Towards understanding the potential, benefits and risks of CO_2 removal by ocean alkalinity enhancement

Earth System Modelling of Ocean Alkalinity Enhancement in EU Waters

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In Short

- Carbon dioxide removal (CDR) is needed, along with greenhouse gas emission reductions, to limit warming and stabilize the climate.
- We will simulate Ocean Alkalinity Enhancement (OAE) with an Earth system model to assess the efficacy, feasibility, and side effects of using this approach for CDR.
- Proposed experiments investigate the importance of: (a) model resolution, (b) the location of OAE, (c) continuous vs. pulsed OAE, and (d) the climate state during OAE.

Governments worldwide have recognized, via the COP21 Paris Agreement that climate change resulting from human-induced forcing must be limited and most countries have agreed to "hold the increase in the global average temperature to well below 2° C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5° C above pre-industrial levels". Many actions must be taken to achieve this goal. In addition to emission reductions urgently needed to achieve this goal, the IPCC [1] highlighted with high confidence that all projected pathways that limit warming to 1.5° C also require use of carbon dioxide removal (CDR) on the order of 100 to 1000 Gt CO_2 over the 21st century. The majority of pathways that limit warming to 2° C also require use of CDR.

CDR encompass a range of methods aimed at reducing atmospheric CO_2 levels by either seeking to engineer the removal and subsequent storage of CO_2 or by deliberately enhancing land and ocean carbon sinks to increase the removal of CO_2 from the atmosphere. One of the more promising ocean-based approaches is Ocean Alkalinity Enhancement (OAE). The idea behind the approach is that if the alkalinity of the surface ocean is increased, seawater carbonate chemistry causes more CO_2 to dissolve in seawater and be permanently stored as ions such as bicarbonate or carbonate, i.e., the general methodology increases the carbon storage capacity of seawater [2]. Understanding of OAE method potentials, feasibilities, and risks are limited, even

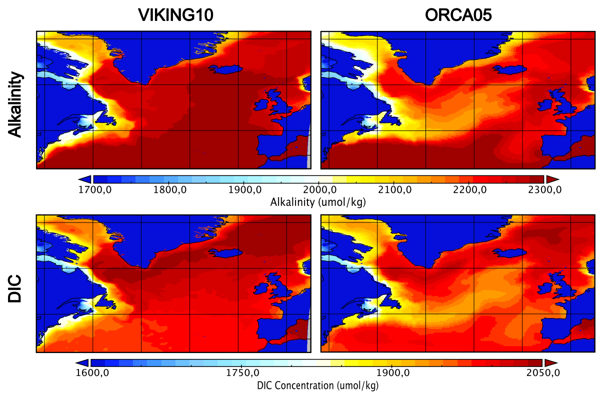

Figure 1: *Comparison between the VIKING10 high resolution nest and the standard ORCA05 FOCI configurations for simulated surface ocean alkalinity and dissolved inorganic carbon (DIC) in the N. Atlantic (year 1850 forcing).*

though it is now clear that CDR will be needed at scale within very few decades to complement other climate change mitigation activities.

Earth system models (ESMs) are one of the key tools that can be used to assess the implications of deploying OAE. There have been a number of idealized ESM studies of OAE that have suggested that OAE has a high CDR potential [3–6]. However, the scenarios used in these studies were very idealized, e.g., instantaneous massive OAE deployed continuously throughout the whole ocean. In addition, due to their coarse resolution, the ESMs used in these studies were unable to resolve mesoscale ocean dynamics such as eddies that could affect the efficacy of OAE. As research on OAE moves forward, there is therefore a need to understand the potential, feasibility, and side effects of OAE when deployed in more realistic scenarios. The next steps in modelling also require the use of higher resolution ESMs that can better simulate ocean physics.

