QUANTITATIVE PRECIPITATION FORECASTING FOR A SMALL URBAN AREA: USE OF RADAR NOWCASTING

by

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ABSTRACT

Quantitative Precipitation Forecasting (QPF) over urban areas is a challenging problem. Many attempts have been made to use weather radar to produce rainfall forecasts with lead times of a few hours ahead. In the UK, the Met Office has developed a stochastic probabilistic precipitation forecasting scheme (STEPS), which merges an extrapolation radar rainfall forecast with a high-resolution Numerical Weather Prediction (NWP) rainfall forecast. This paper presents the analysis of three precipitation events over a small urban area in terms not only of QPF, but also in terms of flow prediction at the urban scale. STEPS was used to produce precipitation forecasts with spatial and temporal scales of 1km and 5min respectively and with lead times of up to 3 hr.

Keywords: Radar nowcasting, Numerical Weather Prediction, Sewer flow prediction

1 INTRODUCTION

Over the past 25 years, urban hydrologists have discovered radar rainfall data. As described by Einfalt et al. (2004), radar data seemed very suitable for the high spatial and temporal rainfall data requirements for urban hydrology. Rainfall forecast possibilities seemed a way of increasing the time available for real time sewer management. Due to concerns regarding the accuracy and the availability of data, actual use of radar data for urban drainage management, however, has been far from universal (Einfalt et al, 2004). Kramer et al. (2006) describe the use of a cell-tracker nowcasting approach to forecast rainfall and run-off in a sub-catchment of the city of Vienna. Three events were studied and the forecasts gave sensible results for for up to 30-45 mins lead time for convective events and up to 75 mins for advective events. Archleither et al. (2009) used a tracking approach for radar rainfall forecasting and used this to simulate the rate of combined sewer overflow spill in the city of Linz. Five events were studied and it was concluded that the level of uncertainties in the forecast was only tolerable for a lead time of up to 90 mins lead time.

This study makes use of composite data from the UK Met Office network of C-band radars, which have been pre-processed by the 'Nimrod' system. The Nimrod system addresses the following specific sources of error: removal of spurious echoes, corrections to account for the variations in the vertical profile of reflectivity and radar sensitivity errors (Harrison et al. 2000). The paper is based on a case study in a single urban catchment with a population of approximately 13,000 and a catchment area of approximately 14 km^2, the majority of the sewer system is combined. The catchment is the subject of a long term flow survey, carried out as part of an ongoing study into the data need for real-time sewer system management, carried out by the University of Sheffield and Yorkshire Water Ltd. The case study catchment benefits from 1 km resolution rainfall radar coverage. This paper describes a preliminary assessment of the use of QPF combining radar and NWP results over a relatively small urban area (see also Rico-Ramirez et al. 2009). For a limited number of rainfall events, rainfall forecasts will be generated using the state-of-the-art rainfall forecasting scheme known as STEPS. The preliminary assessment described in the paper is part of an ongoing study, funded by the UK Flood Risk Management Research Consortium, phase 2.

2 STEPS MODEL

QPF can be achieved by extrapolating consecutive radar precipitation scans (also known as nowcasting), or by solving numerically the equations of a NWP model. It has been found that the former technique has shown better skill when using short lead times (Lin et al. 2005), since radar can capture the initial precipitation. On the other hand, NWP models have an approximately constant skill, and will excel the advection-based radar nowcasting after the threshold time (6h for a continental case, Lin et al., 2005) because the radar nowcasting leaves the development/decay unresolved. 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, 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 such as the STEPS scheme.

STEPS is a stochastic probabilistic precipitation forecasting scheme, merging an extrapolation radar nowcast with a downscaled high-resolution NWP forecast (Bowler *et al.*, 2006). By blending the radar nowcasts with NWP model forecasts a more skilful forecast can be achieved (Golding 1998). Uncertainties affecting an extrapolation nowcast can be partitioned in those related to the determination of the advection velocities and those describing the evolution of the precipitation field (Bowler *et al.*, 2006). Uncertainties in the evolution of the precipitation pattern are modelled using the Spectral Prognosis (S-PROG) model (Seed 2003). The surface rain rate is decomposed in a cascade of features on different scales. The generated cascade is additive with respect to the radar reflectivity field and multiplicative when expressed in terms of rain rate (i.e. this is because the radar reflectivity is proportional to the logarithm of the rain rate). The decomposition of the radar based rain analysis into the multiplicative cascade levels permits the isolation of small features that become dominated by noise, while the large-scale features are maintained. The Fast Fourier Transform (FFT) is used to translate the reflectivity field into the spectral domain. Each cascade level is calculated by using a band-pass filter based on a Gaussian window, that passes the appropriate frequencies and then returns each component into the spatial domain by applying an inverse transform.

