Authors’ responses to RC1’ comments

Hydrology and Earth System Sciences

https://doi.org/10.5194/egusphere-2025-2828-RC1

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

Dear RC1:

Thank you very much for carefully reviewing our manuscript and helping us improve its quality. 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. 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. If you have further suggestions, we are happy to continue discussing them with you.

> This study analyzes the contributions of climate factors, vegetation dynamics, and drought indices to surface (SMsurf) and root-zone (SMroot) soil moisture variability using Random Forest (RF) and Partial Least Squares Structural Equation Modeling (PLS-SEM), while also evaluating SM loss probabilities under extreme scenarios using copula functions. Although the research offers significant insights into SM mechanisms, several critical issues warrant further clarification and discussion.

Thank you for your careful review of our work. We have carefully read your comments, and below is our point-by-point response. If you have any questions, we hope to further discuss them with you.

> [r1,1] The manuscript suggests that the increase in surface and root-zone SM globally can be attributed to vegetation greening and precipitation, respectively. However, this contrasts with findings from multiple studies (e.g., Deng et al., 2020;

Qin et al., 2023; Seo et al., 2025) that document decreasing SM trends globally, particularly in recent decades.

References

Deng et al., Variation trend of global soil moisture and its cause analysis. Ecological Indicators, 110, 105939 (2020). https://doi.org/10.1016/j.ecolind.2019.105939

Ki-Weon Seo et al., Abrupt sea level rise and Earth's gradual pole shift reveal permanent hydrological regime changes in the 21st century. Science, 387,1408-1413 (2025). DOI:10.1126/science.adq6529

Qin et al., Continued decline of global soil moisture content, with obvious soil stratification and regional difference. Science of The Total Environment, 864, 160982 (2023). https://doi.org/10.1016/j.scitotenv.2022.160982

Thank you for your valuable comment. We apologize for any confusion caused by our inappropriate wording. First, we would like to clarify that this may be a misunderstanding. What we intended to express is that vegetation greening and precipitation exert positive contributions to global SMsurf and SMroot, respectively. However, there are other influencing factors that have negative effects on SMsurf and SMroot. For example, atmospheric water demand (Ep) was identified as the primary cause of global SMsurf and SMroot droughts. Therefore, our focus here is solely on the positive roles of vegetation and precipitation in SMsurf and SMroot, rather than claiming that vegetation and precipitation have led to an overall increase in global SM. In this revision, we will remove such inappropriate statements. Taking the sentence you mentioned as an example, we will revise it to: "Vegetation dynamics and increased precipitation exhibit positive promoting effects on SMsurf and SMroot."

Additionally, Seo et al. (2025) noted that after a sharp decline in SM from 2000 to 2002, interannual variability decreased compared to precipitation (P) or precipitation minus evapotranspiration (P - ET) due to SM's intrinsic buffering effect on short-term climate variability. Subsequently, the authors further attributed the slowed decline in SM after 2002 to increased precipitation intensity in recent decades. Although the authors did not consider different soil depths in their study, this inference still supports our view that "increased precipitation exerts a positive contribution to global SMroot."

Reference: Seo, K.-W., Ryu, D., Jeon, T., Youm, K., Kim, J.-S., Oh, E. H., Chen, J., Famiglietti, J. S., and Wilson, C. R.: Abrupt sea level rise and Earth's gradual pole shift reveal permanent hydrological regime changes in the 21st century, Science, 387, 1408-1413, doi:10.1126/science.adq6529, 2025.

Furthermore, your comment has prompted us to think further. To better compare the similarities and differences between our study and previous research, we re-examined the references you cited, which we had already paid attention to. As you noted, these three studies and many others have documented a declining trend in global soil moisture since 2000, which we consider reasonable. We acknowledge all these research findings as valuable, as they provide important insights into the driving mechanisms of soil moisture and lay a solid foundation for us to explain these mechanisms more clearly. However, we must also recognize that different datasets, data processing methods, and analytical approaches may lead to varying results:

1. Deng et al. (2020) used the Ensemble Empirical Mode Decomposition method to decompose the ERA-Interim SM time series and found a significant declining trend of -0.145 m^3/m^3 in ERA-Interim SM during 2001-2017.

