Quantitative expression of uncertainty in nowcasting heavy convective precipitation in central Europe by extrapolation methods

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(Dated: 30 May 2012)

1. Introduction

Methods extrapolating radar reflectivity along Lagrangian trajectories are frequently used for the nowcasting of precipitation. These methods are very fast but they can provide reasonable predictions only for short lead times because storm evolution, which is not usually considered in these methods, plays a significant role especially in summer season events when convective storm interactions are a primary driver.

The forecast errors of these methods have two basic components. The first one stems from inaccurate estimates of the motion fields used for calculating trajectories. The second one follows from the assumption that observed radar reflectivity does not change in another way that by the advection.

Attempts at modelling storm evolution with extrapolation methods have not been very successful. Some extrapolation methods consider a storm or radar echo decay. They decompose precipitation patterns according to their scales and remove selected patterns from forecasts by applying spatial filters. The aim is to filter out patterns which are beyond their lifetime (Bellon and Zawadzki, 1994; Seed 2003; Turner et al., 2004; Germann and Zawadzki, 2002). Applying this approach to multiple time-space scales was investigated by Germann and Zawadzki (2002). They calculated the correlation between forecasts and observations as a function of scale, and the lifetime for a given scale was defined as the lead time of the forecast when the correlation exceeded a prescribed minimum value. These calculations were applied to selected precipitation events over North America. Because the areal extent as well as time duration of such events significantly differ for North America and central Europe we can expect that the results published by Germann and Zawadzki will not be valid for central Europe.

We applied similar methodology to evaluate uncertainty in nowcasting heavy convective precipitation by extrapolation methods for central Europe. Our study was focused on the horizontal resolution of 1 km.

2. Data

In this study we concentrated on the area of the Czech Republic (CR) and its nearest neighbourhood. To investigate the uncertainty in nowcasting heavy convective precipitation we selected 73 hours in 10 days with observed heavy convective precipitation in the area of our interest. The selected terms were from June and July 2009.

We used radar reflectivity data measured by two C-band radars, which are operated by the Czech Hydrometeorological Institute. The frequency of the measurements was 10 minutes and their horizontal resolution was 1 km by 1 km. The measured data were checked and controlled to minimise ground clutter and anomalous propagation artefacts by using an operational procedure described by Novak and Kracmar (2002). Data from single radars were merged making use of the maximum reflectivity value in the overlapping coverage areas. The resulting radar composite is shown in Fig. 1.

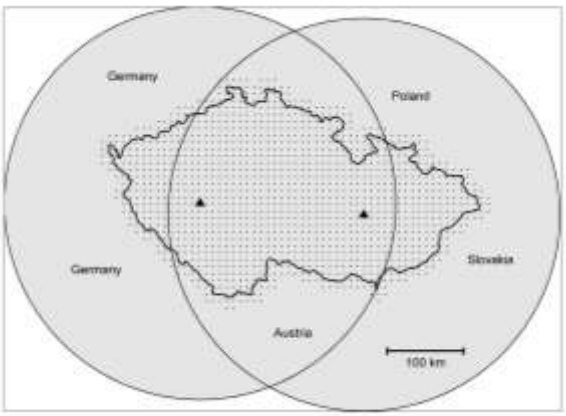

Fig. 1. The shaded area is covered by radar data and black triangles show positions of radars. The model area is indicated by dots.

We used two radar products: (i) the radar reflectivity at a constant elevation 2 km above sea level (Constant Altitude Plan Position Indicator, or CAPPI 2 km) for estimating rain rates and (ii) maximum column reflectivity, MAXR, for the calculation of a motion field by the COTREC technique (Rinehart and Garvey, 1978). CAPPI 2 km data were transformed into rain rates using a Z-R relationship (Novak and Kracmar, 2002)

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

where Z is reflectivity (mm^6/m^3) and R is rain rate (mm/h). The rain rates were integrated over time to calculate precipitation totals.

3. Calculation of motion fields, Lagrangian trajectories and nowcasting of precipitation

To calculate Lagrangian trajectories motion fields were derived from time-lagged digital reflectivity fields using the COTREC technique. COTREC is a radar echo tracking algorithm, applying a pattern recognition technique to derive a motion field. The result of the pattern recognition technique is a set of motion vectors in a considered domain, and by using an interpolation method a motion vector can be obtained at any point of the domain. For the purpose of calculating trajectories motion vectors were prepared with the resolution of 1 km.

