Community Comment 1

This review was prepared as part of graduate program Earth & Environment (course Integrated Topics in Earth & Environment) at Wageningen University, and has been produced under supervision of dr Ryan Teuling. The review has been posted because of its potential usefulness to the authors and editor. Although it has the format of a regular review as was requested by the course, this review was not solicited by the journal, and should be seen as a regular comment. We leave it up to the author's and editor which points will be addressed.

Title paper: "Hydrologic implications of projected changes in rain-on-snow melt for Great Lakes Basin watersheds"

Overall impression

Rain on snow (ROS) melt events can have a big influence on their surroundings and can be either big or small. This manuscript investigates the impact of the climate change on the ROS events in the Great Lakes Basin in northern United States and few states of Canada for the period of 1960 to 2099, focussing on the period of 2040-2069 by the use of the model Soil and Water Assessment Tool (SWAT) with the addition of an energy budget equation to project the ROS events. With the results they looked at relationships and correlations between the different obtained variables. In general, the ROS events tend to happen earlier in the year by mid-21st century compared to the historical 1960-1999 values. The rain to snow ratio changes from around 1.5 historically to 2.0 at the end of the 21st century. This all also has influence on the water yield of the basins which also shift to earlier in the year.

The paper is nicely written and is important in these times of changing climate. The text has a good structure as the results are divided in understandable blocks. The variables are also captured in some good figures, although some changes should be made. Based on these comments, I would recommend publication with minor revisions.

> Response: We thank you, members of the Integrated Topics in Earth & Environment course, for the valuable feedback. We have incorporated the comments into our manuscript and present our responses. We will also include you in the acknowledgements of our revision.

General comments,

Firstly, as definition of a rain-on-snow event in the analysis section is stated that an event occurs on days with >1 mm rainfall on >1 mm snowpack SWE. By reading the Jeong and Sushama, 2018 paper this definition is not complete. It should be days with >1 mm rainfall on >1 mm snowpack SWE and decreasing SWE. By using the wrong definition rain-on-snow events could be wrongfully depicted in the results, and thus possible differences in conclusions. This should be solved by correctly using the definition and changing this in the paper.

Response: Thank you for pointing out our error in stating how we defined ROS events. You are correct that the definition must include snowmelt occurring, which we included in our script but hadn't mentioned in the text. We have now updated it to "ROS melt events were defined as days with >1 mm rainfall on >1 mm snowpack SWE and snowmelt occurring (Jeong and Sushama, 2018)." (to be updated at page 6, line 121 of the preprint)

Secondly, in the research question is stated that the change of rain-on-snow melt and hydrology due to climate change will be assessed for the 21st century. In the method an argument is made about that for informing water resources management and because of better agreement with the models the primary focus will be on the mid-21st century (2040-2069). In the rest of the paper late-21st century is only mentioned for the change in ratio of area-weighted winter+spring rain-to-snow. Which has only a 0.1 change to the ratio change of the mid-21st century where the mid-21st century has a better agreement to the models and thus will probably be more accurate. Also in the conclusion at the end is stated "could help prepare ….. for the climatic changes of the 21st century and beyond" where nothing is known for this latter time period with results from this paper. Thus, either the research question has to be rewritten to only the mid-21st century together with the conclusion or the late-21st century should be included in the rest of the analysis.

Response: Thank you for pointing out this need for consistency. We have removed references beyond the mid-21st century from the research question and conclusions, as well as other locations where late-21st century had been mentioned in the text, to focus our study consistently on mid-21st century changes.

"*Our research asks, "How does ongoing climate change alter ROS melt and hydrology in the Great Lakes Basin by the mid-21st century?"*" (to be updated at page 2, line 44 of the preprint)

"*Implications of this work, specifically involving the influence of changing ROS melt on extreme hydrological events and future water availability, as well as the climate-related sensitivities to changing ROS melt, could help prepare the management of ecosystems and human water uses for the climatic changes of the mid-21st century*." (to be updated at page 20, line 380 of the preprint)

Lastly, again a comment on the research question but now because change in hydrology due to climate change is asked in the question. When stating hydrology I expect more variables to be analysed then only water yield, the rest of the analysed variables either belong to the change in climatic values such as rain and temperature or change in rain-on-snow events. Also, in the methods groundwater is mentioned to be modelled (line 65) but later not analysed in the results. So, either the phrasing of the research question should be altered or more hydrological variables should be assessed in the paper. This is important as the goal of this paper is to inform water managements to prepare for the changes due to climate change. For them the groundwater or

runoff variables are also very important, and as they change with changing ROS melt (as said in line 39-41) this should be addressed.

> Response: Our results focused on water yield because it is normalized streamflow, which our model was calibrated and evaluated for. Similarly, we report snowpack that our model was calibrated and evaluated for. Other variables such as groundwater and soil water clearly are important, but we provided limited results for them, because of space or data limitations and because they had not been specifically calibrated and evaluated for using the observed data. This is definitely an area of future research that we hope to look into further. Thus, we added a sentence about the importance of this additional research at page 20, line 380 of the preprint.
>
> "*Future work could also investigate how changing ROS conditions affect other components of the water balance including groundwater and soil water storage in the Great Lakes Basin.*"

Comments,

1. In lines 312 -320, Myers mentions the difference in findings with Surianon mentioning that the studied times differ. But as the simulation used in this study is done for 1960-2099, the same time periods could be compared as the data will be present after simulations. Why not analyse the same time period (1960-2009) as Suriano to make this comparison possible, to diminish this suggestive difference.

