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Combined use of radar and gauge observations for hydrological applications in the Walloon Region of Belgium

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1 Introduction

The Walloon Region is the southern part of Belgium. It extends over 18.000 km^2 and is drained by two main rivers, the Meuse and the Scheldt. The tributaries of the Meuse are known for their extremely varied characteristics with high flows in winter and very low waters in summer. The altimetry of the basin varies from 60 m to 700 m above sea level. Floods in the Meuse basin are usually produced by continuous rainfalls during several winter days (Dal Cin et al. 2005). The Scheldt has a totally different behaviour. Since the basin topography is almost flat, it is mainly prone to flash flood events.

Radar developments for hydrological applications in the Walloon Region are the result of a collaboration between the Royal Meteorological Institute of Belgium (RMI) and the Hydrological Service of the Ministry of Equipment and Transport of the Walloon Region (SETHY). Two weather radars are operational in Belgium: the radar of Wideumont which is operated by RMI and the radar of Zaventem operated by Belgocontrol (air traffic safety). The Météo-France radar of l'Avesnois provides also a good coverage of the region. The locations of these radars are given in Fig. 1. A first assessment of the hydrometeorological potential of weather radar in this region has been performed through a cooperation with the Wageningen University (Berne et al. 2005). In the present paper, we describe the most recent developments concerning the hydrological use of the Wideumont radar.

2 Gauge and radar observations

SETHY operates a dense and integrated network of 90 telemetric rain gauges (Fig. 1). Most of them are tipping bucket systems providing hourly rainfall accumulations. The collected data are used by SETHY for hydrological modelling and directly sent to RMI. The rain gauges are controlled on site every three months and in a specialized workshop every year. Every day, a quality control of the data is performed by RMI using a comparison with neighbouring stations. Radar data are also used in this quality control for the elimination of outliers.

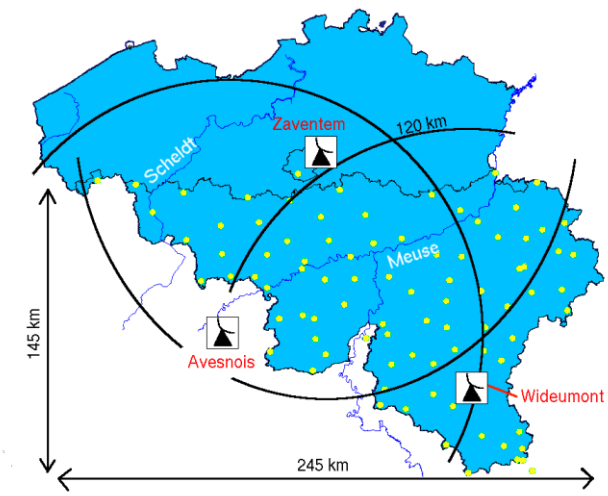

Fig. 1. Study area. Locations of SETHY gauge stations are given by points. Circles indicate the 120-km radar ranges.

RMI maintains a climatological network including 270 stations with daily measurements of precipitation accumulation between 8 and 8 local time (LT). Most of these stations are manual and the data are generally available with a significant delay. The data undergo a drastic quality control. This network is used for the long term verification of radar precipitation estimates.

The Wideumont radar is a single-polarization C-band weather radar from Gematronik. It performs a 5-elevation scan every 5 minutes with reflectivity measurements up to 240 km. A time-domain Doppler filtering is applied for

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ground clutter removal. An additional treatment is applied to the volume reflectivity file to eliminate residual permanent ground clutter caused by some surrounding hills. Reflectivity data contaminated by permanent ground clutter are replaced by data collected at a higher elevation. A Pseudo Cappi at 1500 m is extracted from the volume data and reflectivity factors are converted into precipitation rates using the Marshall-Palmer relation $Z = aR^b$ with a=200 and b=1.6. A monitoring of the electronic calibration is performed using the mean ground clutter reflectivity at short range and the reflectivity produced by three towers in the vicinity of the radar. These point targets also allow controlling range and azimuth assignments.

The 5-min radar precipitation data are summed to produce 1h and 24h precipitation accumulation products. Mean areal 1h and 24h accumulations are calculated for 36 basins. An advection procedure has been recently implemented to correct the effect of time sampling interval on accumulation maps. The method is based on Fabry et al. (1994). It is assumed that the precipitation field moves at a constant velocity during the 5-min sampling interval and vary linearly in intensity. The velocity vector between two successive images is determined using a cross-correlation algorithm. A single velocity vector is calculated for a 240 x 180 km^2 rectangular area including the region of interest. The advection correction allows a significant improvement of the visual aspect of accumulated maps in the case of small-scale precipitation structures which move rapidly (Fig. 2). The impact of the advection correction on the verification results will be discussed in the next section.

