Evaluation of several radar-gauge merging techniques for operational use in the Walloon region of Belgium

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1 Introduction

The Walloon region is 16842 square kilometers large and most of it belongs to the Meuse and Scheldt basins. The regional hydrological service (MET/DGVH) operates an automatic rain gauge network including about 90 stations, which corresponds to a density of 1 gauge per 187 square kilometers. Radar observations are available from a C-band Doppler radar located in the south of the region and operated by the Royal Meteorological Institute of Belgium (RMI). The precipitation data ingested in the operational hydrological forecasting system are currently gauge observations only but a combined use of radar and gauge observations is planned in a near future. The use of radar data in real-time flow forecasting is presented in Leclercq et al. (2008).

In the present study, we evaluate several techniques for merging radar and gauge observations with various degrees of complexity. The merging techniques which have been implemented include mean bias correction, static local bias correction aimed at correcting for visibility effects (beam blocking), range dependant adjustment, Brandes spatial adjustment and sophisticated merging based on geostatistical techniques.

The verification of the precipitation field resulting from the merging will be based on the comparison with the 24h-accumulation gauge observations from the climatological network operated by RMI. This network includes 150 stations in the area of interest. Most of them are manual stations. Verification results will be presented for one year with the aim of selecting the most appropriate technique for operational use in the hydrological forecasting system.

2 Radar and gauge observations

MET/DGVH operates a dense and integrated network of 90 telemetric rain gauges. Most of them are tipping bucket systems providing hourly rainfall accumulations. The collected data are used 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.

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 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

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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 $Z=a\ R^b$ 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. An advection procedure has been recently implemented to correct the effect of time sampling interval on accumulation maps (Delobbe et al. 2006). 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. However, the advection algorithm has been tested on various precipitation episodes with a very significant ripple effect and it appears that the impact on the verification results is very limited. This correction was not applied for the present study.

3 Radar-gauge merging

The merging of radar and gauge observations is applied to daily precipitation amounts between 8 and 8 in local time. Several techniques have been tested.

3.1 Mean field bias correction (MFB)

The adjustment factor is estimated as:

$$F_{MFB} = \frac{\sum_{i=1}^{N} G_i}{\sum_{i=1}^{N} R_i}$$

where G_i is the gauge measurement of the 24h rainfall amount, R_i the collocated radar estimate and N the number of valid radar-gauge pairs. Only the pairs where R and G exceed 1 mm are considered as valid.

An alternative adjustment based on the mean assessment factor (MAF) is also tested:

$$F_{MAF} = \frac{1}{N} \sum_{i=1}^{N} \frac{G_i}{R_i}$$

3.2 Range-dependent adjustment (RDA)

A range dependent adjustment mainly based on the BALTEX adjustment method (Michelson et al. 2000) has been implemented. The relation between R/G expressed in dB and range is approximated by a second order polynomial whose coefficients are determined using a least squares fit. The range dependent multiplicative factor applied to the 24h accumulation factor is derived from the polynomial fit.

3.3 Static local bias correction (SLB)

The static local bias correction aims at correcting for visibility effects. The local bias correction is calculated from a one-year data set as follows. The 24h radar accumulations are first adjusted by a mean field bias correction. Then, for each gauge location the residual mean bias of the 24h radar accumulation is estimated. A spatialized local bias is then obtained through an ordinary kriging. The local bias correction has been calculated for the year 2005 using gauge observations of the RMI climatological network and applied to the radar data collected in 2006. This correction is applied before a range dependant adjustment (SRD) or before a mean field bias correction (SMB).

3.4 Brandes spatial adjustment (BRA)

This is the spatial method developed by Brandes (1975). The assessment factors from each raingauge are interpolated on the whole radar field following the Barnes objective analysis scheme based on a negative exponential weighting. The smoothing is controlled by a parameter linked to the density of the network. This approach is valid here because the gauge network is sufficiently homogeneous.

3.5 Ordinary kriging (KRI)

This is a geostatistical method for the spatial interpolation of a random field (precipitation) from observations at severals locations (raingauges). It requires the definition of a variogram describing the spatial variability of the field. The kriging estimation is the best linear unbiased estimator assuming a constant unknown mean across the field.

In this study we use only the 20 nearest points to reduce the computational cost. The model variogram, assumed isotropic, is a first order linear function of the distance.

This method, based only on raingauges, is tested to evaluate the added value of merging methods.

