Response to RC2:

This manuscript presents a comprehensive assessment of the relationship between atmospheric CO_2 growth rate (CGR) and terrestrial water storage (TWS) at interannual timescales, with a particular focus on tropical forest ecosystems. By combining satellite-derived GRACE data, multiple atmospheric CO_2 inversion products, and land cover datasets, the authors demonstrate a consistent and statistically significant negative correlation (r = -0.70) between global TWS and CGR from 2002 to 2023. Notably, tropical America and tropical forests emerge as dominant contributors to this coupling, despite their relatively small spatial extent. The study also applies multiple methods to partition the spatial and functional drivers of this relationship and evaluates the robustness of the signal using both observational and model-based approaches.

We thank Reviewer 2 for their thoughtful and constructive comments. Below, we provide a point-by-point response, indicating how we will address each suggestion.

Overall, this study is of high quality and reflects substantial analytical and conceptual work. The manuscript is well structured and clearly written. I have several comments and suggestions for the authors to consider:

The abstract reports a strong TWS–CGR correlation, but it lacks a statement explaining how this finding advances previous work (e.g., Humphrey et al., 2018). Please clarify further how this study uniquely extends or deepens our understanding.

In the revised abstract, we will explicitly state how our study builds on and extends prior work, particularly by providing a more detailed regional contribution and temporal breakdown of contributions (e.g., Figures 5 and 9).

Lines 28-31: The sentence "tropical forests exhibit the strongest CGR correlations" is important but could briefly explain why—e.g., due to high productivity sensitivity to water stress—so help readers understand the physiological context.

We will revise the abstract to say "Tropical forests exhibit the strongest CGR correlations due to their high productivity and sensitivity to water stress, which strongly influence interannual variations in carbon uptake."

In Section 2.3, clarify whether all four inversion products use harmonized fossil fuel and biomass burning emissions (e.g., GFED versions). Differences in fire emissions datasets could bias regional flux attribution.

We have re-done the analysis using 8 inversions from GBC2023 that share harmonized fossil fuel and fire emissions (e.g., using the same GFED version). This does not change our conclusions and we will update the text accordingly and clarify this harmonization in Section 2.3.

Table 1 summarizes inversion methods, but the main text should include 2–3 sentences interpreting key differences in transport models, meteorological fields, or prior flux assumptions and how they might affect tropical vs. extratropical estimates.

We will add text such as
"Atmospheric CO_2 inversion products differ in their use of transport models, meteorological inputs, and prior flux assumptions—all of which can significantly influence flux estimates, particularly when comparing tropical and extratropical regions (Peylin et al., 2013; Chevallier et al., 2010). In the tropics, flux estimates are especially sensitive to how transport models represent deep convection and vertical mixing, while extratropical estimates are more influenced by synoptic-scale advection and boundary layer dynamics. Prior flux assumptions, such as prescribed seasonal cycles or vegetation responses, can also introduce regional biases—especially in the tropics where these assumptions often fail to capture complex climate–ecosystem interactions (Munassar et al., 2022; Gaubert et al., 2019). Moreover, the relative scarcity of CO_2 observations in tropical regions amplifies the impact of model structure and prior uncertainty, whereas denser observational networks in the extratropics provide stronger constraints on inversion results (Patra et al., 2005; Schuh et al., 2019).

I don't think it's necessary to place Figure 1 in the main text. It is recommended to put it in the supplementary files. Overall, there are too many figures in the full text. It is suggested to combine them.

We can move Figure 1 to the supplementary.

Lines 293-294: Please explain why some regions with high local correlation contribute minimally to the global signal—e.g., due to small TWS variance or maybe small spatial extent—and explicitly state how these cases are handled.

