Proceedings of ERAD 2006

The effect of radar data assimilation on the accuracy of QPF for flash flood rainfalls

Zbynek Sokol, Daniela Rezacova

Institute of Atmospheric Physics ASCR, Prague, Czech Republic.

1 Introduction

The forecast of local precipitation produced by severe convective storms is a difficult task for numerical weather prediction (NWP) modellers and forecasters. Present high-resolution NWP models with a resolution of the order of 1 km are capable of generating detailed precipitation fields, the structure of which is similar to those observed by meteorological radars, however, the observed and forecast precipitation differs in the amount, area location, and temporal evolution. A large part of the discrepancies can be explained by an inappropriate triggering of precipitation processes within the model. It has been shown that by the assimilation of proper data the convective storm triggering has been improved (e.g. Ducrocq et al. 2000, 2002), which affects significantly the precipitation forecasts.

Numerous studies show (e.g. Jones and Macpherson 1997; Klink 2004; Qiu and Xu 1992; Snyder and Zhang 2003; Tong and Xue 2005; Weygandt et al. 2002; Zhang et al. 2004) that the assimilation of radar data, which contain high resolution information about the development of convective storms, improves the quality of precipitation forecast.

In this study the LM-COSMO (LM, version 3.18) NWP model (Doms and Schaettler 1999) with a horizontal resolution of 2.8 km is used to simulate six convective events with extreme rain rates. All events lasted only a few hours (3-6 hours) and occurred in the territory of the Czech Republic (CR). The areas with convective precipitation were quite small (about 100-500 km^2), however, intensive precipitation caused local flash floods with significant damage in most considered cases. Routinely-used NWP models usually forecasted precipitation but either the amount were significantly underestimated or the position was missed. Therefore, we assimilated radar reflectivity data at the time of storm first appearance into the LM model and investigated whether model outputs are better with respect to the localization of the storm evolution and precipitation forecast. Two assimilation methods were applied. The first one uses the latent heat nudging (LHN, Macpherson 1997; Klink 2004), which is an option of the LM code. This assimilation procedure was used with parameter values recommended by Klaus Stephan, DWD (personal communication). The second method was based on a slightly different approach which consists in the correction of model water vapour content.

Correspondence to: Zbynek Sokol.

sokol@ufa.cas.cz

2 LM application and radar data

The LM was applied in two steps (for details see Rezacova and Sokol 2003). In the first step the LM was implemented over a large part of Europe with the horizontal resolution of 11 km. The model used initial and lateral boundary conditions derived from ECMWF and was run with the Tiedtke cumulus parameterization (Tiedtke 1989). The model integration started at 00 UTC and the projection time was 24 hours. In the second step the LM was integrated over the CR with a horizontal resolution of 2.8 km (Figure 1) with the cumulus parameterization switched off and the integration started at 09 UTC. In both cases the LM used the microphysics parameterization with prognostic variables rain water and snow water.

Radar reflectivity data from two Czech radars, at sites Skalky and Brdy (Havranek and Kracmar 1996) (Figure 1), were used. The data consisted of radar reflectivity values measured at 1000 m (CAPPI 1000) with horizontal resolution of 1 km. The time step of radar scans is 10 minutes. Radar reflectivity Z (dBZ) is transformed into precipitation rate R (mm/h) and liquid water content W (mm^3/m^3) by using the following relationships (Havranek and Kracmar 1996; Hagen and Yuter 2003)

$$Z = 200R^{1.6} \tag{1}$$

and

$$W = 3.4Z^{4/7} \ . \tag{2}$$

The radar-based R and W fields from both radars were interpolated into LM grid points and in the radar overlapping area the maximum of two radar-derived values was taken. The area covered by the radar data is slightly smaller than the LM domain. Radar-derived precipitation was not corrected by gauge measurements since acceptable hourly rain gauge records were not available. It is well known that radar measurements are influenced by various kinds of errors and that the equations (1) and (2) are far from being accurate (e.g. Meischner 2004; Hagen and Yuter 2003). However, the radar data were the only available type of precipitation data that covered the precipitation domains with the horizontal resolution corresponding to the model resolution. Therefore, the radar data were used in both assimilation and verification procedures.

3 Assimilation method

The assimilation method stems from the procedure used by Falkovich et al. (2000) and Davolio and Buzzi (2004), where the idea of the correction of water vapour was applied. In our approach the assimilation was employed with significantly higher horizontal and temporal resolutions. The present application (MQ) is a follow-up of the previous study by Sokol and Rezacova (2006). The method first transforms radar reflectivity with help of equation (2) into the water vapour mixing ratio q_v, which is assimilated into the LM model by the nudging method. The assimilation of q_v is performed at each time step of the model (Δt=30s).

