Authors' responses to RC2' comments

Hydrology and Earth System Sciences

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Title: Distinct mechanisms shaping global surface and root-zone soil moisture

Dear RC2:

Thank you very much for carefully reviewing our manuscript and helping us improve its quality. You believe that this manuscript is not recommended for publication in HESS, and we feel very regretful and sad. However, regarding the comments you put forward, we can make sufficient revisions and reasonable explanations. We hope you will grant us an opportunity to revise the manuscript. We believe that through these revisions, the quality of the manuscript will be significantly enhanced. We acknowledge and have adopted all your comments. Below, we provide a detailed point-by-point response to the explanations we need to offer and potential improvement plans. Text by the reviewer is indented and in blue font. Our reply is in black font and not indented. The "References" are in green and italic, and follow immediately after the reply. For ease of referencing our replies, we numbered them. If you have further suggestions, we are happy to continue discussing them with you.

> This study aims to revealing distinct mechanisms behind changes in surface and root-zone soil moisture (SM) variabilities. However, the basic SM data from GLEAM do not support this study, and the definition for the SM variability is not specific. Therefore, this manuscript is not recommended for publication in HESS.

Thank you for your careful review of our work. We have carefully read your comments, and below is our point-by-point response. In summary, our revision plan can be summarized as follows:

1 **We will use five widely used SM products: GLEAM, GLDAS, ERA5-Land, MERRA-2, and CFSR, as well as the mean value of multiple products for subsequent analysis.** Instead of merely conducting product comparison and validation, we will simultaneously **focus on the calculation results of various**

products and discuss possible inconsistencies.

2 We will **pay special attention to the decoupling regions of SMsurf and SMroot**, and the calculation methods include: Pearson correlation coefficient, lag cross-correlation analysis, ratio of coefficient of variation between SMsurf and SMroot, etc. In the subsequent analysis, we will focus on these decoupling regions and conduct in-depth discussions.

3 We will remove or improve the previous RF or PLS-SEM methods. In the revised manuscript, we will **calculate PLS-SEM at the pixel scale and determine the main impact paths pixel by pixel**; or **use causal Shapley analysis based on machine learning models** to analyze the impact paths of variables on SM and the relative importance of variables.

4 Regarding the above results, we will **focus on areas with different vegetation types, different climate zones, as well as regions where SMsurf and SMroot are significantly decoupled**, and pay attention to the results where SMsurf and SMroot have large differences in their responses to driving factors. Therefore, we will **make great efforts in the presentation and discussion of the results, closely centering on the theme of the decoupling of SMsurf and SMroot**.

We believe that through our careful revisions, we will definitely be able to help us understand the decoupling phenomenon between SMsurf and SMroot, as well as help us unravel the different driving mechanisms of SMsurf and SMroot. If you have any questions, we hope to further discuss them with you.

[r2,1] The authors tried to analyze the differences of changes in surface and root-zone SM. They used the GLEAM SM data and stated that the GLEAM SM data give surface (0-10 cm) and root-zone (10-250 cm) soil moisture estimations (Lines 136-137). However, this statement is not true. In Martens et al. (2017) (the paper gives details on GLEAM, doi: 10.5194/gmd-10-1903-2017), “The depth of the root zone is a function of the land-cover type and comprises three model layers for the fraction of tall vegetation (0–10, 10–100, and 100–250 cm), two for the fraction of low vegetation (0–10, 10–100 cm), and only one for the fraction of bare soil (0–10

cm)”. Given the root-zone SM includes the surface SM, the differences of changes in surface and root-zone SM are not well supported.

Thank you very much for your careful review. You pointed out that our description of GLEAM SM is incorrect; however, there may be some misunderstanding here. Following your suggestion, we carefully re-read the relevant research published by Martens et al. (2017).

