Response to Anonymous Referee #1

The authors present a new approach to quantify the land carbon cycle feedback under negative CO_2 emission. The UVic ESCM, an Earth system model of intermediate complexity (EMIC), is utilized to conduct the CDR-reversibility experiment, where the model is driven by 1-percent ramp-up and ramp-down of atmospheric CO_2 concentration. With the C4MIP-type setup of BGC and RAD, where only the biogeochemical and radiation effects are included in the model in order to separate the CO_2 concentration effect and climate effect, the carbon cycle feedback parameters of land and ocean are quantified for the ramp-up and ramp-down phases respectively. The authors further conduct the emission-driven Zeroemit experiments, which stop the emission and have the carbon cycle freely evolving. The results are again used to calculate the feedback parameters. By comparing the feedback parameters calculated from the ramp-down phase and Zeroemit experiments, the effects of climate inertia are isolated, and the resulting feedback parameters of negative emissions are then closer to that of positive emissions.

The manuscript is well-written and clearly structured. The results are also nicely presented.

We thank the reviewer for taking time to review our manuscript, and for their positive feedback.

There are only some issues remain to be clarified in the manuscript. Please see below for my comments.

1. I have some issues with the terminologies used in the manuscript. For example, in the first research questions raised by the authors, the magnitudes of carbon cycle feedbacks under negative and positive emissions are to be compared. However, it is answered in the manuscript that the feedbacks are different because of the climate inertia after the ramp-up phase. However, under a paleoclimate or future climate change context, negative emission does not necessarily immediately follow a ramp-up phase as in the CDR-reversibility experiments.

    - *We thank the reviewer for their comments. We recognize that in the real world, negative emissions are unlikely to follow a ramp-up phase. In future emissions scenarios consistent with our climate targets, the ramp-up phase is followed by a zero emissions phase (Rogelj et al., 2018). Future emissions scenarios with net-negative emissions typically include several different phases (Rogelj et al., 2018), all of which elicit different system responses (Jones et al., 2016; MacDougall et al., 2020). For example, the first Shared Socioeconomic Pathway (SSP1) includes (1) a positive emissions phase with increasing emissions, (2) a net-positive emissions phase with decreasing emissions (possibly with carbon removals compensating some positive emissions), (3) a zero emissions phase, and (4) a net-negative emissions phase (Rogelj et al., 2018). Understanding carbon cycle feedbacks under negative emissions directly from these scenarios would be difficult because climate system inertia will likely make it difficult to disentangle the responses to each phase. As a result, we selected an idealized simulation that allows us to independently analyze the response to negative emissions. Our approach is similar to that taken in CMIP6; the 1%/yr scenario may be idealized,* *but its simplicity allows for better understanding of carbon cycle feedbacks without confounding model-related factors (Arora et al., 2020).*

<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

Jones, C. D., Ciais, J., Davis, S. J., Friedlingstein, P., Gasser, T., Peters, G. P. ... Wiltshire, A. (2016). Simulating the Earth System response to negative emissions. Environ. Res. Lett., 11, 095012.

MacDougall, A. H., Frölicher, T. L., Jones, C. D., Rogelj, J., Matthews, H. D., Zickfeld, K. … Ziehn, T. (2020). Is there warming in the pipeline? A multi-model analysis of zero emissions commitment of CO_2. Biogeosciences, 17, 2987 – 3016. https://doi.org/10.5194/bg-17-2987-2020

Rogelj, J., Popp, A., Calvin, K. V., Luderer, G., Emmerling, J., Gernaat, D., ... Tavoni, M. (2018). Scenarios towards limiting global mean temperature increase below 1.5 °C. Nature Climate Change, 8(2), 325–332. https://doi.org/10.1038/s41558-017-0064-y

2. While the results of the current study is helpful for understanding the climate system, it would be better if implications can be drawn connected to current climate change and possible future scenarios corresponding to our climate targets.