The method modifies vertical profiles of q_v independently at each grid point in which the radar data are available. When the model rain rate is lower/higher than the observed rain rate then the model q_v is increased/decreased. The correction depends on the difference, D, between the model, RM, and observed rain rates, RR, calculated as the mean of 3x3 grid points:

$$D = Q(RR) - Q(RM), \quad (3)$$

where Q transforms rain rate into the water vapour mixing ratio:

$$Q(R) = \frac{W(R)}{\rho} \quad . \quad (4)$$

W is related to R by equations (1) and (2), ρ is air density (kgm^{-3}), RR and RM are in mmh^{-1}. The RR is calculated at an actual time step by linear interpolation in time between neighbouring measurements. If D>0 the model underestimates observed precipitation, and q_v is increased at each model level k by DIF:

$$q_{v,k}^{new} = q_{v,k} + DIF \quad , \quad (5)$$

where

$$DIF = MIN(\alpha * D, \delta) \quad , \quad (6)$$

and

$$\delta = MAX(\varepsilon_+ * q^s_{v,k}(T_k) - q_{v,k}, 0) \quad , \quad (7)$$

α, ε_+ are constants and $q^s_{v,k}$ is the saturated water $q_{v,k}$ at temperature T_k. If D<0 then $q_{v,k}$ is decreased by DIF:

$$q_{v,k}^{new} = q_{v,k} - DIF \quad , \quad (8)$$

where DIF is given by equation (6) and δ is determined by

$$\delta = MAX(q_{v,k} - \varepsilon_- * q^s_{v,k}(T_k) , 0) \quad , \quad (9)$$

where ε_- is a constant. The constant values α=0.0005, ε_+=1.02, and ε_-=0.95, which were found by preliminary tests, were applied in this study.

4 Results and discussion

The LHN and MQ methods were tested at six convective events: 13 July 2002, 17 July 2002, 26 May 2003, 10 June 2004, 23 May 2005 and 30 May 2005. The studied events differed by synoptic conditions which evoke heavy precipitation. In all cases both methods LHN and MQ improved the precipitation forecast. In most cases the structure of precipitation fields of both methods were similar, however, they differed in amounts. Usually the LHN underestimated and the MQ overestimated precipitation amounts. If the driving model and consequently the LM model with the resolution of 2.8 km apparently missed the location of precipitation then also the LHN and MQ had problems with developing heavy precipitation in the corresponding area. It means that when the atmosphere is far from being saturated then both the methods need several hours of assimilation of observed precipitation to forecast precipitation.

Forecasted and observed precipitation at 13 July 2002 are given as an example. Figure 2 shows quite good agreement of observed and forecasted accumulated precipitation during the first 5 hours of the integration. However, than the model precipitation develops in a different way than it was observed by the radar (Figure 3). The forecast by the LHN and MQ methods is shown in Figure 4. The assimilation started at the beginning of the integration at 09 UTC and finished after 5 hours at 14 UTC. The assimilation significantly improved the forecasted precipitation in comparison with the LM run. The basic features of forecasted precipitation fields are similar but the precipitation amounts of the MQ are higher and closer to the observed one. Although neither the MQ nor the LHN precisely locate the precipitation band in the Central Bohemia the corresponding band is shifted Westerly by only about 50 km.

Acknowledgements: The work was supported by the grant GACR 205/04/0114. We thank the German weather service (DWD) for the provision of the LM code. We also thank the Czech Meteorological Institute for radar data from the Czech territory.

References

Davolio, S. and A., Buzzi, 2004: A Nudging scheme for the assimilation of precipitation data into a mesoscale model. *Wea. Forecasting* **19:** 855-871.

Doms, G. and U., Schaettler, 1999: The Nonhydrostatic LimitedArea Model LM of DWD. Part I: Scientific Documentation, DWD, Offenbach, Germany, 172 pp. Available at: http://www.cosmo-model.org.

Ducrocq, V., J.P., Lafore, J.L., Redelsperger, and F. Orain, 2000: Initialization of a fine-scale model for convective-system prediction: A case study. *J.R. Meteorol. Soc.*, **126**: 3041-3065.

