

This is a review of the manuscript entitled “Asymmetry in carbon cycle feedbacks and transient climate response under positive and negative CO₂ emissions” by Rachel Chimuka and Kirsten Zickfeld. The authors aim to quantify asymmetries in the land and ocean carbon feedbacks and TCRE/TCRR, and test their initial state and rate dependency. They firstly look at the symmetry in response to positive emissions on a 1pctCO₂ trajectory from 2 to 3xCO₂ and the response to negative emissions from 2 to 1xCO₂ (PI). They find that there are asymmetries in the feedback parameters and TCRE and attribute those to the land/ocean processes underlying the changes in carbon inventories and the atmospheric fraction as well as climate sensitivity.

The paper is well written and clear in its methodology and results layout. The approach is novel and UVic provides a testbed to assess its usefulness. To that extent I do not have major comments. I would like to highlight a few points, some of which the authors already address, perhaps a little in passing, so I would welcome some comments on those points.

We thank the reviewer for the positive feedback.

The UVic model and its low-complexity structure with regards to the atmospheric component is casting some uncertainty at how much these results are robust and generalizable. Some missing processes here with regards to the physical climate, e.g. storm track representation, biases in air-sea fluxes, overly stable AMOC, etc make in the sensitivity of the feedback parameters to changes in the climate somewhat uncertain. I would like to know what the feedback parameters & TCRE are in this model compared to the CMIP6/5 ensemble.

We thank the reviewer for this important note. Unlike the feedback parameters computed from CMIP5 and CMIP6 ensemble, our feedback parameters are computed from the 2xCO₂ equilibrium state, and therefore, are not directly comparable because feedbacks are state-dependent. We have, however, in previous work used the same version of the model to compute feedbacks from simulations initialized from a preindustrial state, and compared these metrics to those from CMIP5 and CMIP6 (Chimuka et al., 2023). We have included the table from that paper below. We find that our feedback parameters are generally situated well within the CMIP5 and CMIP6 ranges.

Table 1: Comparison of carbon cycle feedback parameters from the ramp-up phase of the “CDR-reversibility” experiment to CMIP5 and CMIP6 model means and mean±1 standard deviations from Figures 5, 6 and Table 1 in Arora et al. (2020), calculated at the time atmospheric CO₂ concentration quadruples (4xCO₂) and doubles (2xCO₂) respectively. Model means and mean±1 standard deviations for models without a nitrogen cycle are shown in parentheses. Feedback parameters were calculated using the FULL -BGC approach (see Eq. 7), consistent with the BGC-COU (T*=0) approach used in calculating feedback parameters in CMIP5 and CMIP6. Note that there is a small discrepancy with the BGC-COU approach used to calculate the values in Table A1 of Arora et al., 2020, which allows for T*≠0.

Feedback Parameters (taken at 4xCO ₂)	“CDR-reversibility” ramp up	CMIP5	CMIP6

β_L (PgC ppm ⁻¹)	0.96	0.91 ± 0.48 (1.2 ± 0.3)	0.96 ± 0.39 (1.2 ± 0.5)
β_O (PgC ppm ⁻¹)	0.88	0.81 ± 0.07	0.78 ± 0.07
γ_L (PgC °C ⁻¹)	-121.5	-54.7 ± 36 (-75.4 ± 23.9)	-42.7 ± 47.2 (-63.8 ± 70.5)
γ_O (PgC °C ⁻¹)	-22.7	-16.3 ± 3.5	-16.4 ± 4.6
Feedback Parameters (taken at 2xCO₂)	“CDR-reversibility” ramp up	CMIP5	CMIP6
β_L (PgC ppm ⁻¹)	1.27	1.15 ± 0.63	1.22 ± 0.40
β_O (PgC ppm ⁻¹)	0.99	0.95 ± 0.07	0.91 ± 0.09
γ_L (PgC °C ⁻¹)	-83.5	-37.01 ± 25.48	-34.1 ± 38.39
γ_O (PgC °C ⁻¹)	-3.30	-9.42 ± 2.70	-8.59 ± 2.9

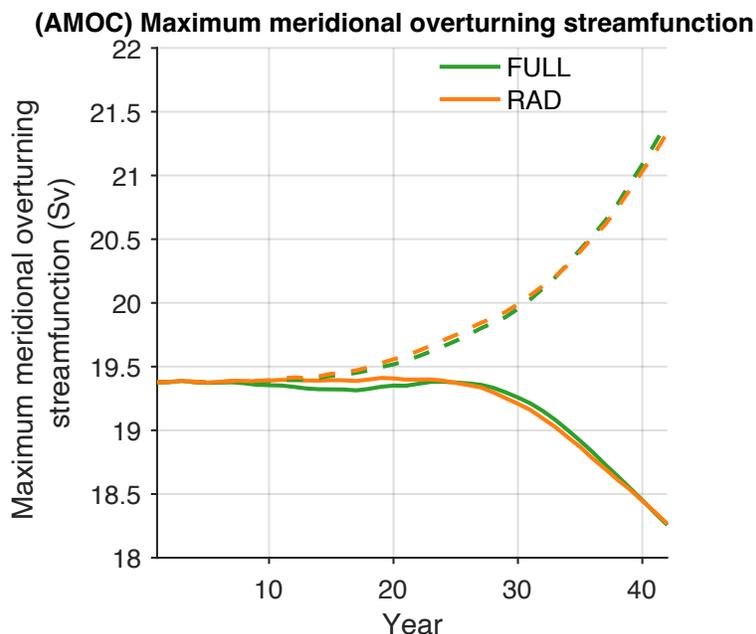
I also wonder how the relative significance of β and γ estimates under fast or slow warming rate as shown in Fig. 5 would compare given the spread of these Arora et al 2020 Fig. 5 -even though they are computed at different levels). In other words, the rate-dependency (especially for the climate-carbon feedback) may not be conclusive if the spread of all the CMIP6 models is considered. Perhaps in subsequent applications of this framework the 3 to 4xCO₂ pathway is chosen to make this comparison more straight forward with, say Arora 2020.

