

Precipitation paper, M. van den Berg, Referee #3

The authors present an interesting investigation into the temporal error structure of spatial rainfall fields. They employ this error structure to generate consistent ensembles. Furthermore, they investigate the effects of temporal correlation on the error, which is of significant interest in hydrological settings.

MAJOR REMARKS The article is well written and fits well in the scope of the journal. Also, its scientific contribution is large enough. However, I do have a few significant comments

Answer: We thank Martinus van den Berg (Referee #3) very much for his constructive review. Below you will find our response to the comments raised by Martinus van den Berg

1) I am unclear why the authors chose to use such a simplistic rainfall cell, rather than use a (slightly) more realistic gaussian kernel design.

Answer: The choice for the selected “circular-shaped” rainfall cell was rather arbitrary. We could have analysed more realistic and complicated rainfall cells, but for the synthetic sensitivity analysis we wanted to apply a simple and easy to understand cell. Next to that, it gives a similar variogram for each time step.

2) I feel that the real world experiment is discussed far too briefly. For example, certain comments are made about the real world semi-variogram, which is never shown. Also, how do the mentioned rainstorms look, and what statistics do they have (besides the autocorrelation). Although the authors refer to another study, some of this information should be repeated here, and study specific data should be shown.

Answer: We will elaborate on the real world data more in detail. However, we would like to point out that some statistics (duration, advection speed, mean and standard deviation) of three real rainstorms are provided in Table 1. In the revised manuscript, we will use real world data to illustrate the direct and cross-semivariogram in Fig. 3 (see answer to comment #6 by Reviewer #2) and we can show three snapshots of the precipitation field observed by the weather radar. Additionally, we will include validation of the presented results on the three real world events in Section 3.3. (see our answer to reviewer's comment #4).

3) The authors seem to implicitly extend many of the conclusions of the synthetic study to that of the real-life study. However, due to the simplistic nature of the synthetic experiment, I highly doubt that this is possible. Furthermore, solid comparison between the synthetic case and the real life case, e.g. through the semivariogram, is not made thus asking the reader to make a leap of faith. I would try to show that the two experiments are comparable,

Answer: The synthetic example is merely used as a sensitivity study to understand relevant space/time scales of precipitation and not for comparison between synthetic and real world data. Therefore we will change the name of the analysis from “synthetic experiment” into “sensitivity analysis” not to confuse the reader.

4) The authors seem to investigate the effects of various conditions on the temporal correlation for synthetic experiments (see 3 and 1 as well) rather than building an ensemble generator. That is, as far as the building of a ‘plausible ensemble precipitation generator’, without validating this for real(istic) fields, and comparing it to ‘unobserved’ (as far as training is concerned) fields, I am skeptical about this. I would either include such a section, or consider repositioning the paper, or including a validation on real(istic) data.

Answer: Yes, we will include a validation analysis of the presented results on three real world events in Section 3.3. This corresponds with the recommendation by Anonymous Referee #2. As follows:

To verify the accuracy of the presented method, validation was carried out in the terms of the mean

error. The mean error is defined as the difference between the rain gauge observation and the corresponding across ensemble mean ($\mu_{J,t}$, Eq. 5). The rain gauge observations employed in the validation were independent from the data used for simulation. To simulate the precipitation fields, 14 rain gauges out of the complete observation network of 27 rain gauges were used (Fig. 6b in the manuscript). The remaining 13 rain gauges were kept for validation and their mean errors were calculated for all time steps and for all eight simulation memories (dashed histograms in Figure I). Additionally, we compared those validation mean errors with the simulation mean errors at the same 13 locations. These simulation mean errors were obtained by simulating precipitation fields using all 27 rain gauges (grey histograms in Figure I). Figure I shows that the validation mean errors at the unobserved locations are unbiased and have consistent behaviour over all simulation memories (dashed histograms in Figure I). Furthermore, the histogram of validation mean errors have smaller peaks than the simulation mean errors. This increase in uncertainty can be expected, because in the validation only half of the rain gauge data are used to simulate spatial precipitation fields. Note that the spread in histograms agrees well with the corresponding standard deviations shown in Table 1.

