Review for Carbon Cycle and Climate Feedback under CO_2 and non-CO_2 Overshoot Pathways by Melnikova et al., submitted to Earth Systems Dynamics (EGUsphere)

This study compares the climate and carbon cycle response to equivalent CO_2 and non-CO_2 forcings using a set of idealized concentration-driven simulations. The authors find that the climate-carbon feedback is dominant under non-CO_2 forcing whereas both the carbon-concentration and climate-carbon feedbacks are important under the CO_2 forcing. Under both CO_2 and non-CO_2 forcings, the land and ocean carbon uptake due to both feedbacks is quantified along with a cross term i.e., a term that quantifies the response to climate change in the presence of CO_2 concentration.

The manuscript reads well – the introduction and methods are written clearly and are easy to follow. My main concern is that the paper does not provide enough background to help the reader understand the results, particularly with regards to the meaning and calculation of the cross term, which is discussed at length in the results section. I suggest an expansion of the introduction section to include: (1) more background on previous non-linearity studies (2) and studies that previously quantified the cross term (if any). Furthermore, an addition to the methods section of: (1) the carbon cycle feedback framework (β, γ) and (2) the meaning of the cross term and how it is calculated under CO_2 and non-CO_2 forcing.

A few minor comments are included below:

Minor comments

L19: I suggest using the term 'climate-carbon cycle feedback' instead of temperature-driven feedback, since that is the terminology most used in the field.

L20: Is this sentence correct? From my understanding, the CO_2 forcing drives both carbon cycle feedbacks through changes in CO_2 concentration and temperature, whereas the non-CO_2 forcing drives the climate carbon cycle feedback only through changes in temperature. Please clarify.

L38: Acronym 'GHG' not introduced - I suggest writing greenhouse gas in full here.

L50: Please specify which forcing components were included in the Richardson et al. (2019) study. If the study included the response to CO_2 and non-CO_2 forcing, I suggest briefly discussing the results from this study in your introduction section, and if possible, comparing these results to your results in your discussion section.

L58: This may be a good point to link non-CO_2 forcing to the climate-carbon cycle feedback. Non-CO_2 forcing induces warming => capacity of the land and ocean sinks reduces => atmospheric CO_2 concentration and temperature affected. It may also help to explain why the non-CO_2 concentration-carbon feedback is not relevant.

L60: It may help readers to preface this paragraph with a brief description of how the two carbon cycle feedbacks work under increasing and decreasing CO_2 concentrations. This will make it easier to understand L62 where you state the results from your Melnikova et al. (2021) study.

L69-71: This sentence is too long. For clarity, please separate the two research questions using (1) and (2) or a semi-colon.

L81: Please clarify which climate factors you are referring to here.

L120: From my understanding of the table format, experiments are above the horizontal line, while combinations of experiments are below the horizontal line. This is why I am surprised that the [CO2bgc+non-CO2] experiment is above the line. Is this an experiment or an addition of two separately run experiments? If it is indeed an experiment, then I assume you prescribed both CO_2 forcing and non-CO_2 forcings, then specified the piControl CO_2 concentration in the radiation code? If so, that would mean that the only warming seen in that experiment would be CO_2 physiological warming, so how then can non-CO_2 γ be included in this experiment? Please clarify.

On the same note, is the additional combination [CO2bgc+non-CO2]-[CO2bgc] necessary? It looks like we could get at non-CO2 γ by taking the difference between [CO2+non-CO2] and [CO2] and this would give the cross term as well. Is there a benefit to using [CO2bgc+non-CO2]-[CO2bgc] over [CO2+non-CO2]-[CO2]?

In the 4th column, the first two combinations of experiments seem to be missing the ΔU_{γ} components.

Figure 1: I would like to commend the authors on this figure – it complements the methods section very nicely.

L146: Section 3.1 assumes that readers have a solid grasp of the carbon cycle feedback framework and the feedback parameters (β, γ) used, which may not be the case. I suggest prefacing this section with a brief description of carbon cycle feedback parameters (equations for quantification, units and sign convention) before introducing ΔU.

L184: I suggest citing Zickfeld et al. (2011) here.

Figure 2: Is the last column of panels on Figure 2 necessary? I notice that these figures are hardly referenced.

Also, I suggest using a different colour for either the CO_2 or CO_2bgc lines? The two are compared several times in the text but the colours are difficult to distinguish on the figure panels.

L219: What is the reason for the higher sensitivity to non-CO_2 forcing than CO_2 forcing?

L262: It appears that the figure in the paper referenced – Chimuka et al. (2023) – shows little hysteresis in autotrophic respiration and GPP, and not in heterotrophic respiration as mentioned in the text.

L283-284: Are there merits to attributing the cross term to γ rather than keeping it as a separate term?