Similarly, a future application of this framework could be to start the esm-flat10-conc simulations from PI to 1000PgC to make the comparison with temperature and land/ocean carbon responses comparable to other models that performed the flat10 simulations (as in Sanderson et al 2025).

We thank the reviewer for these comments and respond to both comments below. This is an important consideration and underscores the importance of multi-model analyses to better assess uncertainty in the rate-dependence results. We opted to initialize simulations from the 2xCO₂ equilibrium state in our framework, so that our negative emissions simulation would span a CO₂ concentration range relevant to present day and ensure numerical stability. However, before we ran flat10 simulations from 2xCO₂, we ran flat10 simulations from preindustrial with this version of the UVic ESCM, and ensured consistency with results from Sanderson et al. (2025).

I am somewhat perplexed about the AMOC in Fig. S1.2. First, maybe a more conventional notation can be used, such as 18Sv rather than $1.8 \times 10^{-7} \text{ m}^3/\text{s}$.

Corrected.



Secondly, it seems that at $2x\text{CO}_2$ equilibrium, the AMOC is quite strong. I suppose it weakened with prior emissions (if I judge from the response to subsequent positive emissions) but recovered during the equilibration period? While this makes sense, I am wondering if that maybe masking the response to positive emissions. Typically, the air-sea flux of CO_2 saturates somewhere between 2 and $3x\text{CO}_2$ forcing on the 1pct scenario (at least in most models), but if the ocean is left to equilibrate, is the air-sea flux further reduced during the equilibration period? Maybe that is why the ocean sink changes so much slower than the land sink in Fig. 3b and picks up again as the AMOC responds to positive emissions (delayed response compared to the negative emissions). The ocean resists taking up more carbon but gives it up easier.

We thank the reviewer for this comment. During the $2x\text{CO}_2$ spinup, the AMOC weakens until it stabilizes at a weaker intensity and the air-sea flux declines until it stabilizes around 0 PgC yr^{-1} . From our state-dependence analysis, we see that the higher the initial state, the smaller the magnitude of the asymmetry for beta. The non-linearity in the buffer capacity results in the ocean losing carbon easier than it takes it up, as the reviewer states, and this non-linearity becomes less nuanced with higher initial states.

It should be noted also, that equilibrated simulations at high levels of CO_2 are difficult to do in ESMs, due to computational cost, if that framework were to be adopted. And that brings me to my last comment.

If mitigation is to occur, it will probably happen on a transient trajectory rather on an equilibrated trajectory (as in the simulations here). How do we translate the responses of an equilibrated system to those of a transient system which experiences negative emissions. I understand the framework needs equilibrium states to produce “clean” feedback parameters, free from the system’s inertia, but we will have to account for this in the actual system’s response to CDR, for example. Perhaps using this framework in conjunction with Chimuka 2023? Some discussion on these last two points would be very helpful.

*We agree that negative emissions will likely be applied from a transient state as in the CDR-reversibility simulation, for instance. Our goal with designing the experiment was to quantify symmetry, that is, determine whether feedbacks under positive emissions would be of equal magnitude and opposite sign to those under negative emissions, which, as the reviewer stated, required “clean” feedback parameters, free of climate system inertia effects. However, we can see the importance of building on previous frameworks, especially when the previous framework (Chimuka et al. 2023) is easier to reproduce in ESMs. We have, therefore, expanded the discussion comparing this framework to that from Chimuka et al. (2023) to highlight the differences between the two frameworks, and highlight what we learn from this new approach. Furthermore, we also compare our ramp-down experiments to a 1% yr⁻¹ ramp-up from preindustrial to 2xCO₂ and have included an additional section **3.4: An Alternative Experimental Design for Quantifying Carbon Cycle Feedback and TCRE Asymmetry** based on this experimental design. Overall, we find that the magnitude of carbon cycle feedback asymmetry is smaller in this experimental design. This arises because temperature change is more symmetric and the range of CO₂ concentrations in both trajectories is the same. The sign of the TCRE is consistent with the main experimental design, whereas the sign of the carbon cycle feedback asymmetry is positive for land feedbacks and negative for ocean feedbacks.*

Overall, I think this is an important contribution that aims to untangle the system’s responses to positive and negative emissions, TCRE and TCRR.

We thank the reviewer for this positive comment.

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