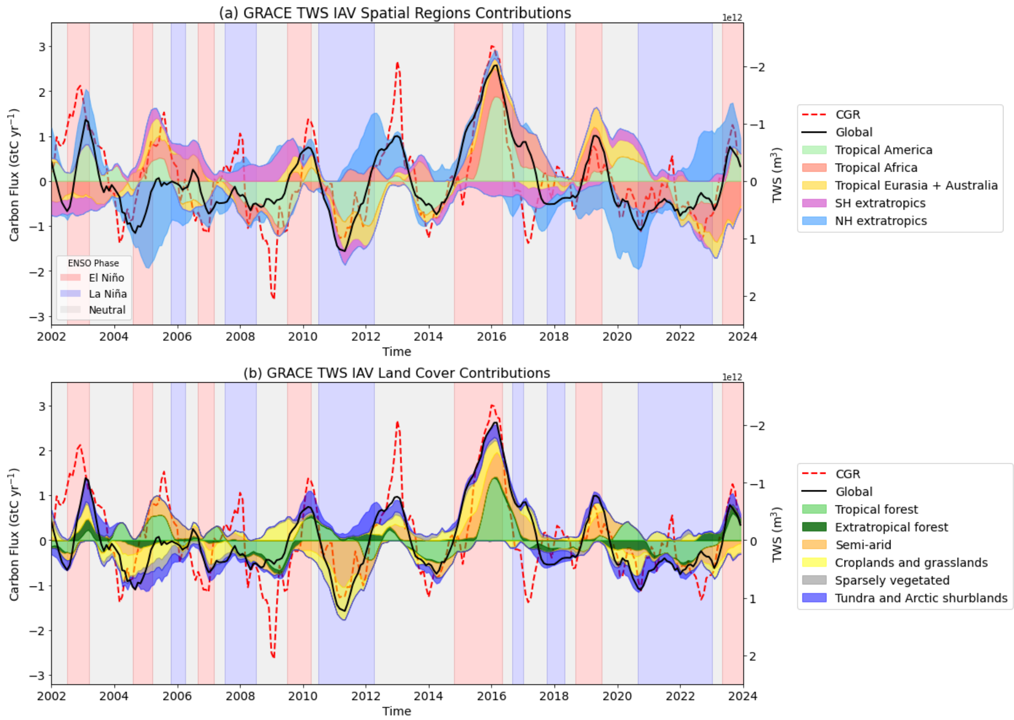
We will add a discussion clarifying that regions with high local correlations may contribute minimally to the global TWS–CGR correlation if they exhibit low TWS variability or have limited spatial extent. Conversely, other regions (e.g., the Northern Hemisphere extratropics) may show large TWS variability but still contribute little due to weak correlation with CGR. Overall, these features highlight the usefulness of considering the three metrics together.

In Figure 4, report the number of grid cells per land cover class and provide standard deviations or interquartile ranges to contextualize variability in contribution estimates.

We have included in Figure 1 caption the percentage of the land surface each region occupies. We can quote regional areas in text (area perhaps better as grid cells vary in size). We can also report standard deviations of storage variations in each region.

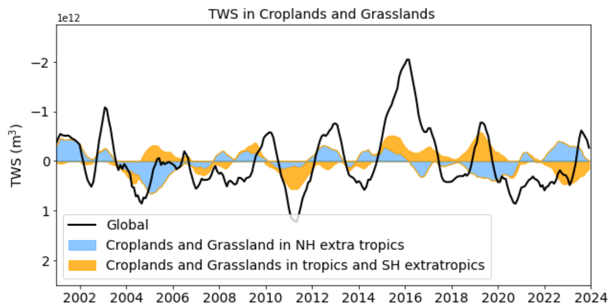
Annotate key ENSO or drought years (e.g., 2005, 2010, 2015–16) directly in Figure 5 to aid interpretation of CGR–TWS relationships and align with the narrative.

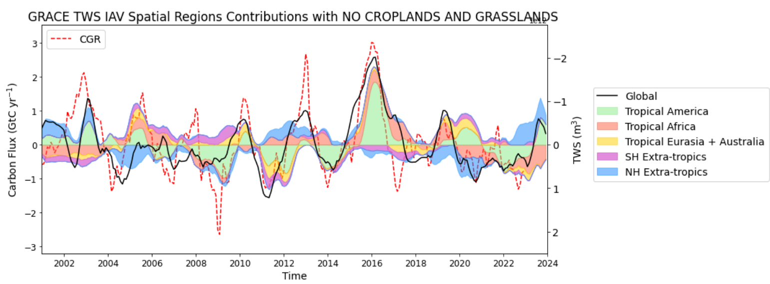
We have added shading in Figure 5 to indicate ENSO index using ONI index from https://origin.cpc.ncep.noaa.gov/products/analysis_monitoring/ensostuff/ONI_v5.php



lines 390–395: reference a figure or appendix that visualizes cross-regional TWS anomaly compensation (e.g., a correlation matrix or spatial covariance map), supporting the claim of cancellation effects in croplands.

