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Event-oriented radar verification of convective precipitation simulated by NWP model

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Abstract. In this contribution we compare radar-based precipitation fields with the forecast of convective precipitation that results from the experimental application of the LM DWD (Lokal Modell of the German Weather Service). The LM DWD code was used in two runs. The driving model, LLM, used the horizontal resolution of 14km. The following nested version, SLM, was run with horizontal resolution of 2.8 km. The LLM/SLM was applied to simulate the evolution of several convective events, which occurred in the region of the Czech Republic (CR). The results, summarized in this contribution, are related to three events that differ in precipitation amount as well as in the extent of precipitation area. The first event in July 1998 is a small, long-lasting squall line that caused a local flash flood in the NE part of the CR. In addition to the 1998 event, the precipitation forecasts are discussed which relate to two convective events from 2000. The events represent convective systems causing local heavy precipitation and accompanied by other severe convective phenomena.

The predicted amounts of accumulated precipitation are compared with corresponding radar-based values. We use the measurements of two radars, which are operated by the Czech Hydrometeorological Institute. The verification procedure applies skill scores, which are based on contingency table, to verify grid-point precipitation. Moreover, attempts are made to verify the grid-point forecast interpreted in a probabilistic form, and to verify area precipitation. The present results show that the verification by radar is suitable for the forecast of heavy convective precipitation. It appears to be more reasonable to consider area precipitation and/or to apply probabilistic treatment to the NWP forecast, instead of verifying single grid-point values.

1 Introduction

Organized convective systems are important producers of heavy precipitation that can cause localised flash floods. That is why NWP model forecast of convective precipitation has been an important topic of investigation for several decades. It has been recognized that non-hydrostatic models with resolution of the order of 1 km are able to simulate the dynamics of organized convective systems provided that adequate convective activities are triggered during the model integration. Nevertheless, the deterministic quantitative forecast of convective precipitation is far from being adequately solved.

The verification of precipitation forecast is an important means of expressing the forecast quality in a condensed way. The networks of ground gauges can be too sparse to provide proper data for the verification of the forecast of local convective precipitation. On the contrary, radar data represent dense area information about precipitation. Consequently the radar measurement can be used to verify the forecast. In this contribution we present some results of event-oriented verification of convective precipitation forecast by using radar data. We use the measurements of two radars (radar Skalky – Gematronik METEOR 360 AC, and radar Brdy – EEC DWSR-2501C), which are operated by the Czech Hydrometeorological Institute (CHMI).

The Lokal Modell of the German Weather Service (LM DWD) was run in an experimental mode to simulate convective events that had occurred in the region of the Czech Republic (CR). In this contribution the results of a few simulations are verified. The first simulated event is an extreme convective storm that caused a local flash flood in the NE part of the CR in July 1998. Additionally two convective events from 2000 were selected to evaluate the ability of LM to model convective systems of different structure. The resultant LM precipitation fields are compared with precipitation as it was indicated by the radar measurement.

Simple verification procedure is applied to compare the forecast with radar-based precipitation. Skill scores based on contingency table are determined to express the quality of model results. Grid-point precipitation exceeding a precipitation threshold is the subject of verification. An attempt is made to interpret the grid-point forecast in a probabilistic form. The probability of exceedence is determined under the assumption that a random sample of the grid-point precipita-

