7th International Conference on Hydroinformatics
HIC 2006, Nice, FRANCE

AN EXPERIMENT OF RAINFALL PREDICTION OVER THE ODRA CATCHMENT BY COMBINING WEATHER RADAR AND A NUMERICAL WEATHER MODEL

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As more and more flood forecasting systems utilise quantitative precipitation forecast (QPF) in order to get a longer lead time, particularly for flash flood, attention has fallen upon the quality of QPF in such a model-train context. Weather radar and numerical weather predication (NWP) are two important sources for quantitative precipitation forecast both of which have pros and cons. In this paper, an attempt to combine rainfall prediction from radar and high resolution mesoscale weather model is discussed to explore the advantages from both sides. Data sets of a weather radar located over the Odra catchment in Poland have been collected for several months during which several heavy rainfall events have been selected. A mesoscale weather model (MM5) with high resolution has been set up over the same area to match the radar scans. The rainfall field is firstly corrected using raingauges values and then displacement is applied in accordance with the maximum cross-correlation between radar images and NWP fields; the final product therefore is able to incorporate both high accuracy forecast field locations from radar and growing-decaying mechanisms from NWP models. This study shows the practical values of applying QPF in flood forecasting.

INTRODUCTION

The quantitative precipitation forecast (QPF) progresses with the development of the numerical weather prediction (NWP) as well as the widely adapted weather radar network. The utilisation of QPF within a flood forecasting system [1][3], demonstrates the facts that: (1) being the most important driving force for a hydrological system, precipitation ultimately determines the ability (specifically, the lead time) of any flood forecasting system; and (2) fast developing NWP, especially meso-scale NWP, has the potential to provide even higher resolution forecasts for a small domain that can be comparable to a catchment scale.

Traditionally, QPF can be achieved by extrapolating consecutive radar scans or by solving numerically the equations of a NWP model. It has been found [9][6] that the former technique has shown better skill when using a very short lead time forecasting (also known as nowcasting), since radar can capture very well the initial precipitation.

On the other hand, the weather model has an approximately constant skill, and will excel the advection-based radar nowcasting after the threshold time (6 hour for a continental case, Lin et al. [6]) because the radar nowcasting leaves the development/decay unresolved. For a local area with much smaller domain size, this time threshold can be reduced to less than 3 hours [10].

In terms of hydrological applications, the advection-based radar nowcasting can make valuable contributions, particularly for flash flood forecasting/monitoring; in the case of river flow forecasting of a larger catchment (which is the typical case), the longer lead time rainfall forecast is obviously more relevant. As a result, hybrid systems have appeared trying to balance the contributions from radar nowcasting and a NWP model. The way to combine both outputs can be characterised as: (1) weighted average, such as Nimrod system [5] that assigns more weights to NWP as leading time increases; and (2) nonlinear combination applying neural network technique [4] to find the optimised representation for two heterogeneous information sources while dynamics can be riskily hidden from the user's view.

An attempt of utilising radar information to improve the skill of QPF is discussed in this paper. It is shown that under favourable circumstances, such a method can efficiently take advantage of both (1) the latest precipitation distribution information from weather radar and (2) well spun-up NWP having resolved weather system structure as well as accounted grow/decay process for longer leading time. The algorithm is developed and verified with the dataset from the experiment over the Odra catchment during the FLOODRELIEF project [see 8].

CONFIGURATION OF MESO-SCALE WEATHER MODEL (MM5)

A community NWP-the mesoscale weather model – PSU/NCAR mesoscale model (MM5) [2] is used in this experiment to produce rainfall prediction over the domains. MM5 is configured to have four nested domains in this study, of which the grid size is 27 Km, 9 Km, 3 Km and 1 Km from outermost to innermost domain respectively, as shown in Figure 1. Domain 3 is set such that it nearly matches the radar coverage and the finest domain covers the raingauge network area. Data sets that provide initial conditions (IC) and lateral boundary conditions (LBC) are adapted from the operational analysis (for IC) and operational forecasts (for LBC) of European Centre for Medium Weather Forecast (ECMWF) [7].

