

Response to the Reviewer 1

General Comment

The study quantifies 1) the efficiency of a continuous global application ocean alkalinity enhancement using several metrics, 2) the subsequent response of the global carbon fluxes, and 3) the long-term potential of OAE to mitigate ocean acidification. The authors used an Earth System Model to simulate three atmospheric temperature stabilization scenarios to year 2500. For each scenario, five realizations with and five realizations without OAE were produced in order to quantify the direct response of the system to OAE, and to quantify the impact of climate feedbacks.

Results indicate that OAE efficiency estimated with the metric that accounts for climate feedbacks is much lower than the maximum potential efficiency only based on carbonate chemistry. The authors rightly discuss in which circumstances one metric should be favoured than the other. The study also shows that in centennial timescales, under continuous global deployment of TA, it is the reduction in atmospheric CO₂ the main driver of acidification mitigation, while the impact of OAE itself is less prominent. This is a relevant message given that ocean acidification mitigation is typically presented as a beneficial side-effect of OAE deployment.

The manuscript is mostly clearly written and the messages are relevant and worth publishing. Some comments and suggestions below:

Response:

We thank the reviewer for the positive assessment and the constructive suggestions to further improve the manuscript. Detailed replies to each specific comment follow below.

Specific Comments

1. The authors acknowledge in their caveats section that the CO₂ emissions related to producing the alkaline material need to be taken into account in future studies. I would suggest bringing this caveat earlier in the manuscript (maybe in the setting of the simulations). Should the reader interpret that the production of alkaline material in this idealized framework does not produce further emissions?

Response: We agree and have clarified this earlier in the manuscript. We now state in the method section: "Additional CO₂ emissions due to the OAE intervention, associated with the mining, processing, and transport of alkaline materials or solutions (*Foteinis et al., 2022*) are not included in this study." We additionally added a clarifying sentence in the definition of the net ocean capture efficiency: "Different to how net efficiency is defined here, this term sometimes also refers to the OAE efficiency including life-cycle emissions (*Foteinis et al., 2022; Delval et al., 2025; Katish et al., 2026*)."

2. Please clarify in which way a continuous global alkalinity addition “approximates” discrete OAE pulses. Please elaborate on the broad shared characteristics mentioned in L470-471. With the experiments presented, is it possible to state that the climate and carbon cycle responses will be similar with continuous global vs discrete OAE pulses?

Response: Based on our understanding, we believe that the response of global carbon cycle feedbacks guiding the net ocean capture efficiency, as also shown by *Tyka* (2025), and the ocean acidification response show the same characteristics for individual OAE pulses, and hence also the large-scale climate response. However, we acknowledge, that we can not state this based on our data and since another reviewer raised the same point, we now refrain from making this rather speculative statement. We now just say: “Continuous addition is likely feasible at specific coastal sites, such as industrial water outlets (*Wang et al.*, 2023; *Burt et al.*, 2024) and continuous alkalinity addition may well approximate the alkalinity release from frequent individual pulses necessary for OAE at scale.”

L25: Ongoing mitigation efforts such as?

L25: I agree that emissions reductions remain inadequate but not despite ongoing mitigation efforts, as these two are different activities. Please consider rephrasing.

Response: Thank you for pointing that out. We have rephrased it to: “Ongoing efforts to reduce emissions remain inadequate and global temperatures are now on track to exceed the 1.5 °C threshold of the Paris Agreement in the next decade.”

L105-106: Please clarify the difference between the observed CO₂ emissions for the 1861-2005 period and the observed CO₂ emissions from 2005 to 2020.

Response: We have clarified that historical emissions follow the CMIP5 protocol and are extended with observed emissions for 2006-2020: “After an initial spin-up (*Burger et al.*, 2020), an emission-driven historical simulation was performed over the period 1861 to 2005, which follows fossil fuel and land-use change CO₂ emissions as well as prescribed non-CO₂ radiative forcing agents from the CMIP5 protocol. This simulation was continued for 20 simulation years in which fossil fuel CO₂ emissions followed observed emissions until 2020 and national determined contributions until 2025 (*Friedlingstein et al.*, 2020; *Silvy et al.*, 2024).”