Reference: Martens, B., Miralles, D. G., Lievens, H., van der Schalie, R., de Jeu, R. A. M., Fernández-Prieto, D., Beck, H. E., Dorigo, W. A., and Verhoest, N. E. C.: GLEAM v3: satellite-based land evaporation and root-zone soil moisture, Geosci. Model Dev., 10, 1903-1925, 10.5194/gmd-10-1903-2017, 2017.

Your description of the root-zone soil moisture physical model in the GLEAM dataset is completely correct, and we fully agree with and appreciate it. It is true that our description of the complexity of the underlying model of GLEAM in the manuscript is not accurate enough. However, the sentence you quoted only introduces the layered depth ranges of soil moisture under different vegetation conditions (tall vegetation, low vegetation, and bare soil) (the underlying calculation model), which does not support the view that "root-zone SM includes the surface SM". In our study, we used the GLEAM dataset (https://www.gleam.eu/). The dataset clearly defines its output variables as two layers: Root-zone soil moisture (SMroot) and Surface soil moisture (SMsurf), corresponding to 0-10cm and 10-250cm respectively. The GLEAM dataset product we used does aggregate the root zone into a "10-250cm" layer, so our analysis method is still valid at the data application level. This is also detailed in previous studies, such as:

1. Xu et al. (2023) used the surface and root zone SM datasets of GLEAM v3.3 to study the variation law of soil moisture along the drought gradient in the drylands of northern China (a detailed description can be found in Section 2.2.1).

Reference: X., Wang, X., Chen, S. H., and Tang, X. L.: Spatio-temporal changes in global root zone soil moisture from 1981 to 2017, Journal of Hydrology, 626, 10.1016/j.jhydrol.2023.130297, 2023.

2. Li et al. (2021) also used the surface and root zone soil moisture data from GLEAM (a detailed description can be found in Section 2.2.1).

Reference: Li, B., Yang, Y., and Li, Z.: Combined effects of multiple factors on spatiotemporally varied soil moisture in China's Loess Plateau, Agricultural Water Management, 258, 107180, https://doi.org/10.1016/j.agwat.2021.107180, 2021.

Therefore, there may be some misunderstandings here that need to be clarified to you. GLEAM does divide soil moisture into surface layer and root zone according to 0-10cm and 10-250cm, which has been widely applied and recognized. We hope our explanation can resolve your confusion.

In addition, in order to respond to your concerns more rigorously and improve the quality of the paper, we plan to revise the expression in the original text and rewrite the relevant sentences to avoid overly simplistic descriptions of its physical model. We hope our revisions will satisfy you.

[r2,2] The authors used another two SM datasets (i.e. GLDAS and ERA5-Land) to validate the GLEAM SM data. First, the depths of SM layers between the three datasets are discrepant. Second, the depth of the GLEAM root-zone varies by land-cover types. The direct comparisons among these datasets are very hard. Last, even if comparing these datasets, it is better to compare changes in surface and root-zone SM among these datasets than original values.

Thank you very much for your valuable opinions. We fully understand your concerns. As you mentioned, there are differences in the depth of soil moisture layers among the three datasets: GLEAM, GLDAS, and ERA5-Land. However, this does not affect the comparison of soil moisture data between different products. For example:

1. Liu et al. (2023) used SM datasets from ERA5-Land, MERRA-2, and CFSR in their study. The SM in ERA5-Land is modeled in four layers (7, 28, 100, and 289 cm), in CFSR it is modeled in four layers (10, 40, 100, and 200 cm), and in MERRA-2 it is modeled in two layers (5 and 100 cm). **For the merging of soil moisture at different layer depths, a weighted calculation using weights**

proportional to the thickness of each layer was employed. This method is widely recognized and used for merging soil moisture at different depths (Reichle et al., 2017)。

Reference: Liu, Y., Yang, Y., and Song, J.: Variations in Global Soil Moisture During the Past Decades: Climate or Human Causes?, Water Resources Research, 59, e2023WR034915, https://doi.org/10.1029/2023WR034915, 2023.