The OceanNETs (https://www.oceannets.eu/) and RETAKE (https://retake.cdrmare.de/en/) projects were funded by the EU Commission and German Federal Ministry of Education and Research (BMBF), respectively, to take these next steps in Earth system modelling as part of larger efforts to understand if ocean-based CDR can play role in climate change mitigation efforts. Both projects investigate the potential, feasibility and side effects of using OAE as a means to reliably and sustainably remove CO_2 from the atmosphere, but with slightly different foci. OceanNETs focuses on OAE in EU pathways for mitigating climate change

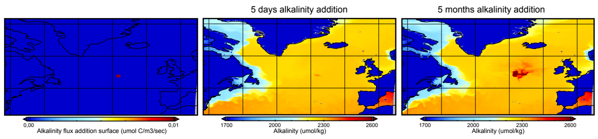

Figure 2: *Example of using the using the mask to increase alkalinity in a specified location (left panel) during a FOCI simulation with the VIKING10 high resolution nest.*

and the importance of model resolution for OAE simulations, while RETAKE focuses on the potential for OAE to help meet German climate change mitigation targets. The results will ultimately, be used to inform EU and German policy for climate change mitigation.

The study proposed here asks for computing time to fulfill the OAE modelling research objectives of OceanNETs (coordinated by D. Keller) and RETAKE (coordinated by A. Oschlies) that the principal investigators are responsible for. The experiments, which are designed to meet the objectives of both projects in a complementary way, investigate the importance of: (a) model resolution, (b) the location of OAE, (c) continuous vs. pulsed OAE, and (d) the climate state during OAE to determine how these factors affect the efficacy, feasibility, and side effects of the approach. Two additional experiments are proposed to address realistic deployment amounts and theoretical potential of this method of carbon dioxide removal.

The model we will use for this work is the Flexible Ocean and Climate Infrastructure (FOCI) Earth system model, which has been developed at GEOMAR [7,8]. FOCI includes a general circulation model of the atmosphere and of the ocean together with a coupler. Additional components include land, sea-ice, atmospheric chemistry, and marine biogeochemistry. Within the ocean, FOCI has the capability to integrate AGRIF nests, which enhance the horizontal resolution over specific regions from 1/2° to 1/10°, thereby affecting the simulation of biogeochemical variables (Fig. 1). In this study we propose to use both configurations, the standard ORCA05 1/2° one and a version with the 1/10° VIKING10 North Atlantic nest, which is between 30° and 85° N. All simulations are run in "ESM" mode with CO_2 emissions being prescribed and atmospheric CO_2 as a prognostic variable. In preparation for the OAE simulations, we have also developed the capability to increase the alkalinity in any surface ocean grid cell using a "masking" approach (Fig. 2).

To investigate the importance of model resolution for OAE we will utilize two FOCI configurations in a series of "paired" experiments with identical climate forcing and OAE deployment (as described next). To investigate how the climate state affects OAE, three climate forcing scenarios with low, high, and an overshoot in CO_2 emissions will be used for most OAE experiments.

To investigate if the location of OAE matters, when done within EU waters, we will begin with a set of experiment where OAE is done along the whole European coastline, excluding the Baltic and Mediterranean seas, which are not included in the VIKING10 nest region. In these experiments OAE will begin in the year 2025 and increase over a 10 year period until the equivalent of 1 Gt yr^{-1} of $Ca(OH)_2$ (quicklime) is being added until the year 2100. Then complementary regional simulations are conducted. To do this we will diagnose how much alkalinity is increased in each region in the "whole EU coastal OAE" experiment and add that same amount only to the specified region. A further experiment will simultaneously increase alkalinity at single coastal grid cells to simulate point source OAE deployments at EU river mouths. Finally, to investigate whether it is better to do OAE continuously or intermittently, simulations similar to the whole EU coast and river point source experiments will be done, except OAE will only done once per year, i.e., a "pulse" addition, in either winter, spring, summer, or fall.

WWW

https://www.oceannets.eu/
https://retake.cdrmare.de/en/

More Information

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