Two types of Lagrangian trajectories were considered. Standard trajectories used within an extrapolation nowcasting method were the first type. Two consecutive radar reflectivity fields, MAXR, from times T_0 and T_0 -10 minutes, where T_0 is the beginning of the forecast, were used to calculate the motion field by COTREC and a “backward-looking” advection scheme was employed to calculate trajectories. The trajectories lengths depended on the lead-time of the forecast. The forecast made use of the latest CAPPI 2km, which was extrapolated along the trajectories assuming no evolution of radar reflectivity for each radar pixel within the CR and the nearest neighbourhood (Fig. 1). Hourly precipitation was obtained by the time integration of forecasted rain rates.

The second type of Lagrangian trajectories was calculated in a similar way as the first one but motion fields were calculated separately for every 10 minute interval using current radar reflectivity data. These trajectories were considered to be optimum and to represent true trajectories. They were used to evaluate the accuracy of trajectories used in the extrapolation. Forecasts were prepared in the same way as described above. All calculations were performed in the 1 km resolution.

4. Uncertainty in trajectories

We compared differences between the end points of the standard and optimum trajectories in dependence on the lead time (on the length of the trajectory) to quantify the uncertainty in calculations of trajectories. The results are presented in Fig. 2. Here we compared end points of trajectories fulfilling the condition that there is at least one radar pixel with more than 1 mm/h at the distance up to 20 km from the end point of optimum trajectories for the corresponding time. The motivation of this condition is that the motion field is not well determined in areas without radar echoes. On the other hand it is not crucial to accurately calculate trajectories in these areas because they are not important from the viewpoint of precipitation nowcast.

The obtained results agree with a natural assumption that differences in trajectories will increase with time. Moreover it turned out that this increase is linear. In some exceptional cases the differences between trajectories can be very large. Such errors are usually located near the boundary of our domain. They are related to insufficient amount of radar data in these regions, which negatively influence COTREC performance. The fact that the error of 25% of trajectories is about 20 km and more for the lead time 90 minutes determines the upper limit of severe storm predictability in central Europe by the extrapolation.

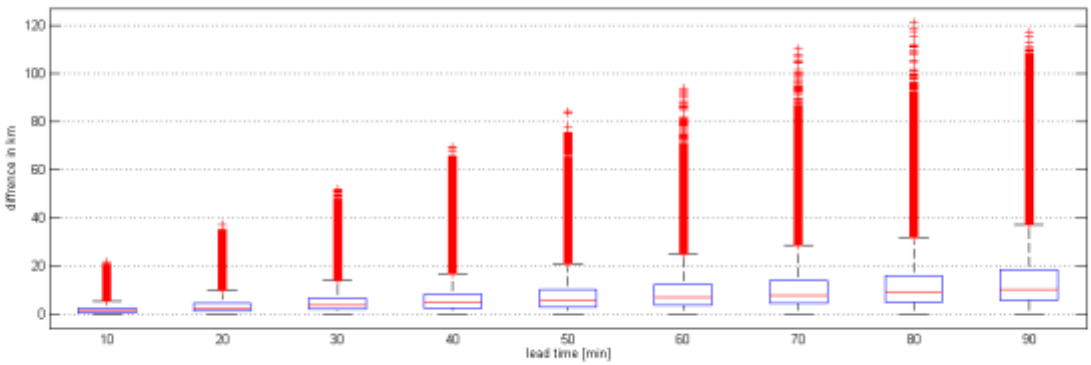

Fig. 2. Differences between the end points of the standard and optimum trajectories in dependence on the trajectory length in terms of the lead time. The differences are represented by box-plots, where the single lines from the bottom show 1%, 25%, 50%, 75% and 99% percentiles and red crosses show outliers.

Another evaluation of differences between the end points of the standard and optimum trajectories is shown in Fig. 3. In this case each pixel represents a vector of the difference between the end points of the standard and optimum trajectories,

which is expressed in a coordinate system where x-axis corresponds to the motion direction derived from the optimum trajectories related to the last 10 minutes. Moreover, the size of the vector is normalized by the length of the optimum trajectory corresponding to the last 10 minutes. In this figure only data with the length of the optimum trajectory corresponding to the last 10 minutes at least 2 km were considered. The vectors are divided into three groups according to the length of the optimal trajectory during the last 10 minutes: turquoise color means 2-4 km, blue color means 4-6 km and red color is more than 6 km. Figure 3 illustrates that the normalized errors do not significantly depends on the flow speed, which means that the absolute errors depend on the speed linearly, but it is clear dependence on the flow direction.