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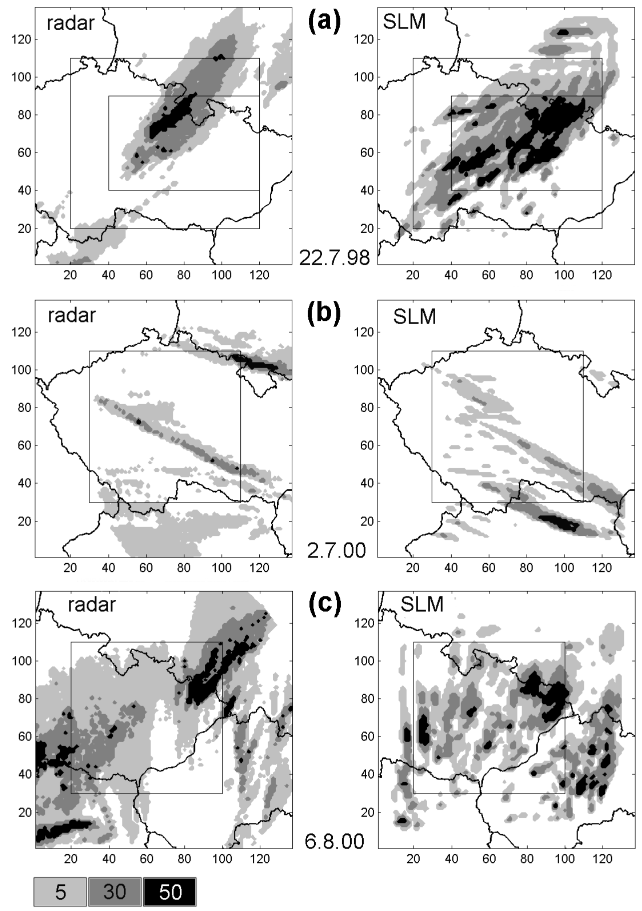

Fig. 1. Accumulated precipitation exceeding a threshold value PT (indicated in the legend). Radar-based precipitation (non-adjusted) is on the left, SLM model precipitation on the right. The border of the CR is depicted by a bold line. Each domain corresponds to 137x137 model grid points. The inner square in each picture marks a verification subdomain. (a) Flood event from 1998. The SLM integration started at 12UTC on 22nd July, the accumulated precipitation relates to 06UTC on 23rd July. (b) The event on 2nd July, 2000. SLM start time at 03UTC, precipitation accumulated at 00UTC on 3rd July. (c) Hail event on 6th August, 2000. SLM start time at 07UTC, precipitation accumulated at 00UTC on 7th July.

tion can be represented by forecast values in the vicinity of the grid-point. Consequently, skill score values can be determined in dependence on the precipitation threshold as well as on the probability of exceedence.

The text is structured as follows. Section 2 describes briefly the configuration of the LM DWD runs. Basic meteorological information about the simulated convective events is presented in Sect. 3, which also provides a qualitative comparison of forecast and radar precipitation fields. The results of quantitative verification are presented in Sect. 4 and the last Sect. 5 summarizes the main conclusions.

2 The arrangement of LM runs

In the simulations we used the LM DWD version 2.12 in two steps. Firstly, the driving LM model (LLM) was integrated with horizontal resolution of 14 km over a domain covering larger part of Europe (161×145 grid-points). Initial and boundary conditions were derived from the objective analysis of aerological data (Sokol, 1993). The LLM integration starts at 00:00 UTC on the day of interest and runs till 00:00 UTC + 24 h and/or + 36 h. Secondly, a nested LM model (SLM) was run with horizontal resolution of 2.8 km. The position of the SLM domain (137×137 horizontal grid-points) depends on the localization of convective event of interest. The initial and boundary conditions for the SLM are obtained from the LLM forecasts. Each convective event was simulated by a few SLM runs that differed in the SLM start time.

When enhancing the resolution of NWP model we have to consider the applicability of existing physical parameterizations. The LM DWD code contained the cumulus parameterization by Tiedtke (Doms and Schaettler, 1999; Tiedtke, 1989) but it enabled switching OFF the parameterization and running the LM with explicit expression of cloud and rain processes. We took the results summarized in Rezacova, and Sokol (2002) into consideration and integrated the driving LLM in the standard way with cumulus parameterization ON. On the contrary, the cumulus parameterization was switched to OFF in the nested SLM.