Reference: Deng, Y., Wang, S., Bai, X., Luo, G., Wu, L., Cao, Y., Li, H., Li, C., Yang, Y., Hu, Z., and Tian, S.: Variation trend of global soil moisture and its cause analysis, Ecological Indicators, 110, 105939, https://doi.org/10.1016/j.ecolind.2019.105939, 2020.

2. Qin et al. (2023), based on GLDAS-NOAH025 SM data, found that global GLDAS SM at 0-200 cm depth declined at a rate of 1.284 kg/m^2 per year from 2000 to 2020 (the converted rate is -0.002568 m^3/m^3).

Reference: Qin, T., Feng, J., Zhang, X., Li, C., Fan, J., Zhang, C., Dong, B., Wang, H., and Yan, D.: Continued decline of global soil moisture content, with obvious soil stratification and regional difference, Science of The Total Environment, 864, 160982, https://doi.org/10.1016/j.scitotenv.2022.160982, 2023.

3. Additionally, Peng et al. (2023) observed a global SM decline rate of -0.0001 m^3/m^3 per year based on ESA CCI SM (0-5cm).

Reference: Peng, C., Zeng, J., Chen, K.-S., Li, Z., Ma, H., Zhang, X., Shi, P., Wang, T., Yi, L., and Bi, H.: Global spatiotemporal trend of satellite-based soil moisture and its influencing factors in the early 21st century, Remote Sensing of Environment, 291, 113569, https://doi.org/10.1016/j.rse.2023.113569, 2023.

While these studies seemingly indicate a declining trend in SM, the rates of change vary significantly, possibly due to differences in SM datasets, targeted soil depths, data preprocessing, and analytical methods. Moreover, some studies have reported an increasing trend in global SM:

1. Liu et al. (2023) found increasing trends in SMsurf and SMroot since 2000 using the average of three SM products (ERA5-Land, MERRA-2, and CFSR) (Figure 2).

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.

A comparison between these studies and ours is as follows:

1. First, Deng et al. (2020) and Qin et al. (2023) only excluded glacial areas in Greenland at the global scale, whereas our study focuses on global permanent vegetation areas, excluding non-vegetated regions (including but not limited to glacial areas in Greenland and the Sahara Desert, etc.).
2. The aforementioned studies primarily focus on SM trends. However, trends are often regarded as indicative of human activity, suggesting that non-stationary conditions could potentially distort the results inappropriately (Boulton et al., 2022). Therefore, prior to subsequent calculations, it is essential to eliminate the trend from the SM time series (Smith and Boers, 2023). In other words, to focus on the actual influencing factors of SM disturbed by environmental factors, we must use residual components after deseasonalization and detrending, a process detailed in Section 2.1.6. In the supplementary materials, you will find that although the original time series of the three SM products show some differences (Figures S4a, b), the residual components after detrending and deseasonalization exhibit nearly consistent

fluctuation patterns (Figures S4c, d). Overall, we emphasize the fluctuation process of SM, and the STL (Seasonal and Trend decomposition using Loess) method used in this study effectively ensures the accuracy of subsequent analyses.

Reference:[1] Deng, Y., Wang, S., Bai, X., Luo, G., Wu, L., Cao, Y., Li, H., Li, C., Yang, Y., Hu, Z., and Tian, S.: Variation trend of global soil moisture and its cause analysis, Ecological Indicators, 110, 105939, https://doi.org/10.1016/j.ecolind.2019.105939, 2020.

[2] Qin, T., Feng, J., Zhang, X., Li, C., Fan, J., Zhang, C., Dong, B., Wang, H., and Yan, D.: Continued decline of global soil moisture content, with obvious soil stratification and regional difference, Science of The Total Environment, 864, 160982, https://doi.org/10.1016/j.scitotenv.2022.160982, 2023.

[3] Boulton, C. A., Lenton, T. M., and Boers, N.: Pronounced loss of Amazon rainforest resilience since the early 2000s, Nature Climate Change, 12, 271-278, 10.1038/s41558-022-01287-8, 2022.

[4] Smith, T. and Boers, N.: Global vegetation resilience linked to water availability and variability, Nature Communications, 14, 498, 10.1038/s41467-023-36207-7, 2023.

