Khanal et al evaluate the relative controls of surface and deeper soil moisture on vegetation using mostly satellite data from CCI soil moisture and GRACE terrestrial water storage. They argue that surface soil moisture controls vegetation generally more than deeper moisture stores depending on climate, but deeper moisture stores increase their control in drier months. I have a positive outlook on the study. It evaluates an unexplored gap about the depth of vegetation water use which remains a highly uncertain part of the biosphere. The use of satellite retrievals was highly appropriate for the (nicely posed) objectives. I do think the study needs more work. I have several concerns about the statistical analysis and interpretation of results that should be addressed. I also think more context needs to be added about the uncertainty of the depth of representation of GRACE and CCI and how their correlation confounds interpretation of results. Because of these issues, I think some of the current conclusion arguments extend beyond what we can say from the analysis and may need to be tempered somewhat. Nonetheless, even with the tempered arguments, the study is very insightful and can be a great contribution to the community. See comments below.

-Andrew Feldman

We thank the reviewer for his positive feedback on our manuscript and thank him for the constructive comments to improve our manuscript.

Major Comments

1. **Is it possible to determine whether CCI or GRACE controls vegetation more only from partial correlations? In reading L246-257, I am wondering if one can conclude greater control from correlation differences that are within 0.1 of each other, especially when the partial correlations do not control for the other soil moisture metric. Much mutual information is thus involved which is difficult to disentangle. Is there some significance metric that can be used to denote the difference in correlations? Or another different metric entirely? At what point do we say that both depths are controlling vegetation in an indistinguishable manner? Ultimately, I think some main conclusions that one depth controls vegetation more than another are not fully supported by the correlations. At least we can say that these variables are largely interconnected and both surface and TWS moisture have some control on vegetation in many places, which is an interesting finding in itself!**

We appreciate the reviewer's insightful query regarding the possibility of ascertaining whether CCI or GRACE exerts a stronger influence on vegetation, particularly when relying solely on partial correlation. This is especially pertinent when we do not control for the other soil moisture metric, as this introduces mutual information, which can be challenging to disentangle. In order to bolster the robustness of our findings, we performed two distinct analyses.

In the first analysis, we computed partial correlations between NIRv and surface soil moisture (SSM) (as well as NIRv and terrestrial water storage (TWS)), while controlling for TWS (or SSM) alongside energy variables (Ta and Rn). This approach enables us to examine the correlation of NIRv with each water variable independently, while accounting for the influence of other water variables. However, it's important to note that introducing additional control variables, which might confound the correlation, results in a reduction in the number of grid cells displaying significant partial correlations between NIRv and water variables, and it also diminishes the strength of both partial correlations. With the new approach, the number of grid cells available was too little to analyze the correlation difference and make inference at the global scale. Therefore, we omitted the significance criteria and focused on all grid cells demonstrating a positive correlation during the growing season months for this particular analysis. We will replace Figure 1 with the new partial correlation maps that take these additional control variables into account and move the former Figure 1 to Supplementary material.

Even with these adjustments, the global spatial patterns in the partial correlation maps, specifically r(NIR~SSM/T,R and TWS), as well as r(NIRvTWS/T,R and SSM), remain largely consistent with those obtained without considering the additional control variables, which is r(NIRv~SSM/T,R) and r(NIRv~TWS/T,R) respectively. This underscores the robustness and confidence in the global spatial patterns of correlations between NIRv and water variables, even after untangling the effects of other water variables.

In the second analysis we conducted a bootstrapping analysis. This analysis allowed us to compute bootstrap means and 97.5% confidence intervals for the difference in partial correlation between r(NIRv~~SSM) and r(NIRv~TWS) for each AI-TC class. We will add the outcome of the bootstrapping analysis to Figure 2.

