

Interactive comment on “Copula-based assimilation of radar and gauge information to derive bias corrected precipitation fields” by S. Vogl et al.

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We greatly appreciate the detailed, constructive, and thoughtful comments of Referee 1. These comments will be individually addressed in the sequel. Please note that the Referee’s comments are bolded and our responses are in regular font format.

General Comments:

The manuscript addresses the problem of combining radar information and gauge measurements by using a novel approach based on copulas. Two methods have been introduced: the Multiple Theta Approach and the Maximum Theta Approach (section 3.3). These methods are grounded on the estimation of the

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parameter of the copula joining the dependence between radar and gauge data. I have three main comments on this procedure.

1) In order to apply these methods the dependence structure (i.e. the copula) between the data should be uniquely selected. However, it may happen that two or more copulas seem “good” for the problem at hand (for instance, a formal goodness-of-fit test gives no evidence against them).

Only the Maximum Theta approach is restricted to cases where one single (one-parametric) Copula can be identified, as the procedure includes the choice of a maximum Copula parameter. This is not the case for the Multiple Theta approach. Here, for each possible radar-gauge pair (in this study 31x10000) marginals, and each possible pair (radar,gauge) can be assigned to its optimal Copula model. The random samples are simulated from this model, are backtransformed to the data space with the respective marginal distribution and are finally combined by IDW. Thus the Multiple Theta approach gives full freedom to the choice of the Copula model and the marginal distributions. In this study the GoF-tests showed that it is possible to restrict the procedure to only one (one-parametric) Copula family. This allows to apply the Maximum Theta approach and reduces the computational effort. Details about the applicability of the Maximum Theta and the Multiple Theta approach are now given in section 3.3.1 and section 3.3.2.

2) The methods are based on the implicit assumption that the copula is described by one parameter. This could be quite restrictive, since, for instance, data with both lower and upper non-trivial tail dependence coefficient are more conveniently described by mult-parameter copulas.

The Multiple Theta approach is also suitable for Copula functions with a multidimensional parameter space (as e.g. the Student-T Copula). Only the Maximum Theta approach is restricted to one-parametric Copula families as the algorithm includes finding the maximum of the estimated Copula parameters for each radar grid cell. We address

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this issue in section 3.3.1 and section 3.3.2 of the revised manuscript.

3) When the copula is known, the methods are based on the estimation of the parameter. Now, the following problems should be explained better in the paper: - how are these parameters estimated? - how much robust are the methods with respect to the estimation method used in getting the parameters? It is known, in fact, that different methods (maximum-likelihood estimation, estimation based on Kendall's tau, etc.) may produce quite different results.

For this study we checked two different methods for parameter estimation namely Kendall's tau and a maximum pseudolikelihood-approach. The two methods lead to relatively small differences in the calculated theta values. However, the results of the GoF-tests remained unchanged, still allowing to use the Gumbel-Hougaard Copula for all radar-gauge pairs. There was also no significant difference for the finally simulated precipitation fields. Therefore we only presented results obtained by maximum-pseudolikelihood estimation which is more comfortable for Copula functions with multi-dimensional parameter space (e.g. Student-T Copula). More details about the different ways to estimate the Copula parameter were included to the revised manuscript in section 3.2.1.

II. Specific Comments:

- Formulas (20) and (21) are wrong

The formulas have been checked and corrected.

- Page 4, page 952: please, give full details about the methods for testing the absence of autocorrelation.

Autocorrelation functions (ACF) and the Ljung-Box Q-test have been applied. We clarified this issue in section 4 of the revised manuscript (see Fig. 4 and Tab. 4). Please see also the answers to the comments of referee 2 for more details.

- Page 4, page 952: please, clarify how absence of heteroskedasticity has been

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tested.

Heteroskedasticity has been checked by the ACF of the squared values and further tested by the Ljung-Box Q-test for the squared values. Details about the revised tests are given in section 4. The test results are given in Tab. 4 for three stations exemplarily.

- Page 953, section 4.1: some formal goodness-of-fit test could be used to validate the choice of the marginals.

We applied both Kolmogorov-Smirnov and Chi-Squared tests (results have not been shown in the first draft). The details about the choice of the marginal distributions are now given in section 4.1 (see also Tab. 5).

- Page 953, section 4.2: while the empirical copula density is asymmetric with respect to the opposite diagonal, the Frank copula is used for modelling the data. This is not satisfactory, since Frank copula cannot capture this asymmetry.

As for the revised manuscript the calculations had to be repeated for the iid-residuals the results of the Copula GoF-tests now show that the Gumbel-Hougaard Copula has to be favoured. This Copula is symmetric with respect to the major, but asymmetric with respect to the minor diagonal of the unit square. This is consistent with the characteristics of the data as a comparison with the empirical Copulas shows (empirical and theoretical Copula are presented for one station exemplarily in Fig. 6).

- Page 958, section 4.4.2: Instead of the standard correlation, I would use some concordance measure like Kendall's tau in order to validate the result. In fact, Pearson correlation measures only linear dependence.

The results of Kendall's tau are now given in Tab. 7 and Tab. B1 to supplement the validation.

- Page 959, section 5: The use of ARMA-GARCH filter to daily precipitation data should be better explained. Is there some volatility cluster in these data? Should the seasonality also be removed? I think that GARCH models have a natural in-

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terpretation in financial time series, but I do not see their relevance with precipitation data. Please, explain better.

Rainfall data are affected by autocorrelation as well as volatility (non-stationary variance) to a certain degree. This can be confirmed by the Ljung-Box-Q test as well as ACF of original and squared values. By application of an ARMA-GARCH transformation both effects can be remarkably reduced and iid variates can be obtained which are required for the further analysis. Seasonality means serial correlation and has to be removed. In our case, an ARMA(1,1)-GARCH(1,1) time series model is shown to be sufficient (see Tab. 4). The relevance of ARMA-GARCH for hydro-meteorological applications is elaborated in detail by Laux et al. (2011). Details about this important issue are now also explicitly addressed in section 4. Please see also our answers to the comments of referee 2 for more details.

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