- *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 have included 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.*

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<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

3. The authors are encouraged to further connect the results of the current study more to the context of some of the following studies:
    a. Jeltsch-Thömmes, A., Stocker, T. F., & Joos, F. (2020). Hysteresis of the Earth system under positive and negative CO_2 emissions. Environmental Research Letters, 15(12), 124026. https://doi.org/10.1088/1748-9326/abc4af
    b. Koven, C. D., Arora, V. K., Cadule, P., Fisher, R. A., Jones, C. D., Lawrence, D. M., Lewis, J., Lindsay, K., Mathesius, S., Meinshausen, M., Mills, M., Nicholls, Z., Sanderson, B. M., Séférian, R., Swart, N. C., Wieder, W. R., and Zickfeld, K.: Multicentury dynamics of the climate and carbon cycle under both high and net negative emissions scenarios, Earth Syst. Dynam., 13, 885–909, https://doi.org/10.5194/esd-13-885-2022, 2022.
    c. MacDougall, A. H.: Estimated effect of the permafrost carbon feedback on the zero emissions commitment to climate change, Biogeosciences, 18, 4937–4952, https://doi.org/10.5194/bg-18-4937-2021, 2021.

    We thank the reviewer for these literature suggestions. We have updated our introduction and results sections accordingly.

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4. Minor comments:
    a. The authors are encouraged to provide some insights of what the differences might be between using a comprehensive Earth system model and an EMIC as UVic.

    We have stated this in the discussion section.

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    b. L12: UVic is not an Earth system model. I would prefer to always specify out that UVic is an EMIC.

    Done.

    c. L13-L14: The carbon cycle feedbacks differ in ramp-up and ramp-down phases, not because the difference between positive and negative emission, but because the climate inertia, as mentioned in the manuscript.

    We have rephrased those sentences to make this more clear.

    d. L125-L129: How long is the Zeroemit simulation? Additionally, it is not mentioned in the manuscript at which time point the feedback parameters are calculated.

    e. *We thank the reviewer for pointing this out. The Zeroemit simulation is 500 years long, and we take the difference between the negative emissions phase (year 141 – 280) and the first 140 years of the Zeroemit simulation for each of the biogeochemically and radiatively coupled simulations. We have now included this information in Section 2.2: Model Simulations and Section 2.3: Approaches to Feedback Quantification.*

f. L301-L305: I would expect at which time point the feedback parameters are calculated should already be presented in Section 2.

g. *We agree. We have moved that paragraph to Section 2.4: Carbon Cycle Feedback Framework for Quantifying Feedbacks.*

h. L353: Figure 7 caption: Should be (e) soil carbon change and (f) ocean carbon change. The meaning of All is not explained.

The "ALL" label refers to the fact that all three modes (fully coupled, biogeochemically coupled and radiatively coupled) are initialized from the same simulation: the ramp-up phase of the CDR-reversibility simulation. We have clarified this in the figure caption.

i. L368-L371: The sentence could be rewritten to made simpler

We thank the reviewer for pointing this out. We have rephrase this sentence.

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Response to Anonymous Referee #2

Authors quantify carbon-concentration and carbon-climate feedback for negative emissions for an idealized scenario and compare the magnitude of these feedbacks for the positive emissions part of an idealized scenario. The manuscript is relatively well written and in principle it all makes sense. However, I would suggest improving the manuscript in the following ways.

Please include equations in the main text that should clarify your methodology (where you subtract the effect of zero emissions run on quantities considered during the rampdown phase). If a picture is worth 500 words, an equation is worth at least 200 words.
In the absence of the equations, it is difficult to understand your methodology

- *We thank the reviewer for their comments and positive feedback. We agree that including equations for our proposed approach would make our methodology easier to follow. We have included the equations for our proposed approach in Section 2.4.1: Isolating the Response to Negative Emissions (Ramp-down – Zeroemit Approach) in the main text.*

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Please introduce your sign notation in the beginning and then use it consistently throughout the manuscript. Recall that carbon-concentration feedback is negative from the atmosphere's perspective because it reduces atmospheric CO2 If you use the term "when carbon is gained" then please clarify explicitly which component is gaining carbon - land/ocean or the atmosphere.