3 Simulated convective events

Three convective events were selected to compare the forecast precipitation with radar-based values. One event represents an extreme local flash flood system in July 1998. Two events from 2000 are convective systems producing local hail. The SLM fields of accumulated precipitation from 1998 were compared with radar precipitation obtained from measurement with radar Skalky. The radar-based precipitation, corresponding to the 2000 events, was determined from combined information of the both radars. The standard CHMI procedure was used to determine accumulated precipitation from maximum reflectivity and to combine the reflectivity fields. The radar precipitation values, available in pixels 2 km $\times$ 2 km, were interpolated to model grid-points.

3.1 Extreme flash flood event on 22 July 1998

The convective storm on 22 July 1998 developed in the form of a nearly steady state convective band that produced a local flash flood in the NE part of the CR. The synoptic setting (e.g. Hancarova et al., 1999) shows that the system was linked to a cold front moving slowly eastwards across the CR during 22 July 1998. Ahead of the front, there was a south flow of a very warm tropical air with maximum daily temperatures reaching up to 34°C. Behind the front, there was a prevailing southwest flow of colder air with ground temperature up to 26°C. In the afternoon the front began to wave

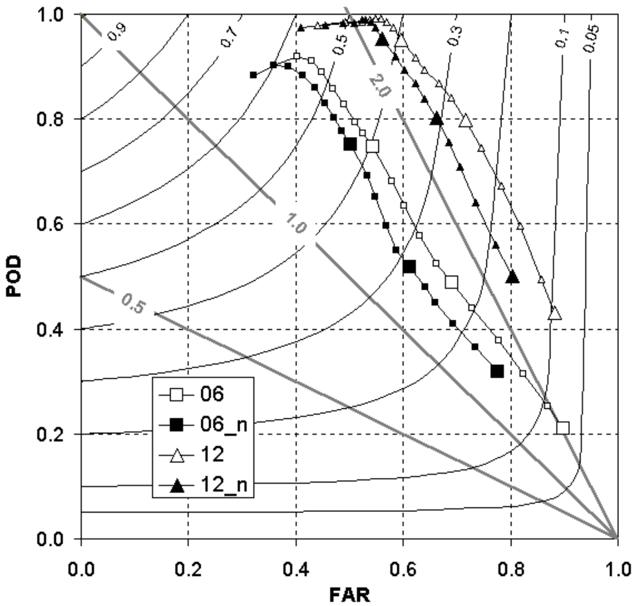

Fig. 2. Verification of precipitation forecast for flash flood event in July 1998. The legend indicates the SLM start time in UTC. The start time values accompanied by _n relate to the verification by adjusted radar precipitation. Accumulated precipitation was determined at 06UTC on 23rd July. The graph coordinates give POD and FAR values. There are the isolines of BIAS = 0.5, 1, 2 (bold grey lines), and TS = 0.05, 0.1, 0.2, ..., 0.7 (labelled curves) depicted in the graph. The markers indicate precipitation threshold values PT = 2 , 3, ..., 9, 10, 12, 14, ...28, and 30 mm with enlarged markers corresponding to the PT = 10, 20, and 30 mm.

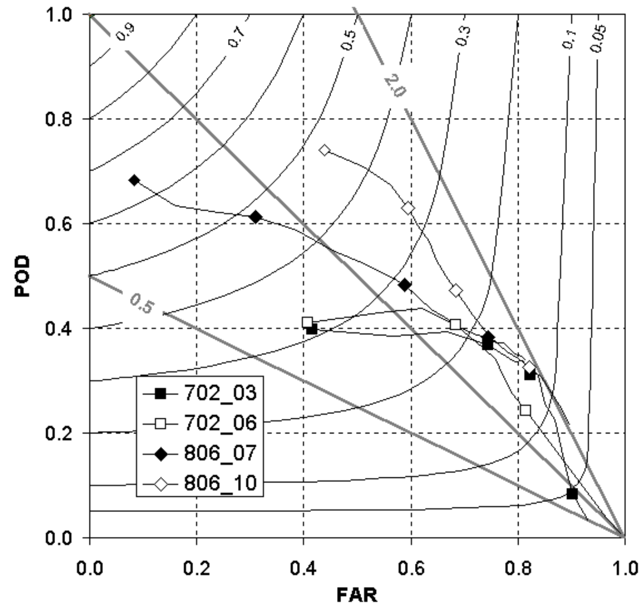

Fig. 3. Verification of simulated precipitation forecast for two events from 2000. The general structure of the graph corresponds to Fig.2. The legend indicates the datum of the event (702 for 2nd July, 806 for 6th August) and the SLM start time in UTC. Accumulated precipitation was determined at 00UTC on the next day. The markers indicate precipitation threshold values PT = 2, 5, 10, and 20 mm. The radar precipitation was not adjusted.

