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Hydrology and Earth System Sciences Discussions

Interactive comment on "Uncertainties on mean areal precipitation: assessment and impact on streamflow simulations" *by* L. Moulin et al.

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1 General answer to the referees

First of all we wish to deeply thank Pr. Pegram and the two anonymous referees for the accurate and helpfull review of our manuscript. In other authors comments, we list how each of the remarks provided by the referees was adressed. The comments made by the referees will be refered as RC and printed in bold ; the authors comments and answers as AC. We summarise hereafter the main changes that were applied in the paper with respect to the main criticisms.

1.1 Concerning the choice of a climatological variogram

Some comments or questions of referees indicate that the interpolation approach was not perfectly clearly presented in the original version of the manuscript. The beginning of section 3.1 has therefore been reformulated in a clearer way. In particular, we underline in the new version that the interpolation method is applied not directly to the rainfall intensities, but to the intensities divided (normalised) by the rainfall field standard deviation (normalised variogram is a typical choice in climatological kriging).

1.2 Concerning the choice of a AR(1) error model

We have to precise here that of course, the selected error model, which remains simple, can not perfectly account for the probably complex statistical structure of the rainfall interpolation errors. Some approximations were made and ackowledged (the use of a climatological, isotropic variogram, the choice of a first order dependance model of errors, the use of a spatially uniform correlation parameter, the extrapolation of a model validated on point errors to MAP errors, etc.). We do not pretend to perfectly represent the rainfall fields and the residuals on their estimates : the available data do not allow us to get a perfect picture of those rainfall fields, and then, of the interpolation errors and their temporal structure. Nevertheless some analyses and some previous works can give arguments to confort our choices :

1. A first evidence is obtained from the cross-validation at a gauge site : when the gauge observed values are hiden and estimated with kriging, the residuals between kriged and observed values have some temporal structure. On our study case, for 1h-lag, the auto-correlation function coefficient is around 0.6 for normalised errors and 0.2 to 0.3 for non normalised errors.

2. When radar data are available, it is possible to derive an indirect estimate from

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the radar and compare it with the observed value. In that case there may be a systematic bias (underestimation by the radar) but quite often there is also a temporal structure in the error *(see e.g. Kirstetter et al. (2008))* which may look autoregressive as a crude approximation. The correlation decay seems variable with the intensity of the event, probably according to its degree of convection.

3. Finally, we aim at estimating error on a mean areal precipitation, i.e. an integrated value. In this case, there is not any observed reference (this could be another estimation with a much denser network, but in our case we have not such). However this could again be an areal estimate based on radar estimation, by summing the pixel values over the catchment of interest. Unfortunately, a good radar information is not available over this study area. Nevertheless, this kind of study has been done on another catchment (Ardeche at Vogue (Datin, 1998), about 650 km^2). The differences between kriged and radar estimates of MAP proved also serially correlated, roughly first order autoregressive with $\rho \approx 0.7$ for normalised errors on MAP.

Thus following a pragmatical approach, we wanted to get a model, simple and, as far as possible, consistent with observations. We chose a AR(1) model.

1.3 Concerning the choice of a constant (spatially uniform) temporal correlation coefficient ρ

ρ does theoretically vary with (i) the surrounding raingauge network (topology and resolution), (ii) the size of the considered area, and (iii) the size of rain cells and their speed of advection compared with working time step (here 1 hour). The selected error model is simple and cannot perfectly account for the complex statistical structure of the rainfall interpolation errors. Moreover, values of ρ were computed on an important number of hours (various events and various raingauges). Then obtained value is a mean value, and to get a more accurate error model, segmentation process should be done. However, when it is computed (for instance with a ACF-1) on the 40 raingauges available for this area, it appears that it does not vary too much from one raingauge to the another (for normalised errors, the 40 computed values of ρ range in [0.4–0.7]). It's why, we considered that a constant – in space (over catchment) and in time – ρ value can be taken with satisfactory. We do not know which is precisely the impact of the stationnary structure of variogram on the uniformity of ρ.

1.4 On the Figure 6

Referees depicted an error in Figure 6 (the wrong figure was included in the manuscript. This is now corrected (please see figure in final response file and final manuscrit)). Pictures have been mixed during the preparation of the manuscript. The initially proposed Fig. 6 corresponds to the Mazet rain gauge and the second one to a ρ value of 0.8. Many thanks to the referees for having depicted this error.

1.5 On the results and comments of Table 5

We modified the comments on Table 5. As mentioned by all the referees, the comments did not agree with the figures presented in the table. The reason is that these comments corresponded to results previously obtained with other confidence intervals (70 and 80%) and were accidentally not readjusted in the final version of the manuscript. Many thanks to the referees for having depicted this error.

1.6 Minor modifications of the manuscript

The suggestions and corrections of the referees on the text (and grammatical corrections of Pr. Pegram) were almost all taken into account.

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1. P. 2070, Line 7 : text replaced by ”The main contributions of the present work are the effort made to build, calibrate and validate a realistic error model on MAP estimates and the detailed analysis of the link between MAP estimation uncertainties, catchment area and streamflow simulation uncertainties”.

2. P. 2073, Line 16 : ”These methods, and in particular ”climatological” kriging,” (Added to have an immediate reference to climatological kriging).