Reichle, R. H., Draper, C. S., Liu, Q., Girotto, M., Mahanama, S. P. P., Koster, R. D., and De Lannoy, G. J. M.: Assessment of MERRA-2 Land Surface Hydrology Estimates, Journal of Climate, 30, 2937-2960, https://doi.org/10.1175/JCLI-D-16-0720.1, 2017.

Therefore, you don't need to worry about the merging of soil moisture at different depths between different products.

In addition, you pointed out that "the depth of the GLEAM root-zone varies by land-cover types". We agree with your comment, but this does not affect the use of the data. However, your suggestion has also inspired us. Previously, we only conducted statistics on the different responses of SM from the perspective of climate zones. In the subsequent revisions, we will conduct statistics from the perspective of vegetation types to further address the issues you are concerned about.

Finally, you pointed out that "even if comparing these datasets, it is better to compare changes in surface and root-zone SM among these datasets than original values". Regarding your concern, in the subsequent revisions, we will use more datasets and aggregate them to the same surface and root-zone depths. **We plan to use five widely used SM products, namely GLEAM, GLDAS, ERA5-Land, MERRA-2, and CFSR, as well as the average of these five products for subsequent research.** Instead of merely using product comparison and validation, we will simultaneously **focus on the calculation results of multiple products and discuss possible inconsistencies**. We hope that our revisions will satisfy you.

[r2,3] In Abstract and across the manuscript, the decoupling phenomenon and difference of changes between surface soil moisture (SMsurf) and rootzone soil

moisture (SMroot) are not specified. For example, in Section 3.1 and Figure 1, the authors do not give what is the trend of SM. For the time series in Figure, it seems as monthly time series with annual cycle. How to estimate trend in the monthly time series as m3/m3/a? In Section 2.1.6, the STL method was used to detend trend and seasonal components in SM time series, why in Figure 1, the two components still remained.

Thank you very much for your valuable comments. As you mentioned, the decoupling phenomenon and variation differences between surface soil moisture (SMsurf) and root zone soil moisture (SMroot) have not been clearly explained, which is a major oversight on our part. We have profoundly recognized this issue and have a detailed modification plan.

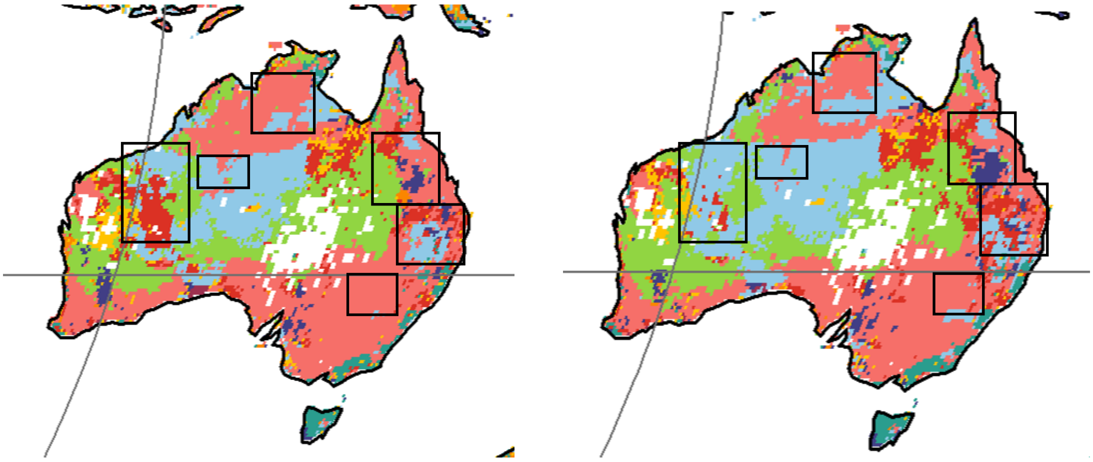
We used random forests, PLS-SEM, and copula functions to try to reveal the differences in the responses of SMsurf and SMroot. However, some results show that the driving factors of SMsurf and SMroot are relatively similar. As we mentioned in the Introduction, Luo et al. (2023) confirmed the decoupling phenomenon between global SMsurf and SMroot, which mainly occurs in high-latitude regions of the Northern Hemisphere and arid regions such as the central and western parts of Australia. Several regional-scale studies have further confirmed the decoupling between SMsurf and SMroot. For example, Li et al. (2021) found that SMsurf in the Loess Plateau is more sensitive to short-term climatic variables such as precipitation and potential evapotranspiration, as well as vegetation cover, whereas SMroot is more significantly influenced by long-term factors such as vegetation type (e.g., water use by deep-rooted plants) and global atmospheric circulation patterns (e.g., ENSO). In East Asia, Zohaib et al. (2017) demonstrated that reduced precipitation is the primary cause of SMsurf decline, while Cheng et al. (2015) highlighted that the dominant factors affecting SMroot vary across different climatic regions. Because the decoupling phenomenon between SMsurf and SMroot occurs locally or in small areas, it may not show significant differences on a spatial scale.