L108: is “current” the right word here? Or maybe “the warming level for the corresponding period”?

Response: We have changed it to: “The pathway is recalculated every five years based on updated estimates of global mean temperature and the remaining CO₂-forcing-equivalent emission budget at the time of the stocktake.”

L114-116: the CO₂ emissions followed for the CDRMIP protocol do not account for any CO₂ produced during the production of TA. If this is correct, please state it here.

Response: That is true, we have added this sentence here: “Additional CO₂ emissions due to the OAE intervention, associated with the mining, processing, and transport of alkaline materials or solutions (*Foteinis et al.*, 2022) are not included in this study.”

L155, Equation 2. the fluxes from which simulation were removed from which other simulation? For the same ensemble? Or from the mean? Please include this clarification. Also, are the differences estimated on a year by year basis?

Response: The used simulations are described below the equation: "The nominator represents the additional CO₂ uptake by the ocean in the 'OAE' simulation relative to the reference simulation 'Ref', both following the same emissions trajectory. F_{ALK} denotes the rate of alkalinity addition of 0.14 Pmol yr⁻¹." We have added the following sentence to further clarify: "Efficiencies are calculated for each ensemble member individually and are based on annual mean carbon fluxes."

L220: But considering the ensemble ranges, the peak is only truly different in the 3 deg OAE scenario compared to the REF.

Response: We have clarified the statement recognizing the ensemble range: "The 31-year mean peak atmospheric CO₂ is lower and earlier with OAE than without on the ensemble average, albeit with overlapping ensemble ranges: at 468 ppm [437-488] in year 2059 [2041-2088] in the 1.5 °C scenario, at 546 ppm [524-560] in year 2085 [2076-2097] in the 2 °C scenario and at 689 ppm [677-708] in year 2167 [2158-2178] in the 3 °C scenario."

L245: "opposite sign" was confusing on a first read, as the global warming pattern is not shown. Please rephrase, if possible.

Response: We clarify: "The regional temperature response to global OAE deployment (Fig. C2a-c) closely mirrors the spatial pattern of greenhouse gas-induced warming (c.f. Fig. 4.19 in *Lee et al.* (2021), but with the opposite sign."

L272 and 273: revise the plurals, change "signals" to "signal" and "oceans" to "ocean"

Response: Thanks for the pointer. Changed.

L292 and Figure 7: In Figure 7 the decline in net ocean capture efficiency seems linear and is hard to note the "before and after the peak in atm CO₂". Does it make sense to indicate with a vertical line the timing of the peak atm CO₂ for each scenario? Also because this pre-peak and after peak measure is used in the following paragraphs.

Response: We have added a vertical line indicating the ensemble average year of peak atmospheric CO₂.

L301-303: stronger stratification would be expected in a warming scenario, and therefore shallower mixed layer depths. How is it that the mixed layer depth increases 10 times by 2500?

Response: This is not the depth of the general mixed layer, but a proxy that estimates the vertical distribution of the alkalinity plume over time. Alkalinity is added at the surface and gets vertically distributed by ocean currents and mixing over time. This "effective mixed layer depth" refers to the alkalinity plume and not the normal mixed layer at the ocean surface. We have clarified the sentence explaining this effective mixed-layer depth: "We use the effective mixed layer depth for

OAE from *Zhou et al.* (2024), characterizing the ocean volume under influence of alkalinity addition. Note that this is not the depth of the commonly used wind-driven mixed layer.”

L309: Please include a noun after “This”, maybe “efflux”? Same comment for L316.
L317: both processes? Would not calcification be considered one process?

