Hydrological modeling of the Ourthe catchment using both radar and raingauge data

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1 Introduction

The Meuse basin is situated in the North Western part of Europe. Together with the Rhine this river is important for the water supply towards the Netherlands. The basin can be characterized as mostly rainfall fed giving rise to a highly variable runoff regime of low discharges in summer and high discharges in winter. Understanding the catchments flood response to a given amount of rainfall is therefore important from both a hydrological and water-management perspective (Leander et al., 2005; Dal Cin et al., 2005). So far, most studies regarding the rainfall runoff response within the Meuse basin have employed precipitation data obtained by raingauges. Although a relatively dense gauge network is available within this basin (10 gauges for a 1600km^2 catchment), this is still too low to capture all the spatial properties of precipitation (Berne et al., 2004). In the year 2001 the Royal Meteorological Institute of Belgium (KMI) installed a C-band Doppler weather radar at Wideumont which is located in the southern Ardennes region of Belgium near the border with Luxembourg, at an elevation of about 600 m. Despite some intrinsic problems, the weather radar in principle allows one to obtain spatio-temporal precipitation data with a high resolution. During the last decades numerous studies have been presented in which the benefits of weather radar compared to raingauge networks was investigated (e.g. Borga, 2002; Smith et al., 2005).

This paper presents a hydro meteorological analysis and the resulting runoff response within the Ourthe catchment. As one of the bigger sub-catchments this tributary forms an important input to the flood response of the river Meuse before it enters the Netherlands. A first step towards using the capabilities of the Wideumont radar in understanding a series of rainfall events in Ourthe basin was performed by Berne et al. (2005). The present paper is the next step in that analysis.

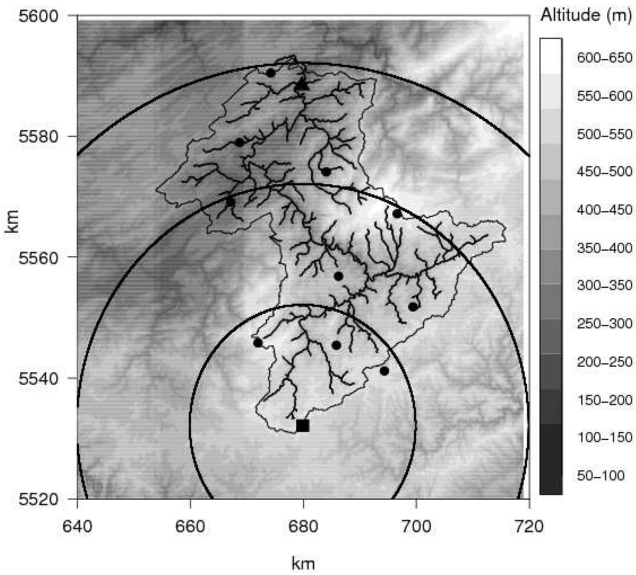

Fig. 1. Contourmap of the Ourthe catchment and the river network with the location of the 10 gauges (•), the Wideumont radar (■) and the discharge measuring point at Tabreux (▲). Circles show the 20, 40 and 60 km distances to the radar.

2 Study site and data description

The ~ 1600km^2 Ourthe catchment (Figure 1) is located in the Belgian Ardennes. Its hydrogeological base consists of shales and sandstones mainly covered by forest and pasture. Previous rainfall-runoff studies using

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raingauge data showed that peak discharges mostly occur in winter and are difficult to model (Velner, 2000; Groot Zwaaftink, 2003). This study analyzes the spatial and temporal characteristics of rainstorms and the resulting catchment response using both radar and raingauge data over the period October 1, 2002 until March 31, 2003. During this winter half year most storms have a stratiform character. The radar scans every 5 minutes at five elevations and every 15 minutes at ten different elevations. In this study the 5-minute data are applied, providing areal information at elevation angles of 0.3°, 0.9°, 1.8°, 3.3° and 6.0°. Conversion from reflectivity to rainrate is performed using the standard Marshall-Palmer relationship, $Z = 200R^{1.6}$ (Marshall et al., 1955).

Reflectivities obtained at the lowest elevation showed clutter contamination. It was decided to use the second elevation, providing precipitation data at a spatial resolution of $1km^2$. A hailcap of 55 dBZ was used. So far, no correction has been applied for attenuation, which can affect C-band radars. Ten hourly raingauges, property of the Hydrological Service of the Walloon Region of Belgium (MET-SETHY), more or less evenly distributed over the watershed are used to validate the radar. Radar data is not available for a period of 8 days between November 4-12 and on March 25. None of the raingauges functioned for the entire period. Basin avaraged precipitation values were obtained by those that did register precipitation with the exception of twenty hours during which all gauges were malfunctioning. This period did not coincide with the periods during which no radar data were available.