   > Response: We decided to remove this comparison since it was not definitive, and we now provide more concrete details about historic ROS in a new Discussion section 4.2 (described in our public comment to Reviewer 1). We used 1960-1999 as the historic time period for this study because that matches previous work we have performed and evaluated (Myers et al. 2021b) using our SWAT ROS model, and fits with the time period of the historical climate observations we used (Maurer et al. 2007).

   Maurer, E. P., Brekke, L., Pruitt, T., and Duffy, P. B.: Fine-resolution climate projections enhance regional climate change impact studies, Eos, Trans. Am. Geophys. Union, 88, 504, https://doi.org/10.1029/2007eo470006, 2007.

   Myers, D. T., Ficklin, D. L., and Robeson, S. M.: Incorporating rain-on-snow into the SWAT model results in more accurate simulations of hydrologic extremes, J. Hydrol., 603, 126972, https://doi.org/10.1016/J.JHYDROL.2021.126972, 2021b.

2. Lines 338-340, the speculation of influence of rain-to-snow ratio on size and timing of spring snowmelt and summer baseflow is made. This could be analysed by simply calculating the

correlation between the COV (center of volume) and the rain-to-snow ratio which are variables present in the results.

Response: We updated the Discussion text with our results for this relationship at the location of page 19, line 339 of the preprint. We decided instead of the correlation to state the size of basin-average effects.

"*Thus, the rain to snow ratio could help explain the earlier COV of ROS melt for the Great Lakes Basin by mid-21st century, since we found that as the basin-average rain to snow ratio increases from approximately 1.5 historically to 1.9 by mid-21st century, the COV of ROS melt becomes two weeks earlier*."

3. Line 99, "thus. Nineteen climate models …… were used". There is a missing argument about why you use 19 models instead of more or less. Please add an argument.

   Response: To improve clarity in this choice, we added the following at the location of page 4, line 100 of the preprint:

   "*We chose to include nineteen climate models because that was the total number of RCP 4.5 models that had been downscaled and bias corrected in the multi-model ensemble (Maurer et al., 2007)*."

   Maurer, E. P., Brekke, L., Pruitt, T., and Duffy, P. B.: Fine-resolution climate projections enhance regional climate change impact studies, Eos, Trans. Am. Geophys. Union, 88, 504, https://doi.org/10.1029/2007eo470006, 2007.

4. Line 165, the word "drastic" is used. Drastic is not a quantitative value as it is more an subjective use when not supported with arguments. Either rewrite the sentence or add an argument.

   Response: We removed the word to avoid the subjectivity.

5. Lines 103-105, this information is a good/ better argument for the statement in line 118-119. As it now seems as random added information but potentially better used in the latter argument.

   Response: We moved the text as suggested.

6. Line 167 , it is as a reader unclear whether the value mentioned for March is also the maximum or the value at the time of the maximum of April. This should be clarified.

   Response: We reworded this sentence for clarity at the location of page 9, line 166 of the preprint:

"*Historically the maximum snowmelt overall has been in April with an area-weighted median of 85.3 mm, while the March median snowmelt has been less at 44.8 mm. By mid-21st century the median amount of monthly snowmelt among subbasins reaches a maximum at 44.8 mm in March, but drops to only 39.5 mm in April, which is a 54% April decrease between the two periods*."

7. Line 172, it is unclear if "proportion of melt" means temperature based melt or ROS based melt. This should be clarified.

   Response: We added an explanation to the location of page 9, line 172 of the preprint to be clearer:

   "*However, the proportion of melt occurring during December ROS days (compared with all December melt) decreases from an area-weighted median of 71% historically (1960-1999) to 59% by mid-21st century (a decrease of 12%).*"

8. Comment on figures in general: in the captions some abbreviations are written out where others are only posted as abbreviation. For the consistency of the paper this should be the same in all figures.

   Response: We fixed the figure captions so that the abbreviations are described at the first mention, and then abbreviated each time after.

9. Line 212, why is 2050s mentioned here instead of the same formulation used in the rest of the paper: "mid-21st century"? This could confuse the reader.

   Response: We changed it to "mid-21st century" to avoid the confusion.

10. Figure 6, Instead of "high flows" state "high water yields" in figure title of 6 e and f as stated in the caption for clarification.

    Response: We updated the figure as suggested, but for space wrote "high WYLD" in the figure title then defined WYLD as water yield in the caption.

11. Figure 7, could be better depicted when the figures with frequencies (b, d and f) are on the right and with melt (a, c and e) on the left.

    Response: We updated the figure as suggested.

Specific comments,

1. Line 168, “a 54% April decrease” should be rephrased, for example”54% decrease in April”.

   Response: We made the improvement as suggested.

2. Line 197, figure 5c should be changed in 5d.

   Response: For the “(Figure 5c-f)” reference, we decided to keep 5c because it shows historic values to compare with.

3. Figure 7, d is never mentioned in text.

   Response: We included a reference for 7d in the text at page 14, line 236 of the preprint:

   “*Changes to the amount of annual ROS melt and frequency of ROS events are not correlated with historic winter and spring total precipitation amounts (Figure 7c and d), as the type of precipitation is more influential, and depends on air temperatures (and thus latitude).*”

4. In figure 3 add in title of figure 3 b, d and f that it is for the period of the mid-century for clarity.

   Response: Unfortunately, we could not fit the extra title in the figure space, but we kept the reference to mid-21st century in the caption.

5. In figure 4 some alterations on the axis titles can clarify the graphs. In 4b “snowmelt” can be clarified by writing “total snowmelt” and for c “proportion ROS” can be “proportion melt by ROS”.

   Response: We updated the figure as suggested.

References

Jeong, D. Il and Sushama, L.: Rain-on-snow events over North America based on two Canadian regional climate models, Clim. Dyn., 50, 303–316, https://doi.org/10.1007/s00382-017-3609-x, 2018