Response to Reviewers

We would like to thank the editors and reviewer for their insightful and constructive comments. Because of these comments, the revised version of the manuscript is significantly improved compared to the original one. We have addressed all concerns in this document and most of them in the revised manuscript. Below, we provide a detailed response to each of the reviewers' comments. For convenience, we put the **reviewer comments in black font**, and author responses in blue. In our responses, the line numbers, when specified, refer to the track-change version of the revised manuscript.

Anonymous Referee #1

Review of Faghih et al General comments Faghih and co-authors investigate the impact of bias-correcting climate models at the sub-daily time scale on streamflow predictions. They find small, but consistent improvement, especially for small catchments. I find the manuscript logically organized and well written although I think several errors are made in English, but I will not go in detail as I am not a native speaker myself either and professional correction seems more appropriate. The goals of the study are clear and so are the conclusions. I have no major comments on the content, but do have some comments on the presentation material and the way this research is embedded in the scientific literature. Overall, I think this manuscript can be accepted subject to minor revisions after the following issues are addressed:

- Self-citations and citing other work. I noted that the manuscript contains 15 self-citations of the second author François Brissette. I strongly wonder whether such a high number of self-citations is truly justified and whether it cannot be reduced. Moreover, other seemingly relevant works are overlooked. For example, but not limited to: Bárdossy and Pegram (2011), Li et al. (2016).

The second author has been working in the field of *climate change impact assessment* on water resources for the past 20 years. A lot of work made in our lab in the past is therefore directly relevant to this paper, some of which has been cited by numerous other scientists. We will plead guilty to being a bit lazy in finding other relevant work to substantiate some of the claims made in this paper, but not to using irrelevant self-citations. We have added a number of additional relevant citations in the revised version (including the above two suggested references). The following reference have all been specifically added to answer this point. Additional references have also been added in light of other reviewer comments. As a result, this revised version of the paper cites around 100 papers.

Huang, L., Wang, L., Zhang, Y., Xing, L., Hao, Q., Xiao, Y., & Zhu, H. (2018). Identification of groundwater pollution sources by a SCE-UA algorithm-based simulation/optimization model. *Water*, *10*(2), 193.

Muttil, N., & Jayawardena, A. W. (2008). Shuffled complex evolution model calibrating algorithm: Enhancing its robustness and efficiency. *Hydrological Processes: An International Journal*, *22*(23), 4628-4638.

Bárdossy, A. and Pegram, G.: Downscaling precipitation using regional climate models and circulation patterns toward hydrology, Water Resour. Res., 47(4), 1–18, doi:10.1029/2010WR009689, 2011.

Li, J., Johnson, F., Evans, J. and Sharma, A.: A comparison of methods to estimate future sub-daily design rainfall, Adv. Water Resour., 110, 215–227, doi:https://doi.org/10.1016/j.advwatres.2017.10.020, 2017.

Teutschbein, C., & Seibert, J. (2013). Is bias correction of regional climate model (RCM) simulations possible for non-stationary conditions?. Hydrology and Earth System Sciences, 17(12), 5061-5077.

Maraun, D. (2012). Nonstationarities of regional climate model biases in European seasonal mean temperature and precipitation sums. Geophysical Research Letters, 39(6).

Wang, C., Zhang, L., Lee, S. K., Wu, L., & Mechoso, C. R. (2014). A global perspective on CMIP5 climate model biases. Nature Climate Change, 4(3), 201-205.

Ashfaq, M., Bowling, L. C., Cherkauer, K., Pal, J. S., & Diffenbaugh, N. S. (2010). Influence of climate model biases and daily-scale temperature and precipitation events on hydrological impacts assessment: A case study of the United States. Journal of Geophysical Research: Atmospheres, 115(D14).

Ajaaj, A. A., Mishra, A. K., & Khan, A. A. (2016). Comparison of BIAS correction techniques for GPCC rainfall data in semi-arid climate. Stochastic environmental research and risk assessment, 30(6), 1659-1675.

