Note) Line numbers correspond to the non-tracked changes in the copy of the manuscript.

Reviewer Comments 2 (RC2)

This paper presents a new parameterization scheme that cooperate the groundwater component to the ESM model, which is a good starting point of considering the effect of groundwater on the energy component in the ESM model.

In general, the manuscript is written in very good and comprehensive english and it is easy to read and follow.

However, I find the manuscript is too long and with some redundant information that reduces the readability. I do agree with the first reviewer that the part describing the energy transport makes the manuscript discontinued, which might be better to put to as a supplementary.

- We appreciate the reviewer's insightful comments. Based on the reviewer's suggestion, we have updated the section 2.3.2 to improve the readability. Specifically, explicit equations for soil, groundwater, and river temperature estimation and heat flux were retained in the main text. In contrast, all other equations (i.e., dynamic heat capacity and details of heat flux estimation) were categorized as Appendix A and excluded from the main text. As a result, section 2.3.2 has been shortened significantly while addressing the essential information of temperature simulation.

I believe with some more efforts for revision, this manuscript could reach the standard of a publication.

- We appreciate the reviewer's encouraging comments. All the specific comments made by the reviewer have been addressed in the following section.

Here follows some specific comments.

* Figure number has been changed due to the added Figure 2 – workflow diagram.

1. Figure 1 appears to be difficult to understand. especially when it appears, there was no proper explanation of what is a "height band" until I read section 2.4. I suggest to have a good explain of the following terms at the beginning: what is soil columns, tiles, height band and characteristic hillslope, respectively and what are their potential relationship. and also the meaning of the black dots and what does the size of the dots mean in each soil layer is not clear.

- We appreciate the reviewer's insightful comments. Referring to the reviewer's comments, we have moved section 2.4 to the very front of section 2, agreeing that the readers need to understand the concept and relationship among CH, HB, and tiles before those spatial units are used to explain the processes. Thus, the definitions and relationships among CH, HB, and tiles are discussed in section 2.1 in the revised manuscript. Also, Figure 1 has been updated to match the dot size. Initially, the different sizes of dots in the top two layers and others implied that there are multiple soil layers (i.e., 20 layers in total) below the top two soil layers. To avoid confusion, the dots' sizes are matched, and what the dots mean is also noted in Figure 1's caption.

2. line 183 states rho is r_j ^j , which does not make sense. and if rho is density, then could you check the unit consisensy of this equation?

- We apologize for the typo and appreciate for pointing this out. ρ is the liquid water density (1,000kg/m^3) and r_i^j is the liquid water flux (mm/sec). We have made the correction in the revised manuscript accordingly (lines 213-214).

3. Line 196 eq 6 seems to be the spatial derivative of the "stream" discharge instead of the time derivative of the "steam" discharge? 195 has typo "steam discharge" as well.

- We appreciate the reviewer's comments. $\frac{dQ}{dy}$ in Equation 6 is the spatial derivative, not the time derivative. The typos in Equation 6 and 'steam discharge' have been fixed in the revised manuscripts (lines 237-238). We apologize for the typo.

4. Figure 3: the analytical area is not explained anywhere (or I missed it), if you present it there, it is better to give some explanations.

- The numerical and analytical area (Figure 4) means the uncertainty band of analytical solutions due to the slope variations implemented in each experiment. Figure 4's caption has been updated to clarify the meaning of the numerical/analytical area. We apologize for the missing information.

5. Line492 "Following the extraction criteria (section 3.3.2).... there is section 3.3.2

- We apologize for the typo. We have corrected the typo in the revised manuscript (line 509). Section 3.3.2 → Section 2.4.2

6. Figure 7 (a)(b)(c): the first subfigure with legend "VWC", which is not explained anywhere. according to the caption it is the soil moisture, then should it SMC? (according to line 581). And what is the meaning of fprec in the third figure? how to interpret it?

- Thank you for pointing this out. According to the reviewer's comments, the term VWC has been replaced with SMC (m^{3}m^{-3}), and the meaning of fprec has also been clarified in Figure 8's caption.

7. Line 636-648 + Figure 9 : It is not clear why reducing spin-up time matters. it is an interesting discovery, but I don't find it important. Do you have any important reason to keep this discussion in the main body of the manuscript? Otherwise consider move it as a supplementary material.

- As suggested by the reviewer, we have moved Figure 10 (a) and the corresponding sentences to Supplemental Information S.2. As a result, section 4.3.2 has been significantly shortened.

8. Section 4.4 is very important since it finally hits the point that the modeled LAI has difference after involving the groundwater to the model, which lead to the potential improvement of the modeled transpiration. It would be better if there are more statistics given to show how much improvement between the lm4 and lm4-sharc.

- We have addressed the reviewer's comments by performing an additional comparison between simulated and observed evapotranspiration. The Critical Zone Observatory (CZO) (at the Providence Creek headwater catchment) vapor flux observation from the eddy flux tower is located within the study catchment, as indicated in Figure 3. Since observations that only measure 'transpiration' are not available and the vapor flux observations measure ET (i.e., evaporation +

transpiration), we compared simulated ET against observed ET when transpiration is above zero (see Figure 12(f)). In the revised manuscript, we also note that 33.5 percent of the data during the observation period was missing, and the loss of approximately one-third of the data reduces the reliability of this comparison. All this information has been organized as Supplemental Information S.3.

9. I see all the catchments the authors selected are headwater catchment. So, before discussing applying the sharc scheme to global scale, could the author elaborate more on how to apply the scheme to downstream catchments where the drainage networks are more complicated? I think the accuracy of the analytical solution of those catchments should be more challenging.

- To address the reviewer's comments, we have revised section 4.5.2 to present the applicability of observationally-derived model data of net subsurface discharge (NSD) to parameterizing the Boussinesq aquifer's diffusivity downstream of the river (lines 799-814) (Hong and Mohanty, 2023a). Essentially, as we respond to reviewer 1's specific comment #3, the LM4-SHARC had to be tested at a headwater catchment since the sub-grid scale reach-to-reach connectivity (i.e., channel network) is not fully operational yet in the GFDL land model, so the inflow from the upstream cannot be simulated due to absence of channel network. As addressed in lines 799-814 in the revised manuscript, directly using the streamflow/baseflow model-derived estimates available at the catchment-scale can be used to extract the NSD data at the catchment level. This could be done by assimilating observational data (in-situ, remote sensing) into hydrologic models for higher spatiotemporal runoff estimates. Lines 780-798 also argue that the local relationship between the soil properties data and recession parameters could also be used to infer groundwater diffusivity parameters downstream of the river (Hong and Mohanty, 2023b).

References

Hong, M., & Mohanty, B. (2023a). A new method for effective parameterization of catchment-scale aquifer through event-scale recession analysis. *Advances in Water Resources*, *174*, 104408.

Hong, M., & Mohanty, B. P. (2023b). Representing bidirectional hydraulic continuum between the stream and hillslope in the National Water Model for improved streamflow prediction. *Journal of Advances in Modeling Earth Systems*, *15*(3), e2022MS003325.