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Hydrology and Earth System Sciences Discussions

Interactive comment on "Copula-based statistical refinement of precipitation in RCM simulations over complex terrain" *by* P. Laux et al.

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First we want to thank the referee for his thoughtful and constructive comments in order to improve the quality of the manuscript. The comments are addressed in detail below.

REFEREE #1: 1 Introduction The manuscript under review uses copulas in order to describe the dependence between modelled and observed precipitations, conditionally on the prevailing large-scale whether situations. The main goal of the manuscript is to show that, knowing the link (the copula) between observed and modelled precipitations, one could reduce the discrepancies between simulated and observed rainfalls. The manuscript presents a novel procedure with some interesting applications. However, in order to provide a more substantial contribution, I would invite the authors to revise

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the manuscript and to devote more attention to a number of aspects that I am going to illustrate.

2 General comments 2.1 ARMA-GARCH time series models As illustrated in section 4.1, the original time series exhibit serial dependence. In order to describe it, an ARMA-GARCH model is adopted. Now, the graphs of figure 3 do not completely support such a choice. I wonder whether a simple ARMA (or GARCH) model could be useful as well. In order to convince the reader about this choice, I would suggest to discuss: 1. why simple models (like AR or MA) fail; 2. what are the orders and the parameters of the ARMA-GARCH model fitted to each time series; 3. what are the results of Ljung-Box Q-test (page 14, line 16).

ANSWER: A comprehensive discussion about the choice of ARMA-GARCH is inserted in the manuscript (see section "Analysis of ARMA-GARCH time series models"). More detailed it is elaborated: 1. the reasons for the failure of more simple models such as AR or MA, ARMA, or GARCH; 2. the order and the parameters of the ARMA-GARCH model fitted to both, the observed and the modelled time series. A table containing the single parameters for the selected 11 stations (see Table 1) is inserted (new Table 3). However, the authors would prefer to show the mean values of the fitted parameters for the selected 11 stations (new Table 2) in the final manuscript and leave out new Table 3; and 3. the results of the Ljung-Box Q-test for three typical types of autocorrelated observation stations and lags of 1, 5, 10, 15, and 20 days before and after the ARMA-GARCH transformation. A table showing the final test results is given in the new Table 4. The "Discussion" and "Conclusions" sections are also modified and extended due to these new and crucial aspects.

REFEREE #1: 2.2 Estimation of the copula models As said, the univariate time-series Mt and Ot related to modelled and observed rainfalls are serially correlated. As such, they have been transformed into other time-series Xt and Yt (the residuals of Mt and Ot, respectively) that are a random sample from a given distribution. Now, it is not clear from the manuscript whether Table 2 considers the copula of (Mt,Ot) or the copula

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of (Xt, Yt). Choosing between these two sets of paired observations makes a big difference! In order to get a full picture of this problem, one should refer to the paper V. Grégoire, C. Genest & M. Gendron (2008). Using copulas to model price dependence in energy markets. Energy Risk, 5 (5), 58-64.

ANSWER: The procedure how to model the dependence structure and how to generate finally random samples of bias corrected pseudo-observations is described in section 3 “Modelling the dependence structure between modeled and observed rainfall” and subsequently in the subsections. To clarify whether the residuals or the original time series are used to estimate the copula model section 3 has been slightly modified. Additionally, this aspect is again gathered in subsection 3.2.2. A reference is inserted here to point at the study by Grégoire et al. (2008) as proposed by the reviewer. In the section “Results” it is mentioned that Table 2 (now Table 5) refers to the residuals instead of the original values. As Table 2 (now Table 5) again refers to section 3.2.2 the authors think that it is not necessary to mention this explicitly in the capture of the table.

REFEREE #1: Following Table 2, I do not see strong motivations in favor of Gumbel copula. I think that other families of copulas should be considered as well, with particular emphasis on copulas that exhibit some upper tail dependence (for instance, survival Clayton copulas, Student copulas, extreme-value copulas, etc.).

ANSWER: We agree to the comment of the referee. However, we think that the three different Copula models considered are sufficient in the context of this study. The main goal of this study is to prove that the methodology, i.e. the Copula-based bias correction, works well, or at least provides a potential alternative to “traditional” methods. Of course, much more different theoretical Copula models could be tested additionally, but we think this is far beyond the scope of this “proof of concept” paper. However, as this comment is found to be valuable, we inserted an additional critical statement in the manuscript (sections section 4.2. “Analysis of the empirical and theoretical Copula models” and “Discussion”).