3 Results and discussion

3.1 Radar-raingauge analyses

One of the ultimate goals of this research is to investigate whether it is possible to use the precipitation data estimated by weather radar for flood forecasting. Previous radar-raingauge studies showed significant bias between the instruments that can be related to the different measurement properties of both devices (e.g. Steiner et al., 1999; Ciach et al., 2000). In order to use the radar on an operational basis the bias between radar and raingauge data has to be limited. As a first analysis the accumulated precipitation for the winter half year between a gauge and the radar pixel directly above it is presented in Figure 2. One of the radar pixels was contaminated by clutter during the measuring period and therefore left out of the analysis. Figure 2 shows that overall bias between both instruments is relatively small when compared to other studies (Steiner et al., 1999; Borga, 2002). This is probably related to the fact that almost the entire catchment lies within 50 km of the radar. As a result the scans represent a relatively small area, attenuation effects become small as well. The difference between the gauge and radar at Flamierge is small during the first months of this study. Over time the radar pixel above Flamierge became contaminated with clutter explaining the deviation that resulted.

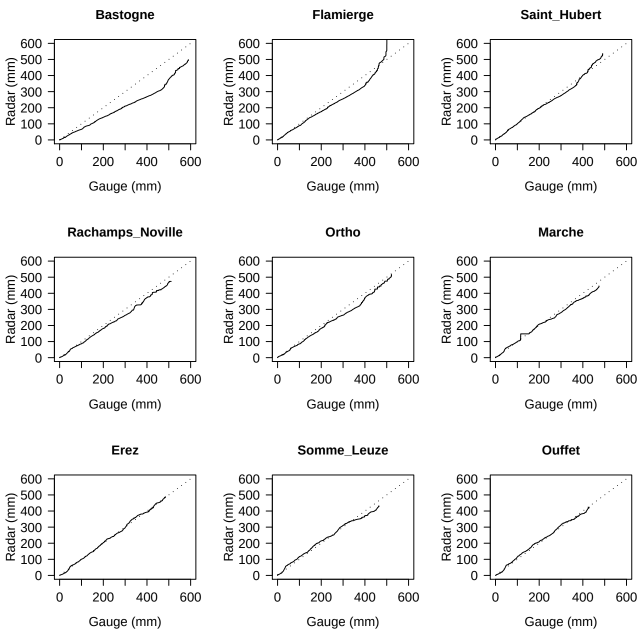

Fig. 2. Difference in accumulation (mm) between the nine raingauges and the radar pixel above the gauges.

As a next step the inter-gauge and inter-pixel correlation function between the nine different measurement points were obtained and fitted by an exponential function (Habib et al., 2004; Ciach and Krajewski, 2006).

$$\rho(d) = \rho_0 \exp\left(-\frac{d}{d_0}\right) \tag{1}$$

Because none of the raingauges was located in the very close vicinity of an other, it is difficult to obtain a proper estimation for the parameter ρ_0. Therefore, this parameter was set to a value of 1. Figure 3 shows the correlation functions for both data sets, the estimated decorrelation distance and the efficiencies, describing the fraction of the explained variance (Nash and Sutcliff, 1970). The exponential fit to both correlation functions are more or less similar though for the radar a closer fit is obtained. Further inspection reveals that the lowest cross correlation values for the raingauges all are related to the one at Marche. For this point in Figure 2 a period can be observed during which the gauge did not register any rain while according to the radar precipitation did occur. This period is followed by a sudden increase of rainfall measured by the gauge which probably corresponds to the fact that the gauge had been clogged and repaired. This shows the necessity of quality control for both the radar and the raingauge data. Removing this point increases the decorrelation distance and efficiency estimated from the raingauge data to around 65 km and 0.55 respectively. The results for the radar data remain the same

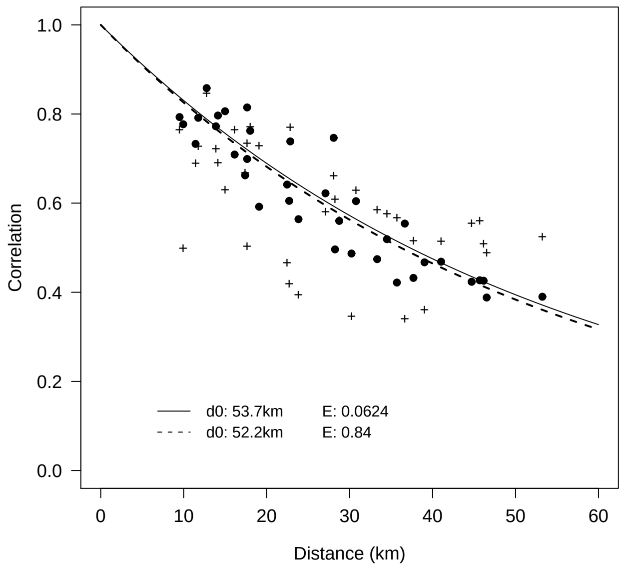

Fig. 3. Interstation correlation for hourly data between the raingauges (+) and radar pixels (•) above the raingauges. Exponential fit for both the raingauges (solid line) and the radar (dashed), decorrelation distance (d_0) and efficiency (Nash and Sutcliff, 1970) are also shown.

as mentioned above. During the winter period most of the precipitation events are stratiform, covering a large part of the catchment. The decorrelation distance for the hourly precipitation data is seen to be more or less similar to the size of the catchment.