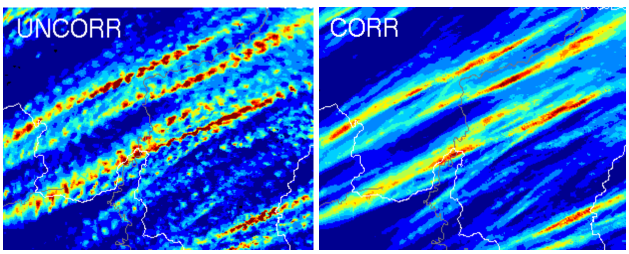

Fig. 2. Impact of the advection correction on the 24h precipitation accumulation starting at 24/06/2004 06 UTC.

3 Verification and gauge adjustment

The verification of the 24h radar precipitation accumulation is performed a posteriori using the gauge data from the RMI climatological network. For each day, the 24h (8 to 8 LT) radar/gauge ratio expressed in dB ($R/G(dB) = 10\ log_{10}(R/G)$) is calculated as the mean R/G over all stations between 0 and 120 km. Only stations where radar and gauge values exceed 1 mm are taken into account. Averaged over the four-year period between 01/05/2002 and 31/04/2006, the mean 24h R/G is -1.37 dB, which corresponds to a mean underestimation of precipitation by 27 %. Expressed in logarithmic scale, the 24h R/G follows approximately a normal distribution. The standard deviation of this distribution is 2.08 dB which indicates the large daily variability of the 24h R/G. The cumulative distribution function is shown in Fig. 3

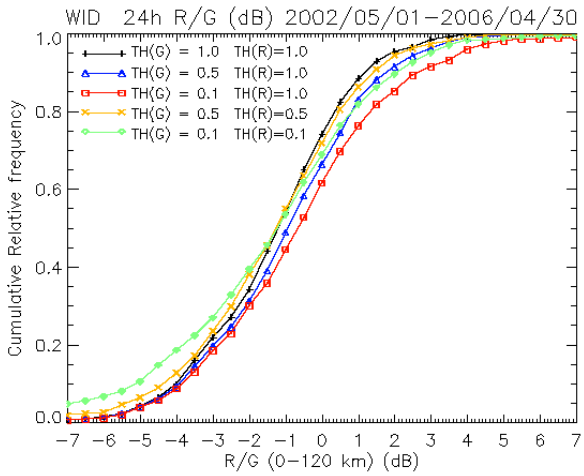

Fig. 3. Cumulative distribution function of the 24h radar/gauge ratio (dB) for different combinations of radar and gauge minimum thresholds (TH(R) and TH(G), respectively).

Table 1. Mean 24h R/G ratio and standard deviation expressed in dB for different radar and gauge minimum thresholds.

mean (std. dev.)		TH(R) (mm)		
		0.1	**0.5**	**1.0**
	0.1	-1.53	-0.86	-0.66
		(3.01)	(2.70)	(2.61)
TH(G)	**0.5**	-2.18	-1.42	-1.04
(mm)		(2.96)	(2.37)	(2.26)
	1.0	-2.51	-1.81	-1.37
		(3.02)	(2.32)	(2.08)

These values have been obtained using gauge-radar pairs with precipitation values larger than 1 mm for both radar and gauge. In practice, various sets of radar and gauge thresholds are used by the operational radar community for verification purpose. It is worth noting that the choice of these thresholds significantly affects the verification statistics. We have performed the 24h accumulation verification for the 4-year period using three different threshold values, i.e. 0.1, 0.5 and 1 mm. This gives 9 combinations of radar gauge threshold pairs. The 24h R/G (dB) mean and standard deviation are given in Table 1. The cumulative distribution function is given in Fig. 3 for a limited number of radar gauge threshold pairs. The results show that selecting different thresholds for radar and gauge values substantially modifies the mean 24h R/G. When equal thresholds are chosen for radar and gauge, the sensitivity of the mean 24h R/G to this threshold is relatively limited. The mean 24h R/G for thresholds of 0.1 mm and 3 mm (not given in Table 1) thresholds are -1.53 dB and -1.29 dB, respectively. Larger thresholds tend to slightly improve the verification statistics by reducing the mean 24h R/G and the standard deviation as well.

