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Toward an error model for radar quantitative precipitation estimation in the Cévennes-Vivarais region, France

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1 Introduction

Characterizing the error structure of radar quantitative precipitation estimates (QPE) is recognized as a major issue for applications in hydrological modelling (Ciach et al. 2000 ; Habib et al. 2004). To go farther than assessing the mean field bias, we want to "equip" rainfall rate estimates with a relevant description of uncertainties in terms of bias, variance and space-time structure. A first approach was proposed by Delrieu at al. (1995) and Pellarin et al. (2002) with the "hydrologic visibility" concept which aims at quantifying a *potential* QPE error for radar systems operating in mountainous regions. This error is linked to the radar waves - ground interactions (ground clutter and screening) and on the vertical structure of the atmosphere. It also depends on the radar parameters (wavelength, beamwidth, operating protocol…). The validity of the concept was demonstrated within the HIRE'98 experiment (Berne et al. 2004) and it is now used by Météo-France for assessing the ARAMIS network.

However, characterizing the *residual* QPE error, that is the error after radar data processing, is even more important. We assume the residual between radar and reference value to be a random variable. We will describe radar error by mean of probability distributions. Due to the variety of the radar error sources and the complexity of the processing algorithms, the only practical solution is to assess the radar QPE with respect to reference rain estimates derived from rain gauge network. .A geostatistical framework is proposed here (section 2) for the establishment of such reference estimates. Basically, the variogram is used to both critically analyse the rain gauge data and to map the rain gauge rain fields. Then, the block kriging estimation variance allows to select a number of rain gauge estimates that can be considered as reliable for various integration time steps and domains.

This preliminary investigation of the radar error model leans on radar and raingauge datasets of the Bollène 2002 Experiment aimed at assessing the interest of a volume-scanning protocol for radar QPE in the Cévennes-Vivarais region. The dataset is composed of five intense rain events, among them the extreme event of 8-9 September 2002 in the Gard region (Delrieu et al. 2005). The space-time adaptative radar processing strategy under consideration hereafter is described in a companion paper (Boudevillain et al. 2006). The statistical distributions and the spatial and temporal structure of the residuals between radar and reference values are established and discussed in sections 3 and 4.

2 Reference rain

The rain gauge networks of the Mediterranean Cévennes-Vivarais Hydrometeorological Observatory (Delrieu et al. 2005) include about 500 daily raingauges and 150 hourly raingauges over a 32000 km² domain operated and maintained by several operational services. The rain gauge data quality control is performed by LTHE using a geostatistical approach (Fig. 1), based on the variogram of the rain gauge measurements. Let us recall that the variogram function is defined as half the expectation of the squared differences between rain gauge accumulations as a function of the interdistance between the points of observation. The distribution of the squared increments in each class of interdistance is evaluated and special attention is payed to its upper (above the 95 % quantile). The rain gauge stations involved, showing abnormal difference with their neighbours, are identified and the corresponding rain accumulations and hyetographs are screened.

The quality control done, we study the rainfall spatial structure with the variogram to map the rainfall field by using the kriging method. Let us recall that this method uses an estimator for evaluating the rain amount over a given geographical support which may be either a point or a domain (e.g., a hydrologic watershed). The kriging estimator is linear and forced to be unbiased and to minimize the estimation variance. The estimation variance is a by-product of the interpolation technique which allows to assess the estimation quality as a function of the rain field spatial structure and the relative position of the rain gauge network with respect to the geographical support of interest. We mapped rainfall fields for hourly (and greater) accumulation time steps over domains of 1 km², corresponding to the radar grid.

