

General summary:

The authors investigate the potential impacts of Ocean Alkalinity Enhancement (OAE) on the Earth system by incorporating carbonate chemistry dependencies into the phytoplankton growth term within an Earth system model (ESM). They perform multiple ESM simulations to assess the environmental impacts of OAE, with particular emphasis on ecosystem responses. This approach highlights the importance of accounting for biological feedback when evaluating geoengineering strategies such as OAE.

This is a timely and important contribution to the fields of climate change and geoengineering. I recommend publication of this work after the authors address the concerns outlined below.

We thank Wentai Zhang for this positive feedback and the constructive comments which will help us to improve our manuscript. We will carefully address each of the comments. Changes and additions to the text are highlighted in bold.

Comments:

Line 20: Please add a reference to support the statement “Efforts...”

We will rephrase this sentence to not give more weight to ocean-based than to land-based approaches, and add two references to highlight the increasing across-sector attention towards marine CDR technologies (the best practice guide for ocean alkalinity enhancement, Oschlies et al., 2023, and a recently published blue paper on principles for responsible and effective CDR development and governance, Doney et al. 2025):

“Because terrestrial CDR technologies are often limited by competition for area (Fuss et al., 2014; Boysen et al., 2017; Friedlingstein et al., 2019), **marine CDR technologies attract increasing attention (Oschlies et al., 2023; Doney et al., 2025).**”

Line 40: I suggest deleting the phrase “, although it was identified as a major risk” to improve clarity and conciseness.

Although OAE is mentioned as a potential ecological risk in Fennel et al. (2023) which is cited in the relevant sentence, this is not a main outcome of their study and we will delete the phrase as suggested by the reviewer.

Line 45: Consider changing the word “minimal” to “little”.

We will change the wording as suggested by the reviewer.

Line 62: The sentence beginning with “In a modeling study, ...” is unclear. Please revise to clarify it.

We agree that the original sentence was very nested. We will rephrase it to:

“For example, a modelling study shows that the addition of nutrients along with alkalinity results in a proliferation of calcifiers, which in turn decreases surface alkalinity and, hence, efficiency relative to a model simulation with the addition of alkalinity alone (Nagwekar et al., 2024).”

Line 70: Please specify which Earth system model was used in this study.

We will rephrase the sentence to:

“In particular, we use **the Alfred Wegener Institute Earth System Model to link** carbonate system changes to phytoplankton growth and calcification, and changes in calcification and calcite dissolution to the OAE efficiency.”

Line 210: I was unable to locate the 16% in Table 1. Please clarify where this number comes from.

We computed the relative difference of the cumulative air-sea CO₂ fluxes between the simulations that are listed in Table 1. For clarification we will add these numbers to the sentence:

“... When accounting for carbonate system effects on phytoplankton, the ocean takes up 11–16% more excess CO₂ than without these effects (**12.6 versus 11.4 Pg C and 26.0 versus 22.4 Pg C, respectively**; Table 1) ...”

Line 221: Instead of ranges or general terms, please provide the exact values here.

We will add the exact numbers for the CSE simulations to the text:

“The biological pCO₂ drawdown is consistently smaller in simulations with OAE than in those without, independent of whether carbonate system effects on phytoplankton growth are represented (**for the CSE simulations: by 22% in the European and US EEZ, by 62% in the Chinese EEZ, and by 5% globally**; p-value<0.05, Fig. 5, Table A3).”

Line 239: The sentence “NPP anomalies globally...” is unclear. Please rephrase.

We agree, the original sentence was not very clear. We will rephrase to:

“**Less pronounced anomalies can be seen on the global scale in the CSE simulations as well as in all NO-CSE simulations, where changes in marine NPP can only be caused by indirect OAE effects such as modifications of the radiative balance, winds, and mixed layer depth.**”

Line 247: The origin of the values “3% vs 97%, 40% vs 58%” is unclear. Please indicate their source or explain how they were derived.

The reviewer is right, these numbers are not indicated in any of the tables in the manuscript as they were derived from a community composition analysis averaged over the last five years prior to the start of the alkalinity deployment. We will add this information to the sentence:

“Enhanced small phytoplankton NPP cannot fully balance the lower diatom NPP because of its smaller contribution to overall NPP (**according to a community analysis in the simulations averaged over five years prior to the alkalinity deployment**, 3% small phytoplankton versus 97% diatoms **contribute to NPP** in the Chinese EEZ, and 40% versus 58% in the US EEZ)”

Line 301: This sentence should be rewritten for clarify. Also, please specify where the associated values can be found in the text or tables.

We will rephrase this sentence to:

“With the motivation to avoid conditions in which abiotic CaCO₃ precipitation could happen, we complemented a CSE-OAE-high simulation in which no alkalinity was added to a grid cell when the saturation state of aragonite exceeded 10 (CSE-OAE-high-lim). **This threshold is only exceeded in the Chinese EEZ, reducing the amount of added alkalinity by up to 4 mol m⁻² year⁻¹ (about 10%) compared to the CSE-OAE-high simulation and dampening the increase in surface alkalinity to 469 mmol m⁻³ (compared to 649 mmol m⁻³ in the CSE-OAE-high simulation).**”

However, as these are the only numbers referring to the amount of added alkalinity as well as surface alkalinity in the CSE-OAE-high-lim simulations, we refrain from adding an extra table and prefer to only mention these numbers in the text.

Figure A4B and A4C: These figures show the difference between modeled alkalinity and observational data. Please revise caption accordingly.

The reviewer is absolutely right, the caption is incorrect. We will revise the caption.

Section 2.3: It would be helpful to include a table summarizing the key details of all simulations conducted in this study.

We will add a summary table for the model simulations to the manuscript.

Figure 2,3, and 4: I recommend revising the captions to first provide an overview that describes the figure as a whole, followed by brief description for each subfigure individually. This will help readers better understand both the overall context and the specific content shown in each panel.

We agree and will add the following overall sentences:

Fig. 2: **“Summary of the alkalinity deployment.”**

Fig. 3: **“OAE effects on atmosphere and ocean carbon.”**

Fig. 4: **“CO₂ fluxes and efficiencies around the alkalinity deployment regions.”**

Please improve the abstract and conclusion section.

We will modify the abstract according to the suggestions of the other reviewer. The conclusion section will be revised entirely to include our key findings as well as details on the type of data needed to improve the parameterization of OAE effects on biology in ocean biogeochemistry models.