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Interactive comment on "The critical role of uncertainty in projections of hydrological Extremes" *by* Hadush K. Meresa and Renata J. Romanowicz

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Dear Editor and Reviewer,

This is the corrected version of the response to the reviewer comments. Please ignore the previous version which was not properly formatted (the lines merged). We also added the tables 1 and 2.

Thank you very much for the constructive comments that will help to considerably improve and clarify the manuscript. All comments have been addressed point-by-point. Following the reviewer' feedback we will make the corresponding changes in the manuscript.

Anonymous Referee #2

Overview

RC. The authors assess the effect of different uncertainty sources on climate change projections. The presentation of the results is easy to follow and interpret. Especially Figure 9 is very informative. However, there is room for improvement using specific comments and checklist below. I recommend major revision as the model calibration part is not clear.

AC. We thank the reviewer for concise and valuable comments.

Specific Comments:

RC1. Table 2: Optimal values of some parameters are out of lowerand upper limits e.g. CFMAX which cannot be reached by an algorithm e.g. SCEUA, CMAES etc. How was this achieved by a calibration algorithm? Did you follow a manual calibration scheme?

AC1.The table 2 is now corrected (included at the end of this file). We do not use deterministic calibration, instead the GLUE -based stochastic calibration is applied. When applying this method there is no unique parameter set chosen, but instead, a multiple set of parameters, each with a weight corresponding to the model performance criterion, represents the solution of a calibration problem. Therefore, there is no 'optimal" single solution to the calibration problem, even though a solution with the best goodness of fit criterion can be specified.

RC2. Demirel et al (2013a) is in the reference list but not in the text.

AC2. Thank you, it has been corrected.

RC3. Please explain the abbreviations used at legend in figure caption. The legend of Fig8 is confusing: "distn"?

AC3. Thank you, it has been corrected. "distn" replaced by "distribution"

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RC4. Did you compare uncertainty in HBV model parameters with other studies (Addor et al., 2014; Demirel et al., 2013b; Osuch et al., 2015) using HBV model for forecasting hydrological extremes? How would the results overlap for 10 day forecast (Demirel et al., 2013b) and long term climate predictions in EUROCORDEX (dataset used in this study)?

AC4. The uncertainty in the HBV model parameters was compared with the other studies, including Osuch (2015) and Demirel et al (2013b). Demirel et al. (2013b) explored the influence of uncertainty in input, hydrological model parameters and initial conditions on a 10-day ensemble flow forecasts. The results showed that parameter uncertainty had the largest effect on the medium range low flow forecasts, which is consistent with the present paper findings. Addor et al. (2014) concentrated on the influence of different hydrological model structure, involving three hydrological models, emission scenarios, climate models, post-processing and catchments. Their results indicate that influence of model structure varies with the catchment. However the authors did not take into account hydrological model parameter uncertainty, which is the main focus of the present paper. Osuch (2015) compared three sensitivity analysis techniques to describe the HBV model parameter interactions. We used the output of that paper to eliminated less sensitive HBV model parameters in order to minimize computational cost.

RC5. Fig5: Parameter uncertainty should be presented differently to assess the contribution of each parameter uncertainty to total uncertainty. From this figure the reader can't see the most uncertain parameter. A figure similar to Figure 4 in Demirel et al (2013b) or Fig9 in the current manuscript can be very useful for modelers. This can be easily done as the GLUE results would allow such ranking.

AC5. Thank you for the comment. We decided to delete this figure and subsection 4.4 following the first reviewer comments.

RC6. Conclusion 2 (ii): Please explain the drizzle effect? Not clear.