Su, T., Chen, J., Cannon, A. J., Xie, P., & Guo, Q. (2020). Multi-site bias correction of climate model outputs for hydro-meteorological impact studies: An application over a watershed in China. *Hydrological Processes*, *34*(11), 2575-2598.

Cannon, A. J., Piani, C., & Sippel, S. (2020). Bias correction of climate model output for impact models. In Climate Extremes and Their Implications for Impact and Risk Assessment (pp. 77-104). Elsevier.

Ayar, P. V., Vrac, M., & Mailhot, A. (2021). Ensemble bias correction of climate simulations: preserving internal variability. Scientific Reports, 11(1), 1-9.

• Figures. The figures and their captions need improvement. Labels ‘a’,’b’, etc. are missing; often unclear whether 1 particular year is considered or an average over 24 years; x-axis time in hours has no reference to what is 0, whether this is local time or UTC, mismatches with the text that discusses AM and PM, and over a year and indication of months would still be more logical; for sample watersheds it is sometimes specified which ones they are and sometimes it simply isn’t making reproduction impossible; legends often refer to multiple panels, thus placing them outside a panel makes more sense; some figures present ‘envelopes’ without defining what exactly these envelopes mean in the caption.

We thank you for the relevant comments about the Figures. We have modified several Figures as well as Figure captions. The new Figures as well as brief comments on changes are presented below.

Additional details were added to Figure 3 and 4 including captions. The locations of legends were changed and labels (A, B) were added to the subplots. Times are all local. With 24h corresponding to midnight. Clarifications have been added in the text and AM/PM time have all been modified to a 1-24 hour format.

