On The Added Value Of Radar Data In Hydrological Modelling And Flood Forecasting

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11th International Conference on Hydroinformatics
HIC 2014, New York City, USA

ON THE ADDED VALUE OF RADAR DATA IN HYDROLOGICAL MODELLING AND FLOOD FORECASTING

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Good quality rainfall data are essential in hydrological modelling and flood forecasting. Classically, rain gauge data are being used as rainfall input for hydrological modelling, but they only provide point information. Because rainfall can be highly variable in space, radar images can provide important additional spatial information, but the quantitative rainfall data quality of these images is often limited. Merging techniques between rain gauge and radar data can provide a solution to this problem. In this research, a simple kriging merging technique, making use of two C-band radars, is tested for the Demer catchment in Belgium. Three periods with different types of rainfall were selected: two winter periods with stratiform rainfall and one summer period with convective rainfall. First, it was tested whether the merging technique is able to correct the quantitative radar rainfall information, by comparing the rainfall volumes at rain gauge locations, which were not used during the merging with the observed values. It was found that the merging technique performed well under stratiform conditions, but this was not always the case for the convective conditions. Secondly, the added value of the radar information was tested, by comparing hydrological and hydraulic model outputs, generated by rain gauge and/or radar data, to flow and water level observations. It is found that the added value of the radar data is limited for the winter periods, but that for the summer periods a significant improvement is obtained.

INTRODUCTION

Classically a network of rain gauges is used to quantify the catchment rainfall in hydrological modelling and flood forecasting. Because rain gauges directly measure the amount of rainfall, they are very accurate at a point location, but they lack spatial information. To acquire spatial rainfall information, weather radar are now commonly used. These radars measure the reflectivity of rainfall at a certain altitude, which can be translated to rainfall amounts at ground level. Several sources of uncertainty can preclude accurate rainfall estimations, e.g. electronic miscalibration, contamination by non-meteorological echoes or range effects [1], [2], [3], [4], [5]. To reduce these errors radar rain gauge merging techniques can be applied.

Different radar rain gauge merging techniques can be found in literature. Goudenhoofdt and Delobbe [1] have tested the following 7 techniques: Mean field bias correction, Static local bias correction and range dependent adjustment, Brandes spatial adjustment, Ordinary kriging, Kriging with radar-based error correction and Kriging with external drift. They came to the conclusion that the techniques which make use of kriging interpolation gave the best results. Therefore, in this study the Kriging with radar-based error correction is applied.

The goal of this study was to investigate whether the use of radar data within an operational flood forecasting context has any added value in comparison with the classical approach of solely applying rain gauge data. As case study two C-band radars were considered in combination with an operational river model of the Demer river in Belgium. The case study is introduced in the following section. In the materials and methods section the applied rain gauge radar merging technique is explained in combination with the assessment methodology used. The results and conclusions can be found in the two final sections.

CASE STUDY

Radar at Wideumont

The Wideumont radar is a single-polarization C-band Doppler radar. The antenna, the transmitter and the receiver are installed on top of a steel tower 46-m high. The radar performs 3 different scans. A watchdog scan is repeated every 5 minutes and includes 5 elevation angles with reflectivity measurements up to 240 km. A second volume scan is repeated every 15 minutes and collects reflectivity measurements up to 240 km. A Doppler scan is performed every 15 minutes. It includes 8 elevations with reflectivity, radial velocity and spectral width measurements up to 120 km [6]. The location of the radar is shown in Figure 1. In this study hourly cumulated rainfall data from the Wideumont radar for the periods November 2010, January 2011 and August 2010 (16^{th}-27^{th}) were considered.

Radar at Zaventem

The Zaventem radar is a single-polarization C-band Doppler radar with a klystron transmitter. The scanning is repeated every 5 minutes. It includes a plan position indicator at 0.5 deg. elevation with reflectivity measurements up to 250 km and a volume scan including 10 elevation angles with reflectivity, radial velocity and spectral width measurements up to 125 km [6]. The location of the radar is shown in Figure 1. In this study hourly cumulated rainfall data were considered for the periods November 2010 and January 2011. Rainfall data for August 2011 were not available for this radar site.