For each selected event, a 24-hour forecast initialised either on 00 UTC or 12 UTC is conducted implying that all of the selected events have a life time less than 24 hours with respect to the radar observation domain. MM5 has several configuration options regarding model parameters (e.g. moisture physics), but only the common options from other studies are applied and no tuning has been carried out as the purpose of this paper is only to demonstrate the algorithm. The vertical resolution is also kept with 23 layers without intentionally increasing them for the same reason. Since MM5 cannot use the local projection of the radar, all the forecasts from domain 3 and domain 4 are interpolated into radar domain using the nearest-neighbour method, since no obvious accuracy loss after interpolation has been detected. Hourly total precipitation accumulation of forecast was produced for use in this experiment.

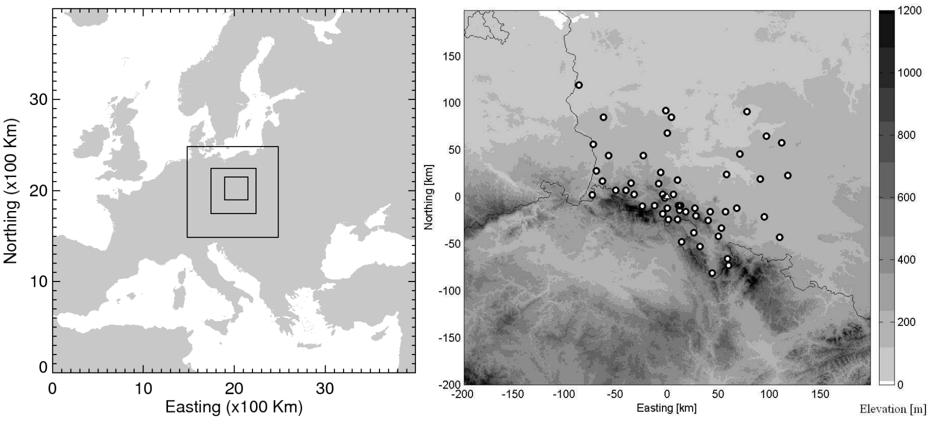

Figure 1. MM5 domains configurations (left, with four domains shown with solid boxes) and the weather radar coverage corresponding to domain 3 of MM5 (right, with triangle and circles representing the radar and rain gauge locations respectively).

RADAR DATA PROCESSING

The radar data set were obtained during a radar experiment in Poland during 2004 [8]. A C-band scanning weather radar provided reflectivity measurements at 4 different elevations (0.5^o, 1.4^o, 2.4^o, 3.4^o) with an spatial resolution of 1 km every 10 minutes. Several events presenting widespread precipitation were selected. The ground-cluttered pixels were replaced with pixels from the next clutter-free higher elevation. Pixels prone to occultation of the radar beam were also replaced with pixels from the next elevation. The calibration constant was adjusted according to the raingauge comparisons. The radar data processing was carried out based on the analysis presented by Rico-Ramirez, et al. [8]. Then the resulting 10-min reflectivity scan is transformed to an estimate of precipitation using the Marshall and Palmer formula, that is Z=200$R^{1.6}$, which is valid during stratiform precipitation. The 10-min scans are accumulated during 1-hour intervals. The resulting hourly accumulated radar rainfall was employed to carry out this analysis.

RAINFALL PREDICTION

A simple method for extrapolation of hourly accumulated radar scans was implemented. The method performs a cross-correlation between consecutive radar scans (e.g. at time *t* and *t-1*) and the point of maximal cross-correlation indicates the displacement of the precipitation event within the time window. This displacement is then applied to the radar scan at time *t* to forecast *t+1*, *t+2*, etc. This method is effective when predicting one or two steps ahead, but the error often increases considerably with longer lead times. On the other hand, the error in the rainfall prediction using mesoscale models does not show abrupt increase with lead time, because the microphysics of precipitation is taken into account. However, the forecasted precipitation cells are very often displaced when compared to the precipitation observed by the radar. Taking advantage of this, it may be possible to obtain an estimate of the displacement between the mesoscale rainfall prediction and the radar-estimated rainfall at time *t*. This displacement is then applied to the mesoscale rainfall prediction at times *t+2*, *t+3*, etc., where nowcasting methods start to struggle in producing good forecasts. As new radar data become available, new displacements are estimated and applied to the rainfall forecasted by the mesoscale model.