and its advance still slowed down. At about 16:00 UTC the first rain cells appeared and a local squall line was evolving by recurrent cell development and their propagation to NE. The heavy convective rain lasted for 10 to 12 hours with the highest precipitation detected in the strip 50 km × 20 km. The precipitation maximum reached the value of 204 mm. It means that the event belongs to the set of extreme events recorded in the Czech territory. In the morning on 23 July, the frontal advance sped up again and the front left the CR.

Because of its stationary position the event is suitable for the simulation by a limited area model. Furthermore, the radar Skalky covered the area of interest very well. Figure 1a shows the accumulated precipitation derived from the radar data in comparison with the precipitation followed from SLM simulation.

3.2 Propagation of isolated cells on 2 July 2000

Shortly after the midday on 2 July 2000 a wavy, cold-frontal surface, connected with a shallow pressure trough, began to pass across the CR from the SW. Since most of the CR territory was affected by the warm part of the front, there was slight warming during the passage. The maximum daily temperatures reached the values of about 25°C. The relatively slow passage of the front was accompanied by local showers and thunderstorms. The maximum daily precipitation up to 20 mm was reported by synoptic stations. Strong downburst and hail was detected locally at the village Krasikovice. The time sequence of radar images shows two isolated rain cells propagating successively from NW to SE with nearly the same trajectory. It produced the accumulated radar precipitation field shown in Fig. 1b.

3.3 Hail storm in North Moravia and Silesia on 6 August 2000

On 6 August 2000 the weather situation over the CR was affected by a deep upper trough coupled with the pressure low centred over Scandinavia. The trough axis moving very slowly eastwards separated colder air over central and western Europe from the warm air over the Carpathians. The trough passage was accompanied by the sharp change of the upper wind from the SE to the NE. In the late afternoon heavy thunderstorms with reported downbursts and hail developed in the NE part of the CR (north Moravia and Silesia). In this area the ground gauges reported daily precipitation not exceeding 45 mm but hailstones up to 4 cm in diameter were observed. Before the hail started in north Moravia, heavy convective rain had been reported in the south of CR with maximum daily precipitation of 90 mm. The SLM model domain was positioned to consider the hail event in the NE part of the CR. Figure 1c shows the resulting fields of accumulated precipitation.

