We would like to sincerely thank the reviewers, Rene Orth and Josephin Kroll, for their helpful and constructive comments. We found the feedback very valuable in improving and sharpening the manuscript and will revise it accordingly. Please find below our detailed point-by-point response in red.

Reviewers #1: Rene Orth and Josephin Kroll.

Review of Heselschwerdt et al., egusphere-2025-5896

“Large impact of extreme precipitation on projected blue-green water shares“

This study investigates the partitioning of precipitation into runoff and transpiration, and its changes through this century. The authors introduce a new metric to describe this partitioning and use output of Earth system model simulations to determine the partitioning and its changes until the end of the century throughout the globe. They identify hot spot regions where precipitation is mainly partitioned into runoff or transpiration, respectively, and regions with strongest projected changes in the partitioning. Finally, they attribute the partitioning changes mainly to changes in extreme precipitation and vegetation and derive management implications.

Recommendation:

We think the paper requires major revisions.

The topic of this study is interesting and timely. Ongoing global change affects climate and vegetation in various ways, and their complex interplay modulates the water cycle. This way, major water fluxes such as runoff and transpiration may change differently, and for partly different reasons. The precipitation partitioning metric introduced by the authors in this paper summarizes relevant water cycle changes beyond individual variables, including an attribution of the resulting spatial patterns of change. This analysis presents a relevant contribution because it helps to identify regions with relevant water cycle changes, and proposes related mechanisms that require additional attention in further research.

However, before the paper can be published we would ask the authors to consider the concerns described below:

General comments:

The introduction section falls short in introducing the knowledge gap that this study addresses. This comes in combination with an insufficient review of existing literature on the topic. The present text claims that not much research exists in this direction (lines 62-63) while there is actually quite a body of literature that jointly analyses runoff and (evapo)transpiration, such as for example the Orth & Destouni 2018 study which is cited later, among others.

We will revise the Introduction and better acknowledge the existing literature on joint runoff and evapotranspiration/transpiration responses and precipitation partitioning, including citing Orth and Destouni (2018). Additionally, we will clarify that our contribution is a global assessment of projected runoff-transpiration partitioning shifts and their dominant controls rather than a claim that little prior work exists.

Related to this, lines 34-61 provide interesting mechanistic background on precipitation partitioning, which, however, is not connected to the rest of the introduction. So we suggest either to shift this to the discussion section, or connect it more to the introduction to motivate the relevance and knowledge gap in the topic.

We will revise the introduction to connect the mechanistic background more directly to the study aim and to the later driver analysis.

While the authors choose transpiration as green water flux, this choice is limiting the scope of this global analysis. For example, in arid areas transpiration is negligible while evaporation constitutes most of the surface water flux which is then ignored in the analysis. Additionally, soil moisture is referred to as green water and is modulated by transpiration but also evaporation.

We will narrow the scope of the study to vegetated and hydrologically active land areas by applying a mask based on precipitation, runoff, transpiration, and LAI. We will also justify the use of transpiration more clearly as the vegetation-mediated green-water flux and clarify that using ET instead of transpiration would address a different question.

A large part of the explanation of the results and the respective discussion, as well as attribution is based on changes in vegetation characteristics. However, at least one model has prescribed LAI dynamics (CNRM-ESM2-1, Seferian et al 2019, see page 4186), which means that its vegetation dynamics may be underestimated and related to this also its contribution to blue-green water

partitioning and related trends. We suggest a review of the current model selection in this context.

We will revise the model selection in light of differences in LAI dynamics and vegetation representation across the CMIP6 models. We will exclude CNRM-CM6-1, for which LAI is prescribed, and add a short description of the vegetation representation of the retained land models in Table S1.

Furthermore, while extreme precipitation is identified as a main control of trends in blue-green water shares, this may not be well represented by Earth system models. For example, a recent study found that the current rather coarse resolution of data from climate and earth system models, as also used in this study, underestimates the impact of such extremes (Brunner et al. 2025).

We will discuss this limitation more explicitly and cite the Brunner et al. (2025) study in the revised discussion.

While we appreciate the comprehensive set of potentially influential variables included in the regression analysis, we would like to suggest some additions. In addition to RX5day, where the chosen time scale is actually not motivated, you could test RX1day to capture even more extreme precipitation. Moreover, the seasonality of precipitation and VPD (even mentioned in line 407, could be expressed as e.g. standard deviation across monthly values) could influence the partitioning which is expected to be different in regions with pronounced rainy seasons versus regions where precipitation is more equally distributed across the year. Also land use change could play a role in some regions. While this is indirectly captured in leaf area index it could be more explicitly included by considering the time-varying crop and forest cover fractions. Further, assessing the role of near-surface soil moisture in addition to that of total-column soil moisture may be insightful because they can be expected to be of different relevance to runoff and transpiration. In this context, it is unclear which "relative changes" of soil moisture (line 99) are evaluated instead of actual soil moisture output, and why.

We will expand the predictor screening to test RX1day, precipitation seasonality, VPD seasonality, near-surface soil moisture, and land-use fractions. We will also clarify the rationale for retaining RX5day and for the earlier treatment of soil moisture.

