In the following responses, reviewers' comments are reproduced in their entirety in black, and the authors' responses are noted in blue.

Reviewer 2

Reviewer: In this work, the authors use the Gravity Recovery and Climate Experiment (GRACE) and GRACE Follow-on (FO) to estimate root-zone storage capacity (Sr). They find estimates of Sr that are much larger than those using mass-balance approaches and rooting depth parameterizations. I found the work interesting, and the writing was succinct and clear. However, I had a difficult time understanding the assumptions and the implications of these assumptions to evaluate the results. I think the authors need to be much clearer about the implications of their assumptions.
Response: Thanks for your overall positive comment.

Main comments:

- Reviewer: The proposed method is quite different from previous work because it directly uses total water storage (TWS) from GRACE. However, GRACE measures a combination of surface water, groundwater, soil moisture, snow and ice. You explain how you remove the streamflow and snow/ice…but how do you remove the effect of groundwater? Are you assuming that groundwater is part of Sr? In some cases, as water table becomes more shallow, conditions become anoxic for plants…wouldn't this decrease Sr? The role of gw in Sr calculations must be better explained and the assumptions clearly laid out.
  Response: Thank you for this comment. Natural groundwater variability is indeed included in our definition of root-zone water storage capacity (S_r), and we provide clarification below. As Reviewer#1 correctly pointed out, root-accessible water does not require roots to physically occupy the entire storage domain. Processes such as the capillary rise can move deep water upward to the root zone for vegetation transpiration, especially during dry seasons and droughts. Many studies have shown that natural groundwater variability (such as its seasonal variation) strongly correlates with precipitation minus evapotranspiration (e.g., Li et al., 2015).

  Including groundwater in the calculation of S_r broadens the traditional definition of the "root zone," which is typically confined to the unsaturated soil layer, by recognizing the fact that the root zone is dynamic and access deep groundwater and bedrock moisture during prolonged droughts and high transpiration demand (Gao et al., 2024). Several recent studies (McCormick et al., 2021; Singh et al., 2020; Stocker et al., 2023) have also included groundwater in their definitions of S_r. This inclusion is well-supported by recent studies based on *in situ* groundwater (Baldocchi et al., 2021; Fan et al., 2017; Li et al., 2015; Thompson et al., 2011), remote sensing observations (Koirala et al., 2017; Rohde et al., 2024), and modeling efforts (Hain et al., 2015; Miguez-Macho & Fan, 2021), all of which showed that groundwater significantly contributes to ET and is accessible to plants, especially during extreme droughts.

In many ecosystems, water stress can stimulate root growth into deep subsurface through the capillary rise effect, with roots extending to the capillary fringe and the water table, as observed in both field and laboratory studies (Fan et al., 2017; Kuzyakov & Razavi, 2019; Naumburg et al., 2005; Orellana et al., 2012). Although individual shallow-rooted plants (e.g., grassland sites) may not directly tap into groundwater, the large spatial scale of GRACE/FO likely captures water uptake across diverse vegetation types. This blending makes it likely that vegetation types not typically associated with groundwater use may still access it indirectly, such as through hydraulic redistribution by neighboring deeper-rooted plants (e.g., Espeleta et al., 2004; Orellana et al., 2012). Indeed, satellite observations have revealed widespread plant-groundwater interactions at large spatial scales (Koirala et al., 2017), even in dryland regions dominated by grasslands (Rohde et al., 2024; Wang et al., 2023).

Neglecting groundwater in root zone storage capacity can lead to underestimation of land and air interactions (Dong et al., 2022; Maxwell & Condon, 2016; Schlemmer et al., 2018), affect accurate runoff simulation (Hahm et al., 2019), and misrepresent vegetation resilience to droughts and heat waves (Esteban et al., 2021; Jiménez-Rodríguez et al., 2022).

Overall, our $S_r^{GRACE/FO}$ definition aligns with our comparison dataset S_r^{accum} from Stocker et al. (2023) and helps explain why the traditional rooting depth approach ($S_r^{RD \times WHC}$), which does not include groundwater, yields lower values than $S_r^{GRACE/FO}$ and S_r^{accum}. This expanded definition is also supported by the latest research on groundwater-vegetation interactions. We will add these discussions to the revised manuscript.