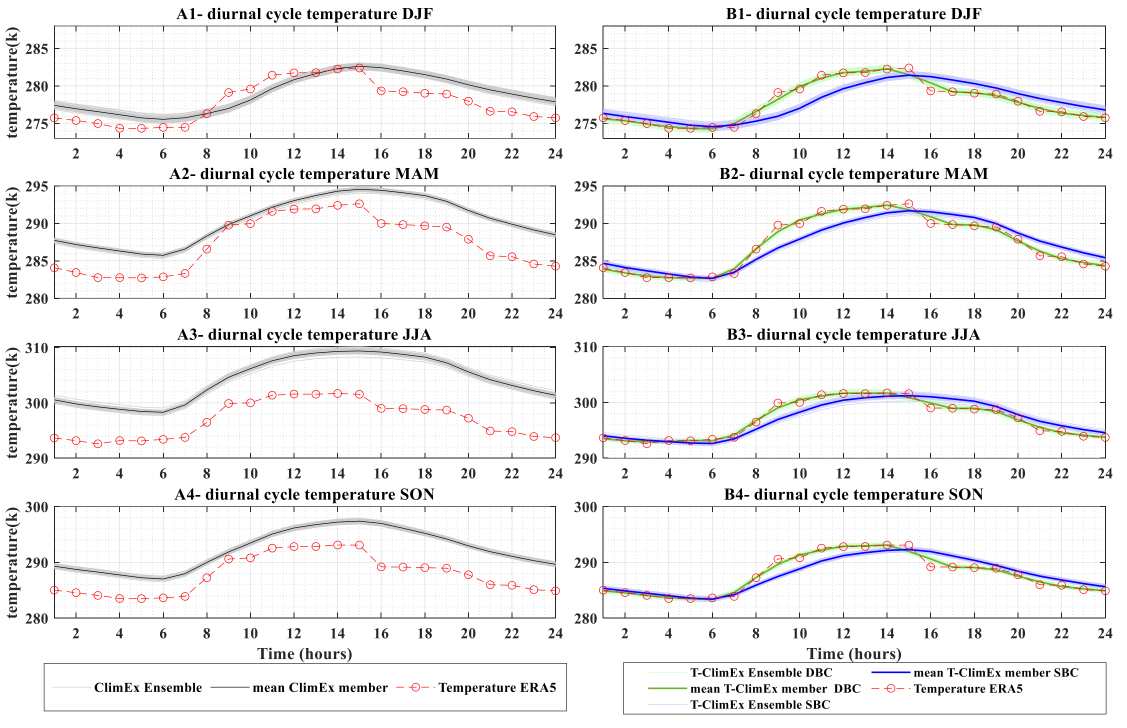

Figure 3 Annual diurnal cycle of temperature before bias correction (first column: A1 to A4) and after bias correction (second column: B1 to B4) for catchment 02143040. Each row corresponds to a different season: DJF (December, January, February), MAM (March, April, May), JJA (Jun, July, August), SON (September, October, November). The right hand side shows both bias correction methods: Standard Bias Correction (SBC) and Diurnal Bias Correction (DBC). The observations (ERA5) are shown in red. Raw (uncorrected) Climex data is in grey, SBC is in blue and DBC is in green. The envelope defined by all 50 Climex members are shown in the corresponding light colours, whereas the dark coloured lines display the ensemble mean. Time is local with 24h corresponding to midnight.

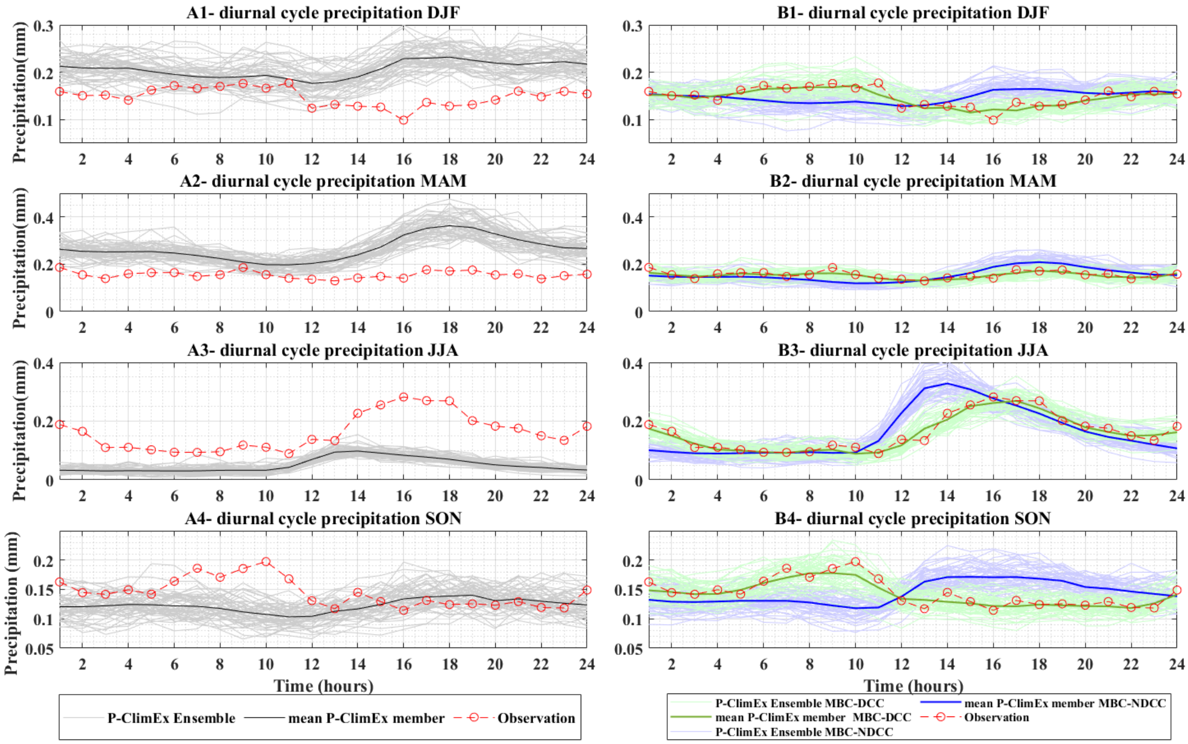

Figure 4 Annual diurnal cycle of precipitation before bias correction (first column: A1 to A4) and after bias correction (second column: B1 to B4) for catchment 02143040. Each row corresponds to a different season: DJF (December, January, February), MAM (March, April, May), JJA (Jun, July, August), SON (September, October, November). The right-hand side shows both bias correction methods: Standard Bias Correction (SBC) and Diurnal Bias Correction (DBC). The observations (ERA5) are shown in red. Raw (uncorrected) Climex data is in grey, SBC is in blue and DBC is in green. The envelope defined by all 50 Climex members are shown in the corresponding light colours, whereas the dark coloured lines display the ensemble mean. Time is local with 24h corresponding to midnight.