On-line verification and adjustment of 24h radar accumulation is performed every day using the gauge data from the 90 SETHY telemetric stations. A range dependent adjustment mainly based on the BALTEX adjustment method (Michelson et al. 2000) has been implemented. The relation between R/G (dB) and range is approximated by a second ordre polynomial whose coefficients are determined using a least square fit. The range dependent multiplicative factor applied to the 24h accumulation factor is derived from the polynomial fit. The range correction is not applied if it does not allow a reduction of the R/G (dB) standard deviation, which expresses here the spatial dispersion of R/G. In this case, a simple mean bias correction is applied.

The impact of the advection correction described in section 2 on the verification results has been evaluated. Nine precipitation episodes where a striking time sampling effect appears on the 24h accumulation map have been selected. The mean and standard deviation of R/G have been calculated with and without advection correction for each episode. The results are given in Table 2. As expected, the advection correction hardly affects the mean R/G. More surprisingly, our results show that the impact on the standard deviation is also extremely limited. These results were obtained using as radar estimate the average over 9 radar pixels, i.e. a 1.8 x 1.8 km^2 area. Similar results were otained using the radar value from the single pixel of the gauge location. No significant impact of the advection correction is observed. This result can be partially attributed to the limited efficiency of the advection correction algorithm. The algorithm assumes that the rainfall intensity varies linearly within the 5-min time interval and that the velocity vector remains constant. These assumptions are not correct, which limits the efficiency of the algorithm. Nevertheless, it is likely that even a perfect correction of the time sampling error would not allow a very strong reduction of the R/G spatial dispersion. The time sampling error provides only a limited contribution to this dispersion. Jordan et al. (2000) point out many other sampling errors which contribute to the R/G dispersion. For example, the spatial averaging inherent to radar measurements causes representativeness errors when comparing radar and gauge measurements. The height of the radar measurements associated with the large variability of the vertical profile of rainfall is depicted by Jordan et al. as the most important source of sampling error.

4 Visualization and analysis tool

A web oriented interface has been recently developed at RMI for visualizing in a unified way both the SETHY telemetric gauge data and the radar precipitation data. This software is a decision support tool allowing the real-time monitoring of the hydrological situation on the 36 Walloon catchments. The software displays 5-min images, accumulation maps and basin-averaged accumulations. Through the product selection interface the user can select a period of accumulation

Table 2. Impact of the advection correction on the mean and standard deviation of the 24h R/G ratio (dB).

Date	Mean R/G (dB)		St. dev. R/G (dB)	
	uncorr.	corr	uncorr.	corr
12/06/2004	0.52	0.54	1.64	1.60
23/06/2004	0.69	0.60	2.20	2.18
02/07/2004	0.45	0.45	1.53	1.52
08/07/2004	-1.84	-1.78	1.48	1.40
17/07/2004	0.09	0.08	1.81	1.70
22/07/2004	-1.97	-2.00	2.04	1.99
13/08/2004	-3.31	-3.26	1.04	1.02
18/08/2004	-3.06	-3.05	1.40	1.35

and a visualization product. Dynamic accumulated maps are generated. By clicking on a catchment the user operates a zoom on that catchment. By clicking on a rain gauge station, or on a catchment in case of basin-averaged accumulation, the user has access to a time series profile.

The gauge accumulation product allows the user to generate an accumulated precipitation map from gauge data. Two kinds of visualizations are proposed : a cumulated precipitation labelled map and a spatialized map produced by kriging interpolation. The gauge-radar accumulation product outputs the gauge accumulation labelled map superimposed on the radar accumulation map for the same time period (Fig. 4). It allows a visual estimation of the precipitation field between gauges for any period of accumulation. Basin-averaged accumulation products are generated from radar and gauge data.

