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The Kessler-type autoconversion/accretion scheme has been replaced by the parameterization of Seifert and Beheng (2001) reading

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

with \( L_c/r \) cloud/rain water content, \( N_c \) cloud droplet number concentration, \( \nu \) shape parameter, \( k_{cc} = 9.44 \times 10^9 \) s\(^{-1}\) kg\(^{-2}\) m\(^3\), \( x^* = 2.6 \times 10^{-10} \) 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 \( N_c = 5 \times 10^8 \) m\(^{-3}\) and a constant shape parameter \( \nu = 2 \).
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 $N_{0,s} = 8 \times 10^5$ 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):

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

with $T_0 = 273.15$ K.

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).
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 to 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. 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