Uncertainty associated with growth and decay affecting the precipitation field are modelled using a second-order autoregressive (AR-2) process (Box and Jenkins 1976), obtained by omitting the noise term that is modelled in an independent cascade for each time step. The extrapolation and the noise cascade are advected using the current estimate of the velocity fields. The values of the AR-2 model parameters are estimated using a temporal sequence of three rain analysis covering a period of 15-min when using 5-min resolution data, by deriving an advection velocity field and computing the correlation coefficients.

The stochastic realization of the noise cascade accounts for the uncertainty in the evolution of the precipitation field, while the stochastic realization of the forecast velocities accounts for the uncertainty in the advection velocities. The advection velocity is determined through the optical flow method developed for the Gandolf nowcasting-system (Bowler *et al.* 2004). The optical flow theory makes use of the optic flow constraint equation, based on the assumption that features in an image sequence only change shape and to not change size or intensity. The equation is used to determine the average motion within an area of the radar analyses. In this scheme a smoothness constraint on the velocities determined for each area is used and linear interpolation is applied to ensure that the velocity varies smoothly across the whole domain.

The extrapolation component becomes less skilful especially at the smallest scales as the forecast proceeds. A deterministic NWP forecast is merged with the probabilistic radar nowcast, in order to achieve a forecast range of at least 6 hours. The NWP forecast can be decomposed into a cascade in the same way the extrapolation nowcast is decomposed. The cascade parameters calculated from the NWP model forecasts are multiplied by scale-dependent factors to account for the lack of variability of the forecasted features at scales below those adequately resolved by the model. Different ensemble members can be generated through different realizations of the noise cascade and allow the scheme to be used in applications where the probability density function of areal and temporal averages of precipitation needs to be forecasted.

3 QPF RESULTS

The STEPS model was provided by the UK Met Office. STEPS requires radar and NWP data with the same spatial and temporal resolutions. Radar data were obtained from the British Atmospheric Data Centre with a spatial and temporal resolutions of 1km and 5min respectively. The NWP results were simulated using the MM5 model. Rico-Ramirez et al. 2009 describes the rainfall events to be analysed and the MM5 model setup. Only the deterministic NWP forecasts were used for the purpose of this study. The MM5 model had four nested domains with increasing resolutions of 1, 3, 9 and 27km. The MM5 domains were combined into a single domain at 1km resolution every 5min to match the radar domain. The radar/NWP domain covered 600x600 pixels at 1km resolution. Figure 1 shows a particular radar scan and the NWP forecast. This figure shows that the spatial resolution of the NWP domain is 1km over the urban area and decreases away from it.

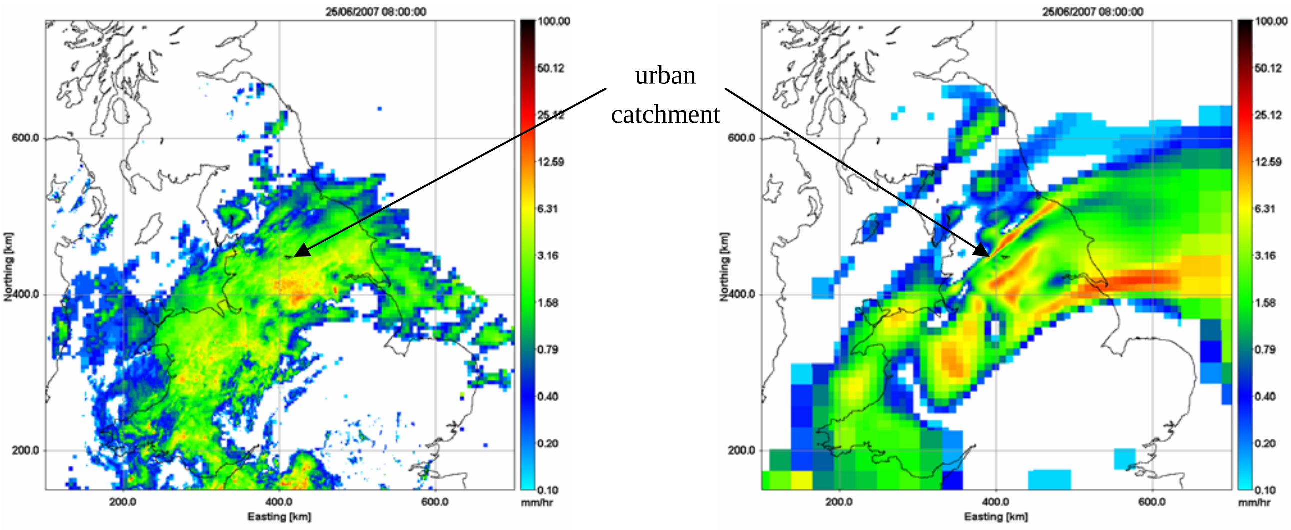

Figure 1 – Radar scan on 20070625 0800 and NWP simulation with 8hr lead time.