Response: We have added “efflux” in L309 and adjusted the latter sentences for clarification: “Calcification reduces DIC, allowing for further ocean carbon uptake and increasing efficiency, but also removes alkalinity and thereby decreases efficiency. Overall, calcification leads to a net reduction in efficiency since calcification removes twice as much alkalinity as DIC, leaving a net increase in $p\text{CO}_2$.”

L339: but also the CO₂-driven was extended? It appears so, as the gross efficiency is shown. Please state so.

Response: Yes, it was. We have adjusted the sentence and moved it to the methods section, following reviewer 3: “To investigate the effect of OAE termination on both the efficiencies and the ocean acidification response, we extended one ensemble member of the 2°C OAE simulations to the year 3000, but terminating OAE in 2500, and extended both reference simulations as well.”

L369: “arising”? Or you could also just remove arise altogether.

Response: We have removed “arise”. Thank you.

L411: an end of sentence period is missing after the references.

Response: Done.

Figure 1. If the reference simulations stabilize air temperature without OAE, what do they do?

Response: We have clarified the description to “The reference simulations (Ref) stabilize global surface air temperature at 1.5 °C, 2 °C and 3 °C following the adaptive emission reduction approach and have no ocean alkalinity enhancement (OAE). Corresponding OAE simulations follow the same emission pathways that would lead to stabilization, but include alkalinity enhancement.” The reference simulations follow the adaptive emission reduction approach (see explanation in the methods). And it does negative emissions, if the climate becomes too warm and the carbon budget is exhausted. The spatial emission field is scaled by the adaptive emission reduction approach and when the climate becomes too warm, the emissions turn negative. So you could say it does Direct Air Capture with perfect storage. Both the OAE and the reference simulation have the same emission forcing (Fig. C1) including the negative emissions. We added another sentence to the description of the AERA approach: “If temperatures overshoot, the algorithm responds by prescribing negative emissions.”

Figure 3. The word “anomaly” is missing from the caption in (a).

Response: Added.

Figure 6. if possible, consider including the frame of reference in the caption (e.g., positive means loss from the atmosphere) in the caption.

Response: That is a good point, we have added "Positive indicates additional ocean carbon uptake."

References

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- Zhou, M., M. D. Tyka, D. T. Ho, E. Yankovsky, S. Bachman, T. Nicholas, A. R. Karspeck, and

M. C. Long (2024), Mapping the global variation in the efficiency of ocean alkalinity enhancement for carbon dioxide removal, *Nature Climate Change*, pp. 1–7, doi:10.1038/s41558-024-02179-9.

Response to the Reviewer 2

General Comment

Grosselindemann et al. employ a fully coupled Earth System Model to simulate OAE scenarios from 2026 to 2500 under different warming scenarios (1.5–3 °C), including a baseline simulation, OAE perturbation experiments, and additional decoupling experiments. Following the OAE protocol defined by CDRMIP, the study systematically evaluates carbon sink flux changes under OAE, particularly focusing on the responses of the ocean, and especially the atmosphere and land carbon reservoirs.

The manuscript highlights several key findings:

1. OAE efficiency depends strongly on the evaluation metric. Whether ocean and land feedbacks induced by reductions in atmospheric CO₂ are considered leads to substantial differences in estimated OAE efficiency.
2. Under higher warming scenarios, the OAE-induced reduction in atmospheric CO₂ is larger.
3. OAE leads to a linear reduction in global mean temperature compared with the control.

A major strength of the manuscript is the systematic clarification of four different efficiency metrics for OAE. The study clearly distinguishes these definitions and quantitatively demonstrates their differences. Figures 1 and 7 illustrate these distinctions particularly well. In addition, the OAE 2 °C reference simulation (Ref*) experiment effectively separates the ocean feedback / anomalous outgassing driven by atmospheric feedback, which is crucial for quantitatively understanding how atmospheric responses after OAE can reduce overall OAE efficiency through the ocean and land feedbacks.

Overall, the manuscript is clearly written and presents a complete set of results, providing useful quantitative insights that will serve as a valuable reference for future studies on OAE. I recommend publication.