In Figure 5, the transparency of the blue color was modified to a lighter tone which better shows the green color. The caption was rewritten and the location of the legend was changed. Labels were added to each subplot.

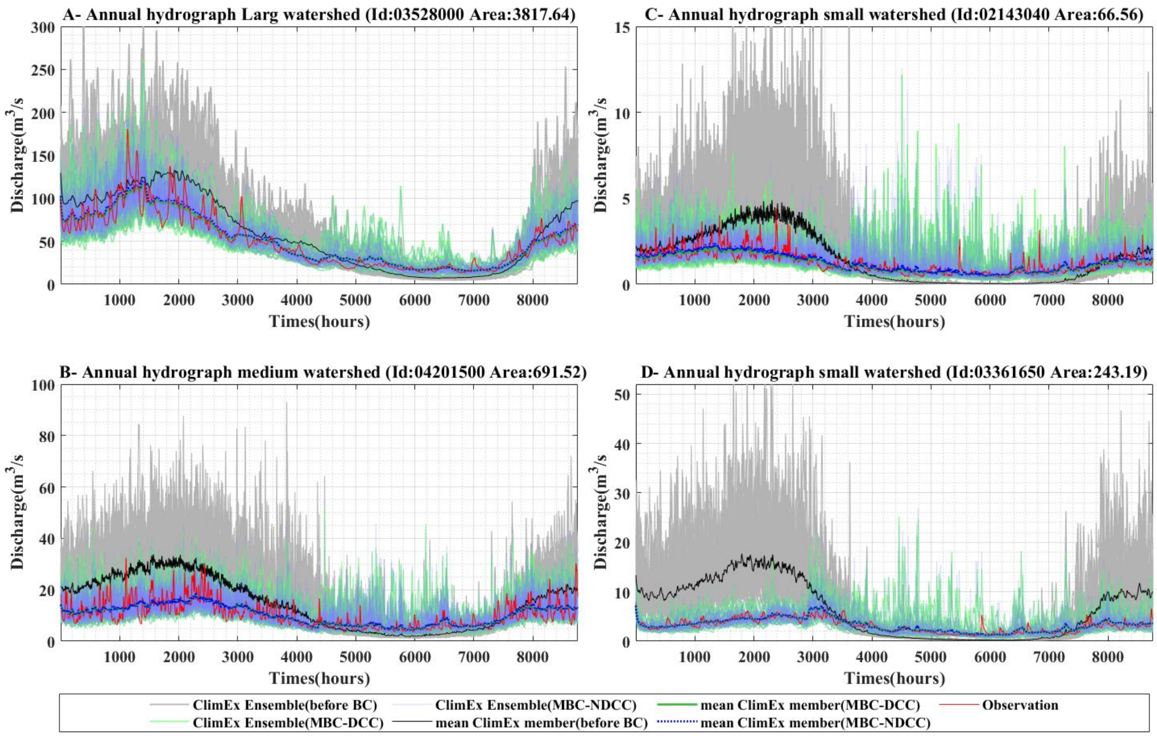

Figure 5 Hydrograph annual cycles for four selected catchments. Catchments A and B are classified as large and medium size respectively. Catchments C and D are classified as small. 0 represents January first at 0h00, and 8760 is December 31st at 24h00.

Labels were added to figure 8 and the caption was modified.

