Legend:

Text: Reviewer’s comments

Text: My responses

Text: Tracked Changes

Open Access Paper (submitted to EGU):
https://editor.copernicus.org/index.php?_mdl=msover_md&_jrl=11&_lcm=oc108lcm109w&_acm=get_comm_sup_file&_ms=106043&c=233471&salt=1224728252505037330

Supplementary to Paper:
https://bg.copernicus.org/preprints/bg-2022-178/bg-2022-178-supplement.pdf

Revised Paper: Revised_manuscript.pdf

Tracked Changes: Tracked_Changes.pdf

RC1

In this manuscript, the authors assessed the impacts of climatic extremes on terrestrial carbon budget, based on the simulation with the CESM2. They analyzed top-5% extreme net biome production (NBP) through historical to future periods, and showed an increasing trend of negative extreme NBP, especially in tropical regions. They attributed the trend to factors and found that compound hot, dry, and fire events had a strong impact.

General comments

This study is well focused on detection and attribution of the impacts of extreme conditions on terrestrial carbon budget, such that the trends of extreme-related carbon budget shown in Figure 1 look convincing. The prevailing impact of soil moisture is reasonable, although it could not be independent from precipitation variability. Several results of regional anomalies and dominant factor were remarkable for me. For example, large loss of NBP in East Asia, as much as 3 Pg C (Figure 3), is surprising, because this region is outside of the tropics. Also, I was impressed by the strong impacts of fire on NBP anomalies in many tropical to temperate regions (Fig. 4).

As stated by the authors, this study used only one model (CESM2), and then uncertainty associated with multiple models were not included. I guess that the authors could analyze output data of other models in the CMIP6, but I agree that this remained for forthcoming studies. Similarly, I felt a bit uncomfortable about the use of sole SSP585 result, because this scenario itself is a kind of extreme case. Nevertheless, I found merits in this study and recommend major revisions.

Response: We investigated climate-carbon feedbacks in detail for the SSP585 pathway because the literature suggests (Schwalm et al. 2020, Abadie et al. 2020, Trugman et al. 2018, Park et al. 2015) that this pathway is possibly the best match till 2050 under the current and stated policies and with (likely) plausible levels of CO_2 emissions in 2100. In future studies, we will include multiple scenarios to investigate changing climate-carbon variability.

Thank you for finding our paper meritorious and providing us the opportunity to further improve it.

Specific comments

Line 1: Abstract. Please give a short sentence explaining methodology used in this study.

Response: We have revised our abstract and included a short description of the methodology. Please see Tracked Changes: ln 3-15 or the text below:

Using the percentile threshold on the probability distribution curve of NBP anomalies, we computed negative and positive extremes in NBP.

. . .

Using regression analysis, we found soil moisture anomalies to be the most dominant individual driver of NBP extremes. The compound effect of hot, dry, and fire caused extremes at more than 50% of the total grid cells.

Figure 2: I guess that this figure shows total NBP for each region, i.e., not only extreme NBP but also NBP of usual conditions.

Response: Figure 2 shows the sum of positive and negative carbon cycle extremes during NBP extremes for 25-year time windows for the period 1850-2100. It shows the strength of negative and positive NBP extremes (PgC) across SREX regions over time. The regions in orange color show net carbon cycle extremes and regions in purple color show positive extremes. However, Figure S4 shows the integrated NBP of SREX regions over time. We have revised the caption on Figure 2 (see below) to make it clearer for the readers [Tracked Changes: page 9].

Figure 2. The figure shows the sum of the magnitude of positive and negative NBP extremes during 25 year periods. The figure shows the total integrated net impact of carbon cycle extremes (PgC) across SREX regions for the following periods: (a) 1850–74, (b) 1900–24, (c) 1950–74, (d) 2000–24, (e) 2050–74, and (f) 2075–99. A net gain in carbon uptake during extremes is represented by a purple color and a + sign, and a net decrease is represented by an orange color and a – sign. For most regions, the magnitude of negative NBP extremes or losses in carbon uptake were higher than positive NBP extremes or gains in carbon uptake.

Line 233: I agree with the mechanism but am unsure whether CESM2 has corresponding root structure.

Response: According to the Technical Documentation of CLM5.0 (Lawrence et al. 2018), the model simulates water exchange across the root structure that varies with the soil depth and plant functional type. The soil water flux is dependent on hydraulic conductivity and hydraulic potential among various soil layers via Darcy's Law. Due to the differences in hydraulic properties of soil layers, their soil water content varies by soil depth. The root-soil conductivity depends on evaporative demand and varies by soil layer and is calculated based on soil potential and soil properties, via the Brooks-Corey theory. The rooting depth parameterizations were improved in CLM5.0 with a deepened rooting profile for broadleaf evergreen and broadleaf deciduous tropical trees (Lawrence et al. 2019).

