Reviewer Comments for: "Soil Parameterization in Land Surface Models Drives Large Discrepancies in Soil Moisture Predictions Across Hydrologically Complex Regions of the Contiguous United States" by Silwimba et al.

The authors present a comprehensive and methodologically rigorous study examining the influence of soil hydraulic and textural parameters on soil moisture simulations in CLM5, using soil parameter sets from the Soil Parameter Intercomparison Project (SP-MIP). Model outputs are compared against the ERA5-Land dataset as a benchmark. The study utilizes various analytical approaches—including means and variability assessments (Figures 4 and 5), as well as Empirical Orthogonal Function (EOF) analysis—to investigate dominant spatial patterns and variability in soil moisture across the CONUS region. The findings suggest that soil parameterization has a substantial impact on CLM5 simulations, with notable discrepancies from ERA5-Land, particularly in hydrologically complex regions such as the Great Plains. The default CLM5 setup captures mean climatological patterns reasonably well but tends to underestimate interannual and seasonal variability.

Overall, the manuscript is well-structured, and the English is of generally high quality. The authors have executed a wide array of experiments that meaningfully contribute to our understanding of soil parameter sensitivities in land surface modeling. However, several critical issues remain that merit further investigation before the manuscript is suitable for publication. I recommend **major revisions** to address the following points:

1) **Limited Benchmarking Against Reference Data**

   The exclusive use of ERA5-Land as a benchmark is insufficient. While the authors acknowledge some of ERA5-Land's limitations, it remains a reanalysis product with inherent model dependencies and does not assimilate in-situ soil moisture observations directly. Prior studies [*Koster et al.*, 2009] have demonstrated that soil moisture estimates are highly model-dependent. The validity of conclusions based solely on a single reference dataset is therefore limited.

   To strengthen the analysis, I strongly recommend incorporating additional observation-based datasets, such as GLEM v3 [*Martens et al.*, 2017], SMERGE [*Tobin et al.*, 2019], and MERRA 2 [*Reichle et al.*, 2017]. Each offers distinct advantages—GLEAM and SMERGE incorporate satellite-based observations, whereas MERRA-2 is a reanalysis-based soil moisture data. A recent study [*Duan et al.*, 2025] has shown ERA5-Land's underperformance compared to these alternatives for sub-seasonal to seasonal forecast validations.

2) **Underestimation of Interannual and Seasonal Variability**

   Figures 5 and 7 clearly indicate that all CLM5 configurations substantially underestimate soil moisture variability relative to ERA5-Land. Notably, Figure 5 reveals a tight clustering of CLM5 experiments, suggesting low variability in contrast to the wider spread of ERA5-Land data. However, this important point is underexplored in the manuscript. For instance, lines 284–285 state: "Despite these discrepancies, … broad agreement," which downplays the observed discrepancies.

This variability gap warrants a deeper investigation and further supports the need for multiple observational references (as per Comment 1).

(3) Neglect of Irrigation Effects

The authors identify significant differences between CLM5 and ERA5-Land EOF modes in agriculturally intensive areas, particularly the central U.S. (Figure 11b). These "hotspots" overlap spatially with known heavily irrigated regions, including the Ogallala Aquifer and Mississippi Valley [*McDermid et al.*, 2023].

However, the manuscript does not clarify:

- Whether Irrigation was included in CLM5 simulations.
- How Irrigation may affect soil moisture in ERA5-Land.

This omission weakens the attribution of model-observation discrepancies solely to soil parameterization. Explicit discussion on irrigation modeling and its inclusion or exclusion is essential to substantiate the attribution claims made (e.g., Lines 14–15).

(4) Initial Conditions Not Explained

The setup of initial conditions in the model simulations remains unclear. Since each experiment involves different soil parameter settings, it is essential that the model reaches equilibrium separately for each case [*Kennedy et al.*, 2024]. Without spin-up or appropriate initialization, differences in the initial soil moisture state could propagate and bias the results.

Please clarify whether each experiment was initialized to equilibrium independently, and if so, provide methodological details.

Minor Comments:

- **Line 32**: The phrase "such as artificial neural networks" requires a reference. A citation demonstrating the use of ANN as PTFs would be appropriate.
- **Line 77**: Parentheses are inconsistent in references; e.g., fix "Ji et al……, Zeng et al., (2021)" to consistent formatting.
- **Line 132**: Typo: "PFTS" should be corrected to "PTFs."
- **Lines 160–179 (Section 2.3)**: Consider revising for clarity. There are some repetitions, e.g., "dominant variability modes and their temporal patterns"…" spatial and temporal patterns"…
- **Line 193**: The term "demeaned" could be clarified or rephrased for general readability.
- **Figure 5**: Further explanation is needed regarding the variability difference between ERA5-Land and CLM5 simulations.
- **Lines 218–319**: The statement about 5 cm in-situ sensors vs. ERA5-Land's 0–7 cm integration is not directly relevant when the analysis uses 0–1 m averaged soil moisture. Clarify or remove.

- **Figure 7**: Please explain the significant differences between EAR5-Land variability and CLM5 cluster, except for Exp4-a.
- **Figures 9 and A2**: Clarify whether maps show EOF loadings or correlation coefficients. If correlation coefficients are used, explain the meaning and implications, e.g., correlation with respect to what?
- **Table 3**: Please include a total cumulative variance explained by the first 10 EOF modes for each experiment.

References

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