CC1: 'Comment on "What Are the Key Soil Hydrological Processes to Control Soil Moisture Memory?" by Farmani et al. (2024)', by Mehdi Rahmati, 23 May 2024

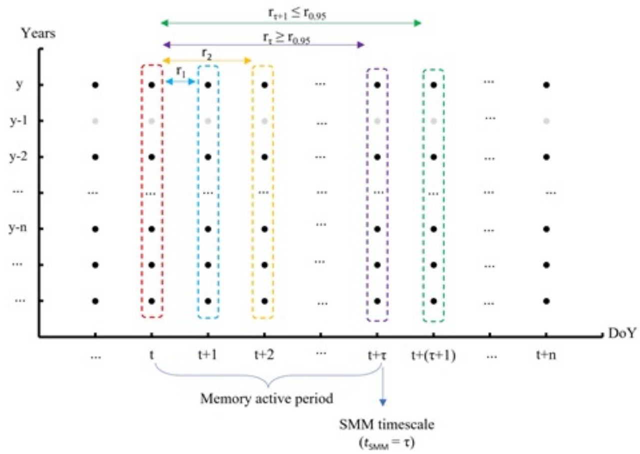
It was with great interest that I read this interesting article written by Farmani et al. (2024). After reviewing and reading almost all works on soil moisture memory (SMM), it must unfortunately be noted that the effects of soil properties on SMM are very rarely investigated, and it's great to see that a research group has conducted such interesting research directly on this topic. To emphasize the importance of this and all similar research looking at SMM and the link with soil properties, I may copy and paste here the part of the "The way forward" section of our review paper on SMM, which has just been published in Reviews of Geophysics (Rahmati et al. (2024); https://agupubs.onlinelibrary.wiley.com/doi/10.1029/2023RG000828):

"Finally, SMM is the result of a complex interplay of physical, biological, and hydrological processes and soil properties (Group 3) (Rahmati et al., 2023). In fact, SMM is rooted in the integrative nature of soil moisture as a water reservoir (Orth and Seneviratne, 2013), which can be influenced by multiple processes (Figure 3), including soil infiltration, soil water redistribution and storage, root water uptake, capillary rise, and drainage. This review shows that the literature, in general, considers soil depth and soil porosity (as it appears in the autocorrelation expression) to be the main soil properties controlling SMM. While we recognize the valuable contributions of previous efforts such as the SoilWat initiatives (e.g., Aliku and Oshunsanya, 2018; Andrews and Bradford, 2016; Oyeogbe and Oluwasemire, 2013), we maintain that additional consideration should be given to pore size distribution, soil mineral composition (e.g., type and amount of clay), soil organic carbon, and other such properties, as these can control water retention, hydraulic conductivity, and diffusivity and accordingly can influence SMM. In addition, the importance of "hydraulic redistribution" by roots (Dawson, 1993), which is of prominent importance during dry periods by bringing water from deep reservoirs to the near surface soil (Caldwell et al., 1998; Jackson et al., 2000), needs to be emphasized in future research. Hagemann and Stacke (2015) have already shown that hydraulic redistribution by a wide range of plant species is significant in many different biomes around the globe and has implications for SMM."

The improper integration of soil memory (as a comprehensive concept that includes SMM, as soil moisture is only one of the carriers of memory in the soil) into LSMs has already been highlighted in another article of our group published in Nature Reviews Earth & Environment (Rahmati et al. (2023); https://www.nature.com/articles/s43017-023-00454-5) where we have already stated that LSMs neglect soil memory.

Finally, although I do not put myself in the shoes of the reviewers of this paper and therefore leave the technical comments to them, I have only one concern that I thought might be overlooked and would be better to mention, namely that in lines 164 to 174, you mentioned several metrics for quantifying SMM (of course you can find more, as listed in our review) and then stated in lines 175 to 177 that "These methods provide insights into the magnitudes of water and energy flux exchanges between land surface and atmosphere, indicating that shorter SMM durations can lead to more intense feedback and larger flux exchanges". However, I think that such an insight cannot be adopted so easily. After reviewing almost all available work on SMM, I can only say that the SMM timescale merely indicates the duration or time window within which the current state of the soil moisture causes feedback to the land surface process. However, we cannot judge from the

SMM timescale how strong this feedback will be. As we mentioned in our review, future research on SMM should examine the strength of SMM in addition to its timescale. So far, the only criterion to investigate the strength of the feedback is the autocorrelation value itself. All the other criteria you have listed here only quantify the SMM timescale, of course, mostly based on the autocorrelation, **which certainly cannot say anything about the strength of the feedback**. In short, the SMM timescale only defines the active period of memory (see the following figure, which is copied from Figure 1 of our review paper), **not its strength**. I may be wrong, but this is how I can understand it, even from a mathematical point of view.