- Reviewer: The proposed method is also quite different from previous methods in the spatial and temporal scale. You are looking at monthly data at 3x3 degrees. This would include several ecosystems that behave very differently. It also includes multi-year droughts…whereas other calculations would account for periods of deficit (calculated at the daily timescale) with a certain return period. This is a completely different metric…is it really appropriate to compare these?
Response: We appreciate the reviewer's comment. Indeed, our method is fundamentally different from previous approaches. However, we contend that the comparability of the two metrics rests on their shared definition of the physical processes involved. Both S_r^{accum} from Stocker et al. (2023) and $S_r^{GRACE/FO}$ define root zone storage capacity in an identical manner, encompassing groundwater and bedrock moisture and averaging across diverse ecosystems at large spatial scales.

- Reviewer: I am having a difficult time understanding physically what it means to calculate deltaTWS as the difference between TWS anomalies. Are you assuming that the soil will be at saturation at the beginning of the drawdawn, but

will never reach saturation throughout the drawdawn period? Is this an appropriate assumption?
Response: No, our method does not assume soil saturation at the beginning of the drawdown. In fact, saturation is unlikely to occur at the spatial and temporal scales of $S_r^{GRACE/FO}$. During the drawdown period, deltaTWS represents the water, in equivalent water heights (mm), that an ecosystem has used for ET consumption beyond what is available from effective precipitation (precipitation minus total runoff). This calculation does not require saturation and provides only a lower-bound estimate of the root zone storage capacity which must exist in order to explain ET patterns.

- Reviewer: I don't think you should use GRACE to evaluate the performance of HydrModel that includes GRACE information. You state that this is not circular…but it is. Another metric could be streamflow, it would be independent.
Response: Agreed. In the revised manuscript, we will evaluate the model performance with the latest version (v4.1) of the Global Land Evaporation Amsterdam Model (GLEAM) ET dataset (https://www.gleam.eu/). The GLEAM ET is an improved dataset, addressing key issues present in other gridded ET products. For example, it combines hybrid learning from eddy-covariance and sap flow to capture vegetation response to drought more accurately (Koppa et al., 2022), and it explicitly accounts for plant access to groundwater (Hulsman et al., 2023). Importantly, the GLEAM ET is independent of GRACE/FO and, therefore, allows robust validation that is free from circularity.

We appreciate your suggestion to use streamflow for model evaluation. Unfortunately, streamflow is not the most reliable measure for evaluating the USGS model. First, the USGS model primarily parameterizes streamflow based on precipitation, with subsurface storage contributing only when the storage "bucket" is full (McCabe & Markstrom, 2007). This oversimplified scheme does not adequately represent base flow, which is more directly influenced by water stored in the subsurface including groundwater (Reager et al., 2014). Second, the two key parameters governing streamflow generation – the fraction of precipitation converted to direct runoff and the fraction of spillover from the storage bucket converted to runoff – are globally uniform and not calibrated to local conditions. This lack of calibration limits the model's capability to capture spatial and temporal variability in streamflow dynamics. Third and more importantly, compared to precipitation, ET, and TWS anomalies, streamflow is the smallest component of the Earth's hydrological cycle. As a result, it is less sensitive to S_r parameterizations. For these reasons, we will use ET as an evaluation metric following Wang-Erlandsson et al. (2016) in the revised manuscript.

- Reviewer: The part about linking Sr to vegetation growth was not very convincing. I think you are comparing maximum GPP to the point of saturation…so if I understand correctly what you are showing is that vegetation activity is enhanced when there is enough water. I don't think this argument is necessary for your paper.

Response: We appreciate the reviewer's comment regarding the linkage between soil moisture storage (S_r) and vegetation growth. (Huxman et al., 2004; Ponce-Campos et al., 2013) We agree that vegetation productivity is often determined by water availability. However, it is insightful to examine the specific role of S_r in influencing vegetation growth.

As Reviewer#1 commented, it might seem intuitive to assume that in regions with abundant precipitation, GPP would be high, and a large S_r might be unnecessary. However, our analysis shows that a large S_r is still essential in these ecosystems, suggesting vegetation growth is not solely determined by the immediate availability of water but also by the ecosystem's capacity to store it. Therefore, our analysis can reveal how S_r modulates plant-water interactions across diverse hydroclimatic conditions.

Furthermore, comparing GPP_{max} to the point of saturation provides an independent assessment of the relative accuracy of the three S_r products, offering additional insights beyond those derived from the USGS models.

In light of these discussions, we believe that exploring the relationship between S_r and vegetation growth provides useful information. In the revised manuscript, we will further clarify and elaborate the rationale for linking S_r to vegetation growth to ensure that the relevance and importance of this analysis are clear.

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