Reference: Luo, X. R., Li, S. D., Yang, W. N., Liu, L., Shi, Y. H., Lai, Y. S., Yu, P., Yang, Z. H., Luo, K., Zhou, T., Yang, X., Wang, X., Chen, S. H., and Tang, X. L.: Spatio-

temporal changes in global root zone soil moisture from 1981 to 2017, Journal of Hydrology, 626, 10.1016/j.jhydrol.2023.130297, 2023.
Li, B., Yang, Y., and Li, Z.: Combined effects of multiple factors on spatiotemporally varied soil moisture in China's Loess Plateau, Agricultural Water Management, 258, 107180, https://doi.org/10.1016/j.agwat.2021.107180, 2021.
Zohaib, M., Kim, H., and Choi, M.: Evaluating the patterns of spatiotemporal trends of root zone soil moisture in major climate regions in East Asia, Journal of Geophysical Research: Atmospheres, 122, 7705-7722, https://doi.org/10.1002/2016JD026379, 2017.
Cheng, S., Guan, X., Huang, J., Ji, F., and Guo, R.: Long-term trend and variability of soil moisture over East Asia, Journal of Geophysical Research: Atmospheres, 120, 8658-8670, https://doi.org/10.1002/2015JD023206, 2015.

The RF results include Figures 2-4: In Figure 2, due to reclassification of the color scale, the differences in spatial scale results are small. However, further statistics based on Figure 2 (Figure 3) show significant differences between the two. In Figure 4, we mainly adopted the dominant factor identification method proposed by Sun et al. (2022) , which determines dominant factors based on the contribution of driving factors and the variation trend of dependent variables (SMsurf and SMroot). In this study, assuming that at a certain pixel, the contribution of Pre to SMsurf and SMroot differs, but Pre has the highest contribution compared to other driving factors, then both SMsurf and SMroot at that pixel are still dominated by Pre. Thus, the spatial distribution patterns may show small differences, mainly occurring in local areas rather than large-scale differences. Taking the results in Australia as an example (left: spatial distribution of dominant factors for SMsurf; right: spatial distribution of dominant factors for SMroot), obvious differences in dominant factors can be observed in the black box we plotted. Additionally, the statistical graphs in Figure 4 (a-2) and (b-2) also show differences in the dominant factors for SMsurf and SMroot. For example, in the Boreal region, WS dominates the largest area proportion (22%) for SMsurf, while Pre dominates the largest area proportion (24%) for SMroot.

Reference: Sun, S. L., Liu, Y. B., Chen, H. S., Ju, W. M., Xu, C. Y., Liu, Y., Zhou, B. T., Zhou, Y., Zhou, Y. L., and Yu, M.: Causes for the increases in both evapotranspiration and water yield over vegetated mainland China during the last two decades, Agricultural and Forest Meteorology, 324, 10.1016/j.agrformet.2022.109118, 2022.