Line 248: Again, I am unsure how CESM2 simulated the post-fire recovery.

Response: There is no explicit post-fire recovery in CLM5.0. It loses biomass from the impact of fire that is possibly restored in subsequent years. CLM5.0 simulates recovery from fire based on the post fire carbon pool and rate of carboxylation among several other factors that govern the plant growth. CLM5.0 does not have post fire vegetation succession.

Line 316: Why Southeast Asia showed such high (much higher than Amazon and Africa) negative sensitivity to temperature? Please explain the underlying reason.

Response: We performed the sensitivity analysis of other carbon cycle fluxes such as GPP (Fig 2.2), Autotrophic respiration (RA: Fig 2.3), and Heterotrophic respiration (RH: Fig 2.4) to temperature. Comparison of these sensitivities for regions of Amazon (AMZ) and Southeast Asia (SEA) show that:

- Rate of increase of negative temperature sensitivity to GPP and RA increased at a high rate in SEA compared to AMZ or other regions from 1850 till 2100. However, AMZ and SEA have similar GPP sensitivity to temperature towards the end of the 21st century.
- The difference of RH sensitivity to temperature between AMZ and SEA was about 150 GgC/month.°C which is large and results in larger negative NBP sensitivity to temperature for SEA than AMZ.

Our results are consistent with the findings of Pan et al. (2020), which investigated the NPP and RH sensitivity to temperature across SREX regions and found that SEA had the highest NPP and RH sensitivity to the temperature.

Your comment highlights an important point and we have revised our manuscript to add additional discussions [Tracked Changes: lines 333-338 or text below].

The negative sensitivity values gradually increased from -20 GgC/month.°C to -33 GgC/month.°C for CAM, and -30 GgC/month.°C to -70GgC/month.°C for AMZ during 1850-2100. South-East Asia (SEA) saw the highest negative NBP sensitivity of -207 GgC/month.°C to temperature by the end of the 21st century. The possible reasons for the large difference in the NBP sensitivity for the region of SEA compared to other tropical regions, e.g. AMZ, are the higher rate of decline in GPP sensitivity to temperature and the highest heterotrophic respiration (RH) sensitivity to temperature of about 90 GgC/month.°C for the region of SEA. Our findings were consistent with Pan et al. (2020), who analyzed seven Terrestrial Biosphere Models and found that the region of SEA had the largest negative NPP sensitivity and positive RH sensitivity to temperature.