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REFEREE #1: 2.3 Conditional stochastic simulations The procedure of stochastic simulations should be described in detail in section 4.5. Moreover, I do not see any strong evidence of the fact that copula-based simulations lead to significant improvements. A detailed and serious simulation study should be conducted in several cases and, moreover, a clear performance measure should be adopted in order to convince the reader about the goodness of the proposed methodology.

ANSWER: The procedure is described comprehensively in section 3.2.3 “Copula-based rainfall simulations”. Section 4.5 is dedicated to present the simulation results. A reference to the theoretical background is inserted in section 4.5. By visual inspection one can see that the generated pseudo-observations follow more closely the observations when the RCM underestimates the observations. It is well-known that regional climate simulations usually underestimate observed rainfall. This benefit can be clearly demonstrated by means of Figure 10. For the other case, i.e. the RCM model overpredicts, the pseudo-observations are generally too high. We agree that is problem is not yet solved satisfactorily. As this paper is dedicated to present the Copula as an alternative to “traditional” bias-correction methods we would like to focus on the theoretical considerations and show results only exemplarily rather than presenting a comprehensive case study. Such a comprehensive case study showing the results for many stations including different bias correction methods and performance measure will be performed in the long run. We fully agree to the fact that the correlation coefficient alone is not a sufficient performance measure. We calculated further performance measures (see Tab. 6) and extended the description of the results accordingly. A new subsection 3.4 should briefly introduce the measures. REFEREE #1: Small comments Here a list of small comments and/or typos. 1. Page 4, line 27: “studied” instead of “studies”. 2. Page 7, line 2: “independent” instead of “independend”

ANSWER: Typos removed.

REFEREE #1: Page 8, eq. (1): I think that past observations of Y also should be taken into account. Thus, eq. (1) could be written in the form $Yt = f(Y1, \ldots, Yt-1, X) + \varepsilon t$.

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ANSWER: We think that the equation is correct. Past observations but also past innovations are already included in the term (t-1). The explanation of this is given in the description of eq. 3. However, we decided to modify the equation for clarification purposes.

REFEREE #1: 1. Page 9, line 3: wrong reference to eq.(5). Please, check. 2. Page 10, line 9: “continuous functions” instead of “steady functions”

ANSWER: Changed accordingly. We decided to use the term “continuous functions”.

REFEREE #1: 1. Page 10, line 10: what are “correlated iid variables”? Copulas describe the dependence among random variables X1, . . . ,Xd that are not necessarily iid. 2. Page 10, line 12: “Nelsen” instead of “Nelson”

ANSWER: Changed accordingly.

REFEREE #1: Page 11, eq. (8): I would use the symbol 1 for the indicator function.

ANSWER: The symbol “1” is already used in the paper. We added the subscript A to indicate indicator function of subset A.

REFEREE #1: Page 11: title of section 3.2.2 should be changed, since the subsection deals with GOF methods, not with estimation.

ANSWER: The title is changed accordingly.

REFEREE #1: Page 11, line 19: please, check a missing reference.

ANSWER: Missing reference added.

REFEREE #1: Page 15, lines 12-13: “opposite diagonal of the unit square” instead of “minor diagonal”.

ANSWER: Changed accordingly.

REFEREE #1: Page 16, lines 4–5: It is said that “no clear functional dependence between the altitude of the stations and the copula parameter exists”. How has this

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fact been proved?

ANSWER: Following the suggestion of reviewer #3 we decided to leave out this section completely. In order to support our statement it would indeed be necessary to show far more results.

REFEREE #1: Page 17, line 22: “assuming” instead of “asssuming”.

ANSWER: Changed accordingly.

REFEREE #1: Page 18, lines 24-25: I do not understand why ARMA-GARCH models “are generally useful to generate iid random variables”.

ANSWER: We modified the “Discussion” remarkably. In this context, we decided to delete this sentence.

Interactive comment on Hydrol. Earth Syst. Sci. Discuss., 8, 3001, 2011.