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für Meteorologie

BM0380 Physical and biogeochemical changes in the North Atlantic Interaction with NW Eoropean shelves and impact on the North Sea

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The North Sea shelf pump

The North Sea absorbs ~ 35 Mio. tons of CO_2 per year. The driving mechanism is the high carbon fixation due to biological production and the subsequent export of carbon rich waters to the open Atlantic. In turn, biological production is extremely sensitive to the availability of dissolved nutrients. The main nutrient source for the North Sea is the adjacent Atlantic. Besides this, the North Sea receives nutrients from rivers. On the yearly average, the North Sea is under-supplied by nutrients. Therefore, the CO_2 - absorption is highly vulnerable to changing nutrient imports. Here, a global ocean and biogeochemistry model with gradually increased resolution in the North Sea and the North Atlantic is used to downscale the IPCC AR 4 A1B scenario results from the MPI - IPCC model.

Model Setup MPIOM and biogeochemistry of HAMOCC

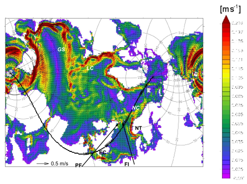


Fig.1: Model domain using constant grid cell sizes independently from the real metrics. Also shown: surface circulation averaged over 1990-1999. Only every second vector ist shown.
EC = English Channel, NT = Norwegian Trench, PF = Pentland Firth, FI = Faire Island.

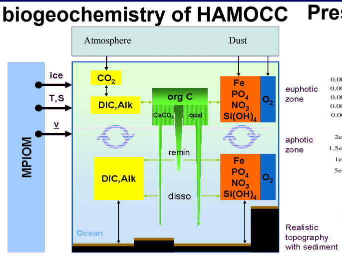


Fig. 2: The carbon and biogeochemistry model

The MPI-M ocean general circulation model MPI-OM was used for this study. Grid resolution was maximized for the NW European shelf and the adjacent Atlantic. In the North Sea, the resolution is comparable with the majority of regional models but avoids the prescription of fluxes at the model borders as it is a global model. To estimate CO_2 absorption on the NW European shelf the MPI-M carbon cycle model HAMOCC was used (Fig. 2).

Prescribed anthropogenic perturbation scenario for the North Sea

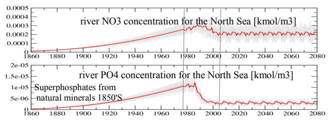
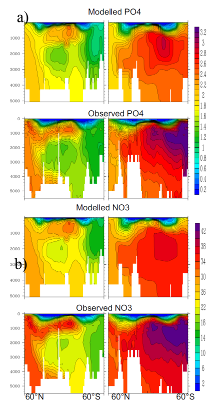


Fig.3: Prescribed riverine input of nutrients. Vertical lines indicate inputs based on observations

An anthropogenic perturbation scenario for the North Sea was developed (Fig.3). For this, preindustrial monthly mean riverine nutrient inputs were assumed which were increased from 1860 to fit values based on observations between 1976 and 2006. The observation data were provided by the Institute for Oceanography, Hamburg. After 2006 the discharges of the preceding 5 years were used repeatedly.

Model Validation



Global	other Models	Model
Primary Production (Pg/yr)	24 - 49 [a]	54
Export Production (Pg/yr)	5.0 - 9.9[a]	7.2
Carbon uptake 1990-1999(Pg/yr)	1.5 - 2.2[b]	1.55
North Sea	**Observation**	**Model**
$Volume_{NB}$ (Sv)	-0.18	-0.19 (±0.05)
$Volume_{EC}$ (Sv)	0.15	0.17 (±0.04)
P-E (Sv)		-0.02 (±0.004)
$Carbon_{NB}$ (Teramol/yr)	-13.3	-9.9 (±3.1)
$Carbon_{EC}$ (Teramol/yr)	10.7	9.0 (±3.9)
$Carbon_{ATM}$ (Teramol/yr)	0.8	0.9 (±0.008)

Tab. 1: Modeled global and regional mass fluxes averaged for the last decade of the 20. century. Mass fluxes for the North Sea refer to Thomas et al. (2005)
NB = northern boundary
EC = English Channel
ATM = atmosphere
P-E = Precipitation - Evaporation

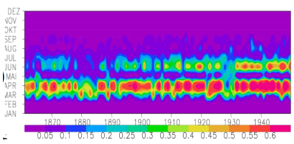


Fig 4: Modelled annual mean distributions for phosphate (a) and nitrate (b) along 35°W (Atlantic) and 180°E (Pacific) compared to observations from the World Ocean Atlas (Garcia et al., 2010)

Fig. 5 Yearly cycle of phytoplankton concentration averaged over the entire North Sea [10^{-7} kmol/m³]

Overall the model compares well with observations. Global distribution of nutrients indicate the main deep and intermediate water masses (Fig. 4). Modelled global and North Sea mass fluxes are well supported by observation. (Tab. 1). The well known spring phytoplankton bloom in the North Sea captured well (Fig. 5).

