

# **Authors' responses to RC1' comments**

## **Hydrology and Earth System Sciences**

**<https://doi.org/10.5194/egusphere-2025-6195-RC1>**

Title: Weakening Correlation and Delaying Response Time of Ecosystem Water Use Efficiency to Drought

### **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 black font. Our reply is in blue 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.

General Comments: This manuscript investigates the long-term changes in water use efficiency (WUE) under water stress, a classic and important topic in ecohydrology. The study contributes to understanding vegetation carbon–water trade-off strategies during drought conditions. However, the manuscript would benefit from substantial improvements in writing clarity and in the mechanistic interpretation of the findings.

1. The current version lacks sufficient mechanistic explanations and reads more as a statistical description rather than a process-based analysis.
2. Different types of drought (e.g., soil moisture drought vs. atmospheric drought) involve distinct mechanisms that influence vegetation responses. The manuscript should clearly specify the drought type throughout and discuss their differing impacts on WUE.

3. The importance of the timing of WUE changes under drought is not sufficiently justified. The authors should clarify why the temporal evolution of WUE under drought matters from a physiological or ecohydrological perspective.

Thank you for your careful review of our work. We fully acknowledge the limitations you have identified, which indeed highlight areas where the manuscript requires further improvement and refinement. As one of the most widely used drought indices, SPEI not only accounts for the cumulative water balance but also incorporates the effects of temperature (Beguería et al., 2014), and has therefore been extensively applied to monitor and quantify the spatiotemporal characteristics of drought at both regional and global scales (Beguería et al., 2010). However, vegetation exhibits distinct response mechanisms to different types of drought; accordingly, we have now explicitly clarified in the revised manuscript that the drought considered in this study refers to meteorological drought. In addition, in this revision we have placed greater emphasis on strengthening the interpretation of the observed phenomena and deepening the discussion of the underlying ecohydrological mechanisms, thereby enhancing the overall scientific rigor of the study.

*Reference:*

[1] Beguería, S., Vicente-Serrano, S. M., and Angulo-Martínez, M.: *A Multiscalar Global Drought Dataset: The SPEIbase: A New Gridded Product for the Analysis of Drought Variability and Impacts*, *Bulletin of the American Meteorological Society*, 91, 1351-1356, <https://doi.org/10.1175/2010BAMS2988.1>, 2010.

[2] Beguería, S., Vicente-Serrano, S. M., Reig, F., and Latorre, B.: *Standardized precipitation evapotranspiration index (SPEI) revisited: parameter fitting, evapotranspiration models, tools, datasets and drought monitoring*, *International Journal of Climatology*, 34, 3001-3023, <https://doi.org/10.1002/joc.3887>, 2014.

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] Abstract: The types of data used in this study (e.g., satellite products, flux data, reanalysis, etc.) should be clearly stated in the abstract.

Thank you for your valuable comment. In response to your suggestion, we will explicitly specify in the Abstract the types of data used in this study, including satellite products, flux observations, reanalysis datasets, and model simulations. We hope that this planned revision will meet your expectations.

[r1,2] Abstract: The stated knowledge gap (L19–20) is not entirely accurate, as several previous studies have already examined WUE under drought conditions. The authors should better position their contribution relative to existing literature and clarify the physical interpretation of the proposed drivers of WUE changes.

Thank you for your valuable comment. As you noted, in recent years, increasing attention has been paid to WUE or vegetation responses to drought, including response characteristics and sensitivity (Jiao et al., 2021; Li et al., 2022; Zhang et al., 2022). However, these studies were largely conducted at specific or fixed drought timescales, neglecting the cumulative and lagged effects of drought on vegetation dynamics (Wen et al., 2019), and primarily relied on single indicators such as gross primary productivity (GPP), which represents photosynthetic activity, or vegetation indices that reflect canopy greenness. In contrast, ecosystem WUE provides a more integrative measure of vegetation carbon–water trade-off strategies under water stress. It is widely acknowledged that drought not only impacts vegetation growth synchronously but also exhibits lagged and cumulative effects, where past drought conditions influence current vegetation growth (Huang et al., 2018; Kannenberg et al., 2020). Vicente-Serrano et al. (2013) emphasized that vegetation responses to drought are inherently multi-timescale in nature. Longer timescales imply stronger memory effects, which may buffer the impacts of recent drought events and thereby reduce vegetation drought sensitivity (Seddon et al., 2016). In contrast, shorter timescales indicate more rapid vegetation responses to moisture deficits, reflecting higher drought sensitivity (Jiao et al., 2021). Despite the growing body of literature on WUE responses to drought, few studies have examined the coupling relationship between WUE and drought, particularly from a multi-timescale perspective. Therefore, incorporating multi-timescale drought effects

into analyses of WUE–drought coupling is essential for a more comprehensive and accurate understanding of vegetation carbon–water trade-offs under drought stress.

*Reference:*

[1] Jiao, W., Wang, L., Smith, W. K., Chang, Q., Wang, H., and D’Odorico, P.: *Observed increasing water constraint on vegetation growth over the last three decades*, *Nature Communications*, 12, 3777, [10.1038/s41467-021-24016-9](https://doi.org/10.1038/s41467-021-24016-9), 2021.

