Geostatistical merging of X-band weather radar and a sparse rain gauge network over an urban catchment

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1 Introduction:

Optimal Quantitative Precipitation Estimation (QPE) of rainfall have been proven to be crucial to the accuracy of hydrological models, especially over urban catchments. Small to medium-size towns are often equipped with a sparse rain gauge networks that struggle to catch the variability of rainfall over high spatio-temporal resolutions. X-band Local Weather Radars (LAWRs) provide a cost effective solution to meet this challenge.

In this study, we examine two geostatistical methods to merge X-band weather radar data with the combination of rain gauge networks of Clermont-Ferrand (13 gauges with a 5 minutes temporal resolution) and Meteo France (5 gauges with a 6 mintes temporal resolution): Conditional merging and Kriging with an external drift according to Velasco-Forero et al (2009). The effects of attenuation correction, using the Hitchfeld Bordan (1954) algorithm as well as correcting the mean field bias of radar data were also investigated.

This extended abstract is organized into four sections. After the introduction, the geostatistical methods are presented in the Methodology section as well as the performance assessment criteria applied to compare the methodes. Section 3 presents the study area as well as the steps taken to pre-process the radar data. Finally, section 4 presents the results of the study.

2 Methodology

Two geostatistical methods: Kriging with External Drift (KED) and Conditional Merging (CM), were chosen to merge the radar and rain gauge data at three different temporal resolutions: 5, 30 and 60 minutes. Similar studies such as Berndt et al (2014) and Goudenhoofdt et al (2008) used a C-band weather radar and a relatively dense rain gauge network in order to compare several merging techniques including geostatistical ones, and found that KED and CM performed the best at several network densities and temporal resolutions scenarios.

Hereafter, we present briefly these two methods, as well as the performance assessment measures chosen to determine the best one at every temporal resoltion investigated.

2.1 Geostatistical Merging methods of rain gauge and radar data:

Both merging techniques use Ordinary Kriging OK, as an intermediate step. A detailed description of OK can be found in geostatistical texbooks (Goovaerts,1997; Isaaks and Srivastava,1990), it uses an experimental variogram capturing the spatial variabiliy of data, which is then fitted to a theoretical one in order to resolve a linear system minimizing the kriging variance.

In this study, a single variogram standardized by the variance was used for every temporal resolution, thanks to averaging variograms of several time steps across the study period using radar data. The exponential model was found to fit best across the three resolutions investigated

2.1.1 KED: Kriging with an External Drift

For practical reasons, we use the Velasco-Forero et al (2009) modified version of KED, because it is more suitable for real time applications, which is the end goal of this study in the Clermont-Ferrand catchment.

The procedure is as follows:

1. First Radar pixels corresponding to the location of every rain gauge is selected and then interpolated over the study area.
2. A deviation map is then computed between observed radar grid and interpolated radar grid.
3. The deviation map is then used to compute the corresponding variogram
4. The variogram computed in in step 3 is then used to interpolate the rain gauge data over the study area.

2.1.2 CM: Conditional Merging

Conditional Merging (CM) described by Ehret (2003) follows the same steps as KED, however the deviation map is used to introduce the radar detected variability of rainfall to the field obtained by OK, through a simple addition.

2.1.3 Performane assessment criteria:

Three criteria are used to measure the performance of every geostatistical technique including OK:

- The bias criterion:

$$Bias = \frac{1}{n}\sum_{i=1}^{n}[Z'(x) - Z(x)]$$

Where n is the number of rain gauges, Z is the observation value of gauge number i at location x and Z' is the estimation at the same location.

- The root mean square error normalized with the average of the observations Z:

$$RMSE = \frac{1}{Z}\sqrt{\sum_{i=1}^{n}[Z'(x) - Z(x)]}$$

- The variance ratio Rvar:

$$Rvar = \frac{Var[Z'(x)]}{Var[Z(x)]}$$

These criteria were also used in the study of Berndt et al (2014), although the study was carried out in Lower Saxony (Germany) using a C-band radar, it is still interesting to compare how these methods compare in different configurations.