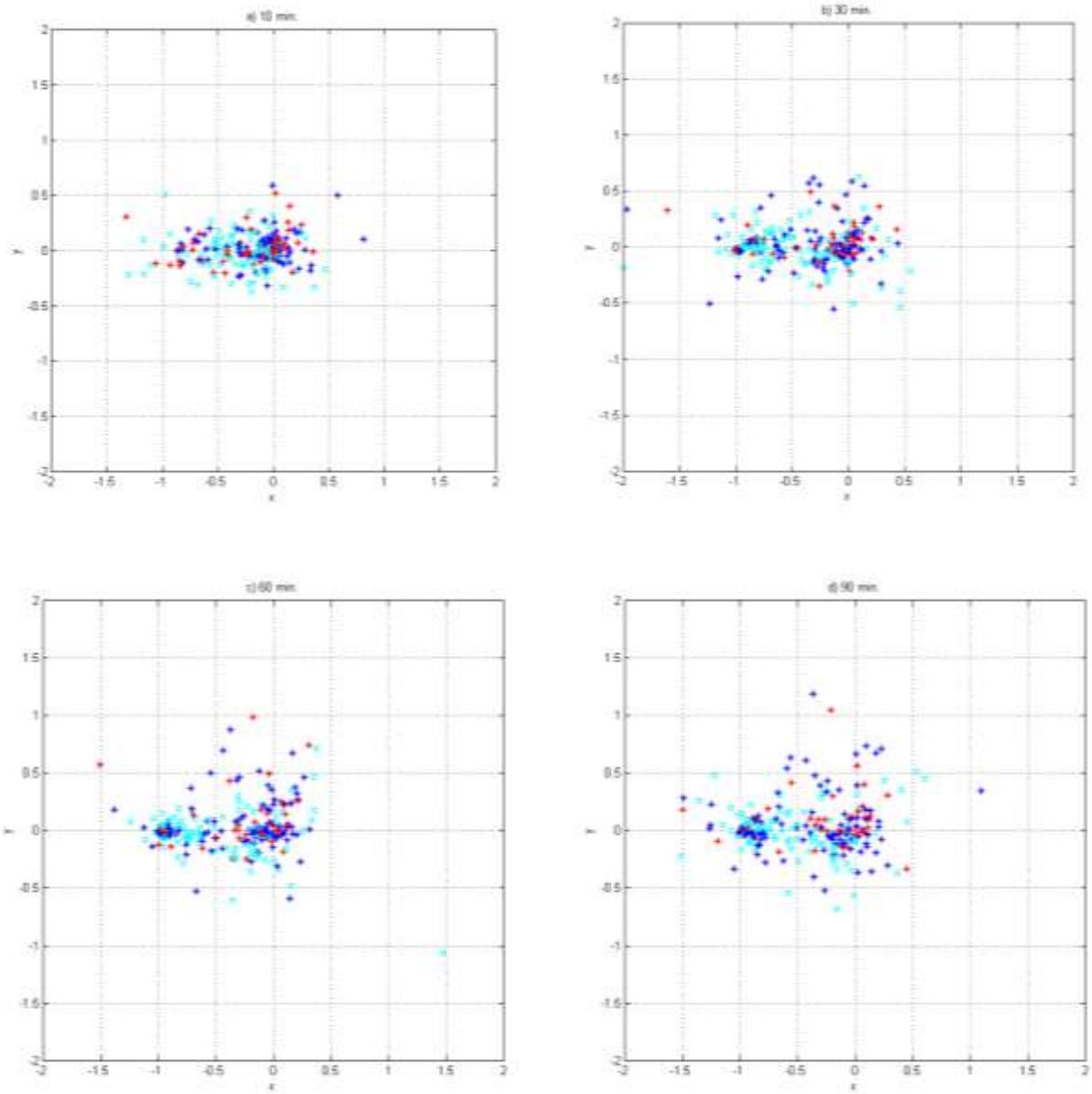

Fig. 3.Vectors of the difference between the end points of the standard and optimum trajectories. See the text for detailed description.

5. Uncertainty in precipitation nowcasting

We employed a similar technique for the investigation of forecast uncertainty as was applied by Germann and Zawadzki (2002). We forecasted rain rates by the extrapolation of the current rain rate by optimum motion fields (i.e. using optimum trajectories), by standard motion fields (i.e. using standard trajectories) and without advection using a persistent forecast. The forecasted rain rates we compared with observed radar-derived rain rates by the correlation coefficient used in the quoted paper. Beside that we also applied Spearman correlation coefficient, which is more robust a more suitable for nonlinear dependencies.

Obtained results are presented in Fig. 4. They confirm that the extrapolation along Lagrangian trajectories is apparently more accurate than the persistence. On the other hand differences between optimum and standard trajectories are not large which confirms that the evolution of convective storms plays an important role. If we use a threshold 1/e for the minimum value of the correlation coefficient, as Germann and Zawadzki, then the limit of predictability would be about 50 minutes. It

worth mentioning that the Spearman correlation coefficient shows apparently lower differences between two applied trajectories than it is in case of the second correlation coefficient.

