mm / 24 h) are improved, while the forecasts for intermediate thresholds (e.g. $>$ 2.0 mm / 24 h) are neutral or slightly worse. FBI and ETS are also shown for various thresholds in Figure 3 which supports the data of Table 1. The reduction of the FBI for weak events can be mainly attributed to the new autoconversion scheme as seen in the example of 20 Dec 2006. The improved FBI and ETS for heavy precipitation are due to improved orographic precipitation structures, like in the example of 11 Jan 2007.

In addition, Fig. 3 shows the results of a statistical test with the null hypothesis that differences of the scores of both model versions are zero. Using the resampling (bootstrap) procedure of Hamill (1999) suggests that all scores are significant at a 5% level (indicated by the inner error bars/boxes) when the resampling is performed over models only (as suggested by Hamill (1999)). If the resampled distribution is constructed by randomly choosing models and days (outer error bars), i.e. the finite length of the time series is taken into account, the difference in FBI for large thresholds is no longer statistically significant. This suggests that a longer test period would have been necessary to prove that the results on the better orographic precipitation structures are robust.

The total amount of precipitation, e.g. the accumulated sum over the period from 20 Dec 2006 to 8 Feb 2007, is hardly sensitive to the changes in the microphysical scheme. Compared the the observed precipitation amount of 121 mm averaged over Germany, both model versions show a strong overestimation of 181 mm in case of the old scheme and 177 mm for the revised scheme. The precipitation amounts are obviously more constrained by the synoptic-scale dynamics, e.g. the intensity of low pressures systems and fronts, rather than being sensitive to the details of the microphysical parameterizations.

Validation of IWC using cloud radar

The modification of the cloud microphysical scheme does not only change the surface precipitation, but also the clouds aloft. Due to the slower formation of precipitation sized particles and the reduced fall speeds of snow, an increase of the mixing ratios of cloud water and snow is evident in the new model. Here we compare the ice water content (IWC) predicted by COSMO-EU with an estimation from cloud radar measurements. Figure 4 shows time-height cross sections of the ice water content of 4 May 2007 as measured by the ARM Mobile Facility (AMF) which was, during 2007, located in the Murg Valley in the Black Forest (Southwest Germany). The IWC retrieval used here is based on the radar reflectivity and temperature only (see Illingworth et al. 2007, and the references therein). On this day a weak warm front passed the AMF site. The clouds extend up to 10 km height and were completely glaciated, resulting in weak precipitation during the late evening hours. We have simulated this event with a slightly smaller domain compared to the operational COSMO-EU, but again using full data assimilation which was initialized from the operational global model on 1 May 2007. The model using the old microphysical scheme (Exp6372) shows only thin ice clouds and a frontal structure is hardly visible. Using the revised cloud scheme (Exp6369), the predicted IWC is about an order in magnitude higher and compares well with the observations.

4. Summary and Conclusions

We have presented a revised version of the cloud microphysical scheme of the COSMO model for mesoscale NWP. The new version includes a more sophisticated and physically-based autoconversion scheme, an improved empirical parameterization of the particle size distribution of snow and other modifications of the ice/snow microphysics.

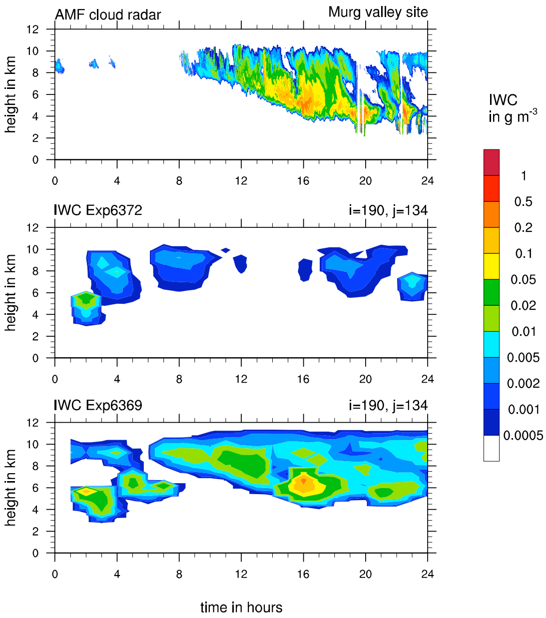


Figure 4: Time-height cross section of ice water content (IWC) measured by cloud radar (top), predicted by the old microphysical scheme (middle) and the revised scheme (bottom).

The results show a better representation of orographic precipitation, e.g. reducing the common overestimation over the Black Forest mountains, and a reduction of drizzle events. Both effects lead to an improved QPF skill during wintertime and demonstrates the importance of cloud microphysics for precipitation patterns on the mesoscale. Unfortunately, but not unexpected, the general overestimation of wintertime precipitation cannot be cured by this change of the microphysical parameterization. The revised microphysics scheme is in operation in the 7-km COSMO-EU at DWD since 31 January 2007. A similar microphysics scheme using the same warm rain and snow microphysics, but with an additional graupel category, is operational in the 2.8-km COSMO-DE of DWD.

Acknowledgments: We thank Ewan O'Connor for providing the IWC retrievals of the ARM Mobile Facility as well as the whole AMF team.

References

Doms, G. and U. Schättler, 2004: A description of the nonhydrostatic regional model LM. Part II: Physical parameterization. Technical report, Deutscher Wetterdienst, Offenbach, (available from http://www.cosmo-model.org/public/documentation.htm).

Field, P., R. Hogan, P. Brown, A. Illingworth, T. Choulartona, and R. Cotton, 2005: Parametrization of ice-particle size distributions for mid-latitude stratiform cloud. *Quart. J. Roy. Met. Soc.*, **131**, 1997–2017.

Garvert, M., B. Colle, and C. Mass, 2005: The 13-14 december 2001 IMPROVE-2 event. Part I: Synoptic and mesoscale evolution and comparison with a mesoscale model simulation. *J. Atmos. Sci.*, **62**, 3474–3492.

Hamill, T., 1999: Hypthesis tests for evaluating numerical precipitation forecasts. *Weather and Forecasting*, **14**, 155–167.

Illingworth, A. J., R. J. Hogan, E. J. O. D. Bouniol, M. E. Brooks, J. Delano353, D. P. Donovan, J. D. Eastment, N. Gaussiat, J. W. F. Goddard, M. Haeffelin, H. K. Baltink, O. A. Krasnov, J. Pelon, J.-M. Piriou, A. Protat, H. W. J. Russchenberg, A. Seifert, A. M. Tompkins, G.-J. van Zadelhoff, F. Vinit, U. Will351n, D. R. Wilson, and C. L. Wrench, 2007: Cloudnet. *Bull. Am. Met. Soc.*, **88**, 883–898.

Lin, Y.-L., R. D. Farley, and H. Orville, 1983: Bulk parameterization of the snow field in a cloud model. *J. Clim. Appl. Meteorol.*, **22**, 1065–1092.

Rutledge, S. and P. Hobbs, 1983: The mesoscale and microscale structure and organization of clouds and precipitation in midlatitude cyclones. VIII: A model for the 'seeder-feeder' process in warm-frontal rainbands. *J. Atmos. Sci.*, **40**, 1185–1206.

Seifert, A. and K. D. Beheng, 2001: A double-moment parameterization for simulating autoconversion, accretion and selfcollection. *Atmos. Res.*, **59-60**, 265–281.