Reviewer 1:

Thank you so much for the detailed and thoughtful feedback. We appreciate that you took the time to engage with our work. We have responded (in blue) to the reviewer comments (in black) as numbered below (and re-organized the order such that comments with responses come after general reviewer summary comments).

Reviewer Summary Comments:

1. The contributions of subsoil layers to the water supply of forests has been documented since the mid-1990s. What was originally interpreted as a rare and unusual phenomenon is now recognized as essential to the ecohydrology of many terrestrial biomes. There have been calls to implement a broader definition of the rhizosphere in global vegetation models to include subsoil strata. Apart from Jimenez-Rodriguez et al (2022) cited by the authors, the present manuscript may be the only other attempt towards this goal. Thus, the paper is timely and important.

2. The authors present a novel tool for predicting the influence of plant-available subsoil water on vegetation composition and the hydrological cycle. This involves a restructuring of the hydrological scheme in the DGVM LPJ-GUESS, an age-structured plant functional type model constructed to predict global biome distributions through an optimization process that maximized NPP. The modification was introduced as having two independent components (Fig. 3): the increase in storage by incorporating the subsoil and the increase in subsoil recharge by modifying runoff prediction. As it turns out, are both needed for the best fit.

3. The substantial result is that root access to subsoil ('rock moisture') AND greater partitioning of precipitation into the subsoil are essential to more accurately predicting tree LAI and summer ET across the continental United States (and in the case study).

7. The authors do a good job presenting their work in the context of prior contributions.

8. The title is fine.

9. The abstract is also fine.

11. The language is fine.

12. The symbols are consistently used and have correct units.

14. The references are appropriate.

Specific Reviewer Comments with Responses:

4. The manuscript is very clear explaining the hydrological modification that affects runoff generation (Q_surf v Q_baseflow). However, I missed an equally clear explanation of the way in which root uptake of water is regulated in the model and how that scheme was adapted to the restructuring of subsurface storage. If that part of the LPJ-GUESS hasn't changed from earlier versions, (Haxeltine & Prentice 1996; BIOME3), water supply is downregulated through a simple linear correlation with the amount of plant-available soil moisture remaining in two soil layers. Furthermore, tree and grass PFTs are distinguished by their relative access to these pools (e.g., grasses = 90% roots in the to 50 cm, versus trees 33%). I would urge the authors to expand on this aspect of the model description. Note that on page 24 lines 25-29 they are actually addressing the issue of root distribution, so it only makes sense to talk about this up-front. I would be curious to know if grasses had access to the second layer (the subsoil) per default parameters.... Seems that they do per line 32 on the same page. The BIOME3 model might not assign *detailed* strategies on root profiles, but it does have a simple and essential one when it comes to distinguishing trees and grasses competing for two soil water pools. One has to look and see if that makes still sense after the redefinition of the two pools.

We agree that the root water uptake was not adequately explained. We focused on the changes we made to the model rather than the overall functioning, but the root water uptake is essential to understanding the changes made to the model. Furthermore, our choice of water uptake scheme within LPJ-GUESS rendered the values of root distributions for trees unimportant. The grasses do, as the reviewer mentioned, still have 90% of their roots in the top 50cm. Unfortunately, we neglected to mention and describe this, apologies for this oversight. We believe that this water uptake scheme gives a better reflection of reality, because trees can essentially explore the whole volume (reflecting that in reality they can utilize tap/coarse roots), whereas grasses are limited to 90% in the top 50cm (no taproots). We have added a description of the existing water uptake strategy as implemented in LPJ-Guess to the methods as follows:

“We used the so-called ``SMART” root water uptake scheme implemented in LPJ-GUESS. This maintains a key feature of the current default water uptake scheme that the supply of water for transpiration is not curtailed until soil water content reaches wilting point (which stands in contrast to previous versions of LPJ and its ancestor BIOME models). In the SMART scheme, unlike the default water uptake scheme, trees are not constrained to access water according to prescribed root distributions. By removing this constraint on trees, we believe that the SMART scheme better reflects the ability of trees to forage for water throughout the available subsurface storage volume using their taproot and other coarse roots. This is supported by our finding that the SMART water uptake strategy allows transpiration to continue further into the summer (more closely matching real transpiration patterns) than any other root water uptake model implemented in LPJ-GUESS (Supplemental Figure A6). This also is aligned theoretically with our approach for determining the subsurface storage capacity, which is sized to hold all of the water that plants are known to have access to. As such, trees should be able to access all of the water stored in the subsurface in either layer. Furthermore, model parsimony is improved by effectively removing the rooting depth parameters. This has the further benefit of avoiding the necessity to reconcile rooting depth profiles developed for the fixed soil layer depths in the default LPJ-GUESS model with the new subsurface structure with spatially variable layer depths. Grasses, however, follow the default root uptake behavior in which they have 90% of their roots in the upper soil layer, with only 10\% of their roots in the lower layer. Their maximum water uptake rates are weighted by this rooting profile regardless of layer depths, implying that grasses have limited access to the lower soil/weathered bedrock water pool and can draw a maximum of 10\% of their water from it. Again we believe this is a reasonable representation of reality because, without coarse roots, grasses mostly draw water from near the surface but may be able to root deeper to some extent if needed."