AC6. Simulated climate variables (precipitation and temperature) by individual GCMs/RCMs often do not reach agreement with observed climate time series. This is due to the effect of systematic and random model errors of GCMs/RCM simulations. Such systematic errors lead to simulate many drizzle days (i.e., too many days with very low precipitation intensity and too few dry days). The drizzle effect is related to the performance of climate models. It presents itself in the form of frequent rainfall of a very small intensity. The physics behind precipitation generation is very complex and involves processes operating on a wide range of scales. The frequent 'drizzle' is produced mainly by convective parameterization. It appears in many climate models and invokes errors in the intensity and frequency of precipitation (Terai et al. 2016). The correction can be performed using the number of wet days in a month (Osuch et al. 2016). Because of this bias in precipitation, using direct climate model output as inputs to hydrological modelling for low flow analysis often leads to unrealistic results and therefore bias correction is required in the case of low flow projections.

RC7. Section 3.6 and Conclusion 5 (v): Is ANOVA method a global or local sensitivity analysis method? Can interactions (parameter etc.) be assessed using this method? Why ANOVA is used instead of other elementary and global methods e.g. Morris, SOBOL, PEST, FAST etc. These aspects of the ANOVA method should be described in section 3.6 and conclusions should follow these details.

AC7. Nowadays, many global sensitivity methods have been proposed and used, such as Fourier amplitude sensitivity test (FAST), Regional Sensitivity Analysis (RSA), Analysis of Variance (ANOVA), Parameter Estimation Software (PEST), Morris, and Sobol method. Among these global sensitivity analysis methods, ANOVA is proved to be one of the most robust and effective tools to analyze both continuous and discrete factors (Montgomery, 1997), and it is widely applied in hydrology (Bosshard et al., 2013; Zhan, et al., 2013; Lagerwalla, et al., 2014; Addor et al.,2014; Giuntoli et al., 2015; Osuch, 2015). We used ANOVA approach due to its numerical facility (MATLAB) and ability to evaluate the main and interactive effects between factors considered.

RC8. Conclusion bullets are confusing. Two times "iv" exists and sentences are not clear. There are typos too. For example Conclusion vi should start with capital. Please rephrase them with short and clear conclusions. And relate them to the results section. Bullet conclusions in Demirel et al (2013b) can be an example. For each result section one paragraph is given in conclusion.

AC8. Thank you, it is corrected in the main manuscript.

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GCM	RCM	expansion name	Institute
EC-EARTH	RCA4	Rossby Center regional	Swedish Meteorological and Hydrological Institute
EC-EARTH	HIRHAM5	Atmospheric model	Danish Meteorological Institute
EC-EARTH	CCLM-4-8-17	Community land model	NCAR UCAR
EC-EARTH	RACMO22E	Regional atmospheric climate model	Meteorological institute
MPI-ESM-LR	CCLM4-8-17	Community land model	Max Planck Institute for Meteorology
MPI-ESM-LR	RCA4	Regional-scale model	Max Planck Institute for Meteorology
CNRM-CM5	CCLM4-8-17	Community land model	CERFACS, France

Fig. 1. Table 1 List of GCM/RCM models used in this study

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Parameter	Description	LB	UB	Unit
FC	Maximum soil storage	0.1	250	mm
BETA	Shape coefficient	0.01	7	-
LP	SM threshold for reduction of evaporation	0.1	1	-
ALFA	measure for non-linearity of flow in quick runoff	0.2255	0.2255	-
KF	recession coefficient for runoff from quick runoff	0.2826	0.2826	d^{-1}
KS	recession coefficient for runoff from base flow	0.0005	0.3	d^{-1}
PERC	percolation rate occurring when water is available	0.01	100	mm d^{-1}
CFLUX	Rate of capillary rise	1.0003	1.003	mm d^{-1}
TT	Threshold temperature for snowfall	1.0145	1.0145	^{0}C
TTI	Threshold temperature interval length	7	7	^{0}C
CFMAX	Degree day factor	0	20	mm $^0C^{-1}$ d^{-1}
FOCFMAX	Rate of snowmelt	0.1484	0.1484	mm $^0C^{-1}$ d^{-1}
CFR	Refreezing factor	0.2779	0.2779	-
WHC	Water holding capacity of snow	0.001	0.001	mm mm^{-1}

Fig. 2. Table 2. HBV parameter ranges: lower band (LB), upper band (UB), unit

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