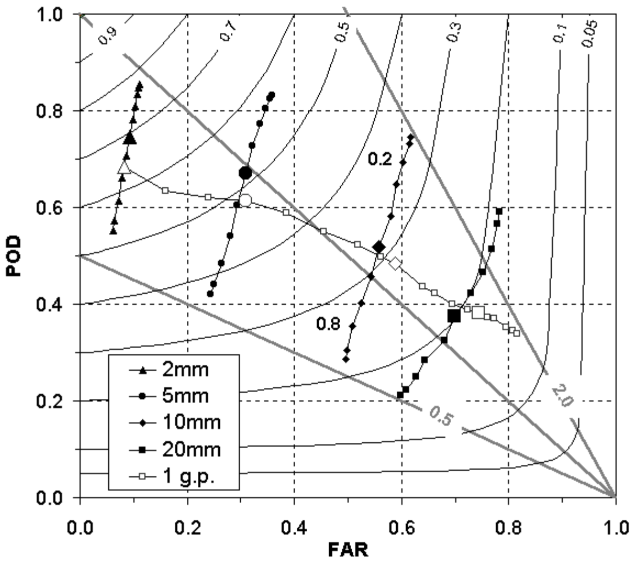

Fig. 4. Evaluation of the forecast interpreted in probabilistic way. The general structure of the graph is the same as in Fig.2. The example relates to the event on 6th August, 2000 with the SLM start time 03UTC. Each line with full markers corresponds to the precipitation threshold PT (see the legend) and connects POD vs FAR points with the values of exceedence probability PE = 0.95, 0.9, 0.8, ...0.1, 0.05. The points for PE = 0.5 are marked by enlarged markers. The results are shown for the squares 5x5 grid points. The line with empty markers shows the skill of the grid-point precipitation forecast (1 g.p.), see also the corresponding line in Fig.3.

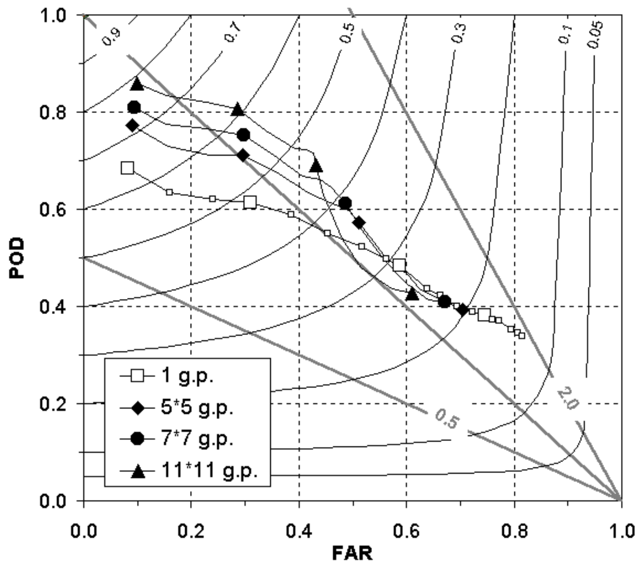

Fig. 5. Evaluation of the area precipitation forecast. The general structure of the graph corresponds to Fig.2. The example relates to the event on 6th August 6, 2000 with the SLM start time 03UTC. The enlarged markers on each line correspond to the area precipitation thresholds PT = 2, 5, 10, and 20mm. The magnitude of the area, expressed in grid point number, is given in the legend. The line with empty markers (1 g.p.) shows the verification of the grid-point precipitation (see also Fig.4 and Fig.3).

4 Verification of SLM precipitation by radar

Grid-point precipitation exceeding a threshold value PT was verified. The scoring, which was employed to assess the skill of the forecast, is based on contingency table. From the set of commonly used skill scores (see, for example, Wilson, 2001; Doswell et al., 1990) we determine the Probability Of Detection (POD), False Alarm Ratio (FAR), Threat Score (TS) and BIAS, which can be expressed as follows:

$$\mathrm{POD} = a_{11}/(a_{11} + a_{10}) \tag{1a}$$

$$\mathrm{FAR} = a_{01}/(a_{11} + a_{01}) \tag{1b}$$

$$\mathrm{TS} = a_{11}/(a_{11} + a_{01} + a_{10}) \text{ and} \tag{1c}$$

$$\mathrm{BIAS} = (a_{11} + a_{01})/(a_{11} + a_{10}) \tag{1d}$$

In Eqs (1a)–(1d) the coefficients a_{OF} denote the elements of contingency table with the indices $O = 0/1$ and $F = 0/1$ relating to radar observation and SLM forecast, respectively.

Skill scores were determined to evaluate the (i) categorical grid-point forecast, (ii) grid-point forecast interpreted in probabilistic way, and (iii) the forecast of area averaged precipitation. We considered only the inner part of the SLM model domain at the calculation of skill scores. The verification subdomains, corresponding to the individual events, are marked in Fig. 1.