The North Sea – An efficient carbon sink ?

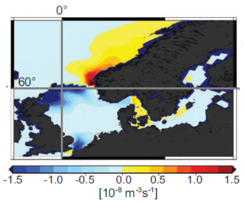


Fig. 6: a) carbon fluxes in the sensitivity experiment described below.

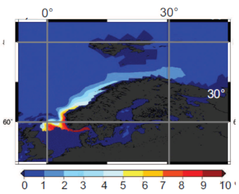


Fig. 6: b) Anomaly of dissolved inorganic carbon at ~100m water depth in the sensitivity experiment described below.

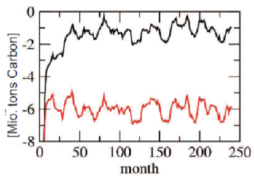


Fig. 6: c) Air-sea carbon flux integrated over the North Sea (red) and the global ocean (black). The difference is shown between a simulation with locally enhanced atm. pCO2 over the North and a control run (see text). Negative fluxes indicate higher carbon uptake/lower degassing in the experiment with locally enhanced atm. pCO2.

The model simulations show, in agreement with observations, that the North Sea is a sink for atmospheric CO2. In an ideal experiment we tested how the carbon absorption in the North Sea influences the global carbon flux (Fig. 6a). For this, the period 1980-2000 was simulated with an atm. pCO2 1112 ppm over the North Sea and 288 ppm elsewhere. In this experiment the North Sea carbon absorption is ~6 Mio. tonsC/month higher (Fig. 6c) than in the control experiment where the atmospheric pCO2 over the North Sea is not enhanced. However, the global degassing of CO2 is reduced by only 1.2 Mio. tonsC/month. Thus, only about 20% of the carbon absorbed in the North Sea remains in the ocean whereas the other degases when waters are exported to the open Atlantic (Fig. 6a). The pathway of North Sea water is marked by DIC anomaly at ~ 100m water depth and indicates that most waters leaving the North Sea are transport to the Barents Sea (Fig. 6b)

Biological productivity and carbon absorption in the course of the 21. century

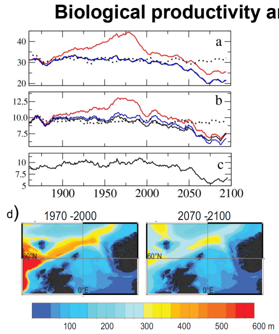


Abb.7: a) yearly primary production, b) net carbon absorption (Mio. tonsC). dashed = control run without climate warming, black line = with climate warming, blue line = as black + CO2 increase in the atmosphere, red line = as blue + anthropogenic nutrient input über via rivers. c) nutrient transport (dissolved nitrate in kmol/s) from the North Atlantic to the North Sea. d) Mixed layer depth at the transition between the North Sea and Atlantic.

Figure. 7a demonstrates the influence of the strong anthropogenic nutrient inputs during the 70's und 80's of the last century. This lead to a substantial increase of the marine promary production and a subsequent absorption of atmospheric carbon dioxide(Abb. 7b).

A drastic weakening of biological productivity and carbon dioxide absorption is predicted for the second half of the 21. century (Abb. 7a,b). Depending on the chosen scenario for future reduction of anthropogenic nutrient inputs marine biological productivity decreases between 32 und 37% on the NW-European shelf. This is related to a weakened nutrient import from the adjacent Atlantic after around 2050 (Abb. 7c). In turn this is forced by a shallowing of the winter mixed layer along the shelf break (Abb. 7d). As a result, less nutrients reach the euphotic zone.

Summary

The model simulations show an increase of CO_2- absorption by ~ 35% in the late 70's/early 80's of the 20[th] Century. This results from the enhanced eutrophication by industrial agriculture. For the projected climate warming in the 21[st] Century a decline of CO_2-absorption of about 33% is predicted depending on the applied scenario for future reductions riverine nutrient input. This is caused mainly by a widespread decoupling of the NW European shelf from the adjacent deep Atlantic. If we assume a total reduction of anthropogenic eutrophication atmospheric CO2 absorption would decline by even 45%. Only about 20% of the carbon absorbed in the Noth Sea is stored for longer in the deep ocean.

The declining biological production will put pressure onto the entire marine food web up to highest trophic organisms and direct human food competitors such as birds and other higher trophic animals.

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