3.2 Catchment response and hydrological modeling

The discharge behavior of the Ourthe in response to a certain amount of basin-averaged precipitation is presented in Figure 4. Over this winter period four main runoff peaks can be observed. Compared to other studies mentioned before, the size of the Ourthe is much larger, resulting in a typical response time of 1-2 days instead of just a couple of hours. Unfortunately, no radar data are available for the rainfall period causing the runoff peak that was observed in November. Although a similar amount of accumulated rainfall was recorded during the ten days preceding the first two runoff peaks, the discharge response of the peak is much more severe. This is probably related to the larger storage capacity of the catchment available at the beginning of the winter period. As the basin fills up, response times decrease.
The next step is to use the spatio-temporal information provided by the radar in a hydrological model and compare it to the observed discharge data at Tabreux. Although usage of radar for hydrological modeling has been described more often, most of these studies are focused on simulating a specific storm event (e.g. Zhang and Smith, 2003), while only a few take a longer period into account

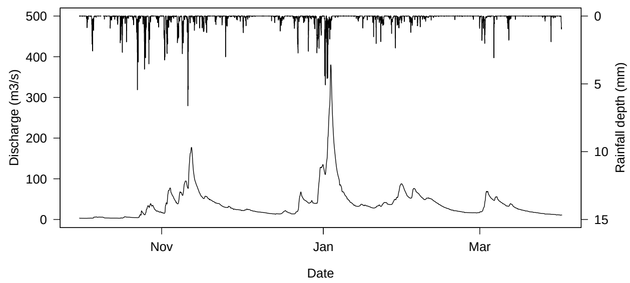

Fig. 4. Average hourly rainfall depth (top) registered by the raingauges over the catchment and the discharge measured at Tabreux (bottom).

(e.g. Borga et al., 2006).
The previous study by Berne et al. (2005) used the lumped conceptual model HBV (Lindstrom et al., 1997) to simulate the catchment response for a single stratiform and convective event. It was concluded from that study that modeled discharges are highly sensitive to initial soil moisture conditions. To diminish these effects the same model has been used here during the half year of interest using both radar and raingauge data. For periods during which no radar data were available gauge data were taken, and vice versa. The upper plot in Figure 5 shows the observed and modeled runoff response using the model parameters of the Ourthe obtained from Booij (2005), who calibrated the HBV model for the whole Meuse basin. The bottom plot shows the first results of calibrating the HBV using the raingauge data presented in this study. Compared to the observed discharge the HBV simulations for both types of rainfall inputs underestimate peak discharges and recession limb behavior. For the Ourthe this was also observed by Velner (2000). For the future it is planned to subdivide the basin into smaller sub-catchments and/or use different hydrological models to gain a better understanding in the runoff behavior of the catchment.

4 Conclusions and further research

In this paper a first analysis was presented using radar and raingauge data for continous hydrological modeling of the Ourthe catchment. Over the whole period the difference in observed precipitation between the radar and gauges is small, which provides the opportunity to use the spatial and temporal characteristics of the radar in trying to understand the discharge behavior of the Ourthe. Gaining insights in the spatio-temporal properties of the storm field above the Ourthe can be obtained by the Wideumont radar but needs to be further investigated. Because the Ourthe is relatively large the positioning of the storm field above the catchment has impor-

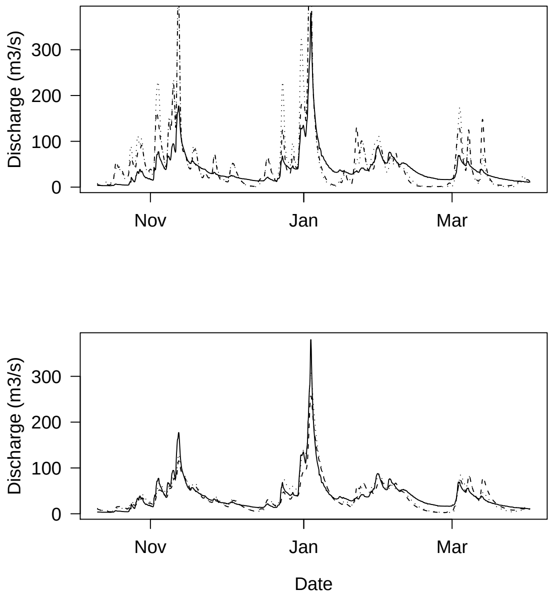

Fig. 5. Observed (solid) and simulated discharges using both radar (dashed) and raingauge data (dotted). In the upper figure the HBV simulation was performed using the calibrated parameters from Booij (2005), lower plot shows values simulated after a preliminary calibration using the available raingauge data.

tant consequences for the runoff behavior. In order to be able to characteristize these properties further research is needed using more elaborate distributed hydrological models, which is a topic of ongoing research.

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