Response to Community Reviewer: Irina Melnikova (with the inputs of co-authors of Melnikova et al. (2021))

The authors explore carbon cycle feedbacks under an idealized 1%CO2-CDR overshoot scenario using an intermediate complexity model UVic ESCM and introduce a novel approach that uses zero emissions simulations to reduce the climate system inertia when quantifying feedback parameters during the ramp-down period.

I and other co-authors of a closely-related study (Melnikova et al., 2021, hereafter M21) would like to draw the authors' attention to our study as it may have been overlooked when the authors say:
L85: "Our study complements the only existing study on ocean carbon cycle feedbacks under negative emissions (Schwinger & Tjiputra, 2018) by exploring the behaviour of these feedbacks on land."

- *We thank the reviewers for bringing this to our attention. We will include this paper in our background section, and potentially, our discussion section based on relevance to our results.*

It would be interesting to see a comparison of the analysis of the carbon cycle feedbacks under the idealized 1%CO2-CDR scenario with SSP5-3.4-OS scenario, and I would be pleased to provide the data if the authors are interested.

- *We thank the reviewers for sharing SSP5 data with us. Indeed, an analysis of that nature would be interesting. For this paper, however, our goal is to compare magnitudes of carbon cycle feedbacks under positive and negative emissions, and we prefer to focus this on an idealized scenario that allows us to separately quantify carbon cycle feedbacks under positive and negative* CO_2 *emissions.*

Particularly, in M21 (section "4.2. The Peaks of Land and Ocean Carbon Uptakes"), we discuss the balance between GPP and TER that could be useful for the proposed analysis by the authors on balance between NPP and soil respiration.

- *We will review that section and include any insights we gain to our paper.*

Most importantly, the conclusions of this new study sound somewhat opposite to the conclusions of M21 where we stated that: "The carbon cycle feedback parameters amplify after the CO2 concentration and temperature peaks … so that land and ocean absorb more carbon per unit change in the atmospheric CO2 change (stronger negative feedback) and lose more carbon per unit temperature change (stronger positive feedback) compared to if the feedbacks stayed unchanged". In contrast, the study by Chimuka et al. concludes on a "reduced carbon loss due to the concentration-carbon feedback and reduced carbon gain due to the climate-carbon feedback."

I am curious about what drove the discrepancy in the conclusions and encourage the authors to add some discussion that could be useful for the scientific community and could prevent any confusion about the conclusions.

While I am not sure for the reasons that drove the discrepancy, I speculate it could be (i) the methodology used to calculate the feedback parameters (i.e., in this study, "Feedbacks under negative emissions are computed at the return to preindustrial levels (end of ramp-down phase) using changes in carbon pools, atmospheric CO2 concentration, and surface air temperature computed relative to the time of peak atmospheric CO2", while M21 computed them relative to piControl). In fact, for our M21 analysis we considered using (1) piControl, (2) time of CO2 and temperature peaks, and (3) "new equilibrium state" at the end of the simulation. However, we chose (1) because using (2) in the more "realistic" SSP scenario would result in too small values of ΔCO2 and temperature during most part of the ramp-down phase, resulting in ill-defined quantities. Besides, UVic ESCM shows no lag between the peaks of CO2 concentration and global surface temperature but it is not the case in some of the more complex models (e.g., Boucher et al., 2012, shows a lag of temperature peak over the ocean; in M21, the lag of temperature peak is up to 30 years, depending on the ESM). The discrepancy in conclusions of the two studies could also be due to (ii) the proposed method to remove the impact of climate inertia by using additional zero-emission simulations. Finally, (iii) the discrepancy could root in the difference between the idealized 1%CO2-CDR and SSP5-3.4-OS scenarios (e.g., due to scenario dependency of feedback parameters). I suggest adding discussion on this matter, especially in terms of the implications of translating the conclusions from the idealized scenarios to the more socially-relevant ones.

- *We thank the reviewers for their comments. Indeed, the differences in our conclusions could cause confusion if not clarified. The main reason for the discrepancy in our view is the methodology, as the reviewers have stated. We chose to compute our feedback parameters under negative emissions relative to the time of peak CO_2 concentration. We initially considered computing the feedbacks relative to preindustrial (closer to the approach used in M21), but encountered an issue with the concentration-carbon feedback parameter. The concentration-carbon feedback parameter* (β) *is computed as:*

$$[3.3.1] \quad \beta_L = \frac{\Delta C_L}{\Delta C_A} \qquad [3.4.1] \quad \beta_O = \frac{\Delta C_o}{\Delta C_A}$$

  Under negative emissions, the CO_2 concentration declines, making the denominator smaller and smaller, leading to β *showing exponential behaviour. Therefore, towards the end of the ramp-up phase,* β *becomes less of a representation of the land and ocean sensitivity to CO_2 changes, as this signal becomes obscured by the exponential behaviour. We found* β *under negative emissions to be more meaningful when computed relative to the time of peak CO_2 concentration.*
- *We would also like to clarify that there are two separate conclusions based on our two research questions:*
    - *In the first approach, we compare the magnitudes of carbon cycle feedbacks under positive and negative emissions, and find that **both feedback parameters***

