Authors' responses to RC2' comments

Hydrology and Earth System Sciences

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

Dear RC2:

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.

> This study systematically reveals the spatiotemporal evolution and driving mechanisms of the coupling relationship between global water use efficiency (WUE) and drought through the integration of multi-scale and multi-source datasets combined with model ensembles. The study represents a significant innovation in ecohydrology and possesses considerable scientific value for understanding carbon-water cycles under a changing climate. Although the methodology is rigorous and the results are scientifically meaningful, there is still room for improvement in terms of presentation and technical details. Therefore, I recommend the acceptance of this manuscript after the following revisions are addressed.

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.

[r2,1] Section 3.1: Why is R_{max} defined as the maximum value of the correlation coefficient rather than the maximum absolute value of the correlation coefficient? The authors should provide a reasonable explanation for this choice. In addition, a more comprehensive explanation of both R_{max} and T_{opt} should be provided in this section.

Thank you for your valuable comment. Lower WUE indicates a reduced capacity of vegetation to utilize water, whereas lower SPEI values correspond to more severe drought conditions (i.e., larger negative SPEI values indicate stronger drought intensity). In general, more severe drought is associated with lower WUE, while under mild or non-drought conditions, WUE tends to be higher. Therefore, WUE and drought conditions exhibit an overall positive relationship. Accordingly, R_{max} was defined as the maximum value of the correlation coefficient rather than the maximum absolute value of the correlation coefficient. This phenomenon and its underlying rationale have also been supported by previous studies (Vicente-Serrano et al., 2013).

Reference:

[1] *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, Proceedings of the National Academy of Sciences, 110, 52-57, doi:10.1073/pnas.1207068110, 2013b.*

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). Different values of T_{opt} represent the characteristic timescales over which WUE responds to drought, whereas R_{max} reflects the maximum sensitivity of WUE to drought.

Reference:

[2] *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.*

[3] *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.*

In response to your comment, we will incorporate the above clarification into the revised manuscript. We hope that this revision will meet your expectations.

[r2,2] Section 3.3: The authors employed XGBoost and Shapley values for attribution analysis; however, essential technical details are lacking, such as key hyperparameters (e.g., max depth, learning rate). These should be provided to improve the clarity and reproducibility of the manuscript.

We sincerely apologize for this oversight. The key hyperparameters of the XGBoost models were optimized using a Bayesian optimization algorithm. Specifically, for the R_{max} model, the learning rate was 0.06, the number of trees (n_estimators) was 1431, and the maximum depth was 4. For the T_{opt} model, the learning rate was 0.07, the number of trees (n_estimators) was 1287, and the maximum depth was 4.

In response to your comment, we will include these parameter settings in the revised manuscript. We hope that this revision will meet your expectations.

[r2,3] Section 3.3: The authors state that "only the seven models that were consistent with the remote sensing results" were used. Please clarify the criteria used to select these seven models. If the selection follows approaches used in previous studies, appropriate references should be provided.

Thank you for your valuable comment. When separating the contributions of different TRENDY model scenarios, only those models whose trends are consistent with remote sensing observations were retained for subsequent analysis (Zeng et al., 2022). The performance of the model simulations was quantitatively evaluated using a Taylor diagram, as shown in Figure S6 of the Supplementary Material.

Reference:

[1] *Zeng, X., Hu, Z., Chen, A., Yuan, W., Hou, G., Han, D., Liang, M., Di, K., Cao, R., and Luo, D.: The global decline in the sensitivity of vegetation productivity to*

precipitation from 2001 to 2018, Global Change Biology, 28, 6823-6833, https://doi.org/10.1111/gcb.16403, 2022.

In response to your comment, we will include additional relevant references in the revised manuscript to better support the model selection criteria for the TRENDY simulations. We hope that this revision will meet your expectations.

> [r2,4] From the figures, it appears that the analysis was conducted in regions with permanent vegetation. The authors should clarify how grid cells classified as permanent vegetation areas were selected.

Thank you for your valuable comment. Studies on the response of WUE to drought are only meaningful in regions with persistent vegetation; therefore, our analysis was conducted within permanent vegetation areas. These areas were defined by excluding non-vegetated and sparsely vegetated land cover types, such as bare land and impervious surfaces, from the land use classification.