The validation of the modelled partitioning against reanalysis and observation-based products in Figure S1 is informative. At the same time you are studying

changes in the partitioning over time which is different from the partitioning itself; for this reason you could consider comparing changes in the partitioning during the observational period between models and reference products. Further, Figure S1 is mentioned several times in section 3.1 such that it could be considered to move it to the main manuscript.

We will extend the evaluation to include recent historical BGWS changes in addition to the climatological benchmark and decide whether the additional figure should remain in the Supplement or be moved to the main text.

Related to this, we appreciate the indication of model uncertainty in Figures 2-4. However, this is not really visible in the maps in Figures 2b-d and 4, and missing in Figure 1. Maybe consider to make this more prominent - or even to introduce a masking to avoid showing results in regions where (i) models disagree or (ii) models disagree with reference products in Figure S1, in order to avoid interpreting results in regions where uncertainties actually largely prevent this. This could also enhance the accuracy of the attribution analysis in Figure 3.

We will strengthen the uncertainty communication in the figures and text, and we will test whether restricting the attribution to robust-sign grid cells changes the main results.

We do not wish to remain anonymous - joint review by Rene Orth and Josephin Kroll.

We have notified the editor of our collaborations with Peter Greve and Lan Wang-Erlandsson.

Specific comments:

Line 4: given that this is the abstract, maybe replace blue/green water shares with a more generally understood terminology

We will revise the abstract to use more explicit partitioning terminology and to define blue and green water flows directly.

Line 4: Climate simulations → Earth system model simulations (this also applies to other mentions of climate simulations throughout the manuscript)

We will change this wording throughout the manuscript.

Line 8: according to the results in Figure 3 it is leaf area index and water use efficiency individually rather than their interaction that influences the partitioning

We will revise the abstract to avoid implying an interaction term and to describe the vegetation effects more directly.

Line 12-16: this motivation of the relevance of precipitation partitioning is very brief, would expand this

We will expand the opening motivation to explain more clearly why precipitation partitioning matters for future water availability.

Line 21: "stabilises Earth system" is unclear and

Line 23: "climate regulation" is unclear and

Line 27: "critical water functions" is unclear and

Line 54: "vegetation activity" is unclear and

Line 57: "runoff-consuming sinks" is unclear

We will revise the introduction to remove these unclear formulations and replace them with more specific wording throughout.

Line 80: required variables are unclear at this point

We will introduce the required variables more explicitly in the Earth system model data subsection.

Line 114: Good point about the non-closure of the water balance. See our recent paper Huang et al. for this. (sorry for the self-promotion)

We will cite Huang et al. when discussing the non-closure of the water balance in the benchmark datasets.

Line 120: The term 'climate indices' does not fit the chosen variables/indices. For example, (i) RX5day is not calculated over a period that would refer to climate (~30 years), (ii) VPD is not an index, and also not referred to over a period considered as climate, (iii) WUE is not representing climate, but rather vegetation characteristics. An alternative could be 'hydroecological variables' as used in the manuscript before

We will adapt the subsection title accordingly.

Line 163: Explain more clearly in this section that this attribution analysis is done for the spatial patterns rather than for the temporal changes in each grid cell or region. Also emphasize this in the discussion of Figure 3 that you are not directly attributing the temporal changes of the partitioning shown in Figure 2 but merely the spatial patterns therein, where determined drivers are not necessarily the same for both.

We will state more explicitly that the regression addresses spatial patterns of projected ΔBGWS and not temporal attribution at individual grid cells or regions.

Line 170: Would start this section with this paragraph.

We will reorder the subsection accordingly.

Line 192: "destroyed" → "removed" and **Line 192/193: not sure we get the point here**

We will simplify this explanation and remove the ambiguous wording.

Line 195: Can you comment on the consideration of lateral flow in the models, and its potential role for the partitioning?

We will add a short discussion of the limited or strongly simplified representation of lateral groundwater redistribution in large-scale land models used in ESMs and its potential contribution to the historical blue bias discussed in Sect. 3.1, and we will add a corresponding limitation statement in the Conclusions.

Line 199-201 & 326 & elsewhere: The results section incorporates interpretation/discussion already such that it would be more clear to adapt the title to 'Results and Discussion' and remove 'Discussion and' from the title of section 4.

We will adapt the section titles accordingly.

Line 202: unclear what's meant with absolute BGWS values and whether it is referring to model-mean data or observation-based results

We will clarify that this refers to the absolute BGWS values of the CMIP6 ensemble mean in comparison with the reference products.

Line 207: why interpret regions with large baseline biases at all?

We will avoid detailed interpretation in regions where the ensemble mean disagrees with both reference datasets and indicate these regions explicitly.

Line 209: Would start the section with this paragraph.

We will reorganise this section so that it opens with a higher-level summary of the main historical BGWS features.

Line 215: Unclear to which average 'below-average' is referring - global?

We will clarify that this refers to the global average.