Our second analysis reveals that, throughout the growing season months, the bootstrapping results show that for most random samples drawn from each AI-TC class, the sign of the correlation difference is the same as for the overall analysis, underlining the robustness of our findings. This consistent positive result underscores a stronger correlation between NIRv and SSM compared to TWS during the growing season months, even after accounting for the influence of other water variables.

Conversely, during the dry season months, the majority of AI-TC classes displayed positive confidence intervals. This observation highlights the greater relevance of SSM for NIRv compared to TWS during the dry season months within these classes. However, the bootstrapping analysis also confirmed the higher relevance of TWS in specific classes. This pattern implies a stronger correlation of NIRv with TWS compared to SSM.

It's worth noting that in certain classes, the confidence intervals did not provide a conclusive distinction, indicating that the TWS and SSM are similarly relevant for the vegetation in these regions in dry months.

Apart from this, we agree with the reviewer that both surface and deeper moisture have some control on plant growth, and we will stress this more in the manuscript.

Lastly, to address the reviewer's suggestion that the primary conclusion, which posits that one depth level exerts greater control over vegetation compared to another, lacks full support from correlations, we will modify the sentence in the abstract as follows: "We find that vegetation functioning seems generally more strongly related to near-surface soil moisture, particularly in semi-arid regions and areas with low tree cover. At the same time we note that this comparison is hampered by different noise levels in these satellite data streams."

2. Discussion early on in the manuscript is needed about depths of representation for both ESA CCI soil moisture and GRACE TWS. There is still much debate about what layers these products represent as well as what layers vegetation uses water from. I would provide context about both of these points in the introduction. (Trying to avoid self promotion but please see references within this WRR study, already referenced in preprint form in this paper, that can help with supporting this discussion: https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2022WR033814)

Thank you for sharing the paper, which is highly relevant to the study of soil moisture and vegetation uptake depth. The paper emphasizes that satellite-driven soil moisture data obtained through microwave remote sensing provides information about soil moisture at greater depths than traditionally considered, both in wet and dry conditions and hence capture water content relevant for studying vegetation water uptake. We will reference this study when discussing vegetation uptake depth in paragraph 2 of the introduction and when explaining our results. Regarding GRACE TWS, it represents the total water content, making it challenging to determine specific depths. As it has been found to exhibit a strong correlation with vegetation activity, we believe it still offers an implicit reference to water content relevant for vegetation, extending beyond surface soil moisture as captured by ESA CCI. However, under specific conditions explained in Line 77.

3. Following the previous point, CCI soil moisture (mostly from C and X band? Please clarify) is theoretically only providing microwave emission from the top 2 cm. Most would argue that plants are sensitive to moisture at much deeper depths. What does is mean that CCI soil moisture is correlated to vegetation behavior? This link needs to be made early on for the reader. For example, surface soil moisture is often correlated with rootzone soil moisture layers below effectively providing more information than only what is shown in 0-2cm layer. Therefore, this correlation can mean 0-2cm moisture are contributing to root water uptake and/or deeper layers correlated to 0-2cm moisture are contributing to root water uptake.

The reviewer mentions a valid point which we will clarify in the manuscript. Even when vegetation activity is well correlated with surface soil moisture, it is challenging to precisely define the depths relevant for vegetation uptake as surface soil moisture often shows a strong correlation with rootzone soil moisture, especially during wet months.

However, our aim is to investigate how vegetation uptake depths vary across different vegetation types and from growing season months to dry periods on a global scale, rather than identifying which exact soil depth is most related to vegetation activity. And while the soil depth of our two dataset (CCI and GRACE) partly overlaps, they do allow for separating surface moisture from overall water availability using partial correlation.

4. One interpretation that could be made clearer (based on findings such as in L213-216) is that both surface and deeper moisture sources can control vegetation. Additionally, when both correlations with TWS and surface soil moisture are found to be positive, it is also not clear if

these are both depths controlling vegetation. Or only one of the depths controls the vegetation but a positive correlation shows up in both because TWS and surface soil moisture are correlated to one another. This point is especially a concern with TWS and surface soil moisture not controlled for in the same regression.