Near lines 308-313, I was confused with the sign notation even more because it seems, as you interpret it, sign notation reverses during the ramp-down phase. This needs to be better explained because I am unable to understand why sign notation reversal is needed. If carbon-concentration feedback is negative from an atmosphere's perspective (let's say a value of -1.0 Pg C/ppm) this implies that an increase in atmospheric CO2 concentration will be reduced from its initial amount due to this negative feedback. The corollary of this is that if atmospheric CO2 is reducing then the change in CO2 is negative (say -2 ppm) which when multiplied by -1.0 Pg C/ppm yields +2.0 Pg C implying 2 Pg C is added to the atmosphere. All this makes sense in my mind. So why is reversal of sign notation needed?

- *We thank the reviewer for highlighting this – we will address both comments here. We agree that the concentration-carbon feedback remains a negative feedback under negative emissions. Likewise, the climate-carbon feedback remains a positive feedback. What changes here is* ***the meaning of the sign of the feedback parameters****. The concentration-carbon feedback parameter is calculated by rearranging equations 3.3 and 3.4 for the land and ocean respectively. Hence, the equations are then expressed 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 positive emissions, CO_2 concentration increases (positive denominator) and both the land and ocean gain carbon (positive numerator) resulting in a positive feedback parameter for both land and ocean. Under positive emissions, a positive β_L and β_O is associated with land and ocean carbon gain. Under negative emissions, when both numerator and denominator decrease, β_L and β_O remain positive as the reviewer correctly stated, but now, a positive feedback parameter is associated with land and ocean carbon loss.*
- *We also agree that the phrase "carbon is gained" is unclear, and we have clarified all instances of "carbon is gained" and "carbon is lost" with where it is gained or lost from.*
- *Lastly, we have added a paragraph in Section 2.4: Carbon Cycle Feedback Framework introducing the sign convention and clarifying the meaning of the sign of the feedback parameters under positive and negative emissions, and hence, the reversal of the sign convention.*
- *We also added the two equations above to the carbon cycle feedback framework, which we have moved to Section 2.4: Carbon Cycle Feedback Framework in the main text (Equations 3b, 4b, 5b, and 6b).*

I would also like to note that feedback parameters are most "realistic" or "relevant" when found using FULL and BGC runs. The real world operates like a fully-coupled simulation. For finding feedback parameters in addition to FULL we need a BGC or RAD simulation. Since the carbon-concentration feedback is the dominant feedback perhaps it makes more sense to use the BGC simulation.

- *We agree that feedback parameters are more realistic calculated using the FULL-BGC approach. We include feedback parameters calculated from this approach in Table 1 (shown in parentheses) as well as the relevant land, ocean, vegetation and soil carbon changes in Figure S5 of the supplement.*
- *We find that the feedback parameters from the FULL-BCG approach are qualitatively consistent with those from the RAD approach: the magnitude of the climate-carbon feedback parameters calculated from both approaches is smaller under negative emissions than under positive emissions. Moreover, we find that results are easier to interpret in our proposed approach with feedback parameters computed using the RAD approach rather than the FULL-BGC approach. In the latter case, we would need to subtract the difference between FULL and BGC zero emissions simulations from the difference between the FULL and BGC CDR-reversibility ramp-down phases. This double difference would make it difficult to make sense of the resulting feedback parameters.*

Finally, my last major comment is that when in the real world we do ramp down emissions then, at that point in time, the land and ocean C cycles won't be in equilibrium with the atmospheric CO2. There will be inertia in the real system, and the response of land and ocean at the time will be affected by this inertia. So is the purpose of attempting to correct the feedback parameters for this inertia on the ramp-down side only to compare them with their ramp-up counterparts?