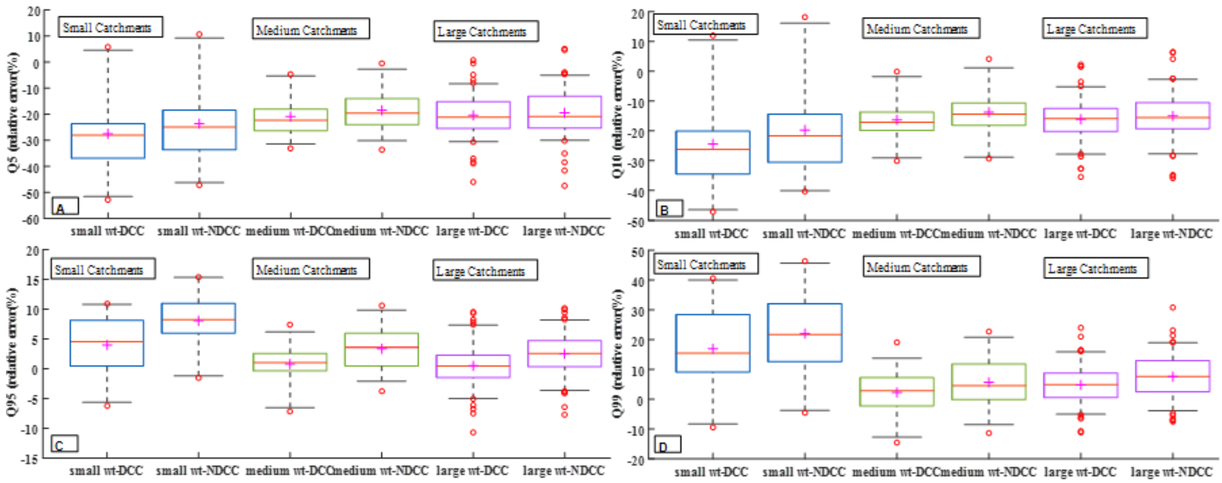

Figure 8 Distribution of the relative error (model-obs)/obs x 100% corresponding to flow quantiles Q5 (A). Q10 (B), Q95(C) and Q99(D). Boxplots for both bias correction methods (DBC and SBC) are constructed from the distribution of relative errors from all catchments within each size class (small, medium, and large)

The location of the legend was changed in Figure 10 and the caption was modified.