Three events representative of different meteorological conditions were simulated. The events were 20070625, 20080701 and 20080707. The STEPS model was configured to run hourly (assuming new radar data are available) and producing 3hr forecasts in each run, the resolution of these forecasts was 2x2 km with a 15-minute time step. In this way, for a single 24hr event, STEPS was able to produce 21 sets of 3hr precipitation forecasts. However, due to some missing radar data, the total number of STEPS simulations were 15, 20 and 21 for the events 20070625, 20080701 and 20080707 respectively. The results are summarised in Figure 2 and represent the whole radar domain shown in Figure 1. The forecasts results were averaged over 5x5, 10x10, 20x20 and 50x50 pixels to represent the skill of the forecasts over large spatial scales. As shown, the skill of the forecasts decrease with lead time, and the forecasts become less skilful at the smallest spatial scales. The results also show that the skill of the forecasts is better in stratiform (20070625) than in convective (20080707) precipitation.

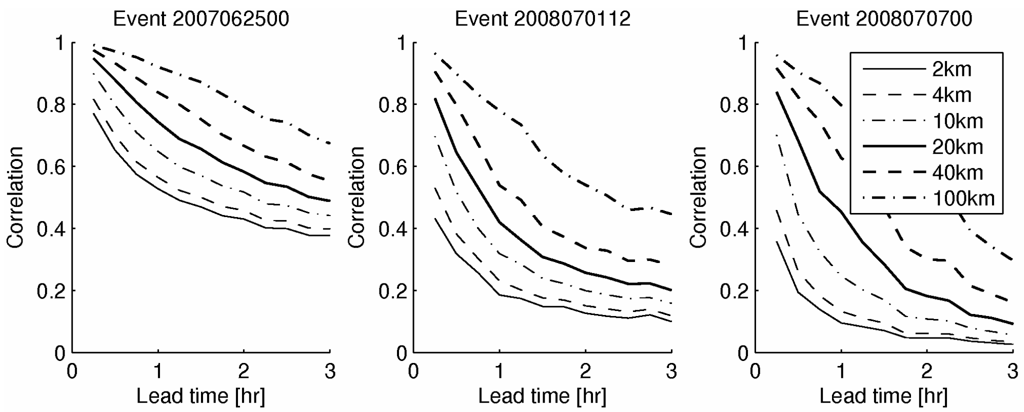

Figure 2 – Skill in the rain rate forecasts against lead time for a precipitation threshold of 0.125 mm/h.

4 URBAN FLOOD MODEL RESULTS

The rainfall forecasts were used to predict sewer flows in the Ilkley sewer system, using the hydrodynamic flow modelling package Infoworks CS v8.0 (Wallingford Software, 2007). Sewer flows have been simulated using rain gauge data, original radar data, radar data averaged to 2x2km & 15min and the 2x2-km 15-min rain rate forecasts. The state of the flow simulations made using radar data was saved every hour, so that every flow simulation made using a rainfall forecast could use this saved state at the forecast start time as initial state. Figure 3 shows an example of flow simulation results compared with measured flow.

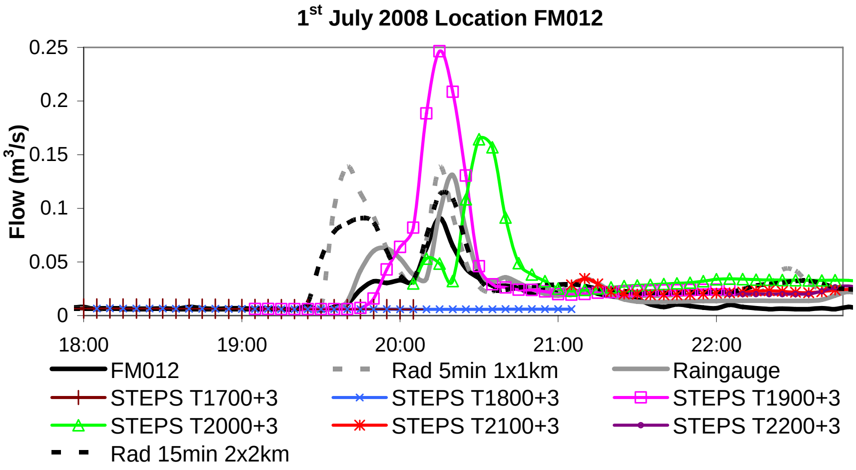

Figure 3 – Sewer flow simulations compared with measured flow, at flow monitor location 012, for the 1st of July 2008.