Response:

We thank the reviewer for the positive assessment and the constructive suggestions to further improve the manuscript. Detailed replies to each specific comment follow below.

Specific Comments

1. Line 355: Regions where efficiency locally exceeds unity are often also regions with high gas transfer velocity (e.g., Zhou et al., 2023). This may suggest that the enhanced local gross uptake results from the combined effects of ocean circulation and locally elevated gas transfer rates.

Response: Thank you very much for raising this point. We have added the following two sentences: " Additionally, these regions exhibit higher gas transfer velocities (Zhou et al., 2023). Therefore, less un-equilibrated alkalinity is transported away from these regions, while incoming un-equilibrated alkalinity can equilibrate faster locally. However, Zhou et al. (2024) show no specifically high efficiency in these regions when alkalinity is only added within the region itself, and Burger et al. (2025) find a strongly increased efficiency in these regions due to resurfacing of alkalinity that was added below the surface in other regions, both indicating that the redistribution of un-equilibrated alkalinity is the dominant process."

Figures 3, 4, 5, 7, 8, 9: It is recommended to add gridlines and minor ticks on the time axis to improve readability.

Response: We have added minor ticks to the time axes in some of the figures to improve readability. However, we opted not to include gridlines, as we find that they reduce visual clarity and make the plots appear overly cluttered.

Figure 9c: The vertical grid line at year 2500 is too similar in color to the background. Please adjust the color to make it more visible.

Response: We have changed the colour to black and slightly increased the line width.

Lines 468–470: The outcomes of continuous OAE deployment and pulse-based OAE deployment are not necessarily equivalent. The studies of Wang et al. (2023) and Burt et al. (2024) do not seem sufficient to support the claim that individual pulses are equivalent to continuous OAE deployment. In addition, the impacts of global-scale deployment and regional deployment of OAE may differ substantially.

Lines 470–471: It is recommended either to add a supporting reference (e.g., Tyka et al., 2025, which suggests that the atmospheric response may be relatively insensitive to OAE deployment scale) or to remove this statement.

Response: The references here are meant to refer to the feasibility of continuous OAE at coastal sites like industrial water outlets and we agree, that they do not properly discuss the similarities between pulse and continuous OAE. Based on our understanding, we believe that the response of global carbon cycle feedbacks guiding the net ocean capture efficiency, as also shown by Tyka (2025), and the ocean acidification response show the same characteristics for individual OAE pulses, and hence also the large-scale climate response. However, we acknowledge, that we can not state this based on our data and since another reviewer raised the same point, we now refrain from making this rather speculative statement. We now just say: "Continuous addition is likely feasible at specific coastal sites, such as industrial water outlets (Wang et al., 2023; Burt et al., 2024) and continuous alkalinity addition may well approximate the alkalinity release from frequent individual pulses necessary for OAE at scale."

References

- Burger, F. A., U. Hofmann Elizondo, H. Grosselindemann, and T. L. Frölicher (2025), Subsurface dissolution reduces the efficiency of mineral-based ocean alkalinity enhancement, *EGUsphere*, pp. 1–27, doi:10.5194/egusphere-2025-5917.
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Response to the Reviewer 3

General Comment

Summary:

This study examines OAE's long-term efficiency and potential to remove CO₂ from the atmosphere by simulating OAE in the GFDL ESM2M model from 2026 until the year 2500 under three different warming scenarios. The simulations show that atmospheric CO₂ drops by 73-130ppm until 2500 with a larger reduction contribution occurring earlier in the simulation and under higher warming scenarios, while SAT tends to decrease nearly linearly over time and independently of the background warming level. This study also goes into detail about different metrics for OAE efficiency and how the chosen metric can influence the narrative and examines the ocean acidification mitigation potential of OAE, which can be traced back primarily to the reduction in atmospheric CO₂ especially over centennial time-scales.