Our improved methodology, where the partial correlations control for the other variable, holds promise in addressing this challenge and enhancing our understanding of variations in vegetation uptake depths.

5. I know it is difficult to test, but could the results change if at a daily timescale? Might we expect TWS and surface soil moisture to be more correlated at a monthly scale and therefore more difficult to pull apart which is controlling vegetation at a monthly scale? Some speculation on this and discussion of result dependence on temporal scale is necessary.

Our study was constrained by the unavailability of daily TWS data. On the other hand, the processes that impact the correlation between NIRv and soil moisture act at longer than daily time scales. For example, the drought effects on NIRv are lagged, and the soil moisture data has a high autocorrelation. Though, performing the analysis at the daily time scale might be beneficial for disentangling TWS and SSM dynamics, a potential drawback would be we could not capture the soil water- vegetation relationship in this scale because of the time lags and soil moisture memory as mentioned before. So, thoughts on changes in correlation strength for the daily time scale would therefore be very speculative, and we prefer to stay away from that in the manuscript.

6. Should the analysis be conducted with anomalies? The seasonal cycle could be larger in either surface soil moisture or TWS which may contribute to a higher correlation in that variable with vegetation, which is not related to the direct control on vegetation. I know this is partially mitigated by using the growing season but be aware that the seasonal cycle can spuriously inflate the partial correlations.

For our manuscript, we calculate the correlation between the monthly anomalies of vegetation activity and anomalies in water storage. It is important to note that we have accounted for the removal of the long-term mean monthly cycle and linear trends, as described in section 2.2.1 and illustrated in Figure S1.

Specific comments

L71-79: It would be helpful to expand on what depths TWS represents from previous literature. I've seen studies noting 1-3m because this is where most of the water variations are that GRACE can detect. This point is uncertain but it would be good to lay out the previous knowledge for the reader.

We will mention that GRACE TWS anomalies include variations in all sub-surface water, including the top soil and deep aquifers. We have not yet found any studies that are more explicit about this, but we will do another search for literature when revising the manuscript.

L83: really great questions

Thank you!

L139: Since GRACE is 0.5 degrees, I recommend conducting the analysis at 0.5 degrees. Some errors may otherwise arise in attribution with higher resolution datasets with the SHAP analysis

We are uncertain about the potential impact of this on our SHAP analysis results. Given that the resolution of the other variables used in the SHAP analysis differs from the 0.05-degree resolution (we employed) and the 0.5-degree (suggested), we opted to omit this comparison. Although there may be some scaling effects in our results, we remain uncertain about the extent of their impact and it would be tremendously valuable to ascertain whether SHAP analysis is robust when conducted at different scales.

However, we did perform additional SHAP analyses, as recommended by another reviewer, which involved including vpd and considering partial correlation with constraints of other water variables, as mentioned in our previous response to question 1. These analyses revealed minimal changes in the ranking of the important variables in explaining the correlation differences. Notably, the SHAP dependence plots retained a similar nature, indicating the robustness of SHAP analysis even when controlling for other water storage in computing partial correlation and introducing vpd. We hope this information proves helpful.

L146: are the results sensitive to this threshold? I imagine this could greatly reduce time periods of the year for arid regions.

We currently remove all grid cells with a SIF value below 0.2. An increase in this threshold would remove grid cells that are partly vegetated and it would remove months with on average little active vegetation. With a higher threshold we potentially exclude grasslands that have low SIF values compared to forests (Chen et al., 2022). Furthermore, a higher threshold would remove months with lower vegetation activity, and therefore reduce the number of grid cells for our correlation analyses. We therefore remain with our 0.2 threshold.

L154-155: It would be helpful to show the regression equation(s) for how this was done. I think this is equivalent to a multiple regression with NIRv as the explained variable and the climate variables as explanatory variables.