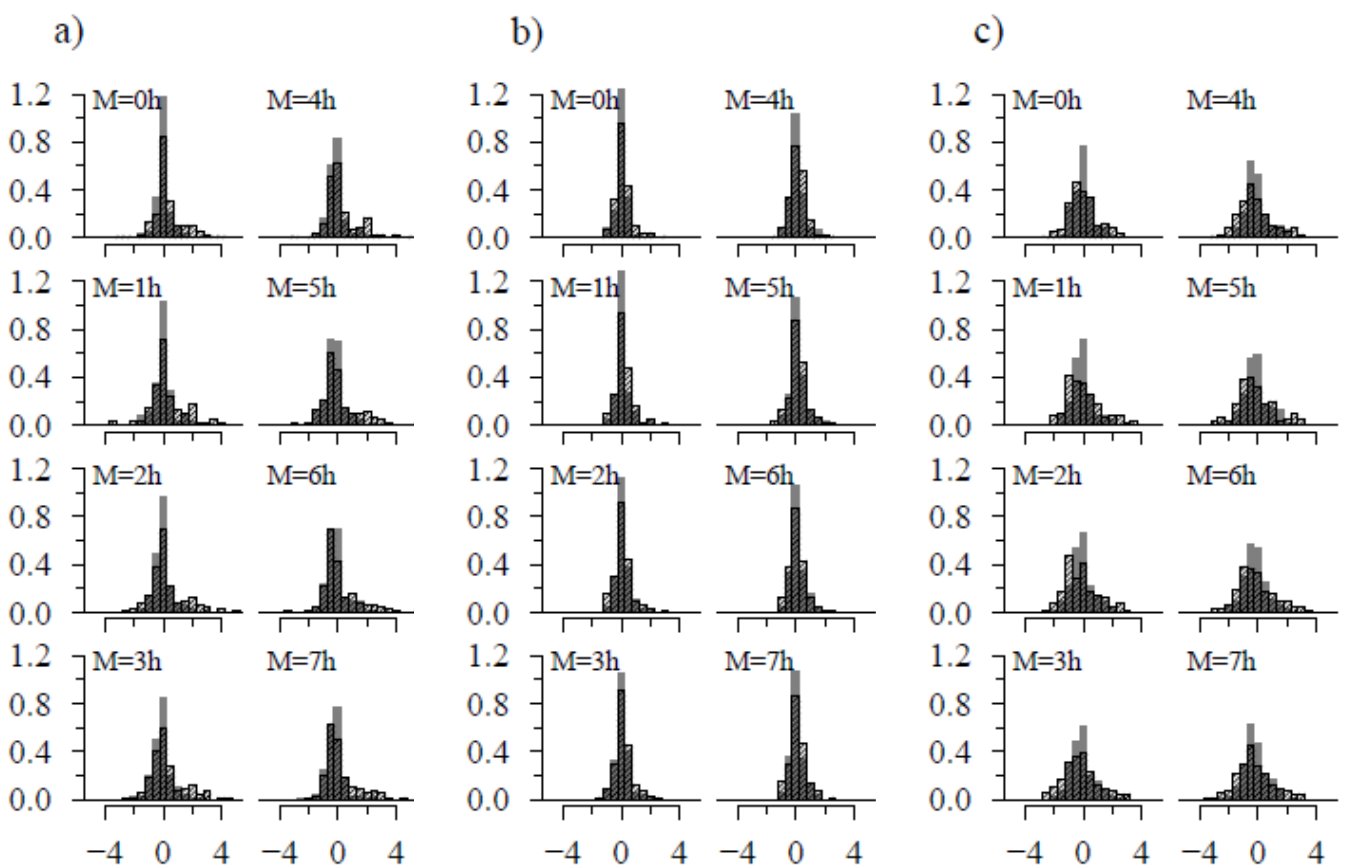


Figure I: Validation for three real world events: a) 22 October 2002, b) 22 December 2002 and c) 1 January 2003. Histograms of the validation mean errors at 13 rain gauges (dashed histograms). Histograms of the simulation mean errors for the same 13 rain gauges (grey histograms).

5) As a semi-major remark, I would include a diagram or very clear and concise description of the experimental setup. These papers can be incredibly hard to read, and I think that having such a figure or list to hold on to when reading the results/conclusions would dramatically improve readability.

Answer: We think that adding a diagram would repeat the description of the experimental setup, which is already described in bullet points on Pages 3096-3097 (Sections 2.5.2 and 2.5.3.) + corresponding figures 5 and 6. So we would prefer to leave out the diagram. However, we shall have a critical look at these bullets in order to ensure its contents are both concise and understandable.

I gather that the authors create a synthetic rainfall field, and then 'measure' it with rain gauges. Based on these gauges, the semivariograms (in space-time) are determined and an ensemble is generated with conditional simulation based on both temporal and spatial variograms. These fields are then statistically compared with the 'true' fields, and the efficacy of the method observed.