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- *Yes, that is correct. Since the feedback parameters under negative emissions include land and ocean responses to both the negative emissions and prior positive emissions, we isolate the response to the negative emissions alone by using zero emissions simulations, bringing the feedback parameters closer to the "true" sensitivity of land and ocean carbon under negative emissions.*

Minor comments

1. I realize the purpose of Figure 1 is to clarify things but for me text for easier to follow. Perhaps you can try to improve Figure 1.

We have revised Figure 1.

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2. Line 107, "generates permafrost". Please reword this sentence. I think it is incorrect to say "generate permafrost". Permafrost is a state which results from sub-zero temperatures.

Done.

3. Lines 145-152 need equations to clarify the methodology used.

As previously mentioned, we have included the equations for our proposed approach in Section 2.4.1: Isolating the Response to Negative Emissions (Ramp-down – Zeroemit Approach) in the main text.

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Deleted: *the carbon cycle feedback framework (including all equations) in Section A of the supplement to Section 2: Methodology of the main text to clarify Lines 145-152*

4. Line 172. "This temperature change is driven by biophysical responses to increasing CO2". Please add another sentence of explanation at the end of this sentence for completeness.

We thank the reviewer for highlighting this. The temperature change in the BGC mode is driven by changes in evaporative fluxes. We have included a sentence explaining this.

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5. Please put a zero line in Figures 3c,d,e,f, and Figures 4a,b.

We have added the zero line to those figures as well as Figures 6 and 7c-f

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6. Lines 258-261 read " … except in the vegetation carbon pool where the width of the hysteresis increases throughout the simulation (figure 5(c)). The land and ocean carbon pools in the RAD mode also exhibit hysteresis (figure 6). The hysteresis in the land carbon pool is dominated by the soil carbon pool (figure 5(d)), and the width of the hysteresis appears to increase throughout the simulation for all carbon pools except the vegetation carbon, which shows nearly constant hysteresis".

I am confused here. Please reword clearly. Hysteresis is defined as the difference in paths going up and down. Isn't hysteresis zero at the point of turn? With this in mind please reword the above sentences.

We agree with this definition and agree that hysteresis should be 0 at the point of turn. We have changed the phrase "… the width of the hysteresis appears to increase ***throughout the simulation*** *for all carbon pools …" to "… the width of the hysteresis appears to increase* ***throughout the ramp-down phase*** *for all carbon pools …" to make this clearer*

7. Lines 273-274 read "The ocean holds only 70PgC less than at preindustrial, but unlike the land carbon pool, a miniscule amount of ocean carbon is regained in the rampdown phase (figure 5d)".

But Figure 5d is the soil C figure. Please refer to the correct figure.

We thank the reviewer for pointing out this error. We corrected the figure reference.

Line 308 reads "For positive emissions, feedback parameters are positive (negative) for a gain (loss) of carbon". Please consider not using sentences that use pair of parentheses to note two points. This can get very confusing. Also, please clarify whether the gain or loss is by which component – land/ocean or the atmosphere.

Done.

9. Line 309 reads " … resulting in a negative denominator (see supplementary equations 3.3 – 3.6)".
There is no denominator in these equations. I think I know what's implied here but it may not be obvious to other readers.

As previously mentioned, we have added the two equations above to the carbon cycle feedback framework, which we have moved to Section 2.4: Carbon Cycle Feedback Framework for Quantifying Feedbacks in the main text to make this point clearer (Equations 3b, 4b, 5b, and 6b).

10. Lines 308 – 313. Please use equations here because the sign convention is becoming confusing.

As mentioned above, we have added a paragraph in Section 2.4: Carbon Cycle Feedback Framework introducing the sign convention and clarifying the meaning of the sign of the feedback parameters under positive and negative emissions, and hence, the reversal of the sign convention.

11. Comparison of Figure 5a and S4a shows there's more hysteresis in BGC run than in the FULL run. Can this be explained? Isn't this a good reason to use the FULL simulation to find feedback parameters on the ramp-up and ramp-down portions?