3.6 Kriging with external drift (KED)

This is a geostatistical method that uses the radar as secondary information. This is the same as ordinary kriging except that the mean of the estimated precipitation field is a linear function of the radar field. Here we use a first order function with two unknown parameters. Additional constrains ensure that the predictor is not biased.

3.7 Kriging with radar-based error correction (KRE)

This method proposed by Sinclair and Pegram (2004) uses the radar field to estimate the error of the ordinary kriging method based on raingauges. Radar values at each gauge site are used to produce a radar-based kriging field. This field is then subtracted from the original radar field and added to the gauge-kriged field.

4 Long-term verification

The performance of the merging has been evaluated by comparing the adjusted 24h precipitation accumulations to the measurements of the climatological gauge network (only pairs with both values larger than 1mm are considered). The gauge data used for the adjustment and for the verification are independent.

Several quality parameters are found in the literature. The Root Mean Square Error (RMSE) is the most common parameter used in verification studies and it will be used here as first quality parameter. A standard for objective judgement of radar performance is proposed in Germann et al. (2006). The bias, the error distribution and the scatter as defined in that paper are also used in the present study. The bias is the total precipitation as seen by the radar divided by the total precipitation measured by the gauges. The error distribution is the cumulative contribution to total rainfall as a function of the radar-gauge ratio. The scatter is half the distance between the 16 % and 84 % percentiles of the error distribution.

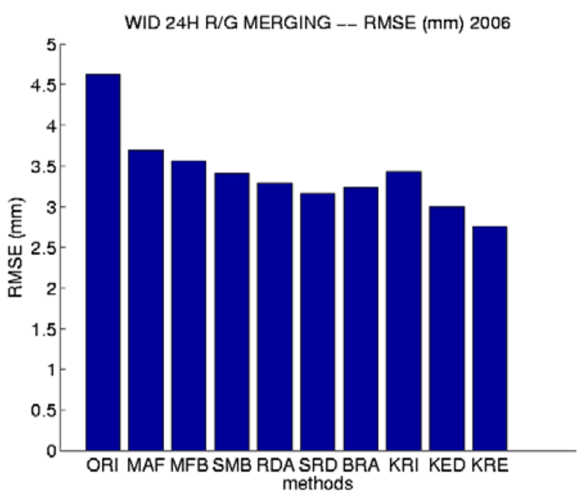

Fig. 1. RMSE score for different merging methods

Figure 1 shows the Root Mean Square Error for the different merging methods.

The RMSE decrease is clear for all methods in comparison with the original data. The worst method is the adjustment by the mean assessment factor (MAF), even if it already shows a decrease of about 20 %. The best method, kriging with radar-based error correction (KRE), reaches 40 %. The best simple method is the one performing a static local bias correction before a range adjustment (SRD) with a decrease of 30 %.

The ordinary kriging method (KRI), using only gauge data, gives a higher score than a mean field bias correction (MFB) but lower than a range-dependent adjustment (RDA). This good result is due to the high density of the raingauge network. The kriging with external drift is the second most effective method.

One notes that the static local bias correction (SMB and SRD) slightly improves the results. The performance of the Brandes spatial method (BRA) lies between the range-dependent adjustment (RDA) and the corresponding method improved by static local bias correction (SRD).

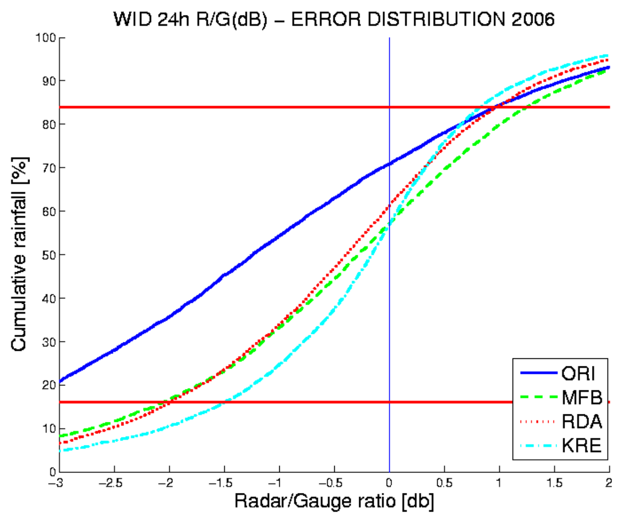

Fig. 2. Error distribution of 24 h R/G ratios based on all valid pairs during year 2006 for 4 different methods

We can see in Figure 2 the error distribution for 4 methods of increasing complexity. The vertical line divides the R/G ratios set in underestimation (left) and overestimation (right). A perfect match should give a step function. The original radar data (ORI) reveal a significant underestimation. The mean field bias correction succeeds in balancing the error distribution. The range-dependent adjustment (RDA) reduces the overestimation while the more sophisticated method involving kriging (KRE) further increases the performance.