[2] Li, H., Wei, M., Dong, L., Hu, W., Xiong, J., Sun, Y., Sun, Y., Yao, S., Gong, H., Zhang, Y., Hou, Q., Wang, X., Xie, S., Zhang, L., Akram, M. A., Rao, Z., Degen, A. A., Niklas, K. J., Ran, J., Ye, J.-s., and Deng, J.: *Leaf and ecosystem water use efficiencies differ in their global-scale patterns and drivers*, *Agricultural and Forest Meteorology*, 319, 108919, <https://doi.org/10.1016/j.agrformet.2022.108919>, 2022a.

[3] Zhang, Y., Gentine, P., Luo, X., Lian, X., Liu, Y., Zhou, S., Michalak, A. M., Sun, W., Fisher, J. B., Piao, S., and Keenan, T. F.: *Increasing sensitivity of dryland vegetation greenness to precipitation due to rising atmospheric CO<sub>2</sub>*, *Nature Communications*, 13, 4875, [10.1038/s41467-022-32631-3](https://doi.org/10.1038/s41467-022-32631-3), 2022b..

[4] Wen, Y., Liu, X., Xin, Q., Wu, J., Xu, X., Pei, F., Li, X., Du, G., Cai, Y., Lin, K., Yang, J., and Wang, Y.: *Cumulative Effects of Climatic Factors on Terrestrial Vegetation Growth*, *Journal of Geophysical Research: Biogeosciences*, 124, 789-806, <https://doi.org/10.1029/2018JG004751>, 2019.

[5] Huang, M., Wang, X., Keenan, T. F., and Piao, S.: *Drought timing influences the legacy of tree growth recovery*, *Global Change Biology*, 24, 3546-3559, <https://doi.org/10.1111/gcb.14294>, 2018.

[6] Kannenberg, S. A., Schwalm, C. R., and Anderegg, W. R. L.: *Ghosts of the past: how drought legacy effects shape forest functioning and carbon cycling*, *Ecology Letters*, 23, 891-901, <https://doi.org/10.1111/ele.13485>, 2020.

[7] Vicente-Serrano, S. M., Gouveia, C., Camarero, J. J., Beguería, S., Trigo, R., López-Moreno, J. I., Azorín-Molina, C., Pasho, E., Lorenzo-Lacruz, J., Revuelto, J., Morán-Tejeda, E., and Sanchez-Lorenzo, A.: *Response of vegetation to drought time-scales across global land biomes*, *Proc Natl Acad Sci U S A*, 110, 52-57, [10.1073/pnas.1207068110](https://doi.org/10.1073/pnas.1207068110), 2013.

[8] *Seddon, A. W. R., Macias-Fauria, M., Long, P. R., Benz, D., and Willis, K. J.: Sensitivity of global terrestrial ecosystems to climate variability, Nature, 531, 229-232, 10.1038/nature16986, 2016.*

In response to your comment, we will further synthesize and highlight these research gaps in the revised manuscript. We hope that this revision will meet your expectations.

[r1,3] Abstract: The abstract contains too many abbreviations, which reduces readability. Consider minimizing abbreviations to improve clarity.

Thank you for your valuable comment. In response to your comment, we will reduce the use of abbreviations in the revised manuscript to improve its readability. We hope that this revision will meet your expectations.

[r1,4] Abstract: The findings derived from the causal analysis should be explicitly summarized.

Thank you for your valuable comment. We acknowledge that the previous version of our manuscript lacked the presentation of results derived from the causal analysis.

In response to your comment, we will incorporate these findings into the Abstract in the revised manuscript. We hope that this revision will meet your expectations.

[r1,5] Introduction: Lines 46–71 list a large number of studies without clear synthesis. This paragraph should be restructured to highlight key insights from previous research. Based on the cited literature, what are the dominant drivers of WUE under drought?

Thank you for your valuable comment. In the original manuscript, Lines 46-71 were organized around three aspects: (i) the impacts of drought events on WUE; (ii) the relationships between drought characteristics and WUE; and (iii) vegetation responses of different WUE metrics to drought across scales (e.g., intrinsic water use efficiency, IWUE; transpiration-based WUE, TWUE; underlying WUE, uWUE; and ecosystem WUE). Your comment has made us realize that this structure lacks logical coherence and a clear, integrative synthesis.

In response to your comment, we will comprehensively rewrite this section in the revised manuscript. Specifically, we will remove studies that are less directly relevant to our research focus and provide a more concise and critical synthesis rather than a simple enumeration of previous work. We hope that this revision will meet your expectations.

[r1,6] Data and Methods: The descriptions of datasets and metrics are mixed in the current “Data” section. It would be clearer to move the definition and calculation of WUE to the Methods section and separate data description from methodological explanation.

Thank you for your valuable comment. In response to your comment, we will move the definition and calculation of WUE to the Methods section in the revised manuscript, thereby improving the overall readability. We hope that this revision will meet your expectations.