In summary, regarding your comment [r1,1], we clarify that we only intend to highlight the positive roles of vegetation and precipitation in SMsurf and SMroot, not that they have caused an overall increase in global SM. Furthermore, your comment [r1,1] has inspired us to add sufficient discussions to reconcile potential differences or even contradictions in these results. We hope our explanations and revisions will satisfy you, and we welcome further suggestions for continued discussion.

[r1,2] Figure 5: At the global scale, the PLS-SEM indicates that the “Climate Change” negatively impacts the “Drought Intensification”. Does it mean climate change alleviates drought? I think it’s unseasonable. In addition, the relationships in the second and fourth columns are chaotic, please further clarify it.

We apologize again for the confusion. With your reminder, we realize that the term “Drought Intensification” is inappropriate and may cause significant misunderstanding. In this study, drought is represented by SPEI, where more negative SPEI values indicate more severe drought (see Table 1 for specific classification criteria). That is, when we stated in the manuscript that "Climate Change" negatively impacts "Drought Intensification," we actually meant that the path effect of "Climate Change" on SPEI is negative, i.e., it exacerbates drought. We apologize for the confusion caused by our inappropriate wording.

Table 1. SPEI drought classification

Class	**SPEI Value**	**Drought Severity**
1	-0.5<SPEI	No drought
2	-1.0<SPEI≤-0.5	Mild drought
3	-1.5<SPEI≤-1.0	Moderate drought
4	-2.0<SPEI≤-1.5	Severe drought
5	SPEI≤-2.0	Extreme drought

In Figure 5, the second and fourth columns are actually further refinements of the first and third columns to reveal the influence paths between factors. As a result, the path relationships may appear complex, but they help us better understand how environmental variables affect SM. For example:

1. Qu et al. (2025) used SEM to describe the biogeophysical and biogeochemical relationships between PM2.5 pollution and spring vegetation green-up (Figure 2).

Reference: Qu, W., Hua, H., Yang, T., Zohner, C. M., Peñuelas, J., Wei, J., Yu, L., and Wu, C.: Delayed leaf green-up is associated with fine particulate air pollution in China, Nature Communications, 16, 3406, 10.1038/s41467-025-58710-9, 2025.

2. Wang et al. (2025b) explored the mechanism of climate impacts on gross primary productivity (GPP) using SEM (Figure 5).

Reference: Wang, T., Zhang, J., Li, Z., Lin, K., Zhou, W., Wu, G., Pan, M., and Chen, X.: Roles of Soil and Atmospheric Dryness on Terrestrial Vegetation Productivity in China - Which Dominates at What Thresholds, Earth's Future, 13, e2024EF005469, https://doi.org/10.1029/2024EF005469, 2025.

3. He et al. (2025) used SEM to investigate the effects of previous-year precipitation and other environmental factors on vegetation (Figure 4).

Reference: He, L., Wang, J., Peltier, D. M. P., Ritter, F., Ciais, P., Peñuelas, J., Xiao, J., Crowther, T. W., Li, X., Ye, J.-S., Sasaki, T., Zhou, C., and Li, Z.-L.: Lagged precipitation effects on plant production across terrestrial biomes, Nature Ecology & Evolution, 10.1038/s41559-025-02806-4, 2025.

These studies all use SEM to explore complex influence mechanisms between factors. Incorporating more variables may make it harder for the model to pass significance tests, but including additional variables (while ensuring model performance) helps us fully understand the direct and indirect influence paths of environmental factors on SM. We hope this can be understood.

In summary, regarding your comment [r1,2], we will revise the inappropriate wording related to "Drought Intensification" in the manuscript and add explanations about the relationship between SPEI values and drought in Section 2.1.5. Additionally, regarding your observation that the relationships in the second and fourth columns of Figure 5 are chaotic, we hope you can understand that this is an effort to better understand how environmental variables affect SM. Meanwhile, we will remove non-significant paths or modify the figure's presentation to improve readability. We will also provide more detailed descriptions of the second and fourth columns in Figure 5. We hope our explanations and revisions will satisfy you, and we welcome further suggestions for continued discussion.