3 Study area and data

The Clermont-Ferrand catchment is located in Central France in the mountainous Massif Central geological region. The average annual precipitation rate is about 600 mm/yr. The city of Clermont-Ferrand monitors precipitations through a network of 13 gauges scattered around the city, operating with a 5 minutes temporal resolution, five gauges belonging to the National Meteorological Service Météo-France operating with a 6 minutes temporal resolution also operate in the study area. Fig. 1 shows the rain gauge network as well as the Digital Elevation Model (DEM) of the terrain and the location of the X-band radar.

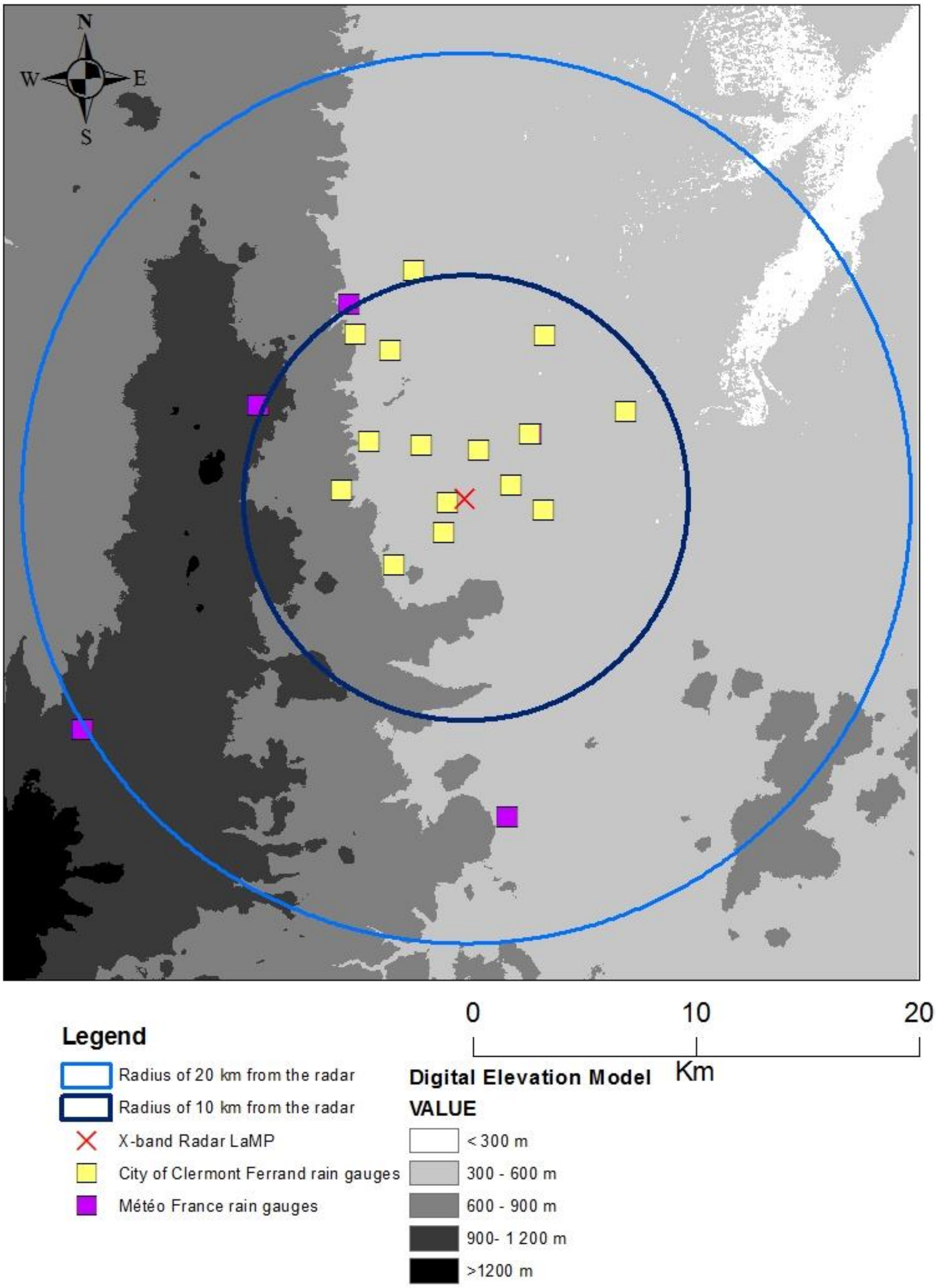

Figure 1:Location of the study area and the rain gauge network

The 6- minutes temporal resolution gauges were disaggregated to 5 minutes using a moving six hours window centered around the target time step. Both the 5 and 6 minutes rain gauges were also aggregated to 30 and 60 minutes.