3. P. 2074, Line 15 : ” The kriging was performed in a standardised mode, which means that instead of working on the absolute values ($P_t(x_0)$ or $MAP_t(S)$), these values are standardised by the variance of the field ${SD^2}_t$ (empirically computed on a window covering the largest of the study catchment). In that case the normalised field variance, and the sill of the variogram, is brought to 1. Next the following assumptions were used :” (Added).

4. P. 2074, Line 16 : ”of the rainfall intensities divided by the estimated standard deviation of rainfall field SD_t”. (Added to clarify the notion of normalised variogram).

5. P. 2075, Line 4 : ”(taken here as spherical)”. (Added).

6. P. 2075, Line 12 : ” Note that since with these hypotheses, the weights λ change only if the neighbourhood used for kriging and therefore the available network of stations changes. It must also be mentioned that the estimation residual for a point normalised value $p_t(x_0)$ is at the maximum (when x_0 far from every raingauge) equal to its field variance SD_t^2 set to 1. For the absolute value $P_t(x_0) = p_t(x_0) \times SDt$ rainfall field standard deviation, its residual is also rescaled by this rainfall field standard deviation.” (Added).

7. P. 2076, Line 1 : ”Since the normalised variogram is supposed to be constant”. (Added to recall the notion of normalised variogram).

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8. P. 2077, Line 8 : the short expression "of rainfall field variance at the location" is replaced by the more rigorous expression "of the normalised rainfall field variance at the location".

9. P. 2078, Line 26 : "Note that, the proposed model does not affect the standard deviation $\bar{\sigma}$ of the normalised interpolation errors. $\bar{\sigma}_t$ does only changes if the rain gauge network structure changes, which rarely happens within a rainfall event." (Added).

10. P. 2079, Line 14 : " It is important to mention that there is no constraint on the value of the interpolation error in the proposed model (Gaussian distribution). The addition of a randomnly drawn error to an interpolated intensity may therefore provide negative intensity estimates. The analysis of the Monte Carlo simulations conducted (see the next section) revealed that 6 to 7% of the simulated intensities are negative accounting for 2 to 3% of the total rainfall amounts. The percentage depends on the location or catchment area considered. Negative values are only generated for low intensities ; they are generally only slightly negative and do therefore not significantly affect the major rainfall events of the studied series. For the purpose of rainfall-runoff simulation, these negative values were set equal to zero." (Added.)

11. P. 2081, Line 19 : "Figure 5 also reveals another feature of the proposed error model. The standard deviation of the interpolation error depends of the standard deviation of the rainfall field SD_t. It is fluctuating but shows a general tendency to increase when the measured rainfall intensity increases." (Added).

12. P. 2082, Line 4 : "Machabert" replaced by "Goudet".

13. P. 2082, Line 15 : "0.6 is also the average 1-hour lag autocorrelation of the normalised interpolation point rainfall error series." (Added).

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14. P. 2082, Line 22 : ”The selected constant correlation coefficient (0.6) has been adjusted to slightly underestimate the quantiles of the error distributions at all validation sites (Table 3). The error model will thus have a general tendency to underestimate the rainfall estimation errors and hence their effects on RR simulations. 0.6 is also the average 1-hour lag autocorrelation coefficient of the normalised interpolation point rainfall error series.” (Removed).

15. P. 2082, Line 22 : ”Although it could not be directly verified, according to the properties of the model presented in the previous section and to the stability of the temporal correlation coefficient, it can be assume that the proposed model certainly also provides reliable MAP estimation error series.” (Added).

16. P. 2086, Line 25 : "This last conclusion holds for the given gauge network structure and density." (Added.)

17. P. 2087-2088 : text modified.

18. P. 2098, Table 4 : Caption replaced by ”Root mean square range (RMSR) of hourly precipitation P (in mm/h) and on streamflow Q (in mm/h) computed for 50%, 80%, 90%, 95% and 100% various confidence intervals.”

19. P. 2104, Figure 5 : Caption replaced by ”Point hourly precipitations ranked in ascending order versus corresponding interpolated values (cross validation) plus or minus computed standard deviation (grey lines). Mazet raingauge.”

20. P. 2105, Figure 6 : Error in inclusion of figures was corrected ; characters and symbols were increased. Caption was modified : ”Comparison of characteristics of distribution of simulated (with the AR error model, left : no temporal dependence ; right : temporal dependence with a correlation of 0.6) interpolation errors (red arrows for mean $\pm$ standard deviation ; blue ’+’ for 2.5 and 97.5 percentiles) accumulated over 1 to 24 hours at Goudet raingauge with those of observed

interpolation errors obtained with a cross validation process (black crosses 'x' for mean ± theoretical standard deviation ; black triangles for 2.5 and 97.5 percentiles)."

21. P. 2110, Figure 11 : This figure was removed.

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Table 1. For each one of the three studied catchments, number of raingauges contained in the catchment area (col. 3) and the corresponding density (col. 4) are computed. The same computations (col. 5 & 6) are made for the total number of raingauges contained in the catchment or whose the distance to the catchment is less than the range of variogram (25 km). In the last column the normalised theoretical error standard deviation computed with all the available network is indicated.

	Area (km^2)	Nb rain gauges in	Density ($1/km^2$)	Nb raingauges in range	Density ($1/km^2$)	Normalised error St Dev (mm/h)
Rieutord	62	2	1/31	17	1/4	0.283
Chambon	139	3	1/46	21	1/7	0.209
Bas-en-B	3234	32	1/101	40	1/81	0.130