RESULTS

Figures 2 and 3 show the actual radar rainfall and the forecasted MM5 rainfall respectively. In this case, the MM5 model was initialized on 20040912 00UTC to produce 24 hr forecasts. As shown, the MM5 captured the frontal precipitation system observed by the radar. However, there is a clear displacement among the actual and forecasted rainfall. The cross-correlation analysis between the radar and MM5 at 0800 shows that there is a displacement between the fronts of approximately 76 km east and 16 km south. The result of applying this displacement to the following MM5 forecasts is shown in Figure 4. These corrected forecasts are more correlated with the actual radar rainfall occurring during every particular hour. Figure 5 also shows the radar nowcastings. Although, the nowcastings follow the frontal precipitation system, they lack of the growth and decay of precipitation captured by the MM5. For instance, the radar nowcasting at *t*+2 and *t*+3 miss out the precipitation formation from the West.

Another example of a clear displacement is shown in Figures 6 and 7. The MM5 model was initialized on 20040812 1200UTC to produce 24 hr forecasts. In this case the displacement was approximately 70 km east and -115 km south. As seen from figure 7, the shifted MM5 hourly forecast fairly reproduces the features of the rainband observed by the weather radar. It is worth noting that in this special case multiple radar scans with various levels are used to obtain a composite of rainfall image of the region alongside the mountainous area to the south west of the Poland-Czech boundary, and the quality of radar image is affected to some extent by the occultation of the radar beam. Thus, there would be a chance to get a better match if the rainfall field could be revealed more clearly without mountain barrier.

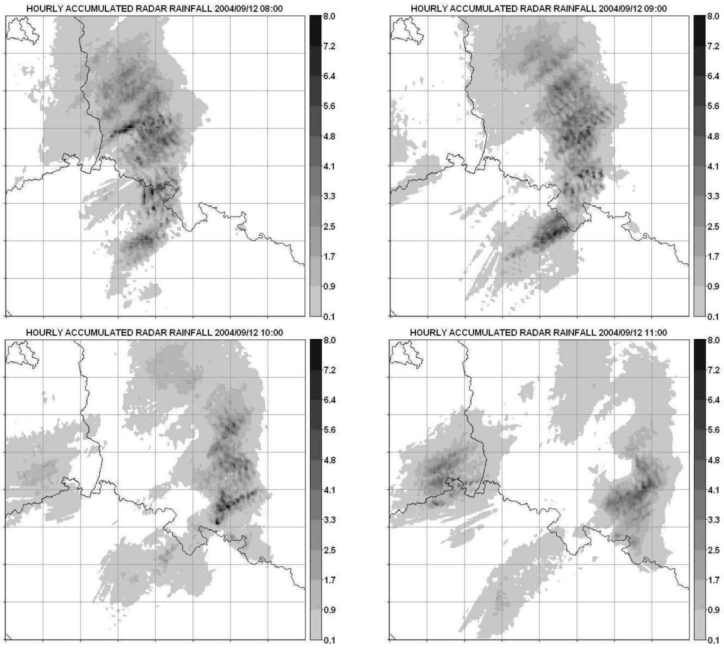

Figure 2. Hourly accumulated radar rainfall (event: 2004/09/12).

