**Response to Reviewer #1:**

Thanks to the authors for addressing all the comments raised by the reviewers. The manuscript has been improved substantially. However, Section 2.2 still needs a few clarifications and the discussion some improvements regarding the comparison to reference models. I am also suggesting some modifications of figure 6 to facilitate results presentation. These are pretty minor revisions and shall not take long to the authors to address.

**Response:** Sincere thanks to the reviewer for the positive evaluation of our revised manuscript and for the constructive suggestions, which have been very helpful to this paper. We have carefully addressed all the comments and revised the manuscript accordingly. A point-by-point response is provided below (in blue), and all corresponding changes have been updated in the revised manuscript. We hope these changes will strengthen our manuscript.

Below are my detailed comments; line numbers refer to those of the tracked changes manuscript.

Line 68: provide the meaning of the acronyms/models WRF, CLM and LIS/Noah-MP.

**Response:** Added. Thanks to the reviewer for the careful observation. The definitions of WRF, CLM, and LIS/Noah-MP have been added to the manuscript (please see lines 67-69).

Lines 134-135: are these lines necessary? Equation 3 is the same as equation 2.

**Response:** Corrected. The redundant equation 3 have been deleted.

Line 146: it should be 'q_e(x)' (e in subscript) instead of qe(x). Shouldn't it be q_e(x) instead of q_e in equation 1, 2 and 3?

**Response:** Corrected. All instances of $q_e$ have been replaced with $q_e(x)$

Line 147 do you mean that q_e(x) can be solved by Eq. (4) (instead of for Eq.)? Isn't q_e(x) rather solved by combining Eq. (2) and Eq. (5), in solving psi first (Eq. 6), here?

**Response:** Corrected. Yes, we have clarified that PF-LPJG solves Richards' equation through free-surface OverlandFlow boundary conditions, fully integrating surface and subsurface water. The logic of formula in Section 2.2 has been revised accordingly (please see lines 129-150).

Lines 148-149: isn't it redundant with ethe sentence of lines 141-142?

**Response:** Corrected. Thanks to the reviewer for the constructive suggestion. The meaning of Equation 4 has been redefined to remove redundancy.

Figure 1: Arrows from and to LPJ-Guess module seem to be pointing the wrong direction, correct?

**Response:** Corrected. The arrow direction in Figure 1 has been corrected.

Line 196: what does CDS stands for?

**Response:** Added. The definition of CDS has been included in the manuscript (please see line 232).

Line 165 & 203: precise that the number provided are the thickness for each soil layer.

**Response:** Added, Thanks to the reviewer for the helpful suggestion, The soil layer description now have been changed to layer thickness (please see line 165 and 203).

Lines 210-225: Which spatial resolution is used for the subsurface model? 10km horizontal resolution? How about vertical resolution?

**Response:** Corrected. The subsurface model uses a 10 km horizontal resolution, and we have added the information on vertical discretization. Below the soil layers, six bedrock layers are represented with thicknesses of 5, 10, 10, 10, 25, and 50 m from top to bottom. This vertical configuration allows the model to resolve both shallow unconfined aquifers and deeper confined aquifers (please see lines 210-214).

Figure 5: subplot d, a colour blind linear colormap would be more appropriate (e.g. from white (0) to red (1))

**Response:** Corrected, Thanks to the reviewer for the suggestion. Subplot d has been updated to a color-blind linear colormap (from white (0) to red (1)).

Figure 5: why is there no middle column for LPJ-GUESS model results, similar to what is done in Figure 4?

**Response:** Corrected, Thanks to the reviewer for the insightful suggestion, we have added the middle column for LPJ-GUESS model results in Figure 5.

Figure 6: I am wondering if histograms wouldn't be easier to interpret than CDFs for subplots c and d. Why are LPJ-GUESS results not compared the same way as in subplots a and b? Potentially, plotting percentiles (10, 50 , 90) of SWC distributions as a function of the months would enable to compare the distributions between PF-LPJG, LPJ-GUESS and ESA CCI simultaneously. Would cross-plots of standardized SM anomaly (PF-LPJG against ESA CCI and LPJ-GUESS against ESA CCI), be easier to

interpret? I am sorry I did not make these suggestions at the first review of this manuscript.