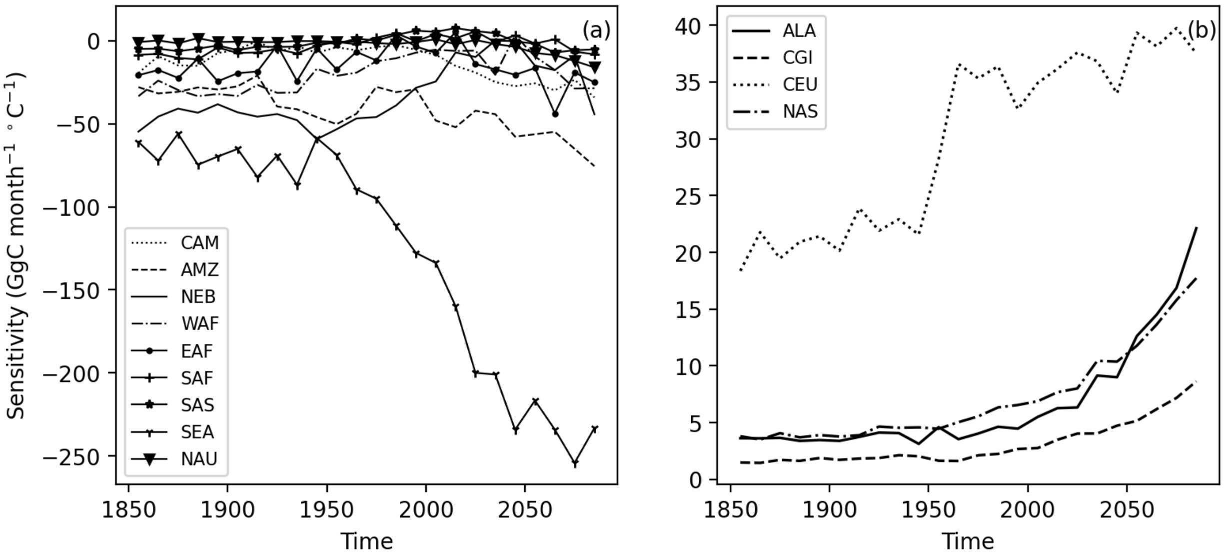

Fig 1.1: Temperature Sensitivity to NBP

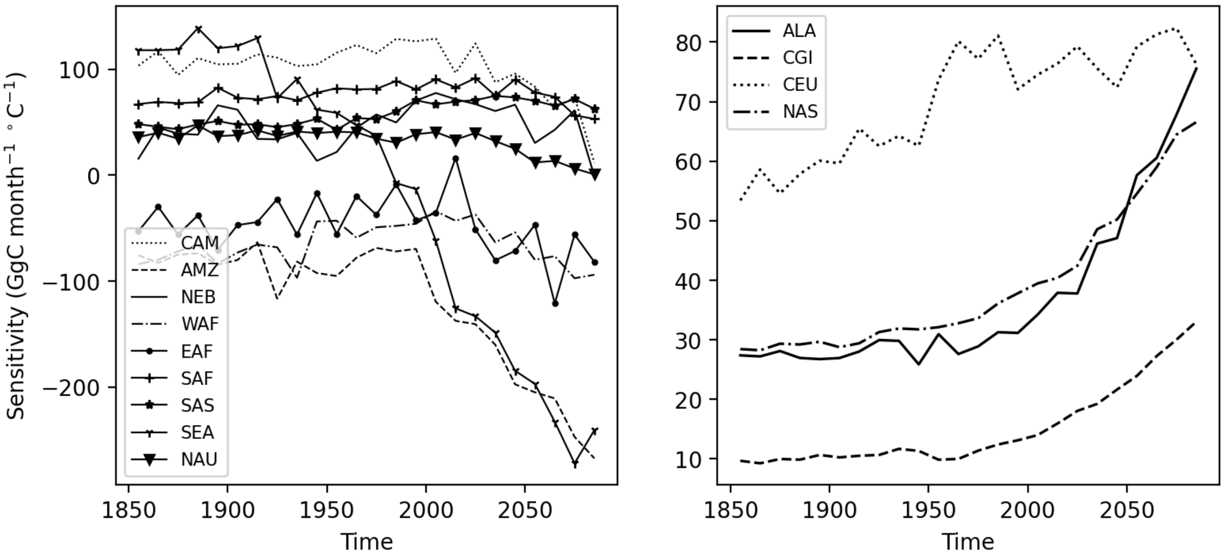

Fig 1.2: Temperature Sensitivity to GPP

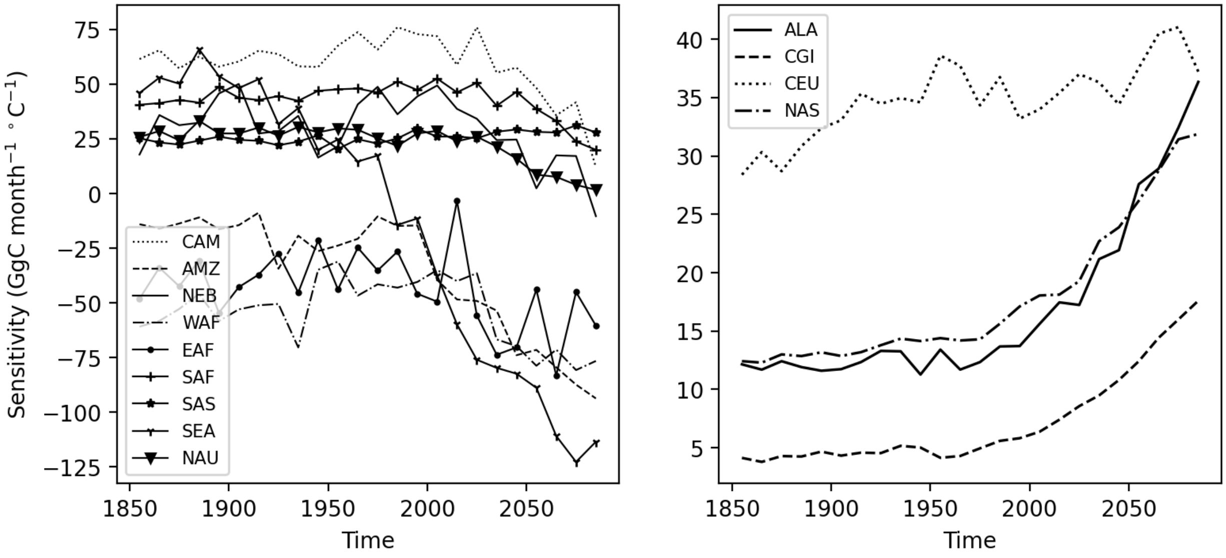

Fig 1.3: Temperature Sensitivity to RA

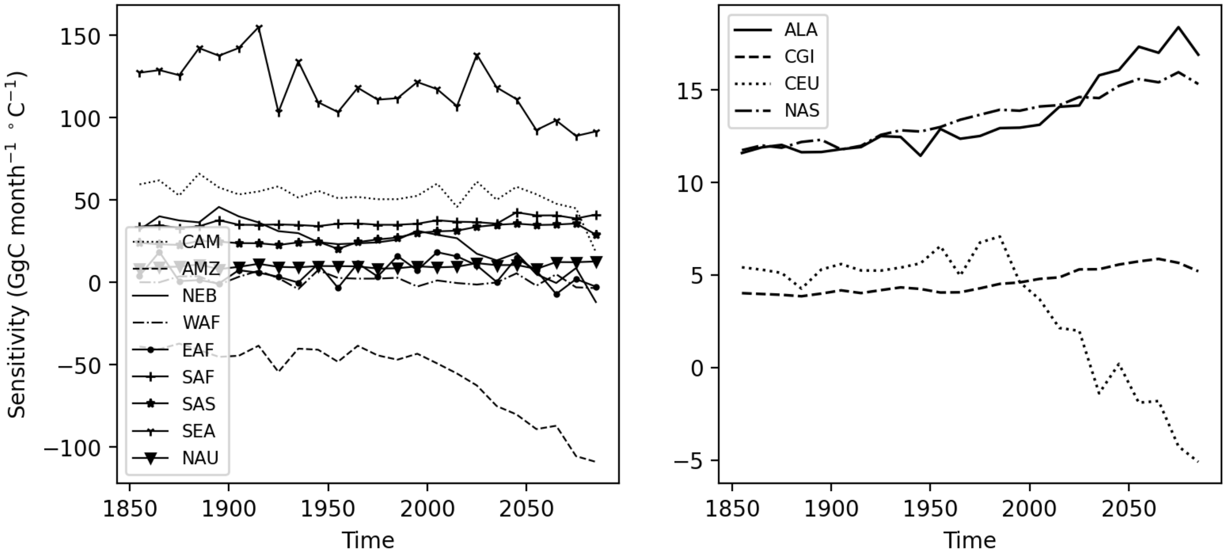

Fig 1.4: Temperature Sensitivity to RH

References:

Lawrence, D. M., Fisher, R. A., Koven, C. D., Oleson, K. W., Swenson, S. C., Vertenstein, M., et al. (2018). Technical Description of version 5.0 of the Community Land Model (CLM). February 2018. https://www.cesm.ucar.edu/models/cesm2/land/CLM50_Tech_Note.pdf

Lawrence, D. M., Fisher, R. A., Koven, C. D., Oleson, K. W., Swenson, S. C., Bonan, G., et al. (2019). The Community Land Model version 5: Description of new features, benchmarking, and impact of forcing uncertainty. Journal of Advances in Modeling Earth Systems, 11, 4245– 4287. https://doi.org/10.1029/2018MS001583

Pan, S., Yang, J., Tian, H., Shi, H., Chang, J., Ciais, P., et al. (2020). Climate extreme versus carbon extreme: Responses of terrestrial carbon fluxes to temperature and precipitation. Journal of Geophysical Research: Biogeosciences, 125, e2019JG005252 https://doi.org/10.1029/2019JG005252