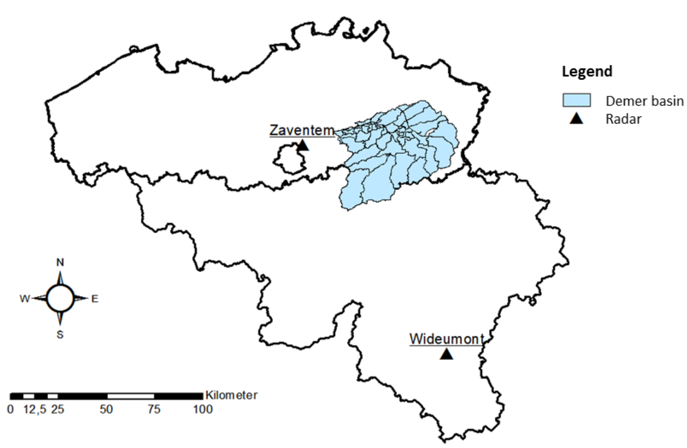

Figure 1: Location of the weather radars and the Demer basin

Demer basin

The Demer river is located in the eastern part of the Flanders region in Belgium. The basin has an area of 2276km² and the total length of the river is 85 km. The Demer basin is characterized by a densely populated area and has often been struck by floods in the last decades (January 1995, September, 1998, December 2002 and January 2011). The average flow is about 15m³/s, it but can rise up to more than 70m³/s. The cities along the Demer are protected by two retention reservoirs with a total storage capacity of 8 million m³ [7].
A network of 14 rain gauges from the Flemish Environmental Agency (VMM) and the Hydrological Information Centre (HIC) in and around the Demer basin are used to correct and validate the radar images. The rain gauges record the rainfall depth on an hourly basis. The location of the rain gauges can be found in Figure 2 .

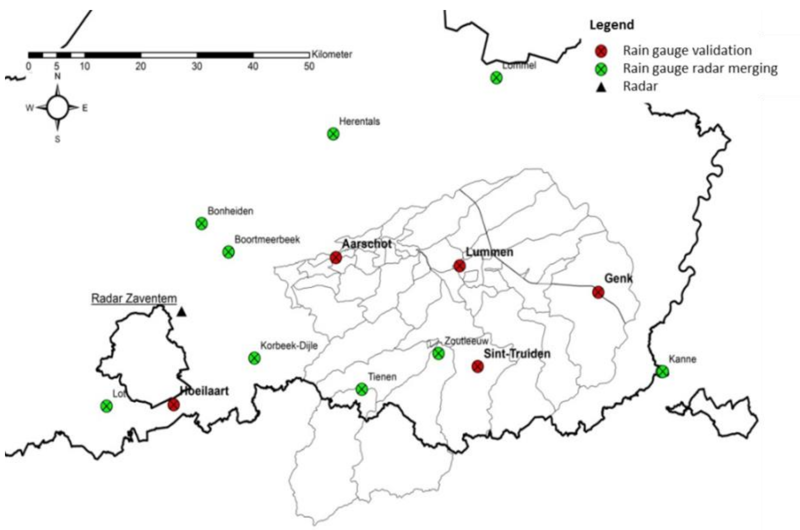

Figure 2: Rain gauge network in and around the Demer basin. Green rain gauges are used for merging the radar data, red rain gauges are used for validation.

Flood forecasting model

The hydrological and hydrodynamic models used in this study are part of the operational flood forecasting system of Flanders Hydraulics Research. The flood forecasting system produces real time forecasts of water levels and discharges several times a day, up to a lead time of 48h, along the navigable watercourses in Flanders. The rainfall-runoff component of the considered flood forecasting system is based on NAM (*Nedbør-Afstrømnings Model),* a lumped conceptual rainfall-runoff model [8], [9]. The hydrodynamic model is implemented in the Mike11 software of DHI [10]. In Van Steenbergen et al. [11] a more detailed description of the flood forecasting system can be found.

MATERIALS AND METHODS

Radar rain gauge merging technique

To merge the rain gauge data with the radar data, kriging with radar-based error correction or also called conditional merging, is applied. The radar data is used to condition the spatially sparse rain gauge data by interpolating between the rain gauges and derive an estimate of the rainfall field which contains the spatial structure of the radar, but is constrained by the rain gauge data [12]. More general information on kriging interpolation can be found in Goovaerts [13].

