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.

Burt, W., S. Rackley, R. Izett, J. Vallis, O. Sadoon, G. Rau, M. Melashvili, and T. Cross (2024), Planetary Technologies' Groundbreaking Marine Carbon Dioxide Removal (mCDR) Project in Halifax, and the Emergence of Halifax as a Global mCDR Hub, in *OCEANS 2024 - Halifax*, pp. 1–6, doi:10.1109/OCEANS55160.2024.10754096.

Tyka, M. D. (2025), Efficiency metrics for ocean alkalinity enhancements under responsive and prescribed atmospheric pCO_2 conditions, *Biogeosciences*, *22*(1), 341–353, doi:10.5194/bg-22-341-2025.

Wang, H., D. J. Pilcher, K. A. Kearney, J. N. Cross, O. M. Shugart, M. D. Eisaman, and B. R.

Carter (2023), Simulated Impact of Ocean Alkalinity Enhancement on Atmospheric CO_2 Removal in the Bering Sea, *Earth's Future*, *11* (1), e2022EF002,816, doi:10.1029/2022EF002816.

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.

Zhou, X., B. Reichl, L. Romero, and L. Deike (2023), A Sea State Dependent Gas Transfer Velocity for CO2 Unifying Theory, Model, and Field Data, *Earth and Space Science*, *10*, doi:10.1029/2023EA003237.