We will provide further details on how Spearman partial correlations are computed in the methodology section.

L157: Both TWS and surface soil moisture have to be negative correlations or insignificant? What if only one of them shows a positive and significant correlation?

In our manuscript, we excluded data points if one or both of the partial correlations were negative or insignificant. However, for the new partial correlations computed (accounting for the other water storage variables), we exclude only the negative partial correlations (as discussed in our response to

Question 1). We will clarify in the manuscript that we remove any grid cells that have a negative correlation for SSM and / or TWS.

L162: More detail is needed for how these dry months are determined. Are these the driest of the growing season months within a pixel?

The dry months were defined based on the lowest 10% value of each grid cell within a pixel, specifically considering the availability of surface soil moisture. These months indeed correspond to the driest periods within a pixel during the growing season. We will clarify this in the methodology section of the manuscript.

Figure 1: It would be helpful to show the pdf of the spatial distributions so the values can be more easily viewed.

Thank you for the suggestion. We have adapted this in Figure 1 accordingly.

Line 206-211: Can this be shown in a figure?

Figure 1 represents the spatial variability of the correlation that is explained here. Could you clarify what you would like to see in a figure?

L216: I think Figure S2 would be valuable to show in the main text. This provides a lot of context especially with regard to my major comments.

Given our focus on emphasizing the correlation between vegetation activity, SSM, and TWS, as well as examining their spatial variations and temporal changes, especially during dry months, we believe that Figure S2, though highly relevant for comprehending the correlation results, it is important to keep in the supplementary section intact. This decision aligns with our aim to effectively emphasize the primary objectives of this paper, while maintaining a smooth and coherent flow of information through figures. Moreover, with our adjusted methodology, in which we incorporate an additional water variable in the partial correlation, it is possible that the correlation between SSM and TWS may be less problematic. We genuinely value your understanding and support in this matter.

L291: Can max rooting depth be included in the analysis? The Fan et al 2017 PNAS dataset can be used.

The existing global maximum rooting depth datasets exhibit significant variability and come with substantial uncertainties (Li et al., 2022). Given these challenges, along with the time constraints we face, we have made the decision not to pursue this avenue of investigation.

L349-351: I think this argument extends beyond what the correlations say. This conclusion is only based on the small correlation differences. Maybe a more specific significance test is needed here. See my major comments.

We believe that through the major revisions, as outlined in response to major comments 1, we can effectively emphasize and strengthen the conclusion that vegetation preferentially takes up water from the top soil. We agree that we did not show any analyses about rooting depth and we will rewrite the second part of this argument.

L351-353: What if surface soil moisture and TWS are correlated and both are correlated with vegetation behavior? This leaves open the possibility that vegetation is only accessing shallow moisture but shallow moisture is also correlated with deep moisture, which confounds the results. I don't deny that vegetation is accessing TWS but the conclusion here may need some more evidence based on the current study setup. See my major comment.

We believe that we have addressed this point with the update of the methodology to take into account the water variables in the partial correlations. As mentioned earlier in our reply, we will discuss and show the strong correlation between SSM and TWS.

L355-359: awesome finding. Well done.

Thank you for your appreciation.

L399: This study is now published in WRR. Please reference that instead of the preprint. https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2022WR033814

We will update this here.

Citations

Chen, J., Liu, X., Ma, Y., Liu, L. (2022). Effects of Low Temperature on the Relationship between Solar-Induced Chlorophyll Fluorescence and Gross Primary Productivity across Different Plant Function Types. *Remote Sens. 14*, 3716. https://doi.org/10.3390/rs14153716

Li, W., Migliavacca, M., Forkel, M., Walther, S., Reichstein, M., & Orth, R. (2021). Revisiting Global Vegetation Controls Using Multi-Layer Soil Moisture. *Geophysical Research Letters*, *48*(11). https://doi.org/10.1029/2021GL092856