Response to Anonymous Referee #1

The authors present a new approach to quantify the land carbon cycle feedback under negative CO2 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 CO2 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 CO2 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).

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

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 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.*

    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

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 will assess the relevance of each paper to our study and update our background and discussion sections accordingly.

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 will discuss this briefly in the discussion section.

    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 2.3: Approaches to Feedback Quantification.*

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 will rephrase this sentence.