Modeling Effects of Bicarbonate Release on Carbonate Chemistry of the North Sea

Julia Kirchner[1,2], Karsten Lettmann[2], Bernhard Schnetger[1], Jörg-Olaf Wolff[2], Hans-Jürgen Brumsack[1]

[1]Microbiogeochemistry, Institute for Chemistry and Biology of the Marine Environment (ICBM), University of Oldenburg, Germany
[2]Physical Oceanography (Theory), Institute for Chemistry and Biology of the Marine Environment (ICBM), University of Oldenburg, Germany

Background

Rising CO_2-emissions accompanying the industrial revolution are presumably responsible for climate change and ocean acidification. Several methods have been developed to capture CO_2 from effluents and reduce its emission, among those is a promising approach that mimics natural limestone weathering. CO_2 in effluent gas streams reacts with calcium carbonate in a limestone suspension. The resulting bicarbonate-rich solution can be released into natural systems. In comparison to classical carbon capture and storage (CCS) methods this artificial limestone weathering (ALW) is cheaper and does not depend on using toxic chemical compounds. Additionally, there is no need for the controversially discussed storage of CO_2 underground.

Limestone Weathering

$$CO_2 + CaCO_3 + H_2O \leftrightarrow Ca^{2+}\,(aq) + 2HCO_3^-\,(aq)$$

Why ?

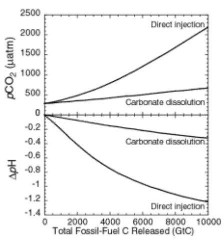

Figure 2. Comparison of the effects of direct CO_2 injection and the carbonate dissolution technique (= ALW), both released into the deep-ocean (mean depth: 1950 m), on atmospheric CO_2 content (top panel) and deep-ocean pH (bottom panel) 1000 years after injection. If the ocean's anthropogenic carbon capacity was determined by the amount of CO_2 that would shift ocean pH by 0.3 units, then the carbonate dissolution technique would increase the ocean's capacity by roughly a factor of six. With the direct-injection method, for large amounts of anthropogenic CO_2 released, over 45 % of the injected CO_2 ends up in the atmosphere after 1000 yr. With the carbonate dissolution method, less than 15 % of the initially released CO_2 degasses to the atmosphere (Rau et al., 2001).

How ?

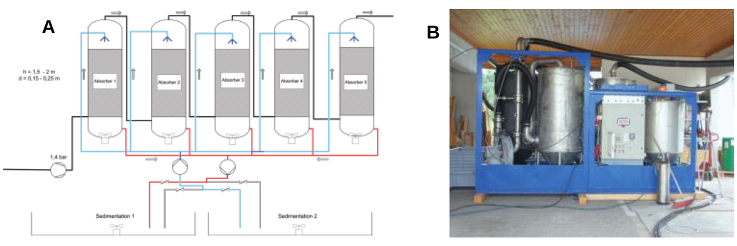

Figure 1: A) Diagrammatic representation of a planned demonstration plant. Blue: Fresh limestone suspension, Red: Excessive limestone suspension and Ca^{2+}-bicarbonate solution, Black: CO_2 gas streams. B) Predecessor demonstration plant of comparable size (Haas et al., 2014; modified).

Models

The ocean circulation model (FVCOM) is combined with a chemical submodul (mocsy) to model the hydrodynamic circulation and the carbonate system within the North Sea. With this tool we can predict the development of the continental shelf carbonate system following external disturbances, e.g. the introduction of bicarbonate-rich waters.

FVCOM

FVCOM is a prognostic, unstructured grid, **F**inite **V**olume, free surface, 3D primitive equation **C**ommunity **O**cean circulation **M**odel. It is most suitable for complex coastlines (Fig. 4) and bathymetry (Chen et al., 2006).

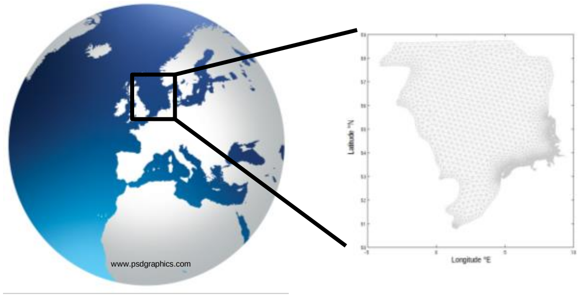

Figure 4: The North Sea as an exemplary grid.

mocsy

Routines to **m**odel the **o**cean **c**arbonate **sy**stem are used to calculate the carbonate system determining variables (Orr and Epitalon, 2015). In addition to parameters needed to run FVCOM the following variables are obligatory for mocsy:

Input	Output	
DIC	pCO_2	pH
Alk	fCO_2	Ω_{arg}
P_T	$CO_2\,(aq)$	Ω_{cal}
Si_T	HCO_3^-	Revelle factor
	CO_3^{2-}	

DIC: Total dissolved inorganic carbon, Alk: Alkalinity, P_T: Total dissolved inorganic phosphorus, Si_T: Total dissolved inorganic silicon, pCO_2: CO_2 partial pressure, fCO_2: CO_2 fugacity, Ω_{arg}: Aragonite saturation index, Ω_{cal}: Calcite saturation index

Conclusions

Not only for trying to reduce climate change effects but also to minimize fees, large CO_2-emitters within the European Union are forced to find cheap methods for emission reduction, as they often cannot avoid CO_2-production. AWL is especially of interest for power plants located close to the coast that are already using seawater for cooling purposes. An estimation of the environmental impacts due to these bicarbonate-rich waters is essential for evaluating appropriate plant sites and release amounts.

References

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Contact julia.kirchner@uni-oldenburg.de