**Response:** Thanks to the reviewer for the constructive suggestion. We agree that alternative visualizations, such as percentile plots and standardized anomaly cross-plots, provide additional perspectives on model performance.

After careful consideration, we have retained the original Figure 6 in the main manuscript, as it most directly highlights the key findings of this study: PF-LPJG tends to overestimate soil moisture during wet months but substantially improves simulations during dry periods, exhibiting higher correlation and lower error compared to stand-alone LPJ-GUESS. The current layout provides a clear and intuitive illustration of the seasonal contrasts that are central to our conclusions.

To fully address the reviewer's suggestions and enhance the comprehensiveness of the analysis, we have added the requested SWC percentile distributions (10th, 50th, and 90th percentiles as a function of month) and standardized soil moisture anomaly cross-plots as Supplementary Figures (Fig. S4 and Fig. S5). These additional figures include comparisons among PF-LPJG, LPJ-GUESS, and ESA CCI, enabling a more complete distributional and anomaly-based evaluation while preserving the clarity and focus of the main figure.

We think this approach strengthens the manuscript by providing both an accessible primary presentation and a more detailed complementary analysis.

While we agree that percentile plots and cross-plots provide additional perspectives, we have retained the original Figure 6 in the main manuscript because it clearly illustrates the key findings: PF-LPJG generally overestimates soil moisture during wet months but substantially improves simulations during dry periods, showing higher correlation and lower error compared to LPJ-GUESS. The current layout offers a clear and intuitive presentation of seasonal contrasts central to our conclusions.

To address the reviewer's suggestions, we have added the SWC percentile plots and standardized anomaly cross-plots as Supplementary Figures (Figs. S4 and S5), including comparisons with LPJ-GUESS. This allows a comprehensive distributional comparison while preserving the clarity and focus of the main figure.

Lines 590-591: it would be nice to provide more details for this explanations (e.g. link to equation, reference, figure of a few soil moisture profiles supporting the statement, …)

**Response:** Corrected. We have added references and clarified that terrain-driven oversaturation can cause simulated water table depths to approach zero in some flat areas, especially in shallow well (please see lines 548-550).

There should be a bit more discussion about the models used as reference for comparison of ET or SWC. Indeed these references are models and the product of some interpretation, so their robustness and weakness points should be emphasised. The differences with the PF-LPJG and the LPJ-GUESS predictions should be explained from a spatial perspective (e.g. with respect to drainage networks or DEM characteristics or specific soil cover) and from a process perspective (equations used). You should clarify why you would put more or less confidence in the results of a model rather than another.

**Response:** Thanks to the reviewer for the constructive suggestion. In the revised manuscript, Section 4.2 has been expanded to provide a more balanced discussion of the strengths and weaknesses of the reference datasets, considering both spatial and process perspectives. This includes explanations of differences with PF-LPJG and LPJ-GUESS predictions, with respect to drainage networks, topography, and process representation. These additions improve the comprehensiveness of the model intercomparison and better contextualize the confidence we place in each model's results.

## Supplementary information

**Figure S1.** The basin characteristics used in the model: (a) Digital Elevation Model (DEM) processed by PriorityFlow, (b) Annual mean landuse distribution, (c) Thickness of unconsolidated bedrock, (d) Annual mean net water input (P-ET) used as recharge flux. Land use from IGBP Global Vegetation Classification (1-17): 1. Evergreen Needleleaf Forests; 4. Deciduous Broadleaf Forests; 5. Mixed Forests; 8. Woody Savannas; 9. Savannas; 10. Grasslands; 11. Permanent Wetlands; 12. Croplands;13. Urban; 14. Cropland/Natural Vegetation Mosaic 15. Snow and Ice.