[r1,7] Results: The figure presentation should be improved for readability. Some text elements are too large, while others are too small. Additionally, abbreviations in figure captions should be reduced.

Thank you very much for pointing out these shortcomings in our manuscript. As you rightly noted, there are still issues with the figure presentation: for example, the text in Figure 1 is overly large, whereas the text in subpanels (c-1) to (c-4) of Figure 2 is too small, and the font size of the colorbar labels in Figure 3 is also insufficient. These issues indeed hinder readability.

In response to your comment, we will comprehensively reorganize all figures in the revised manuscript and reduce the use of abbreviations in the figure captions. We hope that this revision will meet your expectations.

[r1,8] Results: The labeling in Fig. 2 is unclear and should follow a consistent alphabetical format (e.g., a, b, c). Moreover, the color schemes in Fig. 2a(1-2) and Fig. 2b(1-2) are too similar, making global patterns difficult to distinguish.

Thank you for your valuable comment. We would like to clarify that the left and right columns in Figure 2 represent results from remote sensing observations and model simulations, respectively. To facilitate a direct comparison between the two, the same color scheme was intentionally adopted. As you pointed out, “the color schemes in Fig. 2a (1–2) and Fig. 2b (1–2) are too similar, making global patterns difficult to distinguish,” which, to some extent, also reflects the high consistency between the remote sensing based and model simulated results.

In response to your comment, and as noted in our reply to [r1,7], we will comprehensively reorganize all figures in the revised manuscript. This will include, but not be limited to, adopting a consistent panel labeling format (e.g., a, b, c) and improving the overall clarity of visual presentation. We hope that this revision will meet your expectations.

[r1,9] Results: The manuscript lacks a physical explanation for how elevated CO<sub>2</sub> concentrations lead to a decoupling between GPP and ET during drought conditions. A clearer eco-physiological interpretation is necessary.

Thank you very much for pointing out this limitation in our manuscript. As you rightly noted, our discussion of the underlying ecohydrological mechanisms remains insufficient in depth.

In response to your comment, we will further consult and synthesize relevant literature in the revised manuscript to strengthen the discussion on the mechanisms by which CO<sub>2</sub> drives the weakening coupling between SPEI and WUE. We hope that this revision will meet your expectations.

## Reference:

- Beguéría, S., Vicente-Serrano, S. M., and Angulo-Martínez, M.: A Multiscalar Global Drought Dataset: The SPEIbase: A New Gridded Product for the Analysis of Drought Variability and Impacts, *Bulletin of the American Meteorological Society*, 91, 1351-1356, <https://doi.org/10.1175/2010BAMS2988.1>, 2010.
- Beguéría, S., Vicente-Serrano, S. M., Reig, F., and Latorre, B.: Standardized precipitation evapotranspiration index (SPEI) revisited: parameter fitting, evapotranspiration models, tools, datasets and drought monitoring, *International Journal of Climatology*, 34, 3001-3023, <https://doi.org/10.1002/joc.3887>, 2014.
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- Jiao, W., Wang, L., Smith, W. K., Chang, Q., Wang, H., and D'Odorico, P.: Observed increasing water constraint on vegetation growth over the last three decades, *Nature Communications*, 12, 3777, 10.1038/s41467-021-24016-9, 2021.
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- Li, W., Migliavacca, M., Forkel, M., Denissen, J. M. C., Reichstein, M., Yang, H., Duveiller, G., Weber, U., and Orth, R.: Widespread increasing vegetation sensitivity to soil moisture, *Nature Communications*, 13, 3959, 10.1038/s41467-022-31667-9, 2022.
- Seddon, A. W. R., Macias-Fauria, M., Long, P. R., Benz, D., and Willis, K. J.: Sensitivity of global terrestrial ecosystems to climate variability, *Nature*, 531, 229-232, 10.1038/nature16986, 2016.
- Vicente-Serrano, S. M., Gouveia, C., Camarero, J. J., Beguéría, S., Trigo, R., López-Moreno, J. I., Azorín-Molina, C., Pasho, E., Lorenzo-Lacruz, J., Revuelto, J., Morán-Tejeda, E., and Sanchez-Lorenzo, A.: Response of vegetation to drought time-scales across global land biomes, *Proc Natl Acad Sci U S A*, 110, 52-57, 10.1073/pnas.1207068110, 2013.
- Wen, Y., Liu, X., Xin, Q., Wu, J., Xu, X., Pei, F., Li, X., Du, G., Cai, Y., Lin, K., Yang, J., and Wang, Y.: Cumulative Effects of Climatic Factors on Terrestrial Vegetation Growth, *Journal of Geophysical Research: Biogeosciences*, 124, 789-806, <https://doi.org/10.1029/2018JG004751>, 2019.
- Zhang, Y., Gentile, P., Luo, X., Lian, X., Liu, Y., Zhou, S., Michalak, A. M., Sun, W., Fisher, J. B., Piao, S., and Keenan, T. F.: Increasing sensitivity of dryland vegetation greenness to precipitation due to rising atmospheric CO<sub>2</sub>, *Nature Communications*, 13, 4875, 10.1038/s41467-022-32631-3, 2022.