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Hydrology and Earth System Sciences
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Discussions

Interactive comment on "Climate change will increase potential hydropower production in six Arctic Council member countries based on probabilistic hydrological projections" *by* Elena Shevnina et al.

Elena Shevnina et al.

elena.shevnina@fmi.fi

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The Referee #3 recommends to "decline this manuscript from further publication in HESS." The following major issues were mentioned:

1. "[Insufficient GCM Representation]"... If the focus is to identify the most credible projection of future water resources (for hydropower production and other uses), individual runs from 4 selected GCMs are obviously insufficient. During the period of 2020–2050, the main controlling factor is the interannual variability of precipitation (modeled by dif-

ferent GCMs, as well as the ensemble simulations modeled by one single GCM with a series of perturbed initial conditions). With the large interannual variability, a much larger set of GCM projections should be used to capture the uncertainty. As a matter of fact, given the simplicity of MARCS and the selected PHP approach, I see no reason why the authors couldn't and shouldn't use more (if not all) existing CMIP5 results to conduct their analysis and draw more defensible conclusion. With that said, currently I don't think there is sufficient GCM projections to support the assessment and findings of this study. Answer: We agree, that four selected GCMs are insufficient to represent whole spectrum of the future changes on water resources, and ensemble of the outputs may gives more sufficient estimations on a range of changes. It is a regular way to get the probabilistic form of hydrological predictions simulated by the physically based hydrological modeling. In this case, the ensemble of river discharges simulated under the ensemble of the meteorological forcing allow to estimate the river runoff of particular exceedance probability. However, in this study the method used allows to simulate the exceedance probability curves (EPC) of annual runoff already from a single climate projection (see Table 2 in the Supplement), not from an ensemble of projections. In this manuscript 11 climate projections were used to define two types for the future climate: "wet" and "dry", and to simulate the annual runoff for low/high exceedance probability. It is still not clear how to used the ensemble of EPC in long term planning in hydropower production (see discussion on p. 11). Actually, we have trying to define the perspective of the probabilistic form hydrological projections to estimate potential hydropower generation on a long-term perspective. In this study we used the simplest method to transfer water resource to the hydropower production in assumption that these two values linearly related in whole range of probability of exceedance. However, we would guess that it is not enough to show possible application in the long-term planning in hydropower production. Our opinion is that it could be possible only by involving of the methods of risk assessment. Recently, the probabilistic form of forecasts are common in operational practice, and even in this case it is difficult to utilize this form in practice. As soon as the method in how the probabilistic projections of annual runoff to estimate potential hydropower generation will be clear, a number of GCMs used in simulations of the future water resource can be increased. The method used allows to account the interannual variability of precipitation from the climate projections, however we consider to modify the MARCS model for this case on the following study.

2. “[Treatment of Precipitation]” ... I think some gauges examined by the authors are too large for grid-based assessment (i.e., contributing watershed covering multiple GCM grids). In such cases, using a single grid precipitation to represent the total precipitation input to the watershed is inappropriate and biased. With the advance of GIS techniques and data in the recent decade, I believe the authors can use the watershed boundary of each selected site as a spatial filter to more appropriately summarize average precipitation into the watersheds. This can hopefully help reduce some erroneous Q>P cases (i.e., total volume of streamflow is greater than precipitation) reported by the authors in the current manuscript. Answer: Yes, we agree that one grid point per watershed may be insufficient to represent the mean of precipitation for the catchments of small/big sizes. It was discussed in the first paragraph on p. 11. The regional scale climate models provide an opportunity to calculate the mean of precipitation as the average over the values located within the watershed boundary, and it may improve the representation of the hydrological projections. We plan to do it in the near future. This manuscript was addressed more the application of long term probabilistic hydrological projections to estimate the potential hydropower production. While the approach may be accepted, the role of biases on precipitation can be study to define the optimal method to calculate the mean values of precipitation from projected climatology to force the probabilistic hydrological model MARCS.

3. “[Limitations of MARCS and the Overall Statistical Approach]” ... While I see the value of MARCS to potentially support large ensemble assessment (given its simplicity), I suspect if it is a suitable approach to explore future water availability in the context of atmospheric warming and climate change. In essence, the current assessment used statistical approach to estimate the likely change of streamflow ONLY by the change

of precipitation (projected by GCMs). This approach would neglect other temperature CO2 related nonlinear effects such as earlier snowmelt and enhanced evapotranspiration. Answer: The authors agree that the changes in the air temperature affect to the future water availability via enhancing evapotranspiration, and it should be accounted in the hydrological models. In the probabilistic hydrological model MARCS, the projected mean of air temperature is included to the simulations via a regional oriented parameterization scheme allowing to improve the results of the model verification (cross-validation): Shevnina et al., 2017, Kovalenko, 1993. However, in this study the basic parameterization scheme was applied, it gives of over 80 % “good” hindcasts for the simulated exceedance probability curves of annual runoff (Kovalenko, 1993). Thus, only the projected mean of precipitation was used in the simulations. To look forward, we plan to develop the regional oriented scheme for the territory of six Arctic Council members countries, and to include the changes in the air temperature in the projections of water availability. In this particular study, we would prefer to stress the features of the simplest version of the MARCS model, and to found the perspective of long-term probabilistic form of hydrological projections to be apply in evaluations of the future potential hydropower production. In this case, our opinion that the title of the manuscript does not fit the content and should be changed.