4.1 Categorical forecast of grid-point precipitation

The results of the verification of grid-point forecast are summarized in Figs. 2 and 3. Figure 2 relates to the flash flood event from 1998 and to the grid-points inside the innermost subdomain shown in Fig. 1a. The POD vs. FAR curves in Fig. 2 reflect the results of SLM runs with different start time. In addition to the direct radar precipitation we also considered a simple correction procedure. Since the maximum radar precipitation was 157 mm, while the ground measurement gave the maximum precipitation of 204 mm, we have applied the factor 1.3 to correct roughly the radar precipitation. Figure 2 shows that the forecast corresponds better to the corrected values (higher PODs and lower FARs for given PT value). Large BIAS values prove general overpredicting in particular at low PT values. It is also apparent from Fig. 1a.

Similarly, the verification results corresponding to the events from 2000 are shown in Fig. 3. The radar precipitation was not corrected as there was not clear over-/underestimation in radar precipitation.

4.2 Probabilistic interpretation of grid-point precipitation

The verification of grid-point values corresponds to the assumption that even a fine structure of precipitation field can be predicted in a deterministic way. It is conceivable that we expect more from the deterministic forecast than is possible. Theis et al. (2001) consider the problem from the viewpoint of the ensemble prediction concept. Due to the computational demands of such a treatment, they reduce their first experiments to a statistical postprocessing of a model prediction. They follow an assumption that forecast values in a certain neighbourhood of a grid-point can be considered as a random sample of the grid-point forecast. In the first attempt we did not consider meteorological and/or physical effects, which can influence the extent of the sample, and we applied this approach as follows.

Around each grid-point we determined a square neighbourhood where the predicted precipitation is supposed to constitute a sample of the forecast at the central grid-point. From the sample values we can estimate the quantile $X(PE)$ corresponding to the probability of exceedence PE. We test the condition $X(PE) \geq PT$, where PT is precipitation threshold, with given PE value. The categorical, YES/NO, forecast results in YES if the condition is valid and vice versa. It makes possible to determine the contingency table in dependence on PE and the dimension of the square. The skill scores were calculated for $PT = 2, 5, 10, 20, 30$ mm, $PE = 0.95, 0.9, 0.8, \ldots, 0.1, 0.05$, and for the squares with side length of $n * \Delta$, where Δ is the SLM horizontal resolution, and $n = 3, 5, 7, 11$. Figure 4 shows an example of the results calculated for the event in August 2000. It is of note that the POD vs. FAR curves differ from the well known ROC curves, which consider False Alarm Rate defined by $a_{01}/(a_{00} + a_{01})$ (see, for example, Mason and Graham, 1999), but the interpretation can be similar. Figure 4 proves that this interpretation can markedly influence the results of verification. Further experiments are still necessary.

4.3 Verification of area precipitation

It appears reasonable to evaluate area related output as both, radar and model precipitation, represent area information. Therefore, a first attempt was made to verify the area precipitation forecast by area radar precipitation. We simply determined area precipitation by averaging grid-point values that belong to a square around a grid-point. Like in the Sect. 4.2 the squares were considered with $n = 3, 5, 7$, and 11. An example of the results is shown in Fig. 5. Given the area PT value we can see the forecast skill increasing with the area. However, more comprehensive evaluation is to be made.

5 Concluding remark

We present several examples that deal with verification of precipitation forecast by radar-based precipitation. The results follow the simulated precipitation forecast from three convective events that occurred at the territory of the CR. Experimental runs of LM DWD, using two-step integration, provided the precipitation forecasts with horizontal resolution of 2.8 km in the nested model. Radar data from two radars, operated in the CR, were used to the verification.

The results indicate that the model reflects well the basic features of radar precipitation field. They also show the usability of radar information in order to verify the convective precipitation forecast. We showed examples designed to evaluate the skill of (i) the categorical grid-point forecast, (ii) the grid-point forecast, interpreted in probabilistic way, and (iii) the forecast of area precipitation.

The results are to be considered as a first part of a more comprehensive verifying study that is in progress in the framework of COST717 project. The present activity is aimed at extending SLM model domain, increasing the number of evaluated events, and using more complex adjustment of radar-based precipitation to ground values.

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