The effects of Ocean Alkalinity Enhancement on the atmospheric CO_2 concentrations in the 21st century

CO_2 sequestration potential of OAE by olivine dissolution in the global oceans and the deep and bottom water formation regions

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In Short

- The increase in anthropogenic carbon emission leads to elevated global temperatures; in order to mitigate climate hazards due to this, the rise in temperature should be limited well below 2°C by the end of the 21st century. Hence, active efforts are being made to assess various Carbon Dioxide Removal (CDR) methods. One such method which is the focus of our study is Ocean Alkalinity Enhancement (OAE).
- Oceans play an important role in the global carbon cycle. This is especially true for the subduction regions, where the carbon taken up is transferred from surface to abyssal depths of oceans and is sequestered on multi-decadal and centennial timescale.
- Therefore, we compare the efficiency of OAE with a uniform deposition of olivine (alkalinity, iron, silicic acid) in the global and in the deep and bottom water formation regions of the Southern Ocean, Labrador and Norwegian Sea.
- For this, we carry out model simulations with OAE over the 21st century using the ocean circulation model FESOM2.1, which is coupled to the biogeochemistry model REcoM3.
- All the simulations are carried out on a high resolution mesh (BOLD), which has a resolution (∼10km) in the regions with higher dynamical variability; that is in the Southern Oceans and North Atlantic, where deep and bottom water formation occurs.

The rise in atmospheric CO_2 concentrations due to burning of fossil fuels and land use change leads to elevated global temperature causing detrimental changes in the climate. Without reduction in the carbon emissions, global temperature will exceed the Paris Agreement's 2°C limit. Hence, to limit temperature increases and mitigate climate change, significant carbon emission reductions and exploration of various Carbon Dioxide Removal (CDR) methods are necessary. The ocean is a large carbon reservoir as CO_2 dissolves in and reacts with seawater, and it acts as a sink for anthropogenic CO_2 emissions [1]. The Southern Ocean and the North Atlantic are of critical importance as the formation of intermediate, deep and bottom waters occurs there, which is the bottle-neck of ocean carbon uptake. The subducting water masses in these regions can sequester carbon in the interior ocean on decadal to millennial timescales [1]. Owing to the importance of the oceans in global carbon cycling, we study here the marine-based CDR method Ocean Alkalinity Enhancement (OAE).

In order to carry out the OAE experiments we use the ocean-only setup of global physical-biogeochemical model FESOM2.1-REcoM3. We simulate global and regional OAE with spatially uniform and continuous deposition of olivine (alkalinity, iron, silicic acid) as an alkaline mineral over the 21st (2030-2100) under SSP3-7.0 emission scenario. As in [3], the model simulations for OAE are forced with atmospheric output from the AWI Climate Model. For the global OAE, we deposit 3 Pg olivine per year following [2]. The model simulations will be run on the BOLD mesh (Fig. 1a) [5]. It has an elevated resolution of (∼10 km) in the regions with high dynamical variability like in the subpolar oceans. Owing to this fine resolution, the BOLD mesh can resolve the eddies that are responsible for lateral transport of heat, salt and biogeochemical tracers. Thus, the high-resolution simulations are required for understanding the ocean dynamics in these regions and the impact they can have on the overall efficiency of CO_2 uptake capacity of the ocean in general and in response to OAE in particular.

For regional OAE, we focus on the subduction regions in the Southern Ocean, Labrador and Norwegian Sea as the carbon transfer from surface to abyssal depths of the ocean is the bottle-neck of ocean carbon uptake. The subduction/downwelling regions where olivine will be deposited are identified using the Water Mass Transformation (WMT) framework [3,4]. In the WMT analysis, the surface buoyancy (heat and freshwater) fluxes are decomposed into sea ice and evaporation minus precipitation (E-P) components and their contribution to the transformation of water masses in a given density bin is quantified. Fig. 1b shows the subduction and downwelling regions (red regions) in the Southern Oceans south of 40°S, Labrador (50°N-75°N; 70°W-17°W) and Norwegian Sea (62°N-77°N; 60°E-10°W). The

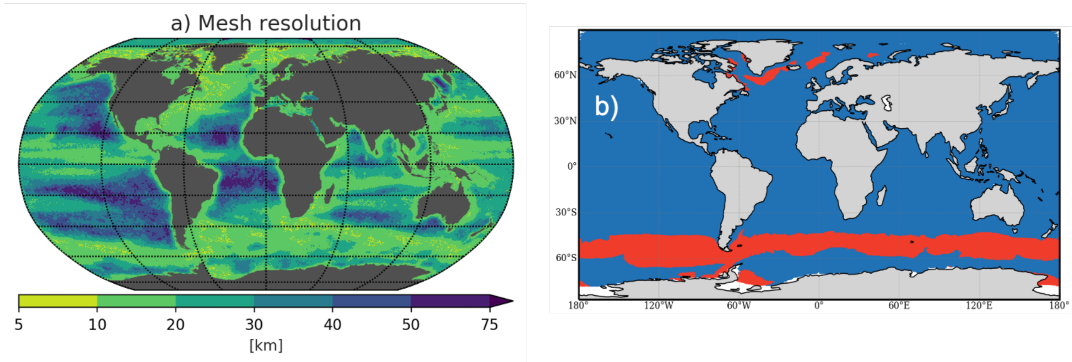

Figure 1: ***a*** *The horizontal grid resolution in km in the BOLD mesh which will be used for the OAE simulations proposed here.* ***b*** *Regional olivine deposition mask. Subduction/downwelling (red) regions are plotted using the isopycnal outcrops obtained from the WMT analysis carried out in the Southern Ocean, Labrador Sea and the Norwegian Sea. Overall, 0.35 Pg olivine per year is deposited using this regional mask.*

isopycnal outcrops (red regions) in Fig. 1b were obtained from the WMT analysis, and they indicate that the waters with density (>36.8 kg m^{-3}) and (<36.2 kg m^{-3} and >35.1 kg m^{-3}) in the Southern Ocean are downwelled/subducted into the ocean interior due to the surface buoyancy fluxes. For the Labrador Sea, subduction occurs in the density bins >35.9 and <34.9 kg m^{-3}. For the Norwegian Sea, it occurs at the densities >36.6 kg m^{-3}. The mask in (Fig. 1b) is used for regional OAE experiments, in which a total of 0.35 Pg olivine per year is deposited uniformly. We used the historical simulation from 1970-1999 for carrying out the WMT analysis.

In the previous project period we completed all the changes to the model code for facilitating OAE experiments. The historical simulation (1950-2014) was completed and we will finish the control run (without olivine addition; 2015-2100) in the current quarter (Q2 2023). In the next project period, we plan to start with our global and regional OAE experiments. Olivine deposition is accompanied by nutrient fertilization due to addition of nutrients like iron and silicic acid, which stimulates phytoplankton growth and thus facilitates additional CO_2 uptake. Hence, in order to differentiate between the contribution of nutrient fertilization and alkalinity enhancement on the oceanic CO_2 uptake, we plan to carry out simulations with and without addition of nutrients in the global case.

The focus of the project is on understanding the efficiency of OAE in subduction regions, and thus the two main experiments are alkalinity enhancement in the subduction regions (mask in Figure . 1b) and in the global ocean. By comparison, the efficiency in the subduction regions can be assessed. The additional nutrient effect will be quantified with one simulation where alkalinity and nutrients are added to the ocean surface. This will be compared to an already conducted simulation on a coarser resolution mesh. This will also allow to estimate the effects of nutrients in the subduction regions, as previous simulations have shown that the nutrient effect is largest in the Southern Ocean.

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More Information

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DFG Subject Area

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