Schwalm, C.R.; Glendon, S.; Duffy, P.B. RCP8.5 tracks cumulative CO2 emissions. Proc. Natl. Acad. Sci. USA 2020, 117, 19656–19657. https://doi.org/10.1073/pnas.2007117117.

Luis M. Abadie, Luke P. Jackson, Elisa Sainz de Murieta, Svetlana Jevrejeva, Ibon Galarraga, Comparing urban coastal flood risk in 136 cities under two alternative sea-level projections: RCP 8.5 and an expert opinion-based high-end scenario, Ocean & Coastal Management, Volume 193, 2020, 105249, ISSN 0964-5691, https://doi.org/10.1016/j.ocecoaman.2020.105249.

Trugman, A. T., Medvigy, D., Mankin, J. S., & Anderegg, W. R. L. (2018). Soil moisture stress as a major driver of carbon cycle uncertainty. Geophysical Research Letters, 45, 6495– 6503. https://doi.org/10.1029/2018GL078131

Chang-Kyun Park, Hi-Ryong Byun, Ravinesh Deo, Bo-Ra Lee, Drought prediction till 2100 under RCP 8.5 climate change scenarios for Korea, Journal of Hydrology, Volume 526, 2015, Pages 221-230, ISSN 0022-1694, https://doi.org/10.1016/j.jhydrol.2014.10.043.