Lines 231/232: There are no visible patterns in the Sahara. and **Line 233: unclear what's the difference between saturation excess vs. infiltration excess**

We will revise this passage to remove the Sahara example and instead discuss retained vegetated drylands more generally. We will also remove the previous sentence on saturation- and infiltration-excess runoff from this location.

Line 244: Can/Should you assume broadly similar soil properties across rainforests?

We will remove this assumption.

Line 257: section 3.2 seems a bit convoluted and was harder to follow: suggestion to rather summarize the main possible mechanisms and then mention example regions instead of selecting regions and describing those

We will restructure Sect. 3.2 to emphasise the main process pathways first and then use regional examples to illustrate them.

Line 265: Fig. 2: place legend in panel a on top or below as for the other figures; brings space for spatial average subpanel

We will revise Figure 2a accordingly and add a compact summary of the area fractions.

Line 268: 'strongly linked' suggests causality, which cannot be derived from covariance across space

We will revise this wording throughout to avoid implying causality from spatial covariance.

Line 342: increases instead of 'is increasing'

We will correct this wording.

Line 351: blue-to-green shift is of similar magnitude, why is this not covered in the text?

We will discuss this more explicitly in Sect. 3.3.

Line 352: Actually this section is about implications rather than management. There is little discussion about land or water management measures and strategies. Either revise this section, or drop the management from the title here, and also adapt the wording in the abstract in line 9 ("impact-relevant", "actionable").

We will revise this section accordingly, retitle it to focus on implications rather than management, and remove the management framing in the text and abstract.

Line 355: One could ask why it matters where the next rain drop goes in the presence of little to no rain in some regions

We will address this directly by clarifying the scope of the analysis and the types of impacts for which BGWS is most relevant.

Line 368: insert Δ before changes as done in the lines below

We will correct this notation.

Line 385: I wonder about the causal direction here: are transpiration increases supporting vegetation productivity or does increased vegetation productivity induce/come with increased transpiration?

We will revise the wording to avoid implying a single causal direction.

Line 387: Figure 5: this is rather a table than it is a figure. For a figure, I would suggest to make two x-y graphics, having dR or dT on the y-axis and dBGWS on the x-axis. Insert text in the respective 4 panels of the graph

We will revise this figure substantially to improve clarity and to communicate the joint interpretation more effectively.

Line 392: 'sizeable areas' is unclear and **Line 398: 'environmental flows' is unclear**

We will replace this wording with more precise language.

- Figure 1: The content of section 3.1 mainly describes and discusses results in the light of the i) water-energy-limitation framework as well as ii) the role of extreme precipitation. Hence, Figure 1 should include maps illustrating the three BGWS features - energy-limited partitioning, water-limited partitioning, precipitation-intensity related partitioning - and the ratio of RX5day/mean precipitation (so fig. S5a). This would make the figure more in line with the title of the manuscript, which emphasizes the role of extreme precipitation and follows the explanation used in the text. Finally, it would be good to cite some more related literature such as Seneviratne et al., 2010 and Denissen et al. 2022.

We will revise Figure 1 to better reflect the hydroclimatic interpretation of the historical BGWS patterns and add the suggested references.

- Figures 1 and 2: Adjust color bar range across panels b-d in both figures.

We will adjust the colour scales in the revised figures to improve cross-panel comparability.

- Figure 3: Do the boxes in panels a and b show the spread of the attribution results for the individual Earth system models? Also, panels c and d are not described and discussed in the text. For example, (i) y-axis unclear, response to what?, and (ii) what is the meaning of the lines connecting 'end-of-century response' across predictors, especially as the y-axis scale changes. Instead, you could use boxplots and depict individual models by differently colored dots or differently shaped points; +/- dBGWS could be indicated by outline of each dot/symbol or by making two boxplots per predictor.

We will revise Figure 3 substantially to simplify it and to show the ensemble-mean and individual-model attribution information more clearly.

- Figure S1: Labelling of panels in the caption is not in line with the figure.

We will correct the caption labelling.

- You could consider adding summary statistics to the maps in the figures as also stated in the text.

We will add summary statistics to the revised figures where most useful.

References:

Orth, R. and G. Destouni 2018: Drought reduces blue-water fluxes more strongly than green-water fluxes in Europe. https://doi.org/10.1038/s41467-018-06013-7

Huang, H. et al. State-of-the-art hydrological datasets exhibit low water balance consistency globally, doi: 10.5194/essd-2025-376

Séférian et al. 2019: Evaluation of CNRM Earth System Model, CNRM-ESM2-1: Role of Earth System Processes in Present-Day and Future Climate. https://doi.org/10.1029/2019MS001791

Seneviratne et al. 2010: Investigating soil moisture-climate interactions in a changing climate: A review. https://doi.org/10.1016/j.earscirev.2010.02.004

Denissen et al. 2022: Widespread shift from ecosystem energy to water limitation with climate change. https://www.nature.com/articles/s41558-022-01403-8

Brunner et al. 2025: A global perspective on the spatial representation of climate extremes from km-scale models. https://doi.org/10.1088/1748-9326/ade1ef