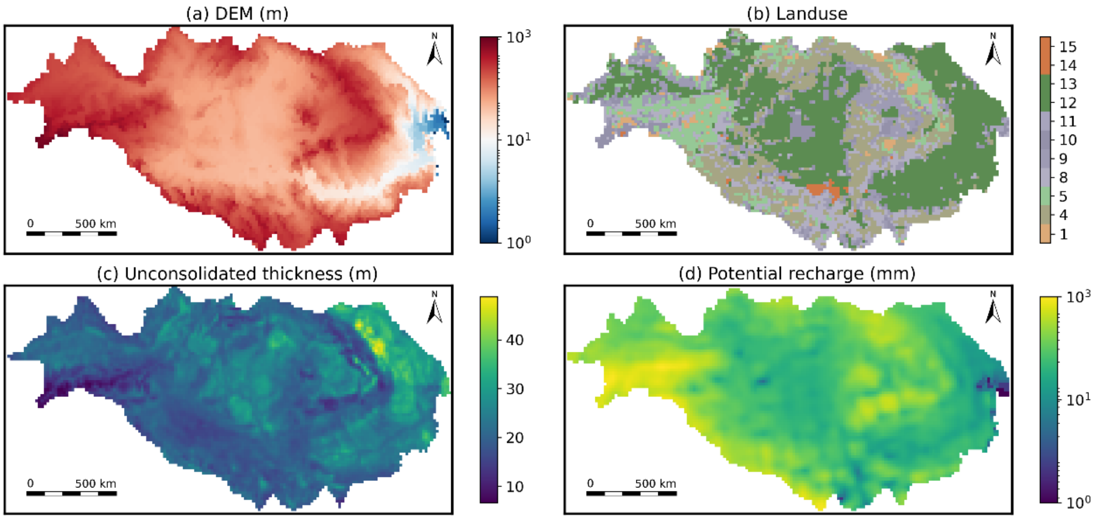

**Figure S2.** Classification of soil properties: (1) sand, (2) loamy sand, (3) sandy loam, (4) silt loam, (5) silt, (6) loam, (7) sandy clay loam, (8) silty clay loam, (9) clay loam, (10) sandy clay, (11) silty clay, (12) clay. Categories with few grid cells have been displayed using the same color.