The technique starts with deriving a semivariogram, which characterizes the spatial correlation of the differences between the rain gauge rainfall and the radar rainfall at the gauge locations. In this study a spherical semivariogram is used to describe the relation between the semivariance and the lag (distance between data points). Based on this semivariogram, the kriging weights can be determined, which leads to an interpolated error field. This error field is then combined by the radar field, leading to a merged rainfall field. An example of a semivariogram derived for the periods November 2010 and January 2011 can be found in Figure 3. A spatial correlation of the error between the radar and the rain gauge data up to 40 km can be noticed.

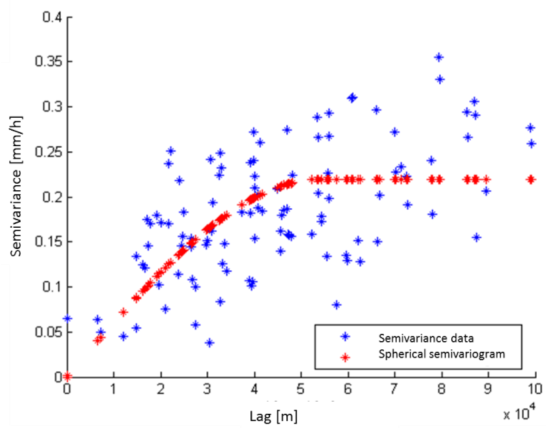

Figure 3: Spherical semivariogram of the difference between rain gauge and radar data derived for the period November 2010 and January 2011 based on the Wideumont radar data.

Assessment of the added value of radar data

The assessment of the added value of the radar data is performed at three stages. At the first stage, the rainfall data obtained by the radar before and after merging is compared with the observed rain gauge data. To allow this comparison, 5 rain gauges, which were not used for merging the radar with the rain gauge data, were used as validation locations. The location of these rain gauges can be seen on Figure 2.

At a second stage, the radar based rainfall serves as input for 9 hydrological models representing 9 gauged subcatchments in the Demer basin. The rainfall-runoff produced by these models is compared with the observed discharge and the runoff generated by only the rain gauge rainfall input.

At the third and final stage, the rainfall-runoff generated by the radar data is used as input for the hydrodynamic Demer river model. Generated water levels and discharge along the Demer river are compared with the observations at gauging stations. Also here a comparison is made with simulated water levels and discharges, which are merely based on rain gauge data.

In all three the stages the assessment is based on the calculation of the root mean square error (RMSE) between model results and observations. Also a comparison is made of the results when the radar data at Wideumont are considered only versus the radar data at Zaventem. The results can be found in the next section.

RESULTS

Rainfall

Figure 4 shows the RMSE between the observed rain gauge data and the radar data. The filled bars show the RMSE of the original radar image, the hatched bars show the RMSE for the merged radar data. In general it can be concluded that by applying the merging technique the RMSE decreases. This is certainly the case for the winter periods. For the summer period (August 2011) an improvement in terms of RMSE is not always visible. The RMSE is comparable between the November 2010 and the January 2011 periods but, for the August period the RMSE is a lot higher. This can be explained by the difference in rainfall type. Summer rainfall extremes are characterized by convective rain storms with short duration rainfall and large spatial differences, whereas winter period are typically characterized by stratiform and spatially more unifom rainfall with rainfall over a longer period. The results in figure 4 do not show a strong difference between the two radar locations.