***are smaller under negative emissions** due to climate system inertia. Here is where we conclude that, with climate system inertia effects, there will be <u>reduced carbon loss due to the concentration-carbon feedback and reduced carbon gain due to the climate-carbon feedback.</u>*

- *If we compute carbon cycle feedbacks under negative emissions relative to preindustrial (closer to the approach used in M21), we find that the magnitude of both feedbacks is larger in the ramp-down phase, consistent with the findings in M21. The caveat here, as mentioned before, is that the magnitude of the concentration-carbon feedback parameter becomes increasingly driven by exponential behaviour as the CO_2 concentration declines.*

- *We then proceed in the second approach, to adjust the magnitude of carbon cycle feedbacks under negative emissions by isolating the response to negative emissions alone, so that they can be more comparable to those under positive emissions. Here, we find that the **concentration-carbon feedback parameter is still smaller under negative emissions as compared to positive emissions**, but now larger than before the correction was done. **The climate-carbon feedback parameter is larger under negative emissions than under positive emissions**, and is also now larger than before the correction was done. Here, is where we conclude that, using uncorrected feedback parameters could be risky because it results in <u>an underestimation of carbon loss under negative emissions and an overestimation of the carbon gain</u>, and given that the latter feedback is more dominant, <u>an overall underestimation of carbon loss under negative emissions and an overestimation of the effectiveness of negative emissions</u>.*

- *We agree that the next step should be to quantify carbon cycle feedbacks in policy-relevant scenarios. Here we use the CDR-reversibility scenario for the methodological reasons given in the response to the previous comment, and for consistency with the literature on carbon cycle feedbacks under positive emissions which uses the 1%/year scenario (Arora et al., 2020). We will include in the supplement feedback parameters at twice the preindustrial CO_2 concentration ($2xCO_2$), which are more relevant, in terms of atmospheric CO_2 levels and warming, for real-world mitigation scenarios.*

<u>References</u>

Arora, V. K., Katavouta, A., Williams, R. G., Jones, C. D., Brovkin, V., Friedlingstein, P. ... Ziehn, T. (2020). Carbon-concentration and carbon-climate feedbacks in CMIP6 models, and their comparison to CMIP5 models. Biogeosciences, 17, 4173-4222. https://doi.org/10.5194/bg-17-4173-2020

Other comments

1. L341: "Surface air temperature remains relatively constant in the BGC mode. In the FULL mode, the land switches into a source of carbon after missions cease, consistent with the behaviour of the UVic ESCM in the Zero Emissions Commitment Model Intercomparison Project (ZECMIP)"

Yes, but there is a variety of responses among models in ZECMIP. The UVic's behavior in ZECMIP is somewhat different from the majority of models (see figures 2.d and 3.a of MacDougall et al 2020). Could some discussion be added?

We agree that the UVic response is different from most other models in ZECMIP. We do not treat this here because analyzing the reasons for differences in ZEC between models is beyond the scope of our paper, but we will include a few sentences stating this difference in our discussion section.

2. Also, we would appreciate seeing a comparison of the 'standard' β and γ (under 1%CO2 experiments) by UVic to the CMIP6 ensemble in a table or figure to get a better idea of where this version of UVic stands.

   We have included a comparison of the feedback parameters we computed to those from CMIP5 and CMIP6 in Table S1 and included a discussion in Lines 417-424.

3. L426: "Models without a nitrogen cycle exhibit greater land carbon gain under positive emissions relative to other CMIP5 and CMIP6 models, that is, the concentration-carbon feedback parameter is more positive (Table S2). They also exhibit greater carbon loss under positive emissions, that is, the climate-carbon feedback parameter is more negative."

   I am concerned that the authors ignore that the climate-carbon feedback may be both positive (i.e., amplifying climate change) and negative in the colder regions.

   *We thank the reviewers for their comment. We would like to first to clarify that we compute carbon cycle feedbacks at the global scale, and therefore, the magnitudes and signs are for the overall feedback. In addition, the signs we refer to in our paper are not the signs of the feedback i.e., negative (positive) feedback parameter ≠ negative (positive) feedback; they are instead the signs of the feedback parameters, which are generally opposite to the sign of the feedback because our feedback parameters are from the perspective of the land and ocean (see **Table 1**). We will clarify this in the text.*

4. L12: "This study investigates land carbon cycle feedbacks under positive and negative CO2 emissions using an Earth system model"

   The fact that UVic is not an ESM but EMIC should be made clear throughout the manuscript

   We have clarified this in the text.

I hope these comments are useful.

Irina Melnikova, with the inputs of co-authors of Melnikova et al. (2021)

We thank the reviewers for taking time to review our manuscript and providing such a useful and constructive review.