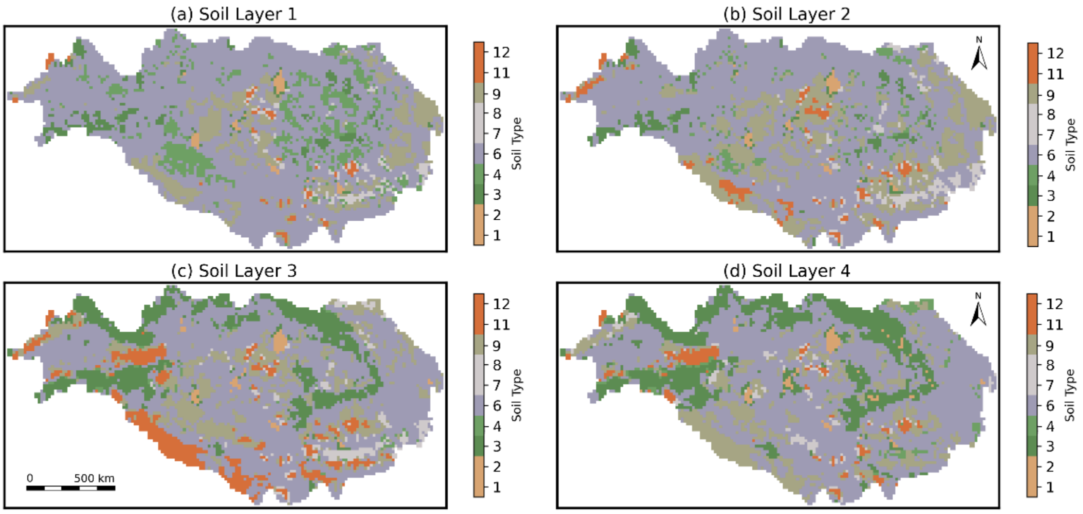

**Figure S3.** Classification of bedrock layers: (19) bedrock 1, (20) bedrock 2, (21) f.g. sil. sedimentary, (22) sil. sedimentary, (23) crystalline, (24) f.g. unconsolidated, (25) unconsolidated, (26) c.g. sil sedimentary, (27) carbonate. Note that f.g., sil., and c.g. represent fine-grained, siliciclastic sedimentary, and coarse-grained, respectively. Hydraulic conductivity increases with increasing layer number.

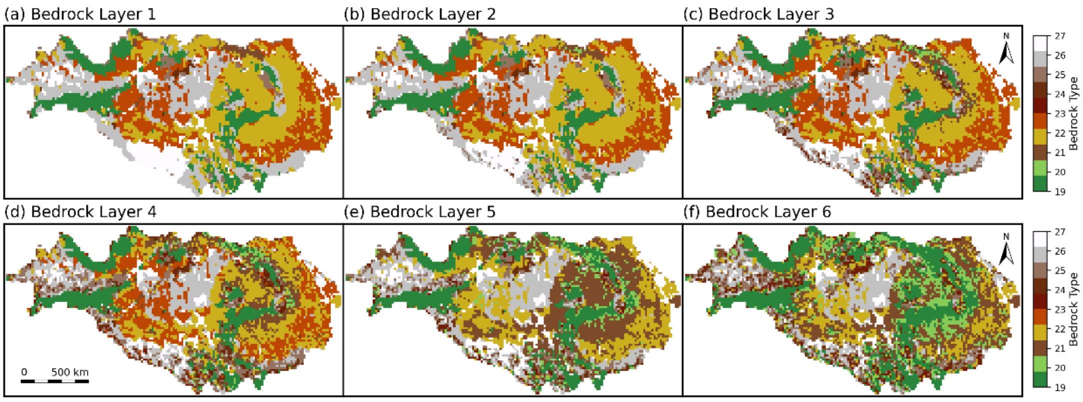

**Figure S4.** (a) Monthly soil moisture (SM) percentiles (P10, P50, P90) for PF-LPJG, LPJ-GUESS and ESA CCI-SM during 1980-2018. (b) Cross-plot of standardized SM anomalies comparing PF-LPJG and LPJ-GUESS against ESA CCI-SM.