The technical characteristics of the radar are specified in Table 1

Table 1:The X-band radar characteristics

A	B
Transmitted frequency	9.41 GHz
Peak power	24 kW
Pulse length	80 ns
Pulse repetition frequency	2100 Hz
Antenna information	*Parabolic with fixed elevation (5°), 2.5° power beam width at 3 dB*

3.1 Pre-processing of radar Data:

The radar have a radial resolution of 60 m, all non clutter radar pixels were interpolated on a 100*100 m grid. The X-band weather radar is well-known for being affected by attenuation. We use Hitscfeld-Bordan (1954) algorithm to correct the raw radar data, clutter is corrected through a clear sky radar reflectivity field corresponding to the study period (The summer of 2013).

The raw reflectivities Z were converted into rainfall intensities R using the Marshall Palmer relationship:

$$Z = 200 * R^{1.6}$$

We apply a Mean Field Bias correction (MFB) to the radar data , assuming that it is affected by a uniform multiplicative error. Goudenfoodt et al (2009) found that this method improves the agreement between tha radar and gauge data.

The MFB factor is expressed as:

$$MFB = \frac{\sum_{i=1}^{n} \mathrm{Gi}}{\sum_{i=1}^{n} Ri}$$

G_i is the rainfall intensity value corresponding to rain gauge i, R_i is the corresponding radar pixel.

Both the attenuation correction algorithm and the radar mean field bias correction method were used seperately then combined to see how it affects the KED and CM merging techniques.

4 Results:

The results are presented in Table 2. Att refers to the application of the attenuation algorithm, while “mfb” refers to the Mean Field Bias correction Method.

The performance assessment tests were applied on a small selection of the time steps where rainfall was detected by both the radar and the gauges for at least 12 of the 18 locations, and where a bright band have not distorted the data (visual check).

Table 2: Performance assessment results

		5 min			30 min			60 min		
		BIAS	RMSE	RVAR	BIAS	RMSE	RVAR	BIAS	RMSE	RVAR
No Att	OK	0.164	0.778	0.351	0.057	0.786	0.333	0.050	0.678	0.123
	KED	0.156	0.812	0.479	0.048	0.852	0.496	0.042	0.736	0.417
	CM	0.338	0.873	0.437	0.119	0.964	0.793	0.097	0.843	0.453
Att	KED	0.165	0.840	0.508	0.042	0.856	0.494	0.042	0.738	0.419
	CM	0.397	0.875	0.451	0.113	1.026	0.994	0.099	0.879	0.570
No Att mfb	KED	0.159	0.813	0.483	0.047	0.851	0.493	0.042	0.739	0.417
	CM	0.346	0.872	0.432	0.108	0.889	0.540	0.089	0.804	0.336
Att mfb	KED	0.170	0.842	0.514	0.044	0.855	0.492	0.047	0.736	0.420
	CM	0.367	0.863	0.426	0.095	0.913	0.587	0.086	0.821	0.392

One of the surprizing findings of this study is that KED have performed marginally better the OK. The attenuation correction algorithm and the mean field bias correction of radar data have not improved the performance of the two interpolation techniques at all, worsening it in most cases. The Conditional Merging technique performed the worst, it was slightly improved by the MFB method when it comes to reducing the bias and the root mean square error normalized by the average of the observations, however it reduced the variance ratio as well which was the only advantage it had compared to KED and OK.

The study is ongoing, the objective is to cover more seasons in order to investigate the effects of seasonal change in the drop size distribution of rainfall as well as their nature (stratiform, convective, mixed…) over the performance of the merging techniques.

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6 References

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