General comments:

The paper is overall of high quality, well structured with high quality figures, addresses relevant scientific questions related to the mCDR method OAE with a state of the art fully-coupled Earth system model and fits the scope of BG. However, the manuscript could be improved by primarily clarifying / adding details in the Methods and Results sections as listed below.

Response: We thank the reviewer for the positive assessment and the constructive suggestions to further improve the manuscript. Detailed replies to each specific comment follow below.

Specific Comments

L106-112: A more detailed description of the AERA would be beneficial here. It is without being familiar with the cited paper unclear how the emission pathways were chosen by the algorithm. Why / how does the algorithm e.g., lead to significantly different time windows for reaching the target temperature? Is a maximum positive / negative CO₂ emission or target year specified?

Response: We have revised the text to clarify how AERA determines emissions pathways and associated timing of reaching the target temperature: " The AERA algorithm determines the emissions pathway by estimating anthropogenic warming, calculating the forcing-equivalent remaining emissions budget for the prescribed warming target using the transient climate response to cumulative CO₂-forcing-equivalent emissions (TCRE-fe), and then distributing the forcing-equivalent emissions budget over future years according to a third-order polynomial that leads to zero emissions. The timing of net-zero emissions, and thus the time window for reaching the target temperature, is an emergent property of the algorithm rather than an externally imposed constraint. If temperatures overshoot, the AERA responds by prescribing negative emissions. The pathway is recalculated every five years based on updated estimates of global mean temperature and the remaining CO₂-forcing-equivalent emission budget at the time of the stocktake (*Terhaar et al., 2022*)."

L206: The results section provides lots of details via numbers, which partly compromises readability and dilutes the key findings. Maybe offloading details mentioned in the text to a new table could be a solution to maintain details and allow for quicker and easier comparison between simulations, while improving text readability.

Response: We appreciate the reviewer's suggestion and agree that the density of numbers can affect readability. Instead of introducing an additional table, we have revised the text to improve clarity by reducing the number of values reported within individual sentences and emphasizing the key findings more clearly. Specifically, we now focus on the most relevant quantitative results in the main text. We chose not to introduce a new table, as this would require frequent cross-referencing between text and tables, which can interrupt the narrative and make it more difficult to follow the interpretation of results. We believe that the revised presentation strikes a better balance between readability and providing sufficient quantitative detail.

L318-319: In the model description the authors mention the possibility of sedimentary calcite shell deposition (L94). In combination with the statement here, it is unclear how much of the added alkalinity via OAE is actually removed from the water column via the ecosystem and enters the sediment.

On that note, the authors mention in the Methods section that the model represents alkalinity well (L99), but don't show a Figure of the background ocean alkalinity inventory and no comparison of how much the inventory changes as a response to the yearly alkalinity addition over time.

Response: We thank the reviewer for highlighting this important point. We have revised the manuscript to clarify the fate of added alkalinity and to better document changes in the ocean alkalinity inventory.

To address the concern regarding alkalinity removal via sedimentary processes, we now explicitly describe how calcification responds to changes in saturation state in the model and how this affects the alkalinity budget. In particular, increased calcification under OAE conditions enhances alkalinity removal from the water column, which is reflected in changes to the internal alkalinity sources and sinks, including sediment interactions.

In addition, we have included a new figure in the Appendix (Fig. C3; also shown below) showing (i) the evolution of the global ocean alkalinity inventory over time, (ii) the additional alkalinity in the ocean in comparison to the amount of alkalinity enhancement and (iii) the combined internal alkalinity sources and sinks, including sedimentary processes. This allows for a direct assessment of how much of the added alkalinity remains in the ocean versus being removed.