To summarize, I would say that an extreme event (exogenous or endogenous, whatever it is) leads to Soil Memory (as a whole, which includes SMM), which is only a descriptive phenomenon to describe the process as a whole: a phenomenon that occurs in the soil (or we can call it an emergent property of the soil, so emerges in soil) that describes how and why information is fed into the soil after a single event or series of events, how the information is stored, and transferred across the time axis, and what mechanisms are involved and how they affect the variables, fluxes, and functioning of the future system. However, when it comes to quantifying it, we can assume three different characteristics, including timescale, strength, and legacy effects:

Soil Memory Timescale: the time period in which the soil can remember these effects. If the carrier is known (e.g., soil moisture, soil carbon, etc.) and we can measure it as a time series, then the memory timescale can be quantified by the time lag at which the autocorrelation of such a time series falls below its e-fold — or we can apply other methods like Hybrid Stochastic-Deterministic Model suggested by McColl et al. (2019), which is also used by Farmani et al. (2024); if the carrier of memory has no time series origin (like change in soil structure or pore size distribution), then other methods should be used for this quantification, such as the metrics used in paleopedology, I think.

Strength of Soil Memory: As used in the literature (e.g., Orth et al., 2013), this quantifies the strength of the drivers of Soil Memory. In this way, we can acknowledge and discuss that this memory is based on changes in atmospheric forcings, management factors, or soil properties and mechanisms. In the case of memory carriers with time series origin, it can be quantified by the value of autocorrelation at each time step from 1 (the day after the event) to the Memory Timescale.

Soil Legacy: This is the value of the impact of extreme events on the functioning, fluxes, and variables of the system after extreme events (which is probably of your interest when you talk about the strength of the feedback). For example, the change (positive or negative) in the fluxes of the system (soil respiration, CO_2 emission, etc.) in time steps after the occurrence of the extreme event. The legacy will certainly be stronger if we study it in close proximity to the event. As the temporal distance increases, the legacy decreases, and the impact is almost zero after a time corresponding to the time scale for memory. According to the literature, legacy can be quantified by comparing the state of the target variable or flux of the system at any time after an extreme event with the long-term average before the occurrence of that extreme event. Thus, it can be positive (e.g., an increase in CO_2 emissions after the extreme event) or negative (a decrease in carbon storage after the extreme event).

Best,

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R: Thanks for the comments. We have deleted the sentence "These methods provide insights into the magnitudes of water and energy flux exchanges between land surface and atmosphere, indicating that shorter SMM durations can lead to more intense feedback and larger flux exchanges."

In the Introduction Section, we did not really summarize the mechanisms of SMM emergency. So, after reading your review paper. We have revised the Introduction to reflect we have learned:
"A recent review on SMM identified soil properties and processes as an important controlling factor of SMM in addition to atmospheric forcings and land use and management for future studies to examine the fundamental mechanisms of SMM emergence (Rahmati et al., 2024). Based on the works of McColl et al. (2019) and He et al. (2023), this study aims to examine the impacts of soil hydrological processes and soil hydraulics on SMM. The current LSMs may not be enough to address the uncertainties of SMM estinmates for incomplete representations of key hydrological processes controlling SMM and uncertainties in soil hydraulic parameters (Rahmati et al., 2024). As such, we use a version of Noah-MP with advanced hydrological representations of preferential flow, surface ponding, runoff of surface ponded water (infilration excess runoff), and lateral infiltration, etc. (Niu et al., 2024). We aim to optimize the soil hydraulics within the model by evaluating various parametrizations of those by Brooks and Corey (1964) and Van-Genuchten (1980), preferential flow, and surface ponding depth. Our analysis investigates the impact of these configurations on soil moisture consistency across different ET regimes and drainage, so it provides insight into physical processes affecting SMM. By comparing SMM produced by various settings of Noah-MP with SMAP Level 3 data and ISMN observations from 2015 to 2019 over the CONUS, we seek to identify key processes and soil hydraulic schemes controlling SMM and thus provide guidance for future developments of LSMs (e.g., reduce the prevalent SMM overestimations in LSMs)."