The flow forecast is not just dependent on the rain rate forecast, but also on the quality of the sewer flow model and the quality of the radar data. From an operational perspective, it would be necessary to find out how often a forecast would need to be supplied and how accurate the sewer flow can be simulated. Table 1 compares the correlation between measured flow and simulated flow using rain gauge data, the original 1x1km 5-min radar data, radar data averaged over 2x2 km and 15min and forecasted rain rate respectively, for all events at 4 of the flow monitor locations. Three flow forecasting simulations were made, with new rainfall forecasts imported every 1, 2 or 3 hours respectively. Generally, Table 1 shows correlation between forecasted flow and measured flow reducing with increasing lead time.

Table 1 - Correlation between measured flow at 4 Flow Monitor locations and simulated flow using radar data, rain gauge data, radar data averaged to 2x2km and 15min and 1hr, 2hr and 3hr lead time rainfall forecasts as model input.

	Event 20070625 03:05-05:00& 13:05-21:00			Event 20080701 19:05-22:00				Event 20080707 10:05–19:00			
FM location	12	15	17	1	12	15	17	1	12	15	17
Rad 5-min 1x1km	0.79	0.67	0.16	0.79	0.58	0.67	0.80	0.81	0.73	0.77	0.69
RG 5-min	0.83	0.70	0.18	0.89	0.86	0.87	0.94	0.75	0.67	0.77	0.81
Rad 15min 2x2km	0.86	0.66	0.17	0.82	0.68	0.75	0.75	0.86	0.78	0.85	0.84
LT T to T+1	0.81	0.68	-0.03	0.67	0.43	0.70	0.84	0.80	0.29	0.56	0.71
LT T to T+2	0.83	0.70	-0.06	0.57	0.93	0.67	0.80	0.66	0.15	0.39	0.51
LT T to T+3	0.69	0.56	-0.12	0.57	0.35	0.67	0.80	0.03	0.16	0.30	0.33

For the stratiform event on 20070625, the flow forecast is reasonable for a lead time of 3 hours, unfortunately FM1 was not working and the sewer model did not simulate the receding peak properly at FM17.In some cases, however, correlation for the flow predictions at longer lead times can be misleadingly high. For the example at FM12, 1st July 2008 (Figure 3), the 2hr lead time flow simulations show a correlation coefficient of 0.93, however, the correlation coefficient for the simulation using the 15-min 2x2-km radar data is only 0.68. In this case, the model with radar data as input simulated an ‘extra’ flow peak before the measured flow peak, whereas the 2hr-lead time flow forecast used rainfall forecasts from 17:00, 19:00 and 21:00 respectively and did not simulate this ‘extra’ peak, but overestimating the actual flow peak, thus seemingly ‘matching’ the measured flow better. Figure 2 shows rainfall forecasting skill reducing with smaller spatial scales as well as with the non-stratiform events. Figure 2, however, was created using all 2x2 km pixels in the 600x600 domain over a precipitation threshold of 0.125 mm/h, whereas the Ilkley sewer system is approximately 7 km^2, and is covered by 41 different 1x1 km radar pixels, hence local variations in forecasted rain can have a larger impact, as shown in Table 1.

5 CONCLUDING COMMENTS

The results of the STEPS model showed that the skill of the forecasts decrease with lead time and smaller spatial scales and that the skill of the forecasts is better in stratiform than convective precipitation. Both the skill of the rainfall forecast and the skill of the radar rainfall estimation as well as the skill of the sewer flow model will need to be taken into account in order to investigate the skill of the flow forecast. Due to local variations, the skill of the rainfall forecast for the whole radar/NWP domain is not a direct indication for the skill of the flow forecasts. For 20080707 the flow could not be forecasted satisfactory, whereas for 20080701 the start time of the flow peak is forecasted correctly at a lead time of 45 minutes, but the height of the flow peak is considerably overestimated. For 20070625 the flow could reasonably be forecasted with a lead time of 3hrs. Thus for the stratiform events STEPS enabled the acceptable forecasting of flow with a lead time of up to 3 hours, longer than compared with studies using nowcasting models found in literature. However, for convective events the results are not better. As concluded in Ramirez et al. (2009), high resolution NWP enabled longer lead times, but it is not accurate enough on the small urban spatial scale. It also has to be appreciated that a limited number of events have been studied.

6 ACKNOWLEDGMENTS

The authors would like to thank the UK Met Office for providing the radar data and the STEPS model, and Yorkshire Water Ltd. for providing the flow data and the sewer model. We like to thank to Dr. Alan Seed and Dr. Clive Pierce for providing valuable advice to run the STEPS model.

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