5. Related to the omission of addressing plant interactions with water storage pools, page 23, lines 16 – 26 was a bit undeveloped. Seems to me, one should always be able to find out why a model acts in a certain way. Furthermore, I don't see why residual storage water at the end of summer is necessarily a problem. One would in reality not expect all water to be used by the end of summer every summer.

The continued downregulation of transpiration late in the summer remains interesting and did not receive enough attention. We agree that it is not necessarily a problem for water to remain in storage at the end of the summer. This indicates that the limitation on transpiration is not entirely water availability (because water was available but not used) but something else related to the plant processes (we clarified this in the discussion). However, this does merit more discussion that was in the original draft. We performed additional analyses, as described below.

From page 11, line 1, I gather that the simulations were run for the period from 1981-2021, and so I assume that model output is composed of multi-year averages, suggesting that on average there should be positive residual moisture.

Yes, additional details on the model runs are now added to the methods section:

"For all model runs, the nitrogen cycle was enabled, and land use was not included, so simulation results represent potential natural vegetation. For all locations, we ran four different simulations based on the same climate data for the period 1981-2021 using a 500-yr spin up period. Results are shown as a mean over the period 1981-2021."

Furthermore, given that Fig. 4 was a model prediction, the fact that 'rate limitation from photosynthetic pathways are still not fully understood' was sort of beside the point. Perhaps the point can be made in relation to Figure 6, though.

We also agree that the comment about photosynthetic pathways was not well-contextualized, and we have clarified (see revised text copied below) that the comment is meant to indicate that the state of knowledge about uptake down-regulation in water-limited conditions may limit our ability to model these processes:

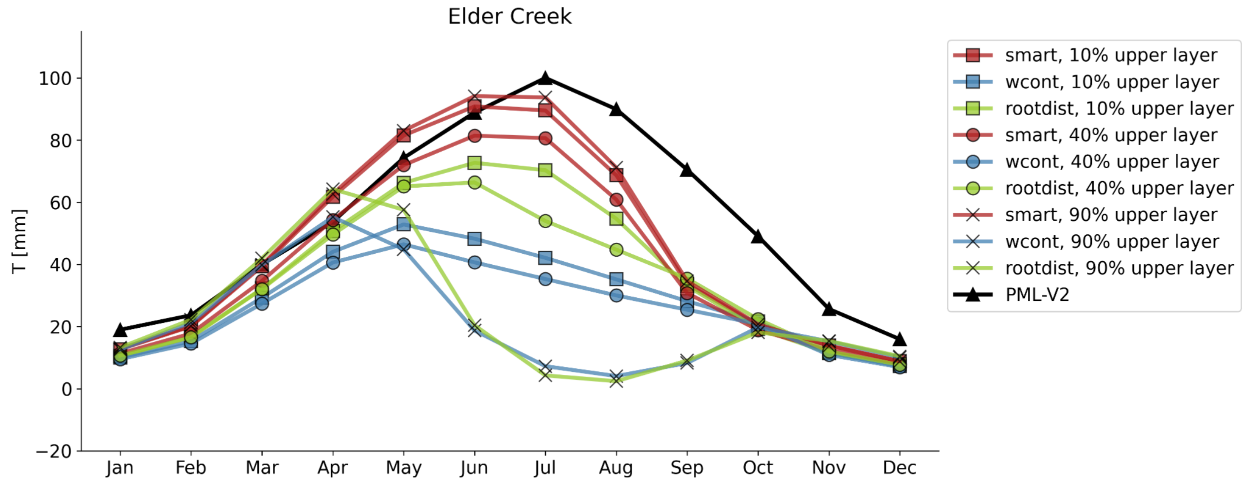
"Since simulated transpiration is given by the smaller of water supply or demand, the fact that supply was not used up indicates that the model identified demand-limited (rather than supply-limited) conditions. The limitation on late-summer T was no longer water availability but related to a rate limitation from photosynthetic pathways that are still not fully understood in water-limited conditions \citep{tezara1999water,tuzet2003coupled,pappas2013sensitivity,zweifel2006intra,vico2008modelling,lawlor2009causes,keenan2010soil,mcdowell2011mechanisms,tardieu2011water,sun2020response}. Thus, if it is necessary to further enhance late-summer T for greater model realism, it is necessary to improve the plant physiology in addition to the hydrology scheme and storage to see further gains. "