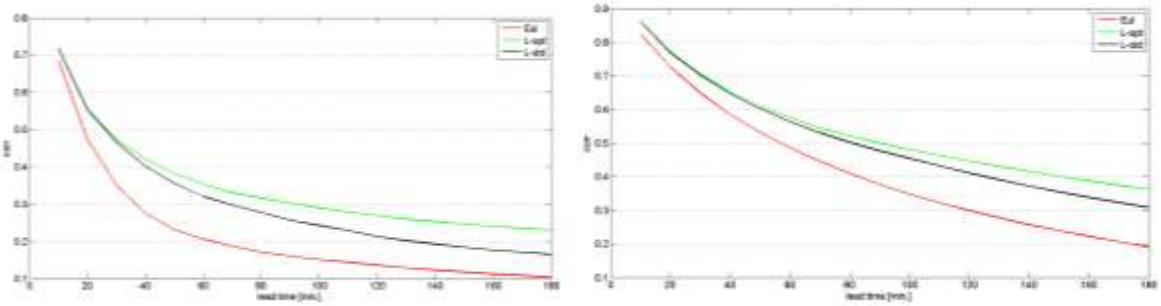

Fig.4. Dependence of the correlation coefficients on the lead time for the extrapolated rain rates along optimal trajectories (L-opt), standard trajectories (L-std) and without advection (Eul). In the left figure, the correlation coefficient defined in (Germann and Zawadzki, 2002) was applied. In the right figure, the Spearman correlation coefficient was used.

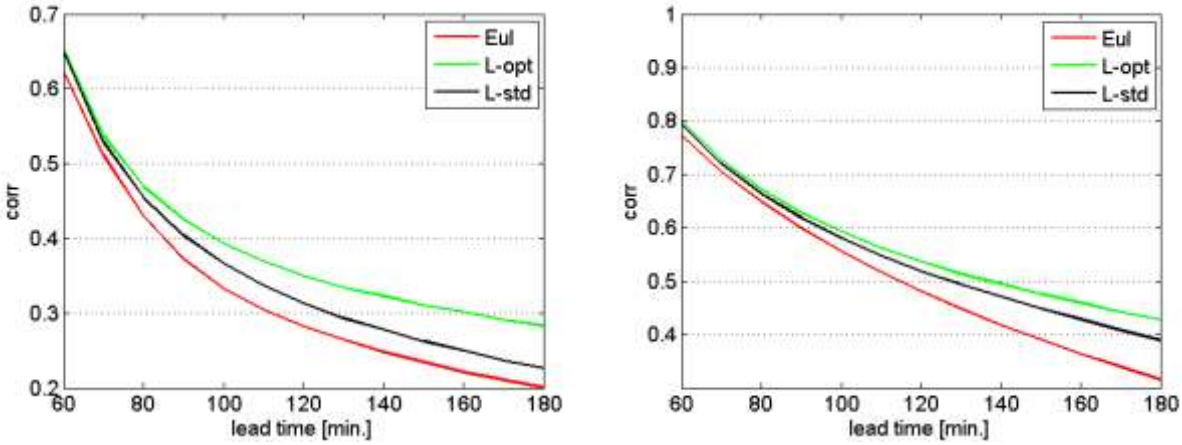

Fig.5. Dependence of the correlation coefficients on the lead time for the forecasted hourly precipitation using optimal trajectories (L-opt), standard trajectories (L-std) and without advection (Eul). In the left figure the correlation coefficient defined in (Germann and Zawadzki, 2002) was applied. In the right figure the Spearman correlation coefficient was used. The lead time indicates the end of hourly precipitation forecasts.

From practical point of view it is more interesting to forecast accumulated precipitation instead of rain rates. Therefore we performed the tests for hourly precipitation. We integrated forecasted rain rates over one hour and compared the forecasts with observed hourly precipitation obtained in the same way but using radar measurements. Obtained results shown in Fig. 5 are similar to those for rain rates but the lead time for which the forecast is useful is apparently longer. If we use again the threshold 1/e for the minimum value of the correlation coefficient then the limit of predictability would be about 100 minutes. This time indicates the end of hourly precipitation forecasts.

4. Summary

We performed similar tests as was done by Germann and Zawadzki (2002) but with a horizontal resolution of 1 km and for heavy convective precipitation in Central Europe. The results concerning applicability of the extrapolation nowcasting technique can be summarized as follows:

- Reasonable limit on the lead time for forecasting immediate rain rates is lower than 60 minutes. Forecasts for longer lead times will not bring reasonable results.
- Forecasting hourly precipitation is reasonable for the lead time up to 100 minutes.
- Evolution of convective storm is probably more important than errors in determining motion fields.

Acknowledgment

This work was supported by the Ministry of Education, Youth and Sports of the Czech Republic under the grant ME09033. The data were kindly provided by the Czech Hydrometeorological Institute.

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