Ducrocq, V., D., Ricard, J.P., Lafore, and F., Orain, 2002: Storm-scale numerical rainfall prediction for five precipitating events over France; On the importance of the initial humidity field. *Wea.Forecasting*, **17**:1236-1256.

Falkovich, A., E., Kalnay, S., Lord, and M.B., Mathur 2000: A new method of observed rainfall assimilation in forecast models. *J. Appl. Meteor.* **39:** 1282-1298.

Hagen, M. and S.A., Yuter, 2003: Relations between radar reflectivity, liquid-water content, and rainfall rate during the MAP SOP. *Q. J. R. Meteorol. Soc*., **129:** 477-493.

Havranek, P. and J., Kracmar, 1996: New weather radar station in central Moravia. *Czech Meteorological Bulletin* **49:** 81-84.

Jones, C.D. and B., Macpherson 1997: A latent heat nudging scheme for the assimilation of precipitation data into an operational mesoscale model. *Meteorol. Appl.* **4**: 269-277.

Klink, S., 2004: Assimilation of radar data in the mesoscale nwp-model of DWD. 3rd European Conference on radar use in meteorology and hydrology (ERAD). Erad publication series, **2:** 155-161.

Macpherson, B., 2001: Operational experience with assimilation of rainfall data in the Met Office Mesoscale model. *Meteorol. Atmos. Phys.* **76:** 3-8.

Meischner, P. (Ed.), 2004: *Weather Radar. Principles and Advanced Applications*. Springer-Verlag 1st ed. 337pp. ISBN: 3-540-00328-2.

Qiu, C. and Q., Xu, 1992: A simple adjoint method of wind analysis for single-Doppler data. *J. Atmos. Oceanic Technol.,* **9:** 588–598.

Rezacova, D. and Z. Sokol, 2003: A diagnostic study of a summer convective precipitation event in the Czech Republic using a non-hydrostatic NWP model. *Atmos. Research*, **67/68:** 559-572.

Snyder, C. and Zhang, F. (2003) Assimilation of simulated Doppler radar observations with an ensemble Kalman filter. *Mon. Wea. Rev.* **131:** 1663-1677.

Sokol, Z. and D. Rezacova, 2006: Assimilation of radar reflectivity into a high resolution Numerical Weather Prediction model. . *Czech Meteorological Bulletin* **59:** 18-29.

Tiedtke, M., 1989: A comprehensive mass flux scheme for cumulus parameterization in large-scale models. *Mon. Wea. Rev*., **117:** 1779-1799.

Tong, M. and M., Xue, 2005: Ensemble Kalman Filter Assimilation of Doppler Radar Data with a Compressible Nonhydrostatic Model: OSS Experiments. *Mon. Wea. Rev.,* **133:** 1789-1807.

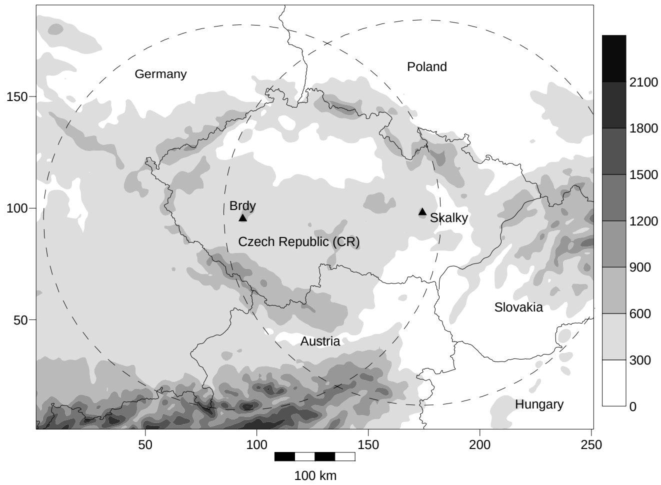

Fig. 1. Integration domain of the LM with the model topography (heights shown in m). The x and y coordinates show the model grids. The black triangles indicate the positions of the radars at sites Skalky and Brdy and dashed line circles show the radar domains with a radius of 256 km.

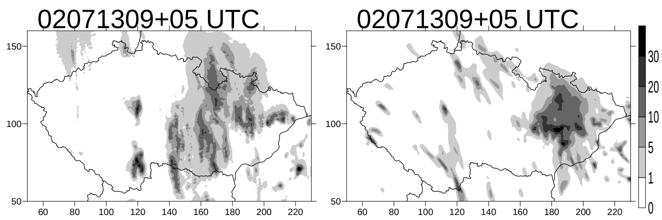

Fig. 2. Accumulated precipitation on 13 July 2002 from 09 UTC to 09+05 UTC observed by the radar (left column) and forecasted by the LM model (right column).