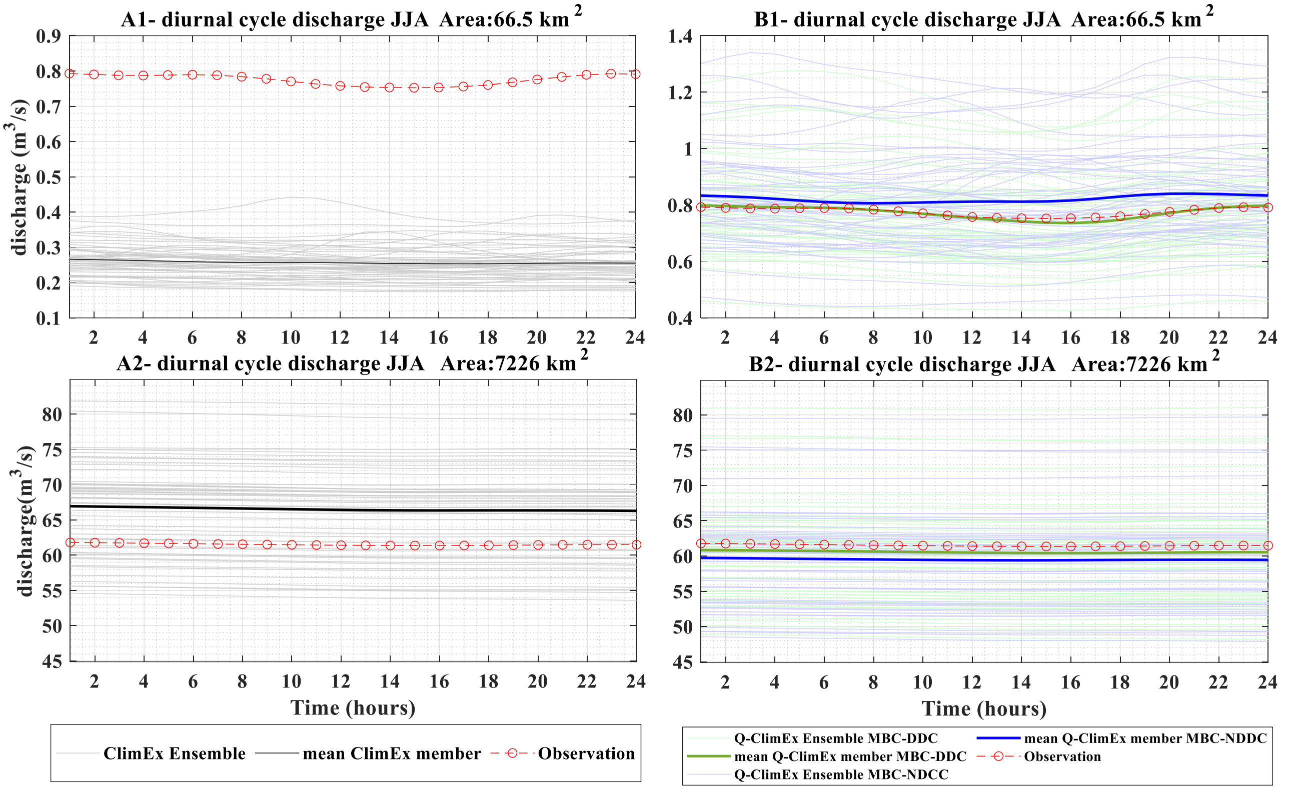

Figure 10 Annual diurnal cycle of discharge in JJA (Jun, July, August) before bias correction (first column: A1 and A2) and after bias correction (second column: B1 and B2) for two selected catchments. First row is for catchment 02143040 (small size classification) and second row is for catchment 02156500 (large size classification). The observations are shown in red. Streamflow simulations using uncorrected ClimEx members are shown in light grey, and the ensemble mean is in black. . Simulations using bias corrected data are in light blue (SBC) and light green (DBC) with the corresponding dark colours showing the ensemble mean. Time is local with 24h corresponding to midnight.

• Code and data availability. The code and data availability statement does not contain any information about the availability of the actual code that was generated to produce the results in this paper.

We have modified the *code and availability* section to include the links to all programs and databases used in this study. We have added the list of catchments selected from the MOPEX database as an Appendix (see Table below). Anyone wishing to reproduce this work has now direct access to all data and programs. We don't have an actual 'plug and play' code that does everything in one click. However, the steps are straightforward – data extraction (MOPEX, Climex database, ERA5), hydrological model calibration (GR4J code, SCE-UA code), bias correction (MBCn code), run hydrological model.

Appendix 1 USGS ID of the selected MOPEX catchments.

Catchment ID								
01197500	03175500	02138500	01567000	02126000	02472000	03324300	03524000	05440000
01518000	03238500	02143000	01574000	02135000	02478500	03326500	03528000	05447500
01520000	03303000	02143040	01628500	02156500	02479300	03328500	03540500	05454500
01541000	03346000	02143500	01631000	02202500	02482000	03331500	04100500	05515500
01556000	03438000	03111500	01643000	02217500	02486000	03339500	04113000	05517500
01558000	03443000	03361650	01664000	02228000	03011020	03345500	04115000	05518000
02018000	03473000	03504000	01667500	02329000	03109500	03349000	04164000	05520500
02058400	03531500	03550000	01668000	02339500	03164000	03361500	04176500	05526000
02118000	04201500	07261000	01674500	02347500	03168000	03362500	04178000	05552500
02475500	04221000	01371500	02016000	02365500	03237500	03364000	04185000	05554500
03079000	05517000	01543500	02055000	02375500	03266000	03365500	04191500	05555300
03161000	01372500	01548500	02083500	02383500	03269500	03451500	04198000	05569500
03167000	01445500	01559000	02102000	02387500	03274000	03455000	05430500	05582000
03173000	01560000	01562000	02116500	02448000	03289500	03465500	05435500	05584500
05592500	05593000	05594000	07029500	07056000	07290000	07363500		

Specific comments

L22-23: “Results show small but systematic improvements of streamflow simulations when bias correcting the diurnal cycle of precipitation and temperature.”