The PLS-SEM results are shown in Figure 5: Since we plotted both significant and non-significant paths, the influence paths of driving factors on SMsurf and SMroot appear relatively consistent. However, there are some differences. For example, in the Boreal region, the path coefficient of SPEI on SMsurf is non-significant, while that on SMroot is significant. Nevertheless, the SEM results do show that the difference in the influence paths between SMsurf and SMroot is relatively small. We have carefully read the study by Su et al. (2025) and plan to use SEM at the pixel scale to identify influence paths in the revised manuscript.

Reference: Su, Y., Zhang, C., Cescatti, A., Yu, K., Ciais, P., Smith, T., Shang, J., Carnicer, J., Liu, J., Chen, J. M., Green, J. K., Wu, J., Ponce-Campos, G. E., Zhang, Y., Zuo, Z., Liao, J., Wu, J., Lafortezza, R., Yan, K., Yang, X., Liu, L., Ren, J., Yuan, W., Chen, X., Wu, C., and Zhou, W.: Pervasive but biome-dependent relationship between fragmentation and resilience in forests, Nature Ecology & Evolution, 10.1038/s41559-025-02776-7, 2025.

The results of SM loss probability calculated by Copula are shown in Figures 6 and 7: Indeed, the Copula results do not show different influences of driving factors on SMsurf and SMroot. This is mainly determined by the characteristics of copula functions, which focus on marginal effects and tail dependence of variables under extreme conditions and are often used to reveal relationships between variables under extreme conditions. As discussed in Section 4.2, we used copula functions to analyze SM loss probabilities under extreme conditions to help us understand the influence of environmental variables on SM from another perspective. RF and PLS-SEM mainly capture the time series process of SM, while Copula focuses on extreme conditions. The combination of multiple methods helps us comprehensively understand the influence mechanisms of driving factors on SM.

Nevertheless, we have also profoundly realized that the above-mentioned method cannot well reveal the decoupling phenomenon between SMsurf and SMroot as well as their differentiated response mechanisms. To better explain the different response mechanisms of SMsurf and SMroot in these significant decoupling regions, we plan to abandon the previous method and make targeted modifications using the following approach:

1. **Identify the decoupling regions of SMsurf and SMroot**: Calculate the Pearson correlation coefficient between SMsurf and SMroot for various products, conduct lagged cross-correlation analysis (since SMsurf responds to precipitation much faster than SMroot, lag analysis is key to revealing decoupling), and compute the ratio of coefficients of variation (calculate the CV for surface and root zone sequences respectively. The CV of SMsurf is usually much larger than that of SMroot, indicating that SMsurf is more active and fluctuates more, while SMroot is more stable. The ratio of their CVs can quantify the strength of this "buffering" or "smoothing" effect), etc.
2. We consider **calculating PLS-SEM at the pixel scale and identifying the main influence pathways pixel by pixel** (Su et al., 2025); or **using causal Shapley analysis based on machine learning models to determine the influence pathways of variables on SM and the relative importance of variables** (Liu et al., 2025). **We will focus on the differences in responses under different vegetation types and climate zones, as well as the regions where significant decoupling between SMsurf and SMroot was revealed in the first step**.

Reference: Su, Y., Zhang, C., Cescatti, A., Yu, K., Ciais, P., Smith, T., Shang, J., Carnicer, J., Liu, J., Chen, J. M., Green, J. K., Wu, J., Ponce-Campos, G. E., Zhang, Y., Zuo, Z., Liao, J., Wu, J., Lafortezza, R., Yan, K., Yang, X., Liu, L., Ren, J., Yuan, W., Chen, X., Wu, C., and Zhou, W.: Pervasive but biome-dependent relationship between fragmentation and resilience in forests, Nature Ecology & Evolution, 10.1038/s41559-025-02776-7, 2025.

Liu, J., Wang, Q., Zhan, W., Lian, X., and Gentine, P.: When and where soil dryness matters to ecosystem photosynthesis, Nature Plants, 11, 1390-1400, 10.1038/s41477-025-02024-7, 2025.

3. Calculate the probability of SM deficit **in areas where there is a significant decoupling** between different vegetation types and climate zones, as well as between surface and root zone soil water, using the Copula function.

Our revisions are expected to more clearly reveal the decoupling phenomenon and differential responses between SMsurf and SMroot. We hope that our revisions can more clearly highlight the scientific questions we have proposed, and that our revisions will satisfy you.

> [r2,4] As the above mentioned, the STL method was used to detend trend and seasonal components in SM time series, and then, the residual component is used for analyzing SM variability. Here, how to define SM variability and at which time scale? Usually, standard deviation is used to define variability (see doi: 10.1126/sciadv.adm9732).

Thank you for your valuable comment. However, there might be some misunderstandings here. Please allow me to explain to you. In this study, the variability of soil moisture is defined as the residual sequence after removing the trend component and seasonal component. Because the original soil moisture time series contains signal components such as seasonal and long-term trends, the seasonal and long-term trend components of the original soil moisture can be removed through the STL (Seasonal and Trend decomposition using Loess) decomposition technique. The long-term trend may include human activities, and the seasonal signal contains periodic information. Therefore, **we only use the STL residual component, which can be considered to contain only the impact of climate and environment on soil moisture**. Therefore, we only focus on the STL residual component of SM. This is widely used in many studies:

1. Before calculating the resilience of vegetation, Wang et al. (2023) performed STL decomposition on kNDVI and used only the STL residual component.

Reference: Wang, Z., Fu, B., Wu, X., Li, Y., Feng, Y., Wang, S., Wei, F., and Zhang, L.: Vegetation resilience does not increase consistently with greening in China's Loess Plateau, Communications Earth & Environment, 4, 336, 10.1038/s43247-023-01000-3, 2023.

2. Wu et al. (2024) used STL decomposition to detrend the time series of terrestrial water storage (TWS) for each grid, and the detrended TWS was then used to calculate the GRACE Drought Severity Index (GRACE-DSI).

Reference: Wu, T., Xu, L., and Chen, N.: Spatial pattern and attribution of ecosystem drought recovery in China, Journal of Hydrology, 638, 131578, https://doi.org/10.1016/j.jhydrol.2024.131578, 2024.

Therefore, we hope you can understand our intention in using STL decomposition. We sincerely apologize for any inconvenience caused by the inappropriate expression. In the subsequent revisions, we will clearly explain the meaning of SM variability in the Introduction. We hope that our explanations and revisions will satisfy you.

[r2,5] Too many statistical approaches were used in this study, leading to these results dizzy and giddy. These methods includes Seasonal and Trend Decomposition using Loess, Mann-Kendall test, Random Forests, Partial Least Squares Structural Equation Modeling, Wavelet coherence analysis, and Copula functions. Some of the results from these methods are not shown in the main text.

Thank you for your reminder. The issue you pointed out is a major shortcoming of ours. We have profoundly realized this problem and have readjusted the structure of the article. After careful consideration, we plan to delete the previous method and use the following method to make targeted revisions:

1. **Identify the decoupling regions of SMsurf and SMroot**: Calculate the Pearson correlation coefficient between SMsurf and SMroot for various products, conduct lagged cross-correlation analysis (since SMsurf responds to precipitation much faster than SMroot, lag analysis is key to revealing decoupling), and compute the ratio of coefficients of variation (calculate the CV for surface and root zone sequences respectively. The CV of SMsurf is usually much larger than that of SMroot, indicating that SMsurf is more active and fluctuates more, while SMroot is more stable. The ratio of their CVs can quantify the strength of this "buffering" or "smoothing" effect), etc.
2. We consider **calculating PLS-SEM at the pixel scale and identifying the main influence pathways pixel by pixel** (Su et al., 2025); or **using causal Shapley analysis based on machine learning models to determine the influence pathways of variables on SM and the relative importance of variables** (Liu et al., 2025). **We will focus on the differences in responses under different vegetation types and climate zones, as well as the regions where significant decoupling between SMsurf and SMroot was revealed in the first step**.