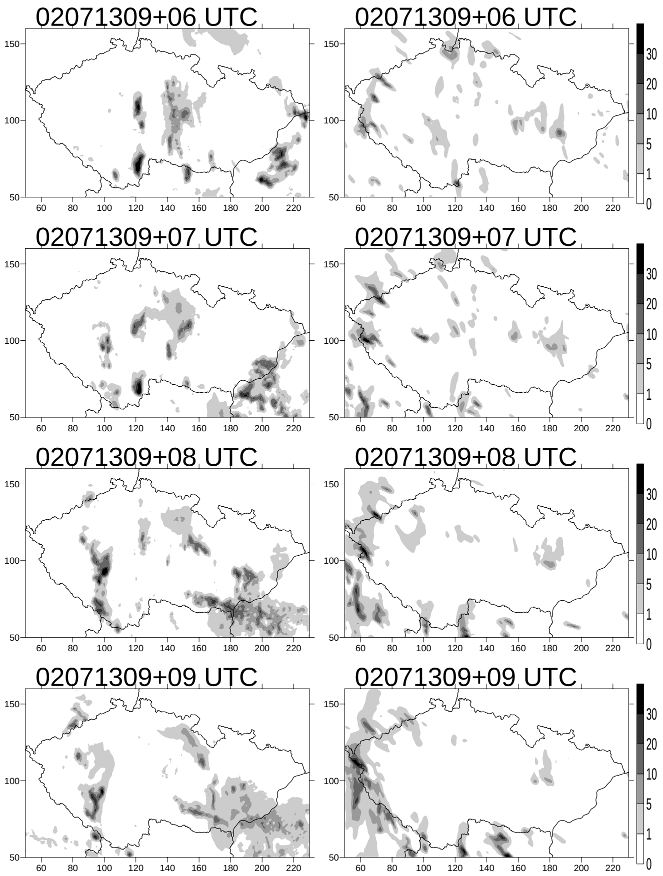

Fig. 3. Hourly precipitation related to the indicated times. The left column shows observed precipitation by the radar and the right column gives forecasted precipitation by the LM for 13 July 2002.

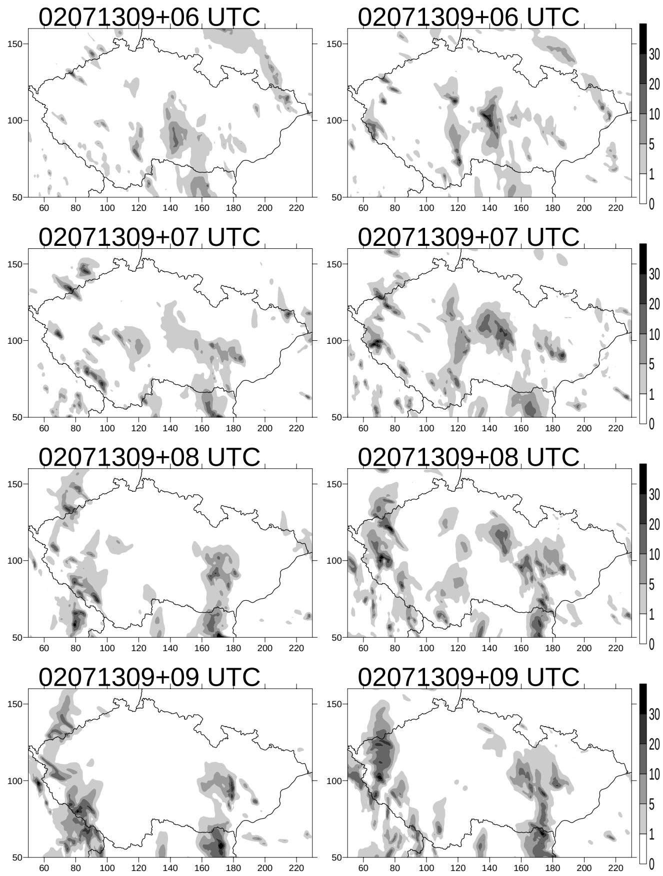

Fig. 4. Hourly precipitation related to the indicated times forecasted by the LHN (left column) and the MQ (right column) for 13 July 2002. The assimilation started together with the integration of the LM model at 09 UTC and ended at 14 UTC.