Please quantify in a summarized way.

The original sentence:

Results show small but systematic improvements of streamflow simulations when bias correcting the diurnal cycle of precipitation and temperature.

has been replaced with:

Results show relatively small (3 to 5%) but systematic decreases in the relative error of most simulated flow quantiles when bias-correcting the diurnal cycle of precipitation and temperature.

L238: “(variability around the ensemble mean expressed in %)” since no quantification is actually given, it seems completely irrelevant to note that it can be expressed as a percentage, whereas the statement would remain valid if expressed as a fraction.

Correct. We have removed the latter half of the sentence. The new sentence reads as follows:

‘The relative internal variability (around the ensemble mean) remains the same before and after correction’

L385-386: “It is also well-known that the NSE criterion that was chosen for the hydrological model calibration is more sensitive to high-flows.” Provide a reference for this statement.

Since the NSE criterion is a normalized root mean square error criteria, it naturally follows that it’s more sensitive to errors in large values. The automatic calibration algorithms will therefore be more influenced by solutions targeting high flows. We have added the following references to support this.

Krause, P., Boyle, D. P., & Bäse, F. (2005). Comparison of different efficiency criteria for hydrological model assessment. Advances in geosciences, 5, 89-97.

Muleta, M. K. (2012). Model performance sensitivity to objective function during automated calibrations. Journal of hydrologic engineering, 17(6), 756-767.

L390-391: “A single climate model was used and our results should be replicated with other climate models.” Why? Is there any reason to expect a different result?

That’s a good question. When it comes to the efficiency of bias correction of precipitation and temperature, the answer is a definite no. Quantile mapping approaches are powerful tools to match one distribution onto another. As was shown in the literature, you could bias correct an atmospheric pressure field onto precipitation and perfectly match the target distribution. However, no bias correction method can correct all statistics and particularly so when it comes to joint distribution properties (between P and T in this case). Hydrological models are good spatial integrators of such data, but they are sensitive non-linear integrators. As such, small changes between two climate models (e.g. spatial resolution, interannual variability) could ultimately results in differing streamflow simulations. While we do not expect dramatically different results using other climate models we might see a different sensitivity to catchment size for example. We have modified the text to better reflect the above in the revised version.

L396: “However the MBCn (Cannon, 2018) is arguably the best quantile mapping method available. Repetition, please delete.

Done.

L447: “correcting the diurnal cycle results in better streamflow simulation,” Please explain ‘better’ and quantify in a summarized way.

Has been modified with:

“Results indicate that correcting the diurnal cycle results in better streamflow simulation, especially for smaller catchments, which have a definite sub-daily response time. For the small catchments, the relative error between observed and simulated flow quantiles was reduced. For example, the median reduction was 5% for the 95th and 99th quantiles, and 4% for the median value of the 20-year flood across all small catchments.”

Technical corrections

L25: “of summer streamflow on small catchments” on --> in

Corrected

L139: “MBCn was chosen ...” No need to start a new paragraph

It was modified accordingly.

L162 and L165. The brackets for these references are not correctly placed.

Corrected.

L169: “PET” Please use the more scientific notation of single symbols, thus Ep instead. See: https://iahs.info/Publications-News/Other-publications/Guidelines-for-the-use-of-units- symbols-andequations-in-hydrology.do

We have changed PET to Ep throughout the document.

L240: “very efficient”

Delete very

Deleted

L331. Do not write single sentence paragraphs

We reviewed the text to eliminate this and other instances of single sentence paragraphs.

References

Bárdossy, A. and Pegram, G.: Downscaling precipitation using regional climate models and circulation patterns toward hydrology, Water Resour. Res., 47(4), 1–18, doi:10.1029/2010WR009689, 2011.

Li, J., Johnson, F., Evans, J. and Sharma, A.: A comparison of methods to estimate future sub-daily design rainfall, Adv. Water Resour., 110, 215–227, doi:https://doi.org/10.1016/j.advwatres.2017.10.020, 2017.

As discussed above, the above two references (and many others) have been added to the manuscript.