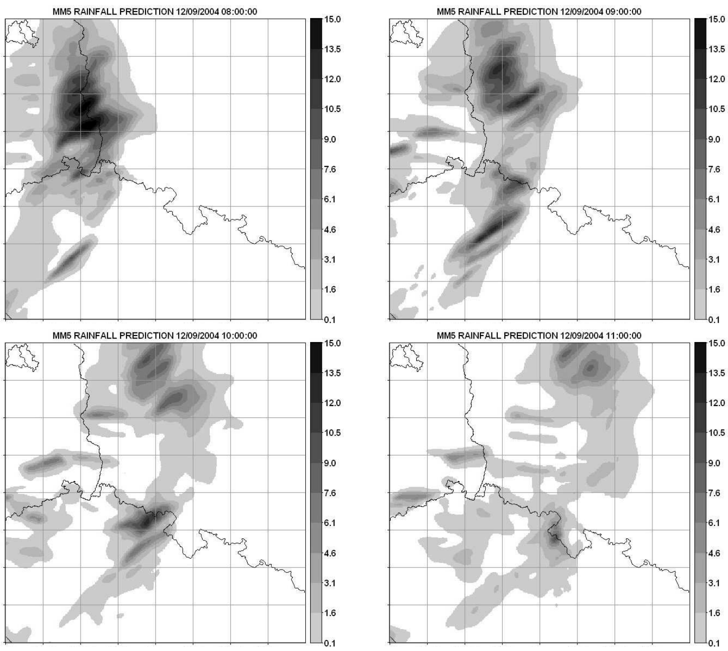

Figure 3. Hourly accumulated MM5 rainfall (event: 2004/09/12).

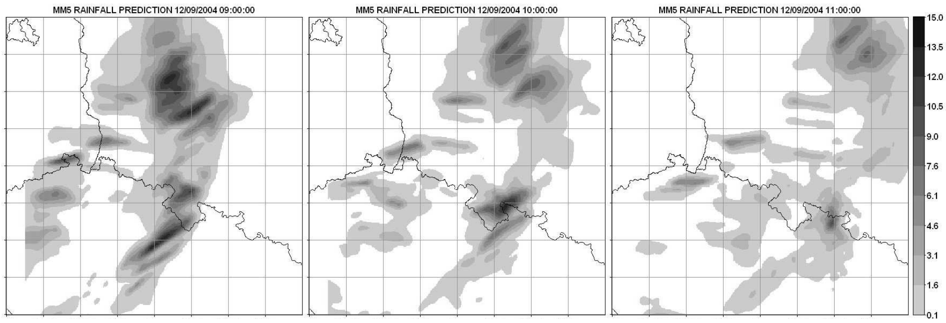

Figure 4. MM5 corrected using cross-correlation with radar at *t*=8 hr (event: 2004/09/12).

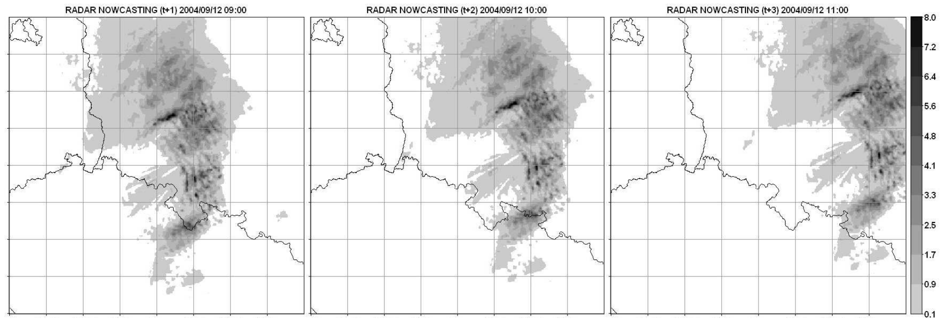

Figure 5. Radar nowcasting *t*+1, *t*+2 and *t*+3 using *t*=8hr and *t*-1=7hr (event: 2004/09/12).

There are some other cases (which are not shown here) where the MM5 performs very well so that the forecasts nearly match the real rainband or in other words, the displacements obtained from the method are too small to make obvious difference. Apparently, for these cases, it is not necessary to apply the correction offered by this method since they can be seen as the best forecasts, which can be used directly.