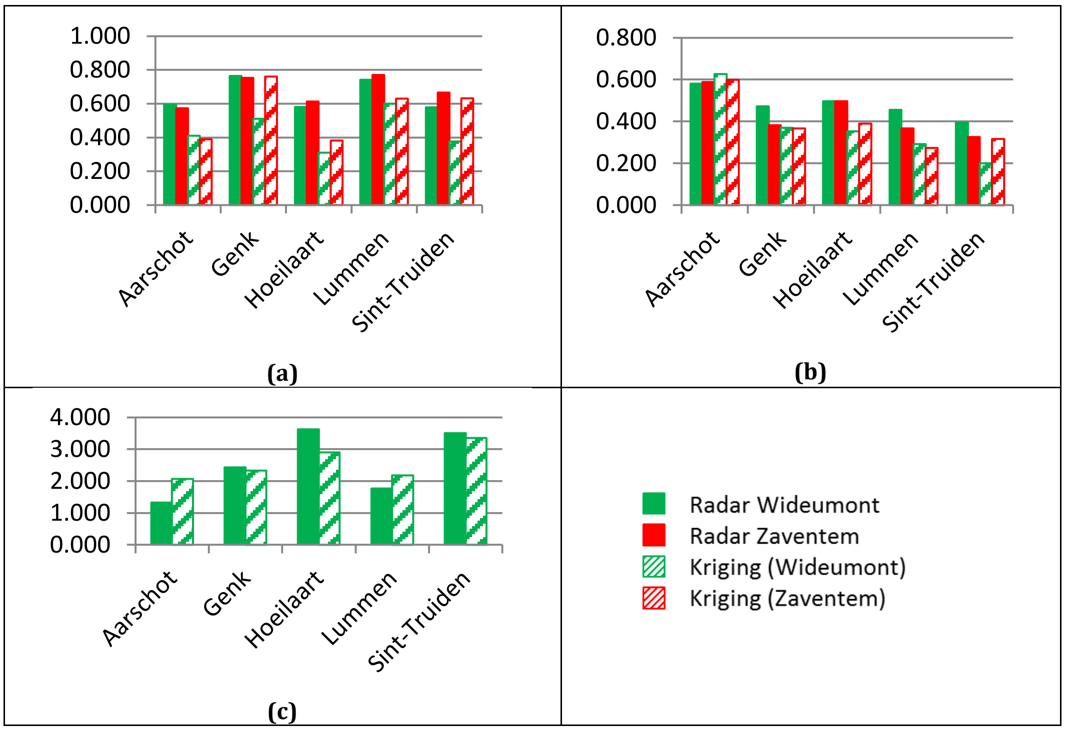

Figure 4: Root mean square error [mm/h] between observed and radar based rainfall for the Wideumont and Zaventem radar, with and without the kriging rain gauge radar merging technique for the periods (a) November 2010, (b) January 2011, (c) August 2011.

Hydrology

The results of the hydrological simulations, making use of the different types of rainfall inputs for November 2010 can be found in Figure 5. No clear difference in terms of RMSE is visible between the radar versus rain gauge based model results. The corresponding model goodness-of -fit is repeated in Table 1. The lowest RMSE value for each subcatchment and period is indicated in grey. For January 2011, the RMSE values are in general lowest when radar based rainfall input are is used. The choice of the radar location does, however, not have a consistent effect on the results. Also for August 2011, the runoff generated by the radar based rainfall provides in general smallest errors.

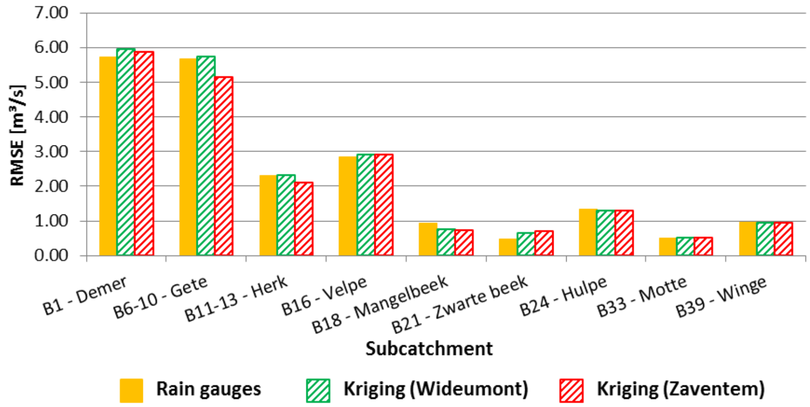

Figure 5: Root mean square error [m³/s] between observed and simulated runoff for different subcatchments in the Demer basin making use of rain gauges or radar data (Wideumont & Zaventem) for November 2010.

Table 1: Root mean square error [m³/s] between observed and simulated runoff for different subcatchments in the Demer basin making use of rain gauges or radar data (Wideumont & Zaventem) for November 2010, January 2011 and August 2011.

	November 2010			**January 2011**			**August 2011**	
RMSE [m³/s]	**Rain gauges**	**Kriging (Wideumont)**	**Kriging (Zaventem)**	**Rain gauges**	**Kriging (Wideumont)**	**Kriging (Zaventem)**	**Rain gauges**	**Kriging (Wideumont)**
Demer	5,72	5,94	5,88	2,46	2,38	2,16	7,34	4,58
Gete	5,66	5,72	5,15	3,40	3,36	3,76	4,23	3,01
Herk	2,30	2,31	2,11	2,52	2,36	2,29	2,55	2,02
Velpe	2,85	2, 92	2,90	1,06	1,09	0,92	0,88	1,52
Mangelbeek	0,94	0,76	0,74	0,71	0,54	0,54	3,28	2,00
Zwarte Beek	0,47	0,66	0,70	0,71	1,03	1,07	1,88	1,26
Hulpe	1,33	1,31	1,29	1,40	1,36	1,37	2,62	2,07
Motte	0,51	0,51	0,51	0,62	0,64	0,58	0,59	0,45
Winge	0,95	0,96	0,94	1,00	1,00	1,00	1,48	1,17