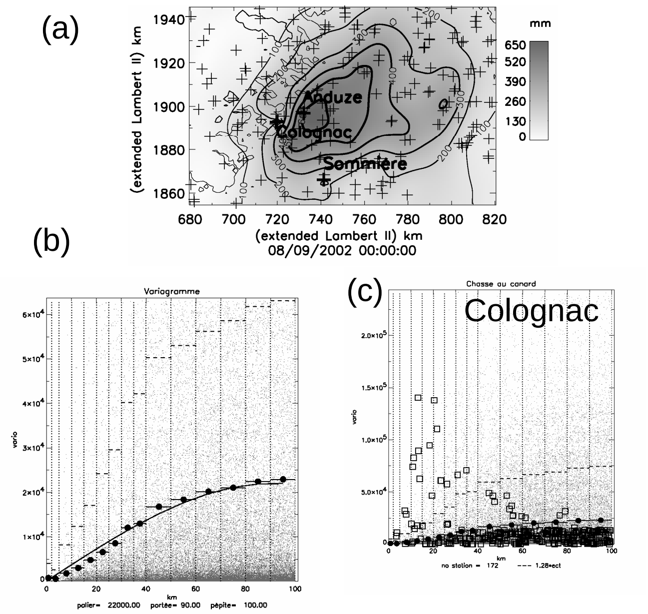

Fig. 1. Illustration of raingauge data quality control method for the 8-9 September 2002 rain event at the event timestep. (a) kriged raingauge accumulation data map ; (b) squared differences between rain gauge accumulations (small points) as a function of interdistance, with the mean value in each class (horizontal line), the fitted variogram model (continuous curve) and the 95% quantile (horizontal dotted line) of squared differences distribution in each interdistance class. Graph (c) shows the squared differences linked to a « suspect » rain-gauge station (Colognac). This case was uneasy to detect and assess because the station was located in a region with high rainfall gradients: it indicated a value of 160 mm while the neighbouring stations reported values between 200 and 700 mm ; a hyetograph check evidenced a telemetry breakdown of the station during part of the rain event.

Taking account of the rain structure through the variogram, we are able to produce maps of the 1-km² estimation standard deviations such as the one displayed in Fig. 2. Although, greater integration space steps are important to consider from a hydrologic perspective, we will limit ourselves hereafter to the 1-km² space step. It is clear from Fig. 2 that the domains with lower estimation variance are those containing one rain gauge. Case of larger domains will be studied in future research.

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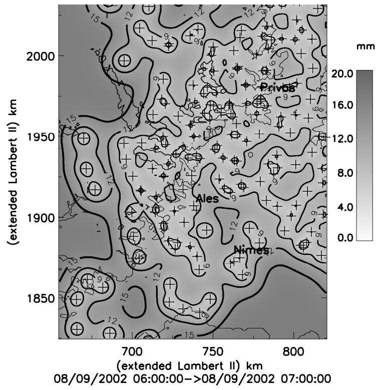

Fig 2. Estimation standard deviation map at the hourly time step over 1-km² domains for the 8-9 September 2002 rain event.

3 Error model : statistical distributions of the residuals

In that presentation of our first attempt to design an error model, we consider radar and referecnce values estimated on 1-km² radar meshes containing a rain gauge for the 1, 2, 6, 12 and 24-hours timesteps. We first analyse classical performance criteria of radar rainfall estimation compared to reference values. Then we consider the statistical distribution of residuals radar – reference as a function of rain rate estimation by radar (conditional distributions). The first two moments of the residual distributions are then modelled as functions of time step and distance from the radar.

Figure 3 presents the scattergraphs of radar versus reference rainfall for the 1-hour and 24-hours timesteps, with a distinction as function of the radar range (comparison meshes located below and above a range of 60 km from the radar site. Let us first consider the impressive rain-rate ranges with maximum values of 120 mmh^{-1} and 25 mmh^{-1} at the hourly and daily timesteps, respectively. Such extreme values occurred mostly during the 8-9 september 2002 rain event in the Gard region. Analysis of the means, determination and Nash criteria shows that: (1) bias is relatively low near the radar and tend to increase at long range and for higher timesteps ; (2) the determination and Nash criteria are rather good and similar for the hourly timestep for the two range classes with values of about 0,70 ; (3) there is a clear (and continuous) improvement of the results as function of the integration time steps, e.g. with Nash values of about 0,93 at close range for the daily timestep. Note also that the heteroscedasticity observed at hourly time step decreases with accumulation timestep.

