Project: **1258**

Project title: **RETAKE—Carbon Dioxide Removal by Alkalinity Enhancement: Potential, Benefits and Risks**

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Report period: **2021-11-01 to 2022-10-31**

In the past year, we have achieved two major objectives as follows:

1) The three dimensional physical-biogeochemical model SCHISM-ECOSMO has been tuned in terms of carbon module updating, parameter tuning and sensitivity analysing so that we obtained the optimal configuration of the model to plausibly describe the North Sea ecosystem dynamics (e.g. primary production) and especially the carbon cycle.

   Based on the optimal model configuration, we conducted a hindcast simulation of the North Sea biogeochemical cycles over the period 1995-2014. The simulation was compared with available observations to provide a qualitative assessment of the model performance. As an example shown in Figure 1, the model is able to reproduce the general pattern of the CO_2 air-sea exchange in the North Sea, as represented by the difference of pCO_2 between the surface water and the overlying atmosphere, which is characterized by outgasing of CO_2 from the ocean to the atmosphere in the southern North Sea while strong CO_2 sinking from the atmosphere to the ocean in the northern North Sea.

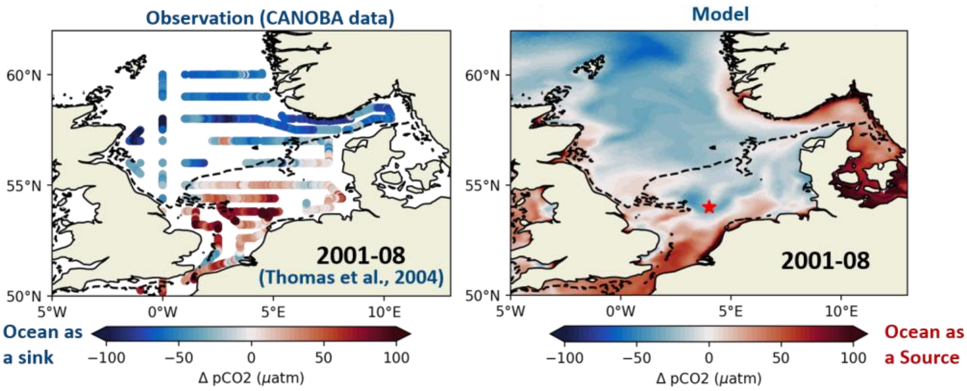

Fig.1 Distribution of ΔpCO_2 between the surface water and the atmosphere in the summer (represented by August) of 2001. Left: observations based on CANOBA data from Thomas et al., 2004. Right: model results.

2) Four scenario experiments over 2003-2010 regarding the alkalinity enhancement (AE) have been conducted.

   The first two scenarios considered the pure alkalinity addition into the surface water but with different deployment locations as shown in Fig.2. For each experiment, we aim at 5Mt of CO_2 removed per year by the alkalinity enhancement. The correspondingly required amount of alkalinity (134Gmol/year) is distributed evenly over the deployment areas and is assumed added to the water continuously. The spreading of the AE effect in the two scenarios is quite different (Figs.3a-b), as in the coastal deployment, the increased AE propagates with two directions, one going from the southeast to the northwest along the depth gradient and the other northward along with the Norwegian Trench, while in the ship track deployment, the AE effect does not spread outside the deployment site except for a constrained spreading along the Norwegian Trench. With continuous AE, the enhanced CO_2 uptake from the atmosphere reaches a stable level since the second year (2004) of deployment in both scenarios, with a higher efficiency of CO_2 uptake when the AE is applied in the European coast (Fig.3c). For both the two deployments, the CO_2 uptake from the atmosphere is more efficient in winter than in summer (Fig.3d).

   The last two scenarios considered the AE implementation via artificially enhanced silicate weathering of olivine, with the later one (2003-2008) additionally including the effect of concomitant silicate release during the olivine dissolution. The silicate supply does not significantly help to draw down the atmospheric CO_2 except for the year 2007 (Fig.4a), in which the primary production, naturally limited by silicate availability, is enhanced due to the additional silicate source (Fig.4b).

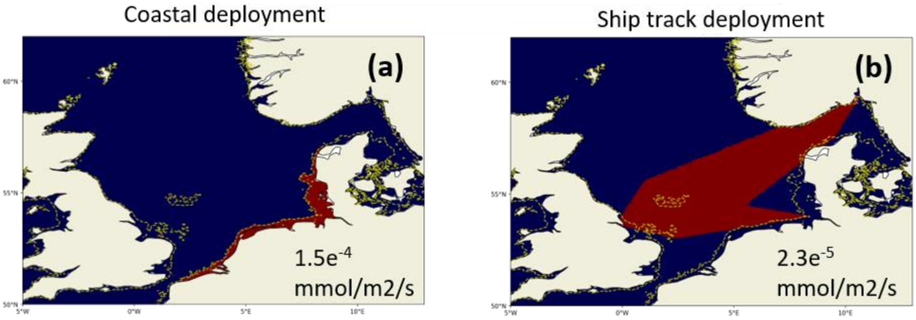

Fig.2 Maps of AE deployment. Areas marked with red colour are places where AE takes place. The numbers are the fluxes calculated based on the fixed amount of alkalinity added to the sea and the size of the deployment area.