CONCLUSIONS

For the selected rainfall events during the period from June to September 2004, the results show that an improved QPF with the leading time about 3 hours can be achieved with respect to the radar tracking method and numerical weather model output. The algorithm proposed, clearly works very well in the circumstances where a single strong frontal precipitation system occurs in the vicinity of the radar coverage. As the displacement correction is still based on the tracking-like method, the similar difficulties are expected to encounter when the precipitation system is a multi-cell one rather than a clearly defined frontal system, or the system is located near the image boundary so that the best-process match would fail. Nonetheless, this new way sheds light on the utilisation of the latest radar information in order to improve the usefulness of NWP-based QPF in the context of application in real-time flood forecasting, and furthermore, this method does provide the comparable skill of QPF with respect to the radar nowcasting but for the longer leading time when the quality of the echo-tracking technique starts to get worse than the acceptable level and no NWP has been spun up properly.

It should be noted that the method proposed here only reduces partly the uncertainty of rainfall forecast in terms of location and pattern matching. Variability across rainfall fields, along with highly intermittent distribution over catchment scale are important factors which need to be addressed in future research.

Acknowledgments

The authors would like to thank the EU FP5 FLOODRELIEF project (EVKI-CT-2002-00117), the EPSRC Flood Risk Management Research Consortium (GR/S76304/01) and CONACYT-Mexico (scholarship 138598) for partial support in the development of this research work. The authors would like to thank ECMWF for access to their datasets and computing facilities. MM5 modelling system software was kindly made available and supported by the Mesoscale Prediction Group in the Mesoscale and Micro-scale Meteorology Division, NCAR, USA.

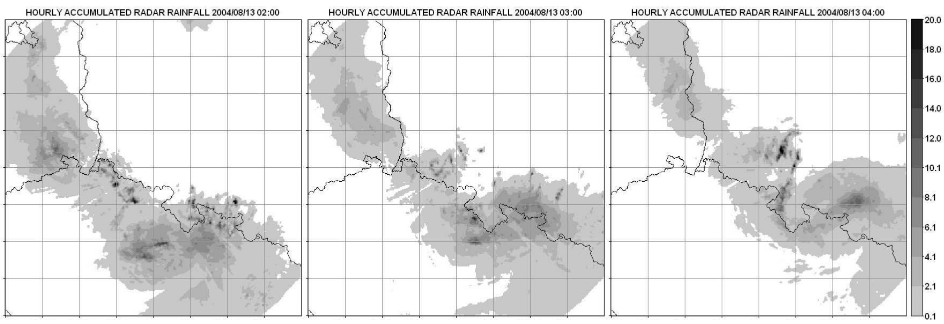

Figure 6. Hourly accumulated radar rainfall (event: 2004/08/12).

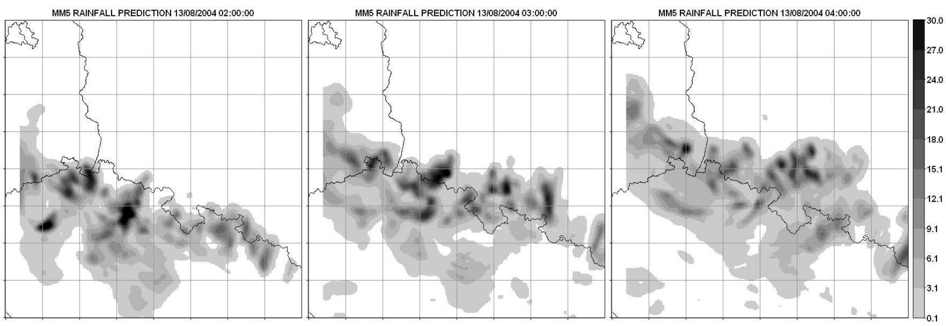

Figure 7. MM5 corrected using cross-correlation with radar at *t*=1 hr (event: 2004/08/12).

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