Although we find the difference in hysteresis between the FULL and BGC modes very interesting, we do not explore or explain this further because reversibility is beyond the scope of our study. In addition, assuming you mean using the FULL-BGC approach for computing the climate-carbon feedback in the two phases, conclusions drawn from feedback parameters

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Deleted: *We will address both comments 9 and 10 here. As mentioned in our response to the second major comment above, we will add the two equations above for β (along with those for γ) to our carbon cycle feedback framework in our supplement as a visual reference and to help readers understand the sign convention.*

computed from the FULL-BGC and RAD approaches are consistent in our study (see response to last major comment).

12. What does "All" means in Figure 7a legend?

The "ALL" label refers to the fact that all three modes (fully coupled, biogeochemically coupled and radiatively coupled) are initialized from the same simulation: the ramp-up phase of the CDR-reversibility simulation. We have clarified this in the figure caption.

13. Zero emissions runs were initialized from the end of ramp-up. What does BGC and RAD mean for these runs? Do the RAD and BGC runs in Figure 7, see and not see temperature change, respectively, relative to end of the ramp-up or relative to the preindustrial state? Please clarify.

As the RAD and BGC runs are initialized from the end of the ramp-up phase, they see and do not see temperature change relative to the end of the ramp-up. Therefore, in the RAD run, the land and ocean see changes in temperature, but see CO_2 concentration fixed at four times the preindustrial CO_2 concentration (~1120ppm). In the BGC run, the land and ocean see changes in CO_2 concentration, but the radiation code remains fixed at four times the preindustrial CO_2 concentration. We have clarified this in the text

14. Lines 375-377 read "Under negative emissions, the magnitudes of b[eta] and g[amma] from our novel approach are larger compared to those from the "CDRreversibility" simulation WHEN RAMPING UP (CORRECT?), implying greater carbon loss due to the concentration-carbon feedback and greater carbon gain due to the climatecarbon feedback under negative emissions".
"Greater carbon loss" and "greater carbon gain" for what component – land/ocean or atmosphere?

Here, we are referring to magnitudes of carbon cycle feedback parameters under negative emissions i.e., in the ramp-down phase. Therefore, we are comparing the feedback parameters from the ramp-down phase of the CDR-reversibility simulation to those from our "ramp-down – zeroemit" approach (the ramp-down of the CDR-reversibility simulation minus zero emissions simulation). We also include an example of this with values of feedback parameters that reads, "For example, a decrease in atmospheric CO_2 of one ppm would result in the loss of 0.68 PgC of land carbon in the standard approach and 0.80 PgC of land carbon in our approach due to changes in CO_2 concentration alone, whereas, cooling by one degree, would result in land carbon gain of 56.4 PgC in the standard approach and almost three times as much (157.1 PgC) in our approach due to changes in climate alone." Finally, "greater carbon loss" and "greater carbon gain" refers to the land and ocean components; we have clarified this in all instances in the manuscript.

15. Lines 383-384 read "… due to the concentration-carbon feedback, carbon pools take up carbon in the ramp-up phase, continue to take up carbon in the early ramp-down phase."
Actually, it's the other way around. Carbon pools don't behave according to the feedbacks

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but rather feedbacks are derived from the behavior of the C pools. Please consider rewording.

16. Next two sentences …
"Due to the climate-carbon feedback, carbon pools lose carbon in the ramp-up phase, continue to lose carbon in the ramp-down phase, then switch into carbon sinks"

"… suggesting that land and ocean carbon changes due to carbon cycle feedbacks …"
Here too, please consider rewording.

We thank the reviewer for their comments. We have reworded all sentences with this wording throughout the manuscript.

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17. Lines 404-405 read " … we subtract the zero emissions simulations from the "CDR reversibility"
simulations …".
Please use equations to show how.

As previously mentioned, we have included the equations for our proposed approach in Section 2.4.1: Isolating the Response to Negative Emissions (Ramp-down – Zeroemit Approach) in the main text.