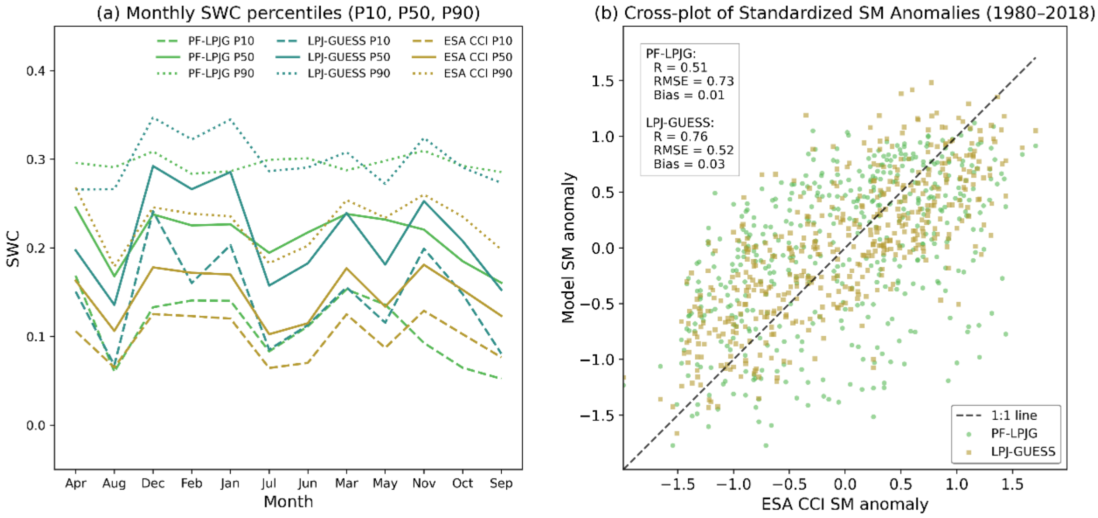

**Figure S5.** Histograms of RMSE and Spearman's ρ for surface SM in wet (4-9) and dry months (1-3, 10-12), comparing PF-LPJG and LPJ-GUESS simulations against ESA CCI-SM.

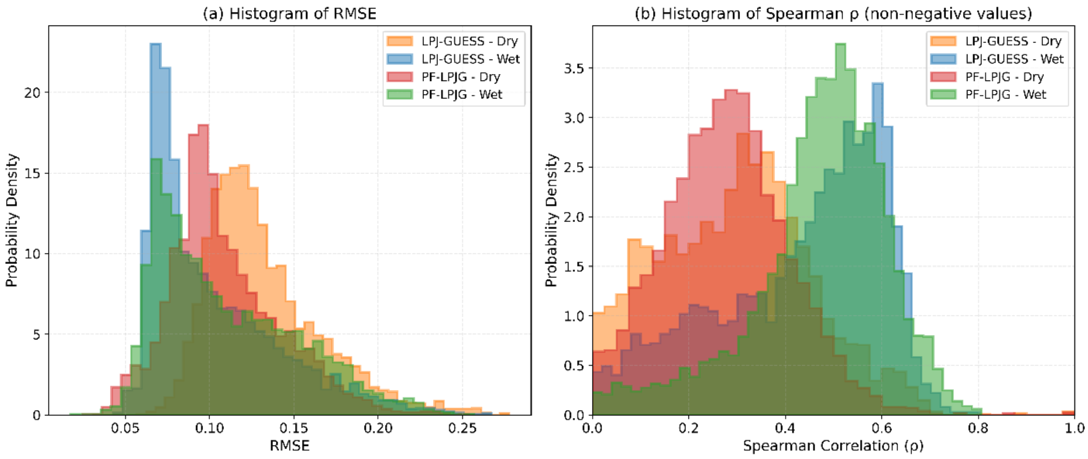

**Figure S6.** Monthly mean groundwater table depth (WTD) averaged over the period 1980-2018, based on simulated results.