We now refer to this figure at several points in the manuscript. At the beginning of Section 'Global carbon flux response', we describe the overall increase in alkalinity inventory due to OAE and its implications for carbon uptake: "Ocean alkalinity enhancement substantially increases the oceans' alkalinity inventory (Fig. C3). The added alkalinity in turn leads to additional ocean carbon uptake and lowers atmospheric CO₂, but part of this drawdown is offset by carbon release from the land biosphere (Fig. 5)." Furthermore, in the section on net ocean capture efficiency, we explicitly link enhanced calcification to a reduction in the effective alkalinity source (Fig. C3c): "In our Earth system model, calcification responds to changes in the calcite and aragonite saturation states and we find more calcification under OAE than in the reference scenarios, leading to an overall reduction in additional alkalinity within the ocean (Fig. C3c)." We also expand the discussion of biogeochemical

feedbacks to clarify that both chemical adjustments and climate-driven responses contribute to reducing the net alkalinity gain, as illustrated by the differences between simulations in Fig. C3c: "Overall, these feedbacks substantially lower the total additional alkalinity in the ocean, where a quite equal part of the reduction comes from chemical changes due to OAE or is related to the reduction in atmospheric CO₂ following OAE (see the difference of OAE and Ref* to Ref in Fig. C3c)."

We believe these additions clarify how alkalinity is redistributed and partially removed within the Earth system, and directly address the reviewer's concern.

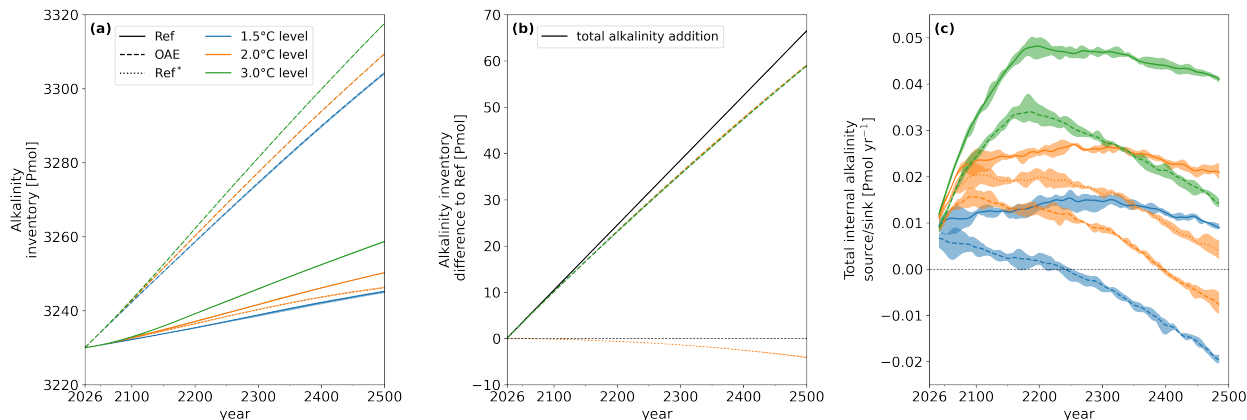


Figure C3. Simulated ocean alkalinity inventories (a), differences in the alkalinity inventory of the OAE and Ref* simulations to the Ref simulation (b) and the sum of all ocean internal alkalinity sources and sinks, including sediment processes (c) for all global warming scenarios with and without OAE. Lines are the five member ensemble mean and shading refers to the ensemble range. Lines in panel (c) are smoothed with a 31-year running mean.

L339-341: This detail should be mentioned in the Methods section and be included in Figure1. Currently, Figure1 is inconsistent with Figures 8-10.

Response: We have adapted Figure 1 and moved the sentence to the end of the "Simulation setup" section, now saying: "To investigate the effect of OAE termination on both the efficiencies and the ocean acidification response, we extended one ensemble member of the 2°C OAE simulations to the year 3000, but terminating OAE in 2500, and extended both reference simulations as well."

Technical Corrections

L30-31: Please add a citation to the statement or rewrite.

Response: We have added a citation here and rephrased it a bit: "Current efforts have largely focused on implementing land-based CDR methods, while ocean-based approaches remain comparatively understudied (*Smith et al., 2024; Boyd et al., 2025*)."