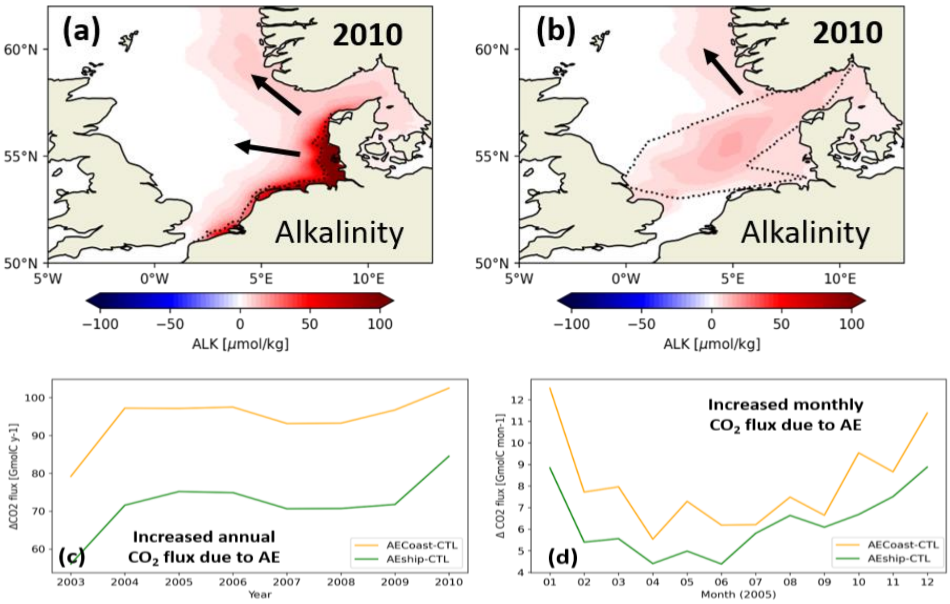

Fig.3 (a)-(b) Spatial patterns of the increased surface alkalinity in 2010 due to AE deployments. (c)-(d) Increased annual CO_2 flux from the atmosphere to the North Sea due to AE deployments.

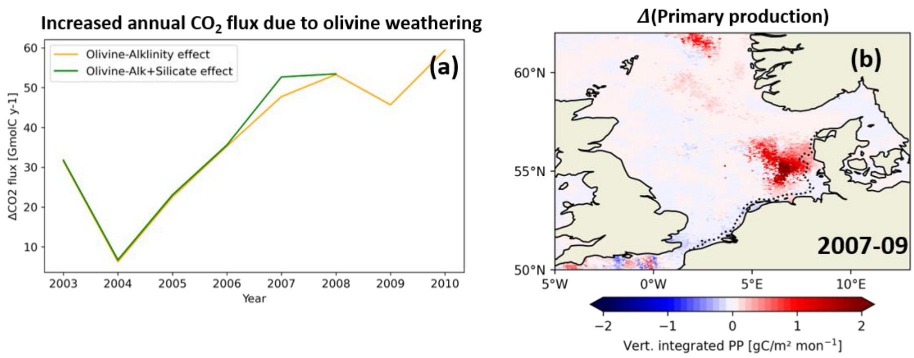

Fig.4 (a)-(b) Increase of the surface alkalinity in 2010 due to the AE. (c)-(d) Increased annual CO_2 flux from the atmosphere to the North Sea due to the AE.

In summary, the hindcast simulation provides a baseline for the AE scenario experiments, while the completed four scenarios suggest that the AE efficiency and ecosystem impacts vary with the different AE methods. More scenario experiments regarding the AE deployment aspects, such as the different alkaline materials (olivine/calcium carbonate/lime), locations of deployments (besides the two locations tested in this report, adding the alkaline materials to the beaches or bottom waters are to be tested), pulsed or continuous use, whether the reactors will be used or not, are planned to be conducted in the next year. By analysing those AE scenario experiments, we will be able to determin the most feasible application methods, for which the sustainability under the future climate conditions will be further tested with forecast simulations.

References:

Thomas, H., Bozec, Y., Elkalay, K., & De Baar, H. J. (2004). Enhanced open ocean storage of CO2 from shelf sea pumping. Science, 304(5673), 1005-1008.