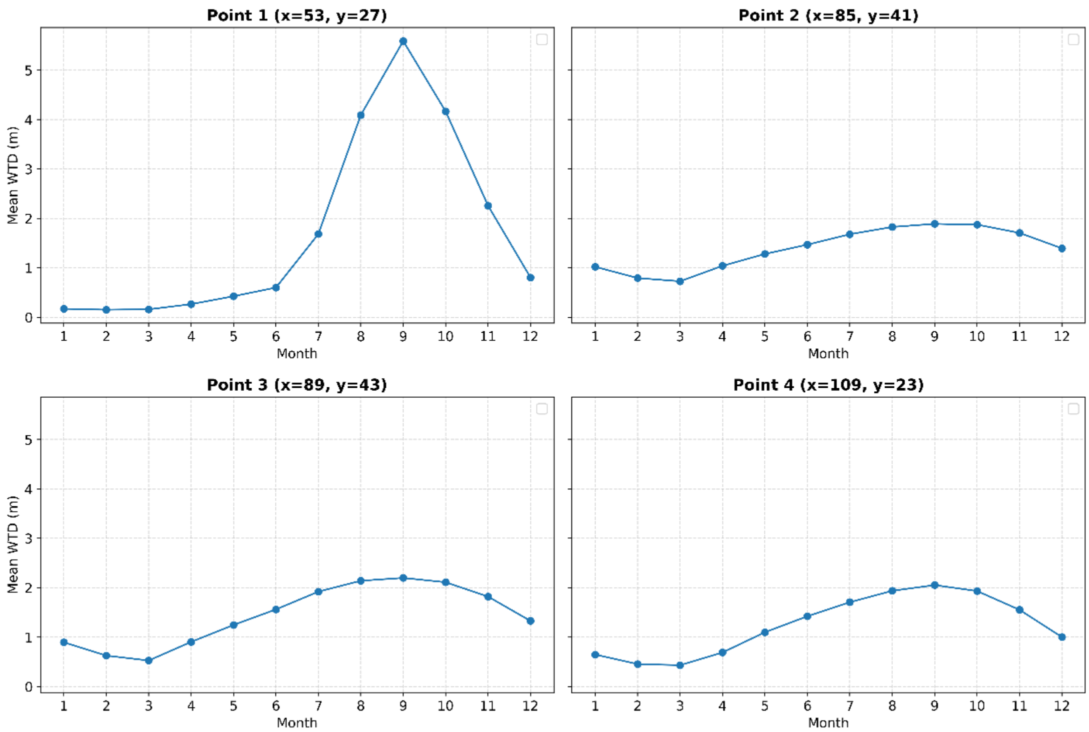

**Table S1.** Parameters of Soil and Bedrock Layers

| Class | Unit Indicator | Classification | Ks (m/h) | porosity [-] | sres [-] | alpha (1/m) | n [-] |
|---|---|---|---|---|---|---|---|
| Soil Units | 1 | Sand | 2.69E-01 | 0.38 | 0.14 | 3.55 | 4.16 |
| | 2 | Laomy Sand | 4.36E-02 | 0.39 | 1.26 | 3.47 | 2.74 |
| | 3 | Sandy Loam | 1.58E-02 | 0.39 | 0.10 | 2.69 | 2.45 |
| | 4 | Silt Loam | 7.58E-03 | 0.44 | 0.15 | 0.50 | 2.66 |
| | 5 | Silt | 1.82E-02 | 0.49 | 0.10 | 0.66 | 2.66 |
| | 6 | Loam | 5.01E-03 | 0.40 | 0.15 | 1.12 | 2.48 |
| | 7 | Sandy clay loam | 5.49E-03 | 0.38 | 0.16 | 2.09 | 2.32 |
| | 8 | Silty clay loam | 4.68E-03 | 0.48 | 0.19 | 0.83 | 2.51 |
| | 9 | Clay loam | 3.39E-03 | 0.44 | 0.18 | 1.58 | 2.41 |
| | 10 | Sandy clay | 4.78E-03 | 0.39 | 0.30 | 3.31 | 2.20 |
| | 11 | Silty clay | 3.98E-03 | 0.48 | 0.23 | 1.62 | 2.32 |
| | 12 | Clay | 6.16E-03 | 0.46 | 0.21 | 1.51 | 2.26 |
| Bedrock Units | 19 | Bedrock 1 | 5.00E-03 | 0.33 | 0.001 | 1.00 | 3.00 |
| | 20 | Bedrock 2 | 1.00E-02 | 0.33 | 0.001 | 1.00 | 3.00 |
| | 21 | f.g. sil. Sedimentary | 2.00E-02 | 0.30 | 0.001 | 1.00 | 3.00 |
| | 22 | sil. Sedementary | 3.00E-02 | 0.30 | 0.001 | 1.00 | 3.00 |
| | 23 | crystalline | 4.00E-02 | 0.10 | 0.001 | 1.00 | 3.00 |
| | 24 | f.g. unconsolidated | 5.00E-02 | 0.30 | 0.001 | 1.00 | 3.00 |
| | 25 | unconsolidated | 6.00E-02 | 0.30 | 0.001 | 1.00 | 3.00 |
| | 26 | c.g. sil sedimentary | 8.00E-02 | 0.30 | 0.001 | 1.00 | 3.00 |
| | 27 | carbonate | 1.00E-01 | 0.10 | 0.001 | 1.00 | 3.00 |