Reference: Su, Y., Zhang, C., Cescatti, A., Yu, K., Ciais, P., Smith, T., Shang, J., Carnicer, J., Liu, J., Chen, J. M., Green, J. K., Wu, J., Ponce-Campos, G. E., Zhang, Y., Zuo, Z., Liao, J., Wu, J., Lafortezza, R., Yan, K., Yang, X., Liu, L., Ren, J., Yuan, W., Chen, X., Wu, C., and Zhou, W.: Pervasive but biome-dependent relationship between fragmentation and resilience in forests, Nature Ecology & Evolution, 10.1038/s41559-025-02776-7, 2025.

Liu, J., Wang, Q., Zhan, W., Lian, X., and Gentine, P.: When and where soil dryness matters to ecosystem photosynthesis, Nature Plants, 11, 1390-1400, 10.1038/s41477-025-02024-7, 2025.

3. Calculate the probability of SM deficit **in areas where there is a significant decoupling** between different vegetation types and climate zones, as well as between surface and root zone soil water, using the Copula function.

According to our revision plan, the structure of the revised article will be roughly as follows:

1 Abstract

2 Introduction

3 Materials and Methods

3.1 Materials

An exploration is conducted on five widely used SM products: GLEAM, GLDAS, ERA5-Land, MERRA-2, and CFSR, as well as the mean value of these five products. Instead of merely comparing and validating different products, we will simultaneously focus on the calculation results of multiple products and discuss possible inconsistencies.

3.2 Methods

3.2.1 Pearson correlation coefficient, lag cross-correlation analysis, and ratio of coefficients of variation between SMsurf and SMroot. These are used to identify regions where SMsurf and SMroot are significantly decoupled.

3.2.2 Calculate PLS-SEM at the pixel scale and determine the main influencing pathways pixel by pixel (Su et al., 2025); or use causal Shapley analysis based on machine learning models to analyze the impact paths of variables on SM and the relative importance of variables (Liu et al., 2025). And focus on different vegetation types and climate zones, as well as areas where SMsurf and SMroot are significantly decoupled.

Reference: Su, Y., Zhang, C., Cescatti, A., Yu, K., Ciais, P., Smith, T., Shang, J., Carnicer, J., Liu, J., Chen, J. M., Green, J. K., Wu, J., Ponce-Campos, G. E., Zhang, Y., Zuo, Z., Liao, J., Wu, J., Lafortezza, R., Yan, K., Yang, X., Liu, L., Ren, J., Yuan, W., Chen, X., Wu, C., and Zhou, W.: Pervasive but biome-dependent relationship between fragmentation and resilience in forests, Nature Ecology & Evolution, 10.1038/s41559-025-02776-7, 2025.

Liu, J., Wang, Q., Zhan, W., Lian, X., and Gentine, P.: When and where soil dryness matters to ecosystem photosynthesis, Nature Plants, 11, 1390-1400, 10.1038/s41477-025-02024-7, 2025.

3.2.3 Calculate the probabilities of SM deficits of different degrees in regions where SMsurf and SMroot are significantly decoupled under different scenarios, in different vegetation type areas, and in different climate zones based on the Copula function.

4 Results

4.1 Identify the regions where SMsurf and SMroot are significantly decoupled.

4.2 Use pixel-scale PLS-SEM or causal Shapley analysis based on machine learning models to simultaneously reveal the impact paths of driving factors on SM and the relative importance of variables.

4.3 Calculate the probability of SM deficits of different degrees in regions where SMsurf and SMroot are significantly decoupled under different scenarios, different vegetation types, and climate zones.

5 Discussion

Discuss the differences in calculation results among different SM products, with a focus on different vegetation types and climate zones, as well as the differences in the responses of surface and root-zone soil moisture in regions where SMsurf and SMroot are significantly decoupled.

Our current revision will no longer only focus on global results, but will pay special attention to key regions. For example, we will conduct analyses according to different vegetation type zones, different climate zones, and regions where SMsurf and SMroot are significantly decoupled. We believe that this measure will effectively address the shortcomings of the previous manuscript. We hope that our revisions can more clearly reveal the scientific questions we have raised and that you will be satisfied with our revisions.