L34: "alkaline materials" - not just materials, but also alkaline solutions, which would actually represent the model OAE implementation much better due to not modelled mineral dissolution processes in the surface ocean, but instantaneous dissolution.

Response: We have clarified: "OAE involves adding alkaline materials, such as olivine or quicklime, or alkaline solutions to seawater to enhance its natural ability to absorb atmospheric CO₂."

L36: 'bicarbonate and carbonate ions ... stable ... for 10000 to 100000 years': This is a bit misleading formulation. First of all bicarbonate and carbonate ions are not conservative tracers, i.e. they are not even stable wrt mixing. More importantly, this quote ignores potential non-stability (or reduced durability) wrt to interactions with CaCO₃ sediments and also wrt to modified terrestrial weathering. While this is often not considered in OAE studies (since they usually focus on centennial timescales) and also not by the paper under consideration, it has been studied by Köhler et al. 2020 (<https://doi.org/10.3389/fclim.2020.575744>) with a box model that can simulate such long time scales. I suggest to rephrase and refer to Köhler's work here.

Response: We thank the reviewer for this important clarification. We agree that the original wording was misleading, as bicarbonate and carbonate ions are not conservative tracers and their long-term persistence is influenced by processes such as CaCO₃ sediment interactions and changes in terrestrial weathering. We have therefore rephrased it to better reflect the timescale dependence and underlying assumptions, and we now explicitly acknowledge these longer-term processes and cite Köhler et al. (2020). The revised text reads: "Through this process, aqueous CO₂ is converted into bicarbonate and carbonate ions, which represent longer-lived forms of inorganic carbon in the ocean on centennial to millennial timescales (*Renforth and Henderson, 2017; Middelburg et al., 2020; National Academies of Sciences, Engineering, and Medicine, 2022; Ho et al., 2023*). On longer timescales, the persistence of the added alkalinity is limited by CaCO₃ sediment interactions and weathering feedbacks (*Köhler, 2020*)."

L43: "CO₂ sequestered" - additional ocean carbon uptake

Response: Changed.

L52: "decrease" - reduce

Response: Changed.

L56/64: 'most modelling studies' (56) vs. 'only a few ... modelling studies' (64), however, in both cases you cite six studies, each - I don't see your rationale for 'most' vs. 'few' here

Response: We thank the reviewer for pointing out this inconsistency. Our original wording ("most" vs. "few") was not sufficiently precise given the similar number of cited studies in both cases and could therefore be misleading. We have revised the text to avoid this ambiguity and now use more neutral and consistent wording. In particular, we rephrased the latter sentence to: "Recently, more fully coupled modelling studies have become available, although the complexity of the models differs. They consistently show that interactions among the atmosphere, ocean, and land biosphere strongly reduce OAE efficiency compared to modelling experiments with prescribed atmospheric CO₂ (*Jeltsch-Thömmes et al., 2024; Schwinger et al., 2024; Tyka, 2025; Wey et al., 2025; Sathyanadh et al., 2025; Nagwekar et al., 2026*)."

L68: Unclear what is meant with "single" Earth system models. Maybe "other" or "previous"?

Response: Changed to "other". Thank you.

L88: Please change to 'It simulates marine and terrestrial anthropogenic carbon uptake ...', to be explicit here. (I assume you refer to both marine and terrestrial uptake and storage.)

Response: Yes, this is correct. We have changed it to: "It simulates the uptake and storage of anthropogenic carbon by the marine and terrestrial carbon sinks close to observations (*Frölicher et al.*, 2015; *Bronse laer et al.*, 2017), and it represents alkalinity well by actively simulating both calcite and aragonite cycling in comparison to other climate models (*Planchat et al.*, 2023)."

L126: Can you please clarify how/weather non-CO₂ GHG forcing was applied in the Ref* simulations.

Response: We have added: "The non-CO₂ forcing is the same as in the OAE and Ref simulations."