> [r1,3] Significant discrepancies exist between RF and PLS-SEM results concerning vegetation's role in SM dynamics. While RF analysis identifies vegetation as a primary driver of SMsurf increases (Fig. 3a), PLS-SEM shows minimal direct vegetation effects on SMsurf (Fig. 5f-1). Furthermore, RF indicates vegetation contributes to SMroot decreases (Fig. 3a), whereas PLS-SEM suggests vegetation greening promotes SMroot increases (Fig. 5-3).

Thank you for pointing out this issue. As you noted, there are differences and seemingly contradictory results between the Random Forest and PLS-SEM analyses. Please allow us to explain.

Although the results of the two methods show the differences you mentioned, we believe that the results of RF and SEM are complementary rather than contradictory, as the two methods differ in principles and focuses. For example, the input data for RF are monthly grid data of all variables, and the program runs pixel by pixel. The results for each pixel are independent, ultimately yielding global spatialized results. The mean of the calculation results for each grid is used to generate Figure 3. In contrast, the data input to SEM is global aggregate data, not run independently for each pixel. Thus, the inherent connections between pixels are considered, and SEM aims to reveal structured causal networks between variables rather than the importance of driving factors.

Additionally, as shown in Figure 2, the impact of LAI on SMsurf and SMroot exhibits significant spatial heterogeneity. For example, it shows a strong positive contribution in the Congo Basin and Amazon Basin, but a strong negative contribution in the Indian Peninsula, etc. Figure 3 interprets factor contributions from a global perspective. That is, although RF results indicate that vegetation increases SMsurf and decreases SMroot at the global scale (Figure 3a), this does not mean that vegetation only increases SMsurf and decreases SMroot. In fact, due to significant spatial heterogeneity in the response of global SM changes to vegetation and climate change, the contribution and impact of any factor on SM vary across regions. It is just that the effect of vegetation in increasing SMsurf and promoting SMroot decrease is stronger.

For example: Zhang et al. (2022) analyzed the potential associations between phenology and WUE in the Luanhe River Basin, a typical semi-arid region in China from 1988 to 2015 using methods such as linear regression, partial correlation analysis, and structural equation modeling. The results of linear regression and partial correlation analysis are shown in Figure 5, and the results of structural equation modeling are shown in Figure 6. You will find that in the UR region, SOS and WUE show a strong negative correlation in spring (Figure 5B), but the path coefficient of SOS on WUE is $0.348 * 0.870 = 0.30276$, which is positive (Figure 6A).

Reference: Zhang, Y., Zhang, J., Xia, J., Guo, Y., and Fu, Y. H.: Effects of Vegetation Phenology on Ecosystem Water Use Efficiency in a Semiarid Region of Northern China, Frontiers in Plant Science, Volume 13 - 2022, 10.3389/fpls.2022.945582, 2022.

Therefore, we believe that the two methods used in this study have different focuses. We aim to leverage the advantages of each method to analyze the influence mechanisms of environmental variables on SM from different perspectives. Different perspectives may lead to inconsistent mechanistic results, but our attention on the results of different methods also varies. We hope this can be understood. For example, Su et al. (2025) used SEM at the pixel and climate zone scales, focusing more on the main influence paths between forest fragmentation and resilience (Figure 5). Shen et al. (2024) and (Wang et al., 2025a) first identified dominant factors using machine learning + SHAP analysis, then used SEM to explain the driving mechanisms between factors.

Reference: [1] 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.

[2] Shen, P., Wang, X., Zohner, C. M., Peñuelas, J., Zhou, Y., Tang, Z., Xia, J., Zheng, H., Fu, Y., Liang, J., Sun, W., Zhang, Y., and Wu, C.: Biodiversity buffers the response of spring leaf unfolding to climate warming, Nature Climate Change, 14, 863-868, 10.1038/s41558-024-02035-w, 2024.

[3] Wang, J., Wang, X., Peñuelas, J., Hua, H., and Wu, C.: Nitrogen deposition favors later leaf senescence in woody species, Nature Communications, 16, 3668, 10.1038/s41467-025-59000-0, 2025a.