However, I am not convinced that the problem lies necessarily in the physiology: It is very possible that assumed water and root distribution could affect the calculation of optimal LAIs in the LPJ-GUESS model. Really, the model probably needs three layers to maintain the partitioning of soil moisture between grasses and trees. At least for the case study, the authors could have tried to optimize the assumed root distributions, or at least do a sensitivity analysis to investigate the question of root distribution as another source of uncertainty. In my opinion this would add a useful message, rather than dismissing the topic out of hand.

Thank you for this suggestion. In our original exploration, we did adjust some parameters in the model to see if the late-summer transpiration would bump up (for instance, the emax parameter that sets the maximum transpiration allowed on a given day), but we did not see significant changes. We have now tried adjusting the root distribution and switching the water uptake routine as well, and these results have been added to the supplement and referenced in the discussion:

"This observation indicates that the limitation on late-summer T was no longer water availability but something related to plant physiology or root water uptake. To rule out root distribution or water uptake strategy, we perturbed the root distributions (10\%, 40\%, and 90\% of roots in

upper soil layer) and applied three of the built-in water uptake schemes (smart--used in this study--, root distribution-based, and water content-based) in the Elder Creek case study site. Across all of these permutations, none resulted in an enhanced transpiration signal that extends later into the dry season than the results presented in the main text (see Appendix C), indicating that plant physiology routines are driving the down-regulation of T late in the summer.”
Here is the new figure in Appendix C that demonstrates this:



6. It would have been helpful to have more information on the implementation of the model. From page 11, line 1, I gather that the simulations were run for the period from 1981-2021, and so I assume that model output is composed of multi-year averages and that tree and grass LAIs were optimized over the same period. But this has not been explicitly stated in the manuscript.

Thank you for pointing out the need for further detail on the model runs. We have added a statement with more information:

“For all locations, we ran four different simulations based on the same climate data for the period 1981-2021 using a 500-yr spin up period. Results are shown as a mean over the period 1981-2021.”

10. In general, it would have been better to have fewer and/or less complex figures. The figure content was excessively comprehensive, given that the main results were quite straight forward. For example, after the first few results, it is quite evident that the second storage pool needs the enhanced recharge to have the desired effect on ET. Once this is established (and the most fitting place to establish this in the case study, e.g. Fig. 10 is really good in this respect), it is perhaps enough to contrast only the

default model, the fully modified model and the ET data product. Perhaps consider Figs 5 and 8 for supplementary data.

Thank you for the suggestions. We have moved Figures 5 and 8 to supplemental material. We have also reorganized the results so that (the original) Figure 10 is used to establish that we need to compare only the default and fully modified models in the remainder of the study. We then removed the partially modified models from all additional figures.

13. See comments above: more should be said about the way in which LPJ-GUESS predicts functional type composition and how plants interact with storage, i.e., how transpiration is constrained by supply not demand.

We have (described above) added description of the root water uptake strategies. We also added a methods section describing briefly how LPJ-GUESS determines PFT:

“LPJ-GUESS is a dynamic global vegetation model, which simulates how different Plant Functional Types (PFTs) compete for resources (here light, water and nitrogen). The traits of the PFTs determine which PFTs are most successful and thus reach the largest biomass or cover under given environmental conditions. For example, a summer- or raingreen phenology is beneficial in seasonal environments, and PFTs with such a phenology then outcompete evergreen PFTs because individuals grow faster. Root distributions influence the competition for water, whereby deep rooting yields more water access in Mediterranean areas with winter rain. These outcomes are not predefined but they emerge from the functional traits of the PFTs in a given environment. The distribution of PFTs is further constrained by bioclimatic limits (adopted from Sitch et al. 2003) and disturbance by wildfires also affects vegetation dynamics”

15. I recommend expanding the supplementary information section, in exchange for striving for greater synthesis in the results figures.

We have taken this advice, as described above in the responses to comments 5 and 10.

Reviewer #2: