The Third Reviewer

It's my pleasure to review egusphere-2024-1256 "What Are the Key Soil Hydrological Processes to Control Soil Moisture Memory?" by Farmani et al. The authors conducted several numerical experiments using the Noah-MP LSM to investigate the impact of soil water retention characteristics (or soil hydraulics), soil permeability (or preferential flow), and surface ponding on simulating profile soil moisture dynamics as well as capturing the long-term and short-term soil moisture memory as observed by SMAP satellite and in situ ISMN networks over the contiguous United States (CONUS). The research is very interesting and should be useful for improving the simulations of soil moisture dynamics and memory using the LSM. However, the design and validation of numerical experiments can be further improved given the fact that several other processes (e.g. infiltration, evapotranspiration and drainage) affecting the simulation of soil water flow are not well considered. In addition, detail descriptions on the adopted Noah-MP model should be provided since the version adopted in this paper is not an official released one. Accordingly, major revision is recommended. My comments are as follows.

Thank you for reading the paper and your valuable feedback!

Major:

1. The design of numerical experiments should be improved to consider the impact of several other processes (e.g. infiltration, evapotranspiration and drainage) and hydraulic parameters on simulating profile soil moisture dynamics and memory.

   R: Thanks for the comments, which force us to rethink the main purpose of this this study.

   The focus of this paper is primarily on the impacts of key hydrological processes that may be missed by mainstream LSMs on SSM, e.g., preferential flow and surface ponding. So we changed the title to
   "Do Land Models Miss Key Soil Hydrological Processes Controlling Soil Moisture Memory?" instead of
   "What are the Key Soil Hydrological Processes Controlling Soil Moisture Memory?"

   Accordingly, we revised the Abstract, Introduction, and Discussion, and Conclusion sections. Please see the doc with tracked changes.

   Actually, in the review paper of Rahmati et al. (2024), they have summarized the major mechanisms of soil moisture memory emergence, including all factors affecting ET and drainage (10s of papers on the effects). Experiments to investigate the effects and ET and drainage would make this paper too general.

2. Besides the physical process and parameterization, the uncertainty related to hydraulic parameters could also affect the simulation of soil moisture dynamics. The authors should at least discuss the potential impact of this.

R: Thank you for your insightful comment. While we acknowledge that uncertainty in hydraulic parameters can impact soil moisture dynamics, our prior objective of this research is to investigate the missing physical processes (model structures) instead of uncertainties in model parameters. Although uncertainties in hydraulic parameters may reflect uncertainties in model structure and finally can solve the problem e.g., directly increase the hydraulic conductivity (to mimic the preferential flow model), but it does not help understanding the effects of biotic (worm holes and dead roots etc.) and abiotic factors (freezing-thawing cycles and drying-wetting cycles).

We have revised the Discussion Section, accordingly.

Minor:

1. The validation of numerical experiments can be improved given the fact that the ISMN networks also provide measurements of surface soil moisture. The authors can consider validating the model simulations at point/pixel scale using soil moisture measurements at both surface and deeper layers from the ISMN networks, and using the SMAP product for regional-scale validation. In addition, the penetration depth of L-band can be shallower than 5 cm, how the mismatch between the sampling of SMAP satellite and model layer thickness affect the validation?

   R: The primary aim of this study is to analyze the effects of missing physical processes on soil moisture dynamics rather than to conduct a full validation of the Noah-MP model. While ISMN data does provide valuable point-scale surface soil moisture measurements, the spatial scale of these observations is considerably smaller than the 1/8-degree grid scale of Noah-MP and SMAP. This scale mismatch makes direct comparisons challenging for surface soil moisture, especially given the spatial heterogeneity at point scales.

   SMAP, on the other hand, provides continuous surface soil moisture data across the U.S. at a spatial resolution closer to that of Noah-MP, allowing for a more consistent comparison. SMAP is also widely recognized in the literature as a benchmark for model validation, enabling us to align our results with those from previous studies. For these reasons, we focused on SMAP for surface layer analysis and used ISMN data primarily for root zone validation, where point-level observations are less impacted by scale limitations.

   The SMAP L-band penetration depth can indeed be shallower than 5 cm, especially over wetter regions like the eastern CONUS, which may introduce a mismatch when comparing SMAP observations with the Noah-MP 5 cm layer. SMAP's reliability is particularly affected by plant water storage changes in the eastern U.S. and specific mountainous areas, which can introduce variability in SMM values when used as a benchmark. While SMAP observations may be less reliable over these densely vegetated areas, they still support our objective of enhancing our understanding of the physical processes in soil hydrology. Additionally, the SMM patterns observed from SMAP offer valuable insights into regional variability, which aligns with our study's goals.

   The following part in the paper is modified to reflect your concern: "Some sources of uncertainty may affect our results in this study, including uncertainties in input data, and models. The SMAP L-band penetration depth can indeed be shallower than 5 cm, especially over wetter regions like the eastern CONUS, which may introduce a mismatch when comparing SMAP observations with the Noah-MP 5 cm layer. SMAP reliability is affected by plant water storage change (in the eastern part and some mountainous sites), introducing uncertainties into SMM values for the benchmark. While SMAP observations may be less reliable over these densely vegetated areas, they still support our objective of enhancing our understanding of the physical processes in soil hydrology. Furthermore, the SMM patterns captured from SMAP can be insightful in understanding regional variabilities in SMM.

Another concern is the influence of ISMN spatial representation on SMM analysis. ISMN stations are point-based, and it is assumed that one point represents a 1/8-degree grid area. It is possible that the point measurements cannot fully capture the spatial variability within the Noah-MP grid cells, leading to discrepancies in the representation of values and spatial patterns. The limited number of stations may further amplify this issue. One potential solution to address the scale mismatch between point-based observations and grid-scale simulations is the use of high-resolution or hyper-resolution models. These models can provide finer spatial detail, allowing for a more direct comparison between observational data and model outputs, thereby improving the accuracy of the analysis and reducing scale-induced biases. Incorporating such approaches in future studies would help mitigate the limitations posed by the current scale differences."

2. Detail descriptions on the adopted Noah-MP model should be provided since the version adopted in this paper is not an official released one. For instance, how many options are available for each process listed in Tables 1 and 2, and what are the criteria for determining the options listed in Table 1? Particularly, detailed introduction (e.g. relevant equations) of the processes and options related to the simulations of soil moisture dynamics is necessary, which can be included in the Appendix.

   R: Thank you for the suggestion to provide additional details on the Noah-MP model version used in this study. The specifics of the underlying physics, parameters, and details related to this new version of Noah-MP are thoroughly documented in a separate paper, where we cover all parameters listed in Table 2. Additionally, the options presented in Table 1 are derived from the existing publicly available Noah-MP model, and all options are described in detail in Niu et al. (2011) and later in He et al. (2023), which is publically accessible. Together, these references provide comprehensive coverage of the parameters, equations, and process options related to soil moisture dynamics in our simulations.

   We summarize the equations of Niu et al (2024), which is included in the Supporting Information. Also, we provide the updated model code through a github link: (https://github.com/mfarmani95/NoahMP_Dual).

He, C., Valayamkunnath, P., Barlage, M., Chen, F., Gochis, D., Cabell, R., ... & Ek, M. (2023). *The community Noah-MP land surface modeling system technical description version 5.0* (p. 5). NCAR Technical Note NCAR/TN-575+ STR, doi: 10.5065/ew8g-yr95.

3. L213: I suggest to introduce the model/experimental design and datasets in two separate sections.

   R: The manuscripts is revised accordingly

4. L236 and others: the number of sections and subsections in the manuscript is wrong.

   R: The manuscripts is revised accordingly

5. L288-292: it's not clear how the authors use the IMERG precipitation product to run the model?

   R: To incorporate the IMERG precipitation product, we modified the forcing component of the Noah-MP code. Specifically, we used an average of NLDAS-2 and IMERG precipitation in cases where NLDAS-2 generated negative precipitation values, which was particularly relevant for coastal regions. This adjustment helped improve the accuracy of precipitation inputs in these areas.
   The following is added to the paper:
   "To integrate the IMERG precipitation product into the model, we modified the forcing component of the Noah-MP code. Specifically, an average of NLDAS-2 and IMERG precipitation was employed when NLDAS-2 reported negative precipitation values, which was particularly significant in coastal regions. This adjustment enhanced the accuracy of precipitation inputs, contributing to more reliable simulations in these areas."

6. L307-300: the time span is 2015-2019 as given in Abstract, please clarify. In addition, why the authors only choose the product of these years give the fact that the product is available up to now.

   R: We selected the 2015-2019 time span to ensure consistency with previous studies, specifically MacColl et al. (2019) and He et al. (2023).

7. L404-405: did the groundwater level reach equilibrium after only five iterations (i.e. 25 years for spin-up)?

   R: a good question! For the groundwater level to reach an equilibrium state, it would take more than 100 years and even longer e.g., 1,000 years in some regions, e.g., the drylands of Arizona with a thick vadose zone (100 meters) with very slow processes like vaporization and diffusion of groundwater to the ground. However, as the critical zone affecting surface processes and the top 2 m soil moisture dynamics is ~5 meters (Kollet and Maxwell, 2008), indicating that the water table below ~5 meters would have negligible effects.

For the top 2m soil moisture to reach an equilibrium, it takes several years with a maximum of 10 years in most cases. This is also consistent with the soil moisture memory analysis. It is generally accepted that the soil moisture memory is important for climate predictions at S2S scales (the ocean's memory lasts longer).

Kollet, S. J., and R. M. Maxwell (2008), Capturing the influence of groundwater dynamics on land surface processes using an integrated, distributed watershed model, Water Resour. Res., 44, W02402, doi:10.1029/ 2007WR006004.

8. L406-409: I think detail descriptions should be provided, e.g. provide a list of parameter values adopted in this study.

   R: There is another paper in which we provide the detail of the underlying physics, parameters and all the details related to this new version of Noah-MP.

   Niu et al, (2024) is publicly available online:
   https://d197for5662m48.cloudfront.net/documents/publicationstatus/216663/preprint_pdf/7f3141f24161bbc7b24e562e983640b2.pdf

   Because it is published, we provide more details of the model descriptions and parameters in the SI.

9. L416-421: the official version of Noah-MP only include four soil layers with depth up to 2m, how the authors solve both soil water and heat flow processes with the new configuration of layer thickness and depth?

   R: There is another paper in which we provide the detail of soil moisture solver, hence the following sentences is added to the paper:
   "A detailed description the underlying physical mechanisms of the schemes used in this study could be found at Niu et al, (2024), also a brief description of equations and parameters is included in supporting material"

10. L448: for the results presented, how the authors match the model simulations with SMAP product? For instance, the SMAP product include ascending and descending overpasses, how the authors match their simulations results with these?

    R: In the paper we mentioned "In this study, we selected the SMAP Level 3 morning overpass due to the greater likelihood of air and surface temperature equilibrium during these hours, a critical condition for the SMAP retrieval algorithm."