However, we strive to address your concerns. In the upcoming revisions, we will conduct robustness analyses using other methods, such as recalculating SEM or supplementing with PCMCI+ methods, to verify the robustness of our conclusions. Additionally, we plan to use machine learning + SHAP interpretability analysis to identify the driving factors of SMsurf and SMroot, and further explore the interactive relationships between driving factors and SMsurf/SMroot based on global and local interpretations. Furthermore, we will elaborate from multiple perspectives and conduct in-depth discussions on potential inconsistent results in the discussion section. We hope our explanations and revisions will satisfy you, and we welcome further in-depth discussions on any other suggestions.

[r1,4] Although the study aims to elucidate distinct mechanisms governing surface and root-zone soil moisture, the results reveal remarkably similar spatial patterns and driving factors for both layers (e.g., Figs. 4-7).

Thank you for your valuable comment. The driving factors of SMsurf and SMroot are indeed relatively similar in some results.

As mentioned in our Introduction, Luo et al. (2023) confirmed the decoupling of global SMsurf and SMroot, which mainly occurs in high-latitude regions of the Northern Hemisphere and arid regions such as central-western 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. Since the decoupling of SMsurf and SMroot occurs locally or in small areas, it may not show significant differences at the spatial scale.

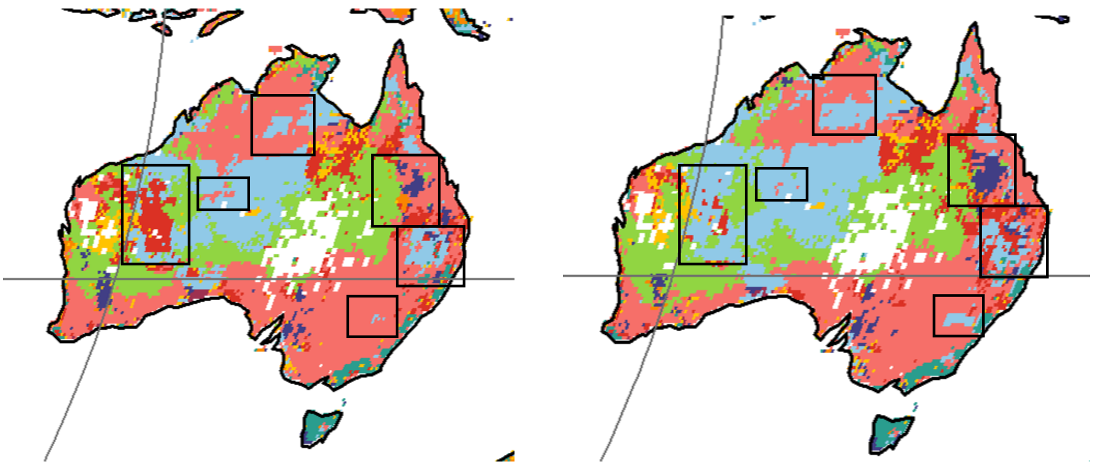
Reference: [1] Luo, X. R., Li, S. D., Yang, W. N., Liu, L., Shi, Y. H., Lai, Y. S., Yu, P., Yang, Z. H., Luo, K., Zhou, T., Yang, X., Wang, X., Chen, S. H., and Tang, X. L.: Spatio-temporal changes in global root zone soil moisture from 1981 to 2017, Journal of Hydrology, 626, 10.1016/j.jhydrol.2023.130297, 2023.

[2] 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.

[3] 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.
[4] 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.

The above is our response to your comment [r1,4]. After fully considering your opinions and extensively reviewing the literature, we plan to use machine learning + SHAP interpretability analysis to identify the driving factors of SMsurf and SMroot, and further explore the interactive relationships between driving factors and SMsurf/SMroot based on global and local interpretations. Additionally, we consider calculating PLS-SEM at the pixel scale and determining the main influence paths for each pixel (Su et al., 2025). Furthermore, in the Results and Discussion sections, we will focus more on content showing significant differences in the driving mechanisms of SMsurf and SMroot, with detailed descriptions and in-depth discussions. Finally, we will reconsider our title. We believe these revisions will help us more clearly demonstrate the different driving mechanisms of driving factors on SMsurf and SMroot. We hope our explanations and revisions will satisfy you, and we welcome further suggestions for continued discussion.

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.

[r1,5] Minor Comments

Figure 3: Please modify the figure caption.

Line 491: Please check “he”.

Line 530: Please check “conFigureurations”.