Hydrodynamics

In a final stage the rainfall-runoff results are used as input for the hydrodynamic model. Figure 5 shows the results for the water level at the Aarschot river flow gauging station for August 2011. The rain gauges based input leads to a strong underestimation of the water levels,

whereas the radar based simulation results are much closer to the observations, both qualitatively and quantitatively.
This result is further confirmed by Table 2 for the periods August 2011 and January 2011. The simulations based on radar data give the lowest RMSE for all considered locations. For November 2010 the difference between radar and rain gauge based simulations is a lot smaller. In addition, the simulations based on the radar data of Wideumont prove to be better in comparison with those of Zaventem for November 2010 and January 2011.

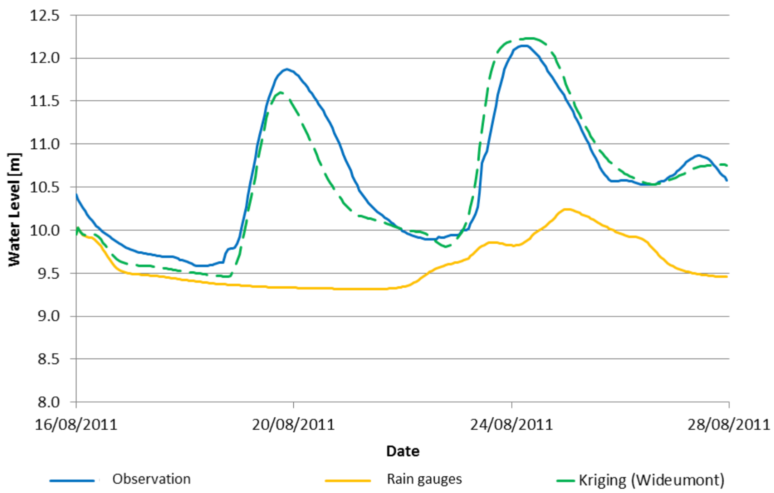

Figure 5: Observed and simulated water level, based on rain gauge and radar rainfall input along the Demer at Aarschot, August 2011.

Table 2: Root mean square error [m³/s] between observed and simulated water levels and discharges along the Demer river at Aarschot, Diest and Zichem making use of rain gauges or radar data (Wideumont & Zaventem) for November 2010, January 2011 and August 2011.

		November 2010			**January 2011**			**August 2011**	
		Rain gauges	**Kriging (Wideumont)**	**Kriging (Zaventem)**	**Rain gauges**	**Kriging (Wideumont)**	**Kriging (Zaventem)**	**Rain gauges**	**Kriging (Wideumont)**
RMSE [m] Water level	**Aarschot**	0,66	0,65	0,66	0,70	0,61	0,62	1,23	0,26
	Diest	0,58	0,59	0,62	0,37	0,34	0,36	0,77	0,38
	Zichem	0,47	0,45	0,46	0,56	0,49	0,49	0,92	0,28
RMSE [m³/s] Discharge	**Diest**	11,65	11,65	11,87	11,40	9,96	10,05	13,63	5,58
	Zichem	11,20	11,10	11,48	11,74	10,33	10,41	13,17	5,45

CONCLUSIONS

In this paper the added value of the application of radar data in hydrological modelling and flood forecasting within an operational setting was tested. First a merging technique was applied to combine radar and rain gauge data. In general, it could be concluded that the input from the merged rainfall sources improves, in terms of rainfall depths, in comparison with the original radar data. This is particularly the case for the winter periods, which are characterized by stratiform rainfall. Secondly the merged rainfall data were used as input for hydrological models, whose rainfall-runoff output was then further transferred into a hydrodynamic model. By comparing the output of the different models with observations it became clear that the added value of the radar data is limited for the winter periods. However for the summer period, which is characterized by convective rainfall, significant improvements could be noticed.

ACKOWLEDGEMENTS

The results presented in this paper were obtained by a research project on flood forecasting for Flanders Hydraulics Research of the Flemish Government of Belgium.

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