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18. Lines 427-428 read "… concentration-carbon feedback parameter is more positive (Table S2)".
Please clarify if this is from the land's perspective. Please use a single notation consistently.

This is from the land's perspective. We say, "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)."*

19. Lines 428-429 read … "They [i.e. land models with N cycle] also exhibit greater carbon loss under positive emissions, that is, the climate-carbon feedback parameter is more negative".

This seems incorrect. Note that land models with N cycle typically have a smaller absolute magnitude of carbon-climate feedback because increase in temperature promotes vegetation growth due to enhanced N mineralization which somewhat compensates for increased soil C respiratory losses.

*We thank the reviewer for their comment. Here, we are referring to models without a N cycle, by saying, "****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."*

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20. Lines 433 – 435 read "With the consideration of nitrogen limitation, the already weakened CO2 fertilization effect under declining CO2 concentrations would be further constrained, exacerbating the carbon loss due to the concentration-carbon feedback".
This seems like a bit of speculation. Why would this be? It could be the other way around too. If increasing CO2 causes C:N ratios to increase and constrain photosynthesis, more than the case when the N cycle is not represented, then decreasing CO2 should lower C:N ratio and help vegetation photosynthesize a bit more (compared to when the N cycle is not represented).
Of course, overall photosynthesis will still be reducing since CO2 is going down but off the top of my head it's difficult for me to imagine the effect of N cycle when CO2 is reducing.

Perhaps is prudent to not speculate.

We thank the reviewer for bringing this to our attention. We had only considered the impact of nitrogen limitation on the CO_2 fertilization effect. We have also consider C:N ratios and instead of making a definitive statement of the effect of the N cycle, we have suggested both as potential responses

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21. Finally, what is the CDR-reversibility simulation? Does this refer to both the ramp-up and ramp-down portions or just the ramp-down portion? Note that the ramp-up portion already has a standard experiment name i.e. 1pctCO2. Please clarify this in the beginning and then use the correct terminology throughout the rest of the manuscript

This is correct. The CDR-reversibility simulation is the combination of the ramp-up and ramp-down simulation. We say, "To explore how the magnitude of carbon cycle feedbacks under positive emissions differs from that under negative emissions, we ran the "CDR-reversibility" simulation from the Carbon Dioxide Removal Model Intercomparison Project (CDRMIP) (Keller et al., 2018). Starting from a preindustrial equilibrium state, atmospheric CO_2 concentration was prescribed to increase at 1% per year until quadrupling, then decline back to preindustrial levels at the same rate." We also chose to refer to it as the CDR-reversibility ramp-up phase as opposed to "1pctCO2"as we find it clearer which portion of the CDR-reversibility we are referring to. We will make sure to use consistent terminology throughout the manuscript.

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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 have included this paper in our introduction and results sections.*

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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 have reviewed that section and included insights gained in our introduction.*

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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 generally smaller under negative emissions*** *due to climate system inertia.*

Here is where we conclude that, with climate system inertia effects, there will be reduced land and ocean carbon loss due to changes in atmospheric CO_2 concentration alone (concentration-carbon feedback) and reduced land carbon gain due to changes in climate alone (climate-carbon feedback) compared to what is expected using feedback parameters from the positive emissions phase. The ocean's response to climate change is the exception as there is increased carbon loss to the atmosphere compared to what is expected using the feedback parameter from the positive emissions phase.

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- 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 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 an underestimation of carbon loss under negative emissions and an underestimation of carbon gain, and given that the concentration-carbon feedback is more dominant, an overall underestimation of carbon loss under negative emissions and an overestimation of the effectiveness of negative emissions.

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- 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 have included 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.

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References

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 have included 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 some discussion in our discussion section.

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 under positive emissions because our feedback parameters are from the perspective of the land and ocean (see **Table 1**). We have clarified this in the text in Section 2.4: Carbon Cycle Feedback Framework.*

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

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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.