L175: 'to reduce atmospheric pCO₂ and therefore global warming', I find this formulation a bit awkward, since in a transient climate warming is related to cumulative emissions (i.e. the TCRE), not the atmospheric pCO₂

Response: We agree that, in a transient framework, global warming is more directly related to cumulative CO₂ emissions (via the TCRE) rather than instantaneous atmospheric CO₂ concentrations. However, we chose to retain the original formulation for clarity, as ocean alkalinity enhancement directly reduces atmospheric CO₂, which in turn affects radiative forcing and thus contributes to limiting warming.

L190-4: I am not really convinced by the name of the term delpH-Hysteresis

Response: We thought about this again and came up with a new description. We now refer to the process as the "equilibrated pH response" and refer to it in the formulas and figures as " $\Delta pH_{equilibrated}$ ". We chose this to also refer to the analogy of equilibrated and un-equilibrated OAE often used in research about the ecosystem impact of OAE and added a description about this in the methods section: "Research about the ecosystem impact of OAE often distinguishes between equilibrated and un-equilibrated OAE (*Hartmann et al.*, 2023). Equilibrated OAE assumes that the alkaline solution added to the ocean has already re-equilibrated with the atmosphere and taken up CO₂ according to the maximum ocean capture efficiency, characterized by the equilibrated pH response. Un-equilibrated OAE assumes that pCO₂ is not yet back to equilibrium with the atmosphere, and the pH response is here characterized by the equilibrated pH response together with the pCO₂ disequilibrium effect (described below)."

L212 / caption Fig. 3: 'air temperature anomalies'

Response: Changed.

Caption Fig. 4: alike: indicate that you show anomalies here

Response: We refrain from adding anomalies here, since it is just the difference between the two simulations, as stated.

L255: 'when global warming is stabilized': sounds as if the warming (carbon-climate feedbacks) is the central point here, but I guess that the decrease in marine CO₂ uptake (rate) is primarily carbon-concentration driven, i.e. related to having negative emissions in Ref

Response: That is a good point, we have rephrased it to be more precise: "In the reference simulations, the total cumulative ocean carbon uptake since pre-industrial increases rapidly initially with increasing CO₂ emissions and slows markedly toward the end of the simulation when emissions reach near-zero or become negative (solid blue lines in Figure 5)."

Fig. 5: Interesting that in this model the land is a net source of carbon until about 2050 in OAE and Ref. Please add a comment on why this behaviour occurs (c-climate vs. c-concentration feedback?) and point to a reference, if this was discussed in a previous paper.

Response: We thank the reviewer for this interesting comment. The negative cumulative land carbon flux in the early period is primarily driven by historical land-use change emissions, which dominate over the land carbon uptake, as shown by *Silvy et al.* (2024). Until around 1970, the land is a net carbon source following land-use change, but a sink thereafter. It takes until 2050 for this initial loss to be compensated by additional land carbon uptake. We have clarified this in the manuscript: "The reduction in atmospheric CO₂ is modulated by anomalous carbon release from the land biosphere. Note that the historical carbon release from land is due to land-use change emissions, which dominate over the land carbon uptake due to increases in atmospheric CO₂ (*Silvy et al.*, 2024)".

L272: "signal(s)" typo

Response: Changed.

L417: "experimental setups" - such as carbon / temperature overshoot scenarios.

Response: Thank you. We now state: "Nevertheless, the robustness of this result remains to be tested across other Earth system models and experimental setups, such as carbon and/or temperature overshoot scenarios."

L436: Please add a comment if this difference is (in)-significant.

Response: We have highlighted the difference but we think a detailed statistical analysis about significance is not necessary here. We do not infer the significance of differences between lines or scenarios throughout the manuscript and we do not see an extra benefit of stating, if the two lines are significantly different or not at the specific time in 2500, further based on defining a significance level and the chosen statistical test. We now say: "In 2500, inventory-based and flux-based efficiency differ by 0.01 units with distinct ensemble ranges."

Figure C2: Please add temperature labels above the three columns similar as done in Figures 4-5.

Response: Good point. We have added it.

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