If that is correct, I have another remark:

Answer: Yes, you are correct.

6) How do the authors condition on previous fields? Nowhere do I see a temporal/spatial semivariogram, and if the shown semivariograms are already conditional on the previous fields, nowhere is it shown how this influences the shape.

Answer: The multivariate simulation for realization j and time t is conditioned on:

a) rain gauge observations at time t and **b)** previously simulated realizations j at times $(t-1, t-2, \dots, t-M)$, where M is the memory of the system (Page 3094, line 18). This means that the observed precipitation by rain gauges at times $(t-1, t-2, \dots, t-M)$ is substituted by the simulated fields, which encounter all the points from the whole simulation grid.

We did not show the difference of the temporal/spatial semivariograms based purely on rain gauge observation and in combination with the simulations at times $(t-1, t-2, \dots, t-M)$. The presented variograms in Fig. 8 are based only on rain gauge observations.

TECHNICAL REMARKS

The authors refer to a 'plausible precipitation ensemble generator', they should elaborate on what this entails.

Answer: In the introduction and in the abstract, we will describe more clearly our aim of developing/testing such a plausible precipitation ensemble generator. However, currently this is explained at the end in Summary and Conclusions on Page 3104, last paragraph. Additionally, we will add a reference to Rakovec et al. (2012), the actual hydrological application of the presented spatial precipitation ensemble generator, which is currently under review for HESS in this special issue on "Latest advances and developments in data assimilation for operational hydrologic forecasting and water resources management".

Rakovec, O., Weerts, A. H., Hazenberg, P., Torfs, P. J. J. F., and Uijlenhoet, R. (2012) State updating of a distributed hydrological model with Ensemble Kalman Filtering: effects of updating frequency and observation network density on forecast accuracy HESSD, 9, 3961-3999, doi:10.5194/hessd-9-3961-2012

The authors consistently refer to the raincells as spherical, however, they are circular (as they are 2D) or, more technically, disk-shaped.

Answer: We thank the reviewer for this remark. Proper description seems to be "a circular-shaped rainfall cell" (because of 2D), which was suggested by Anonymus Referee #1. We will change this

in the revised manuscript.

I assume that the variograms are fitted using the gstat package, this should be acknowledged.

Answer: Yes, the variograms are fitted using the same R package gstat, which will be more explicitly acknowledged in the revised version.

Figure 2 appears to be somewhat useless. The authors should either use it, or remove it.

Answer: Figure 2 is shown to illustrate the autocorrelation coefficients of the real areal data. Figure 2 shows that the time/memory scales of the precipitation are highly relevant and that the memory follows the traditional exponential decay. We will refer back to it when we will discuss the recommended simulation memory of 2-3h for the real world simulations.

The interpretation and use of Figure 9 isn't completely clear to me. In the paper, it apparently corroborates various findings, but I am not entirely sure how.

Answer: Figure 9 is shown to illustrate the temporal variability of individual ensemble members and to visualize temporal coherence (Page 3099, lines 9-16). Indeed, the individual lines are very difficult to distinguish. We will try to improve the readability of this figure or elaborate more on its content within the text.

As a final remark, I find the paper very interesting indeed. However, it appears to lack a clear goal to which all experiments and questions are geared. This makes it hard to read, and difficult to really get a handle on. If the authors have questions regarding my review, feel free to contact me at: Martinus.vandenBerg@Ugent.be

Answer: We will provide this clear goal in abstract and in the introduction in the revised manuscript.

The main goal is to present and analyse a technique to generate spatial precipitation ensembles, which can be easily implemented within a hydrological data assimilation framework to be used as an improvement over currently used simplistic approaches to perturb the interpolated point or spatially distributed estimates (as referred to in the introduction). As shown in the current study, using the time-dependent rainfall simulations with at least one hour simulation memory, but preferably longer, we were able to reach this goal and obtain precipitation ensembles with temporal correlation structures that are plausible from a hydro-meteorological perspective. Therefore, the corresponding simulated spatially distributed hydrological model states obtained by that ensemble should inherit this temporal aspect as well. The advantage of having the temporal coherence in model states is that it eliminates smoothing of possible extreme state values, which can be the case when neglecting it.

The actual hydrological application of the presented spatial precipitation ensemble generator (Rakovec et al., 2012) is currently under review for HESS in this special issue on "Latest advances and developments in data assimilation for operational hydrologic forecasting and water resources management".

We will provide the clear goal in abstract and in the introduction in the revised manuscript.