Response to RC3

"Strong relation between atmospheric CO2 growth rate and terrestrial water storage in tropical forests on interannual timescales" by Petch at al. analyzes CO2 fluxes derived from atmospheric inversions in conjunction with space-based terrestrial water (TWS) to understand what regions drive the accumulation of CO2 in the atmosphere (CGR). Past studies had shown a strong correlation between the atmospheric CGR and global TWS, suggesting that ecosystem water availability is the dominant mediator of the strength of the terrestrial carbon sink and thus TWS. This paper expands on this analysis to show that tropical forests, followed by semi-arid ecosystems, are the drivers of this strong correlation, with tropical America contributing almost 70% of the global TWS-CGR correlation. The manuscript provides some improvement on analysis of globally integrated covariates by elucidating the geographic and ecosystem-type drivers.

A major concern with this analysis is lack of discussion of northern extratropics. Previous analysis has shown that these areas are important contributors to CO2 IAV (Guerlet et al., 2013 – who showed that inversions using in situ CO2 only did not see the flux variability that was visible from space-based data; Keppel-Aleks, et al., 2014 – who showed that taking annual averages of CO2 data, which is what is done to calculate CGR in this paper – masked variations that were attributable to northern extratropics). I point out these two papers in particular because the authors use inversions driven by surface CO2 rather than satellite CO2, and because their global correlations are derived from global averaged CO2. Given the four inverse models show a huge spread in the northern extratropical contribution to CO2 IAV, with NISMON showing these areas contribute only 5% to global CO2 IAV and CT2022 showing contributions closer to 35% of global CO2 IAV, more analysis of the impact of this discrepancy is required.

We thank Reviewer 3 for their thoughtful and insightful comments, particularly regarding the role of the northern extratropics, robustness across inversions, and the interpretation of TWS–CGR correlations. We agree with the need for more discussion. We will explicitly address the NHet, referencing Guerlet et al. (2013) and Keppel-Aleks et al. (2014), and discuss whether some NHet contributions may be muted in CGR derived from surface-based inversions alone.

The analysis in the revised manuscript will now be based on 8 inversion products. (See new figures in response to RC1). The additional products still highlight NISMON as an outlier and support the main results.

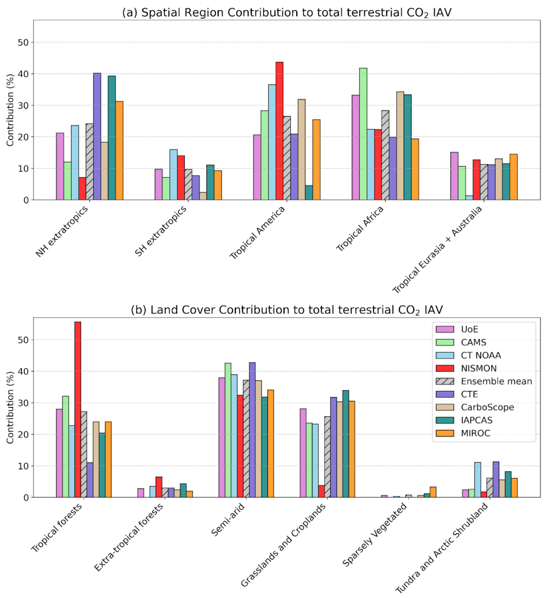
A second concern is that tropical Africa contributes almost as much CO2 IAV as tropical America, but this variability is not as well correlated with variations in TWS. What, then, does this mean for the utility of the high correlation between CGR and TWS? The authors diagnose the regions that drive the apparent global correlation with TWS, but they do not provide much analysis or any conclusions about in what way the emergent global correlation can or should be used in carbon cycle research.

We will discuss that TWS may not be the dominant constraint in all regions. In tropical Africa, factors such as fire emissions, solar radiation, or phenology may drive CO2 variability independently of water availability. We will expand this discussion and caution against overinterpreting global TWS–CGR correlation as a universal proxy.

I am also somewhat skeptical how robust are the results from these four inverse models. The models do show substantially different regional fluxes, by at least a factor of two for each of the geographic

regions considered. More inverse models are available for analysis, and I am curious about what a larger ensemble would reveal. Section 2.5 stated that correlations were calculated from an ensemble mean flux product. I am curious as to what the correlations with TWS variations would look like from each model separately. Would the conclusions be robust to this change in methodology?

The contributions to the total land variability were calculated for each inversion product individually, and this has now been done for a larger ensemble size consisting of 8 inversion products. See new figure below. The correlations we have given throughout the study are between regional water storage and the global CGR, which use the GRACE data and the CGR timeseries and do not use the inversions.



Analysis from the OCO fluxMIP shows significant distinctions between inversions that are configured to adhere tightly to the ocean prior and those where the ocean can move. Are the differences in terrestrial fluxes within this small 4 member ensemble associated with tight ocean priors? And related to a point above, what would the analysis look like based on inversions that use space-based CO2 observations to constrain fluxes? In theory, the space-based data provides better spatial constraints than the sparse surface network.

We have now expanded our ensemble to include 8 inverse products that fit our time period, all using in situ data only. We agree it would be useful to look at products that use satellite observations as constraints, however, these are only available from 2015 onwards therefore we did not include, as our analysis relies on interannual correlations over a whole 20 yr period. We hope to address this further in collaboration directly with inverse modellers.

In summary, I recommend more discussion and stronger conclusions about what it means that many regions that contribute a fair amount of CO2 variability do not have a strong correlation with TWS, and other regions that have strong TWS variability do not show much variation in CO2 flux. The paper would have more impact if it provided recommendations about what key carbon cycle inferences are being obscured by using the global relationship between CGR and TWS as a shortcut.

Thank you for your suggestions. We will add more discussion about points addressed above, and will address what carbon cycle inferences could be missed by using TWS as an indicator. We believe that several of these concerns will be addressed through revisions detailed in responses to RC1 and RC2.

Guerlet, S., Basu, S., Butz, A., Krol, M., Hahne, P., Houweling, S., et al. (2013). Reduced carbon uptake during the 2010 Northern Hemisphere summer from GOSAT. *Geophys. Res. Lett.*, *40*(10), 2378–2383. https://doi.org/10.1002/grl.50402

Keppel-Aleks, G., Wolf, A. S., Mu, M., Doney, S. C., Morton, D. C., Kasibhatla, P. S., et al. (2014). Separating the influence of temperature, drought, and fire on interannual variability in atmospheric CO2. *Global Biogeochem. Cycles*, *28*(11), 1295–1310. https://doi.org/10.1002/2014GB004890