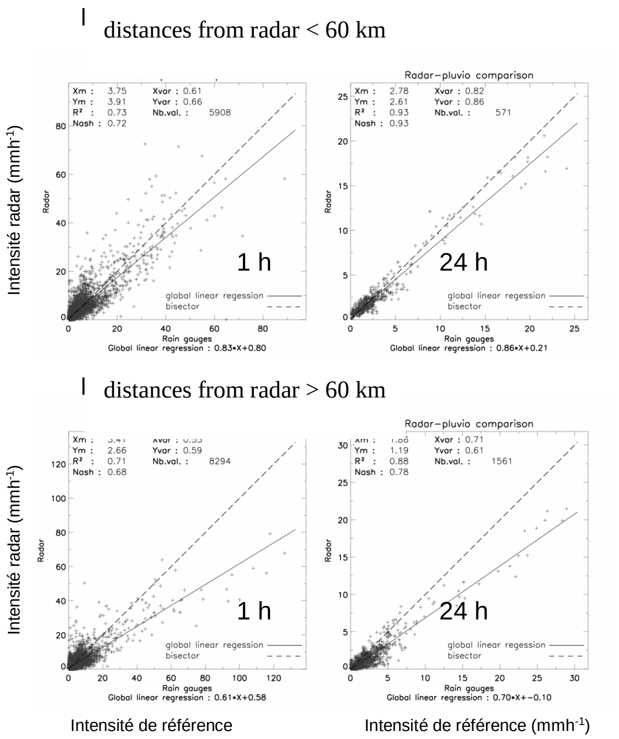

Fig 3. Radar–raingauges comparisons at hourly time step (left) and daily time step (right) on 1 km² domains with a raingauge, for two class of distance from the radar (closer and farther than 60 km).

To go further, Fig. 4 presents an attempt to model the residuals between radar and reference values as function of the radar intensity.We want to describe radar rainfall estimation error structure. For all the time steps and distance intervals considered, symmetric distributions (Gaussian or better centered exponential models) were found to conveniently approximate the empirical distributions.

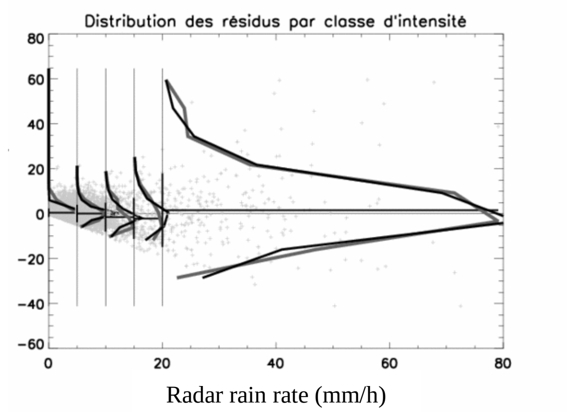

Fig 4. Distribution of the residuals (i.e. radar-reference) for several radar rain rate classes at the hourly time step (all ranges). Empirical distributions are in displayed with the grey curve and exponential model fitted is represented by the black curve.

These models have two parameters: the first two distribution moments, i.e. the mean and the standard deviation. It is shown in Fig. 5 that these two parameters can be conveniently approximated by linear functions of radar rain rate. For the mean, we confirm the underestimation trend at large distances from the radar. There is however no clear relationship of the mean with the integration timestep. The 24-hour mean curves are notably different from those corresponding to shorter timesteps. Standard deviation have a more regular evolution than the mean, with a linear increase with radar rain rate, a decrease with the integration timestep and an increase with distance from radar. Although, such statistics probably still lack of robustness, they allow a preliminary assessment of the radar errors for various rain rates, integration time steps and radar ranges.

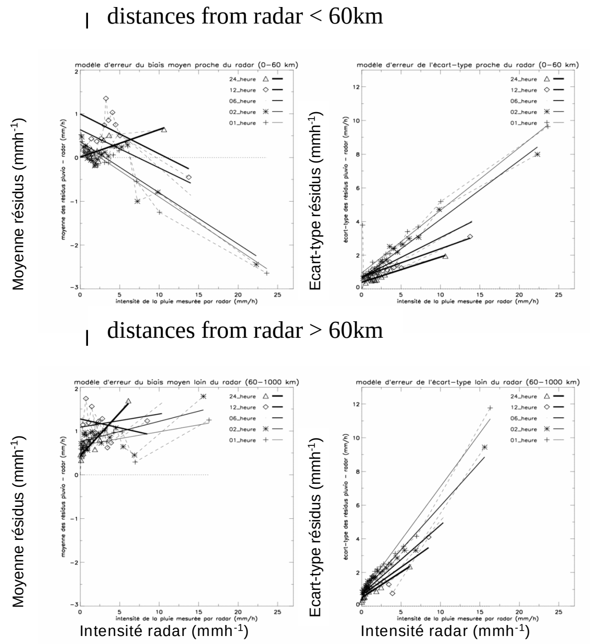

Fig 5. Expectation (left) and standard deviation (right) residuals evolution as a function of radar rain rate estimation for several time steps near (top) and far (bottom) from the radar.