We will add supplementary figures which demonstrate the cancelling effects seen in the Northern Hemisphere appear to occur within croplands and grassland. See figures below, which show contributions of croplands and grassland in the NHet and tropics + SHet in top figure, then the bottom figure shows the same as Figure 5a but with croplands and grasslands removed from the NHet, where we no longer see the large storage variations that were causing the cancelling effect.





The sensitivity analysis in Figure 10 is valuable, but the ecological interpretation of why tropical forests show both high correlation and high sensitivity should be more deeply discussed—e.g., in terms of water-use efficiency or rooting depth.

We will expand the discussion on ecological mechanisms, including deeper rooting systems, water-use efficiency, and stomatal control, to explain both high correlation and sensitivity in tropical forests. We will add text such as

The strong correlation and sensitivity in tropical forests could be attributed to several possible factors. For instance, tropical rainforest trees tend to have relatively shallow rooting systems and are hence more likely to be affected by changes in TWS when prolonged or severe droughts deplete soil moisture (Kleidon, 2004). While some trees can develop deep roots that provide drought resilience, the majority of water uptake in tropical forests occurs from shallower soil layers, making them especially sensitive to reductions in available water.
Additionally, tropical forests generally have high WUE, which allows them to maximize carbon uptake under favorable conditions but also makes them vulnerable to rapid declines in productivity when water becomes limiting (Keenan et al., 2013; Saleska et al., 2016). Another reason for this sensitivity could be due to the ongoing drying of parts of the Amazon—especially the southeastern region—which has pushed these forests into a state of heightened vulnerability to drought, further amplifying their sensitivity to interannual variability in water storage and the observed coupling between terrestrial CO_2 and water storage variability.

lines 530–534: Clarify whether TWS–CGR correlations were adjusted for or confounded by co-varying climate factors (e.g., temperature, VPD). If not adjusted, include a cautionary note on potential indirect effects.

We will add a cautionary note to say "We acknowledge that the reported correlations between TWS and CGR have not been adjusted for co-varying climate factors such as temperature or VPD. As a result, these relationships may partly reflect indirect effects mediated by such variables. However, previous studies (e.g., Humphrey et al., 2018) have demonstrated that the influence of TWS on carbon fluxes remains significant and largely independent of temperature, suggesting that the observed coupling is robust despite potential confounding factors.

lines 543–548: In discussing cases where TWS is weakly correlated with CGR (e.g., tropical Africa in 2016), could consider fire activity, radiation, or phenological anomalies as alternative drivers.

We will revise the text to acknowledge these alternative drivers and include a brief discussion highlighting their potential influence in regions or periods where TWS–CGR correlations are weak.

In the conclusion, clearly articulate how your findings can inform terrestrial biosphere model development. For example, suggest that ecosystem models should incorporate regional water constraints with higher fidelity, particularly in tropical forests.

We appreciate this suggestion and will revise the conclusion to emphasize that terrestrial ecosystem models should prioritize improved representation of water constraints, particularly in tropical forests where water availability plays a critical role in modulating carbon fluxes. As highlighted by Humphrey et al. (2018), current models often underestimate the strength of the coupling between water availability and carbon uptake. Moreover, recent findings by Liu et al. (2023) indicate that this coupling is intensifying over time, further underscoring the need for models to better capture regional water–carbon interactions to improve future projections.

References

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Keenan, T. F., Hollinger, D. Y., Bohrer, G., Dragoni, D., Munger, J. W., Schmid, H. P., & Richardson, A. D. (2013). Increase in forest water-use efficiency as atmospheric carbon dioxide concentrations rise. *Nature, 499*(7458), 324–327. https://doi.org/10.1038/nature12291

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