In response to your comment, we will provide a more detailed description of the method used to identify permanent vegetation areas in the Data section of the revised manuscript. We hope that this revision will meet your expectations.

> [r2,5] In the Results section, many geographically specific terms referring to relatively small regions are used, such as the Chersky Range, Chad Basin, Katanga Plateau, and Karaganda Basin. I believe that such detailed geographical descriptions may hinder readability. I suggest replacing them with broader regional descriptions, such as "central Africa".

Thank you for your valuable comment. We agree with your point that the use of numerous specific geographic terms for relatively small regions may hinder readability. In response to your comment, we will replace these terms with broader regional classifications in the revised manuscript. We hope that this revision will meet your expectations.

[r2,6] In the Results section, the authors repeatedly state expressions similar to "the results remain consistent under the 16-year and 20-year moving window analyses." I understand that the authors conducted extensive work to ensure the robustness of the results; however, this repeated wording appears redundant. It is unnecessary to reiterate this statement multiple times, and I suggest placing it once in the Methods or Discussion section instead.

Thank you for your valuable comment. We agree that there are still issues with our English expression, including occasional inappropriate phrasing and redundancy.

In response to your comment, we will remove statements such as "the results remain consistent under the 16-year and 20-year moving window analyses" from the Results section and retain them only in the Methods or Discussion. In addition, we will invite a native English-speaking co-author to carefully review and polish the manuscript to improve its overall clarity and readability. We hope that this revision will meet your expectations.

[r2,7] The Discussion section should further elaborate on the physiological mechanisms. The Results indicate that atmospheric CO2 is the most important driver of the weakening coupling between WUE and SPEI, yet the manuscript provides insufficient mechanistic discussion regarding this key conclusion. The authors are encouraged to consult relevant literature and expand the discussion to better elucidate the underlying ecohydrological mechanisms.

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 review and synthesize relevant literature to strengthen the discussion on the mechanisms by which CO_2 drives the weakening of the coupling between SPEI and WUE in the revised manuscript. We hope that this revision will meet your expectations.

[r2,8] Please carefully check the grammar, tense, and other issues throughout the full text.

1. Line 49: Forests.

2. Line 67: Grammatical error; revise to applied machine learning methods and found.

3. Line 80: increased - Check the tense.

4. Ling 168: Equations.

5. Line 196: were.

6. Line 208: varying the width of the moving window: Here directly state the width of other moving window used.

7. Line 224: The standard expressions for "training/test sets" in scientific papers are training and test subsets, not "testing".

8. Line 248, Line 249: Was.

9. Line 266-Line 272: According to aridity index, the globe is classified into arid, semi-arid, sub-humid, and humid. These are dryness or aridity gradients, instead of drought gradients.

10. Line 332: Provide an explanation of the sub figures in the figure caption.

11. In the discussion section: academic papers require a clear statement of the study limitations to guide future research, but this subsection is missing in the manuscript. It is recommended to add a subsection entitled "Study Limitations" to objectively analyze the shortcomings of the present work and propose directions for future research.

Thank you very much for your careful review. We acknowledge that there are still shortcomings in the grammar and overall English expression of the manuscript.

In response to your comment, we will thoroughly check the entire manuscript for issues related to grammar, tense, and clarity. In addition, we will invite a native English-speaking co-author to further polish the language to improve readability. Meanwhile, we will include a dedicated "Limitations and Future Perspectives" section to provide a balanced assessment of the current study and to offer guidance for future research. We hope that this revision will meet your expectations.

Reference:

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.

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.

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, Proceedings of the National Academy of Sciences, 110, 52-57, doi:10.1073/pnas.1207068110, 2013.

Zeng, X., Hu, Z., Chen, A., Yuan, W., Hou, G., Han, D., Liang, M., Di, K., Cao, R., and Luo, D.: The global decline in the sensitivity of vegetation productivity to precipitation from 2001 to 2018, Global Change Biology, 28, 6823-6833, https://doi.org/10.1111/gcb.16403, 2022.