4. “[Oversimplification of Hydropower Assessment]”... While hydropower was specifically called out in the title, the authors only used a very simplified model (PHP) to infer the likely influence of climate change on hydropower production only from water availability perspective. Yes, for the selected region, the overall runoff is likely to increase as the result of increasing precipitation suggested by many GCMs, but the increases are likely in forms of more severe hydrologic extremes. With the intensified hydrologic extreme events, will our current reservoirs have sufficient storage to accommodate these highly varied inflows and be able to operate in the same fashion? For run-of-river types of hydroelectric projects, they may end up spilling most of the increased runoff due to limited storage so won’t see a corresponding increase in hydropower generation. These more pressing issues cannot be addressed through an over-simplified hy-

dropower model selected by the authors. Answer: We agree that the method to transfer the water resource to the economic value (the hydropower production) is very simple, and it needs only for the mean value of annual runoff, the site-specific head and the technology-specific constant (see the Eq. 1). Moreover, the very simple assumption that the changes on the annual runoff is simply related to the changes in the potential hydropower production in whole range of exceedance probabilities. However, these assumptions allow to evaluate the potential hydropower production in terms of probability, and to “look up” the risks connected to the annual runoff of low and high exceedance probability (or percentiles of annual runoff in terms of the statistic). In our opinion, the methods of a risk assessment should be applied to transfer the water resource to the hydropower production in the future study. In this case, it would be possible to answer questions as “will our current reservoirs have sufficient storage to accommodate these highly varied inflows and be able to operate in the same fashion?” or how to account the side-specific information on the hydropower type, head and operational rules. This study is focused more in the features of the probabilistic hydrological projections, and show the global scale assessment on the potential hydropower production. The study provided more details on the method applied to simulate the probabilistic projections of annual runoff, and the title is about the hydropower production. In our opinion, the title of the manuscript should be changed.

5. “[Bias-correction Method]”... The delta bias-correction approach has become an outdated method. The authors should at-least consider the quantile-based bias-correction approach that can better adjust the GCM biases. Answer: It is not clear what does it mean that the “bias-correction approach has become an outdated method”? Does it means that this method gives significant errors to be applied to correct the forcing for the hydrological physically-based, balance or probabilistic models? In our opinion, a simple method is preferable if it gives results similar to a complex method. Thus, it is important to answer the question: how the method of climate correction affects to the results simulated by the probabilistic hydrological model MARCS. In this study we started from the simplest version of climate correction, and in the future, more

sophisticated methods of climate correction can be applied to study the sensitivity of the MARCS model to biases in the climate forcing. We added this circumstance in the section of Discussion in the revised version of the manuscript.

6. “[Regulated Streamflow]” ... I suspected that many of the gauge data used by the authors are in-fact regulated by existing reservoirs. How will this affect your assessment? Answer: In fact, the existing regulation by reservoirs may affect to the yearly values of observed river discharges only in case if there is a multi-year re-distribution of water inflow. The “regulated” gauges located for example on the territory of Norway operate on seasonal redistribution of water inflow, thus the regulation rules are not affect to the yearly discharges. In our study, the observed yearly time series of river discharges were filtered by applying the statistical tests to reveal non-homogeneity/trends in the time series and to calculate the length of the reference period. However, the current regulation rules can affect on the projected statistical moments of the annual runoff for the catchments with present hydropower network. To answer to the question: how?, a new study would be required. In this study we added the information on the current regulations for the catchments (e.g. Norway), which were chosen to model set-up, and we discussed the possible effects as well.

Other minor concerns were also mentioned by the Referee: 7. “[Line 27] "Engineering hydrology" sounds awkward.” Answer: This term was replace by the “environmental engineering”, and comments were added to specify this branch of the hydrology withing the environmental science.

8. “[Line 186] Are you referring the "University of Delaware Air Temperature & Precipitation"? If so, a proper reference and citation should be provided.” Answer: The proper reference is now included into the text.

9. “[Lines 212–213] I don’t think the statement is true. In the U.S., the cumulative streamflow originated from inland is far more important than the near-coast water resources for the purpose of hydropower generation.” Answer: The statement is re-

moved.

10. “[Lines 216 and 217] Should be Figure 3d” Answer: we agree.

11. [Line 218] Should be Figure 3c. Answer: we agree.

12. [Line 236] Should be Table 3. Answer: we agree.

13. [Line 242] Should be Figure 4. Answer: we agree.

14. [Line 282] Typo – "ew". Answer: we correct the typing mistake.

15. [Table 3] The first CA should be NO? Also, please provide the unique CMIP5 ensemble number (e.g., r1p1i1) so that the authors may know which exact GCM runs were used. Answer: We add this information into the text.

16. [Figure 1] In the bottom left box, "protected" should be "projected"? Answer: we correct the typing mistake.

17. [Figure 2] It is very difficult to differentiate sites with overlapping ST, FR, or SRC. Answer: we correct the figure.

Please also note the supplement to this comment:
https://www.hydrol-earth-syst-sci-discuss.net/hess-2018-473/hess-2018-473-AC3-supplement.pdf

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