The best simple method (SRD) is compared with the 3 kriging methods in Figure 3. The SRD method shows more underestimation than the others. KED and KRE methods give similar results.

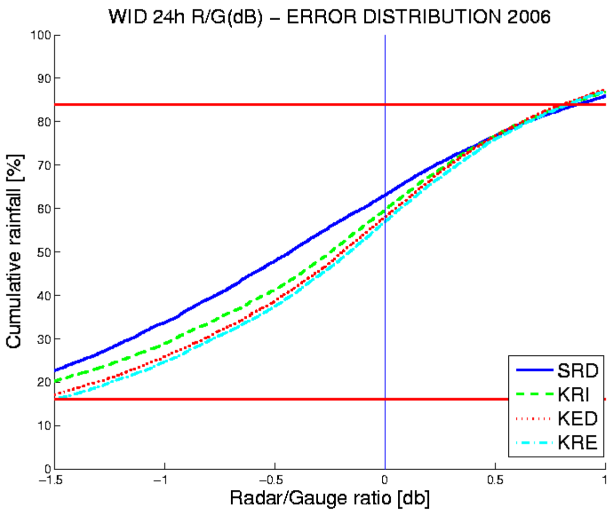

Fig. 3. Error distribution of 24 h R/G ratios based on all valid pairs during year 2006 for the best simple method and all kriging methods

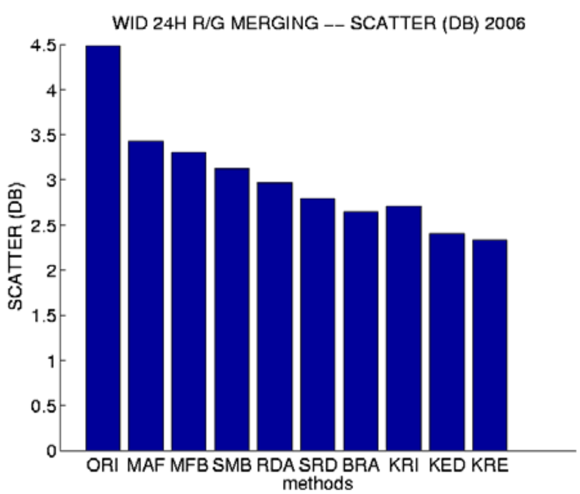

Fig. 4. Scatter score for the different merging methods

When we look at the scatter score (Fig. 4), the superiority of the kriging merging methods clearly appears. The Brandes spatial method (BRA) lies just behind and gets its best ranking for this quality parameter.

More statistics are available in Table 1 including mean field bias (MFB), mean assessment factor (MAF), standard deviation (STD) and the number of valid pairs (NVP). One notes that the KRE method has less valid pairs than the other methods. This could result from a bad behaviour in some problematic cases.

5 Conclusion

Several methods merging radar and raingauges have been implemented and evaluated. The verification over the year 2006 against an independent gauge network has allowed comparing them using some appropriate statistics. We first note that even simple methods like mean field bias (MFB) or mean assessment factor (MAF) correction allow a significant improvement. It is also clear that the improvement depends on the complexity of the method. It is worth pointing out that different scores give different rankings but the radar-gauge merging methods based on kriging are clearly the most effective.

Table 1. Quality parameters statistics for different merging methods and for the year 2006 (see text for explanation, bold = best, italic = worst)

	RMSE [mm]	Scatter [db]	MFB [db]	MAF [db]	STD [db]	NVP
ORI	4.62	4.48	-0.68	-0.61	2.57	15632
MFB	3.56	3.31	**-0.03**	0.04	*2.07*	16124
MAF	*3.69*	*3.42*	-0.43	-0.36	2.05	16004
SMB	3.41	3.12	-0.11	-0.03	1.96	16175
RDA	3.28	2.96	-0.18	-0.06	1.84	16240
SRD	3.16	2.79	-0.23	-0.12	1.80	16282
BRA	3.24	2.64	*-0.15*	*-0.14*	1.86	15896
KRI	3.42	2.70	-0.16	**-0.01**	1.84	**16662**
KED	2.99	2.40	-0.11	**-0.01**	1.69	16549
KRE	**2.76**	**2.33**	-0.07	**-0.01**	**1.66**	*15719*

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