Line 558: Don’t repeat the definition of an abbreviation (Ep)

Line 561: Please use the abbreviated form (SPEI).

Thank you for your reminder. During the revision, we will thoroughly check the wording of the manuscript to eliminate any potential textual errors. We hope our revisions will satisfy you.

Reference:

Boulton, C. A., Lenton, T. M., and Boers, N.: Pronounced loss of Amazon rainforest resilience since the early 2000s, Nature Climate Change, 12, 271-278, 10.1038/s41558-022-01287-8, 2022.

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.

Deng, Y., Wang, S., Bai, X., Luo, G., Wu, L., Cao, Y., Li, H., Li, C., Yang, Y., Hu, Z., and Tian, S.: Variation trend of global soil moisture and its cause analysis, Ecological Indicators, 110, 105939, https://doi.org/10.1016/j.ecolind.2019.105939, 2020.

He, L., Wang, J., Peltier, D. M. P., Ritter, F., Ciais, P., Peñuelas, J., Xiao, J., Crowther, T. W., Li, X., Ye, J.-S., Sasaki, T., Zhou, C., and Li, Z.-L.: Lagged precipitation effects on plant production across terrestrial biomes, Nature Ecology & Evolution, 10.1038/s41559-025-02806-4, 2025.

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.

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.

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.

Peng, C., Zeng, J., Chen, K.-S., Li, Z., Ma, H., Zhang, X., Shi, P., Wang, T., Yi, L., and Bi, H.: Global spatiotemporal trend of satellite-based soil moisture and its influencing factors in the early 21st century, Remote Sensing of Environment, 291, 113569, https://doi.org/10.1016/j.rse.2023.113569, 2023.

Qin, T., Feng, J., Zhang, X., Li, C., Fan, J., Zhang, C., Dong, B., Wang, H., and Yan, D.: Continued decline of global soil moisture content, with obvious soil stratification and regional difference, Science of The Total Environment, 864, 160982, https://doi.org/10.1016/j.scitotenv.2022.160982, 2023.

Qu, W., Hua, H., Yang, T., Zohner, C. M., Peñuelas, J., Wei, J., Yu, L., and Wu, C.: Delayed leaf green-up is associated with fine particulate air pollution in China, Nature Communications, 16, 3406, 10.1038/s41467-025-58710-9, 2025.

Seo, K.-W., Ryu, D., Jeon, T., Youm, K., Kim, J.-S., Oh, E. H., Chen, J., Famiglietti, J. S., and Wilson, C. R.: Abrupt sea level rise and Earth's gradual pole shift reveal permanent hydrological regime changes in the 21st century, Science, 387, 1408-1413, doi:10.1126/science.adq6529, 2025.

Shen, P., Wang, X., Zohner, C. M., Peñuelas, J., Zhou, Y., Tang, Z., Xia, J., Zheng, H., Fu, Y., Liang, J., Sun, W., Zhang, Y., and Wu, C.: Biodiversity buffers the response of spring leaf unfolding to climate warming, Nature Climate Change, 14, 863-868, 10.1038/s41558-024-02035-w, 2024.

Smith, T. and Boers, N.: Global vegetation resilience linked to water availability and variability, Nature Communications, 14, 498, 10.1038/s41467-023-36207-7, 2023.

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.

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.

Wang, J., Wang, X., Peñuelas, J., Hua, H., and Wu, C.: Nitrogen deposition favors later leaf senescence in woody species, Nature Communications, 16, 3668, 10.1038/s41467-025-59000-0, 2025a.

Wang, T., Zhang, J., Li, Z., Lin, K., Zhou, W., Wu, G., Pan, M., and Chen, X.: Roles of Soil and Atmospheric Dryness on Terrestrial Vegetation Productivity in China - Which Dominates at What Thresholds, Earth's Future, 13, e2024EF005469, https://doi.org/10.1029/2024EF005469, 2025b.

Zhang, Y., Zhang, J., Xia, J., Guo, Y., and Fu, Y. H.: Effects of Vegetation Phenology on Ecosystem Water Use Efficiency in a Semiarid Region of Northern China, Frontiers in Plant Science, Volume 13 - 2022, 10.3389/fpls.2022.945582, 2022.

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.