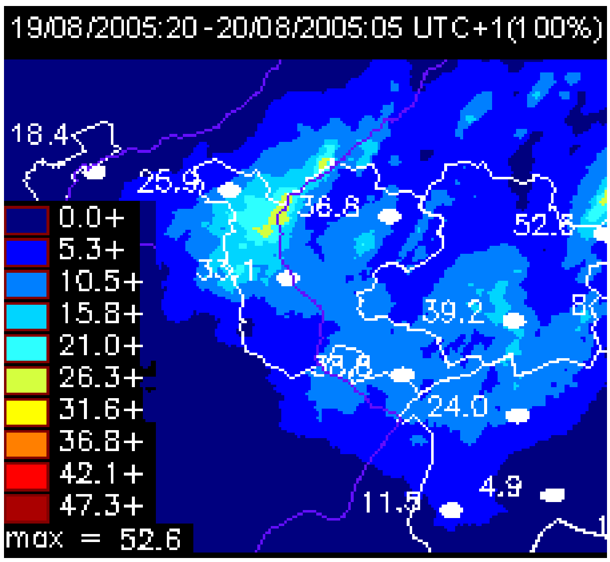

Fig. 4. Gauge-radar product with catchment borders

5 Hydrological ensemble predictions

The radar precipitation data are used in a hydrological ensemble forecasting system. Every day, the state variables of a hydrological model are updated by running this model with the 24h accumulated radar data as input. Starting from the new initial conditions of the hydrological model, 50 streamflow predictions are performed according to precipitation scenarios for the next 9 days given by each of the 50 members of the Ensemble Prediction System (EPS) of ECMWF. Then, the risk of high flow is estimated as the fraction of members with streamflow predicted values exceeding a threshold corresponding the 95th Percentile. Using EPS archives, the hydrological ensemble predictions have shown skill and value for early warning (Roulin and Vannitsem 2005, Roulin 2006). This method is currently tested for the Demer catchment at Diest in the Scheldt basin and the Ourthe catchment at Tabreux in the Meuse basin. The streamflow of the Ourthe the simulated by the hydrological model using radar data is compared to measured values on Figure 5 and an example of probability forecast for the Ourthe is presented on Figure 6. In the current procedure, the simulated streamflow is not updated with observed discharge data. The results are expected to improve by the use of gauge adjusted radar data at least for short lead time.

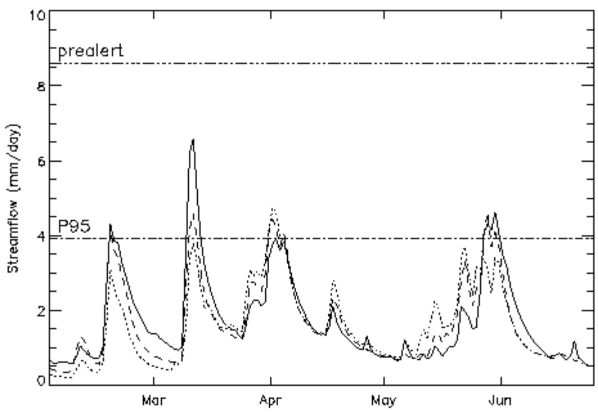

Fig. 5. Streamflow of the Ourthe in 2006: observed by SETHY (continuous line), simulated in real time with 24h accumulated radar data (dotted), simulated with 1 month delay with RMI daily raingauge data (dashed).

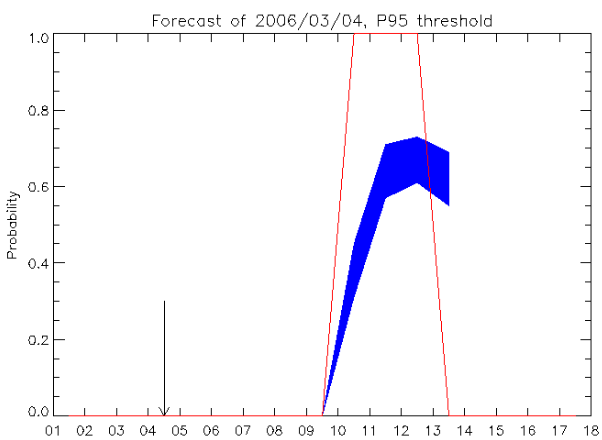

Fig. 6. Probability [0,1] that the streamflow of the Ourthe will exceed the 95th percentile as predicted from the 4th of March 2006 (arrow) for the 9 following days; probability forecast (uncertainty band obtained with a bootstrap method); the ”observations” (continuous line): 1 if the streamflow threshold is actually exceeded and 0 if not.

6 Conclusions

In this paper, we have described various developments aiming at improving the combined use of radar and gauge observations for hydrological applications in the Walloon Region. A careful verification of radar precipitation estimates is required for such applications. We have shown that the choice of minimum thresholds for gauge and radar 24h accumulations significantly affects the verification statistics. In contrast, the advection algorithm for the correction of time sampling error has very little impact on the verification results.

A gauge adjustment scheme has been implemented and a recently developed visualization and analysis tool strongly facilitates the combined use of radar and gauge data by operational hydrologists. Further use of radar data is made for the estimation of the initial conditions of a hydrological model in probabilistic forecasts of high flows based on ECMWF Ensemble Prediction System. The first results look very promising.

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