4 Error model: space-time structure of the residuals

Describing radar rainfall uncertainties in terms of bias and variance needs to be complemented by the characterisation of the residual structure both in the space and time domains. That will enable to design fields of radar rainfall error by mean of conditional simulation of residuals in further study.
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Spatial variograms of reference and radar estimates are displayed in Fig. 6, together with the variogram of the residuals. We fit spherical models of variogram that are defined by three parameters, among them the range which correspond to the decorrelation distance of the measurements, and the nugget value which parameterizes a possible discontinuity of the variogram at the origin. This discontinuity may be due to the process variability at scales poorly resolved and/or to measurements errors. Variogram of residuals are also fitted by a spherical model.

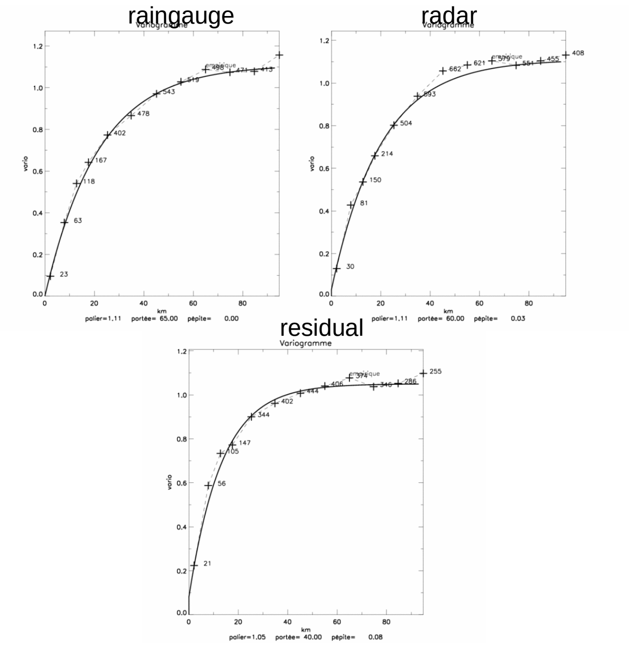

Fig 6. Spatial variograms of raingauge values (left), radar estimations (right) and residuals (bottom) for hourly time step.

It is noteworthy that the radar and reference variograms are very similar. The variogram of the residual has a smaller range compared to the radar and reference variograms but presents no nugget effect. Ideally, for a perfect radar data processing with respect to the reference values, the variogram of the residuals would be characterized by a pure nugget effect (nugget equal to the sill). Therefore, from the variogram analysis, it can be concluded that the radar data processing is efficient (reduction of the range) but still can be improved (the residuals still remain correlated in space).

We see also in Fig. 7 a real temporal correlation structure of the residuals at the hourly time step, despite the fact that the nugget is greater than for spatial one.

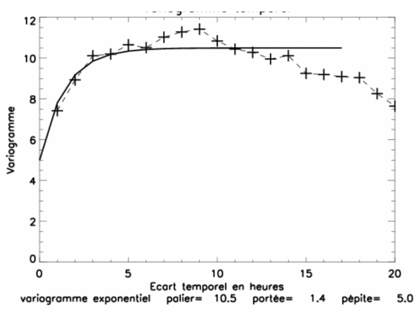

Fig 7. Temporal variogram of residuals at hourly time step

5 Conclusion

We presented a preliminary version of an error model for radar QPE. It was designed upon radar and reference rainfall data derived from raingauge measurements using a geostatistical framework..We consider residuals between radar estimations and raingauge reference accumulations for 1-km² domains (containing one rain gauge) and for 1, 2, 6, 12 and 24-hours timesteps.

The model consists in a random error, described by a random distribution, to be associated to rainfall estimates to approximate true rainfall. The distribution is conveniently approximated by a Gaussian model or better a centered exponential model. It can be parameterized by the mean of the residuals (global bias of rainfall estimation by radar) and their standard deviation.

This parameterization depends on the rain rate, the integration time step and the distance from radar. A detailed analysis of different rain events of autumn 2002 (not illustrated here), shows we could expect also dependence on the rain type (deep convective versus orographic processes).

Residuals show spatial and temporal structure which have to be taken into account for rain field simulation.

We expect to increase data set upon which the error model is designed within the establishment of rain re-analysis over the period 2000-2006 in the Cévennes-Vivarais region. The hourly rain gauge data set will be reserved for the reference rainfall and error model parameterization. In a further step, we will develop a conditional simulation of the residuals in order to derive ensemble QPEs that will be used to assess the impact of rainfall uncertainties upon hydrological modelling at the regional scale.

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