[r2,6] Readability. The manuscript has a bad readability because of many statistical approaches, many variables, and many climatic zones. Especially, the globe is divided into many climatic zones. However, the results varies with these zones, without consistent performance. Maybe, the climatic zones do not have strong reasonable.

Thank you very much for your valuable comment. This is also a significant shortcoming of ours. As you pointed out, due to the large number of statistical methods, numerous variables, and multiple climate zones, the expression in our manuscript is not clear enough, and the main theme is not distinct enough. Our previous expressions were rather confusing. In the subsequent revisions, **our presentation of the results will focus on different vegetation type areas, different climate zones, and the areas where SMsurf and SMroot are significantly decoupled**. Moreover, **we will only focus on the phenomena where the responses of SMsurf and SMroot to environmental variables have significant differences**. **We will make great efforts in the presentation and discussion of the results**, and we believe that through our revisions, the readability of the manuscript will be significantly improved.

[r2,7] Seasonality. As we know, SM in many regions has seasonality. Changes in SM vary by seasons, and reasons behind the changes vary by seasons. For example, in mid- and high-latitude regions of the Northern Hemisphere, drivers behind winter and summer SM are very different. The authors clearly overlooked this issue.

Thank you very much for your valuable comments. Please allow us to explain. Seasonality is a crucial factor affecting SM; however, our study did not focus on the seasonality of SM, and this was a deliberate choice. Like other studies (Wang et al., 2023; Wu et al., 2024), we focused on the STL residual component of variables, which will help us understand the interannual variability of SM. Our approach is based on the focus of this paper. Nevertheless, we fully agree with your comment and will therefore add relevant content in the "Limits" section. We hope our explanation is satisfactory to you.

Reference: Wang, Z., Fu, B., Wu, X., Li, Y., Feng, Y., Wang, S., Wei, F., and Zhang, L.: Vegetation resilience does not increase consistently with greening in China's Loess Plateau, Communications Earth & Environment, 4, 336, 10.1038/s43247-023-01000-3, 2023.

Wu, T., Xu, L., and Chen, N.: Spatial pattern and attribution of ecosystem drought recovery in China, Journal of Hydrology, 638, 131578, https://doi.org/10.1016/j.jhydrol.2024.131578, 2024.

[r2,8] Physical mechanisms. The authors used Random Forests, and Partial Least Squares Structural Equation Modeling to quantify drivers and reveal influencing pathways. However, the analyses of results are shallow, like day-to-day account. For example, in Figures 2-4, the clear spatial heterogeneity between these drivers and between regions makes reader hard to understand which is the dominant driver and pathway, and why.

Thank you very much for your valuable comments. As mentioned in your previous comments, we have conducted in-depth reflections. In the subsequent revisions, **we plan to use pixel-scale PLS-SEM or causal Shapley analysis based on machine learning models to simultaneously reveal the impact paths of driving factors on SM and the relative importance of variables**. This way, we can adopt a method to answer both questions regarding the dominant driving factors and the paths. Moreover, **our presentation of the results will focus on areas with different vegetation types, different climate zones, and areas where SMsurf and SMroot are significantly decoupled**. At the same time, we will **only focus on phenomena where SMsurf and SMroot show significant differences in their responses to environmental variables**. We believe that through our revisions, the quality of the manuscript will be significantly improved.

[r2,9] Figures. Many of the figures in main text and supporting information lack aesthetics and clear description. For example, in Figure 1, the font size is too small and the caption expressed very vague. In Figure 6e, h, and others, the colourbars loss the ability to reflect spatial changes.

Thank you very much for your valuable comments. As we mentioned earlier, **we will revise the article using a new method and redraw all the pictures**. In the new revisions, we will definitely pay special attention to the issues you mentioned. We hope that our revisions will satisfy you.

Reference:

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