The role of coastal seas/margins in the global carbon cycle and the importance of interacting with terrestrial and atmospheric communities

Subtitle:

CO_2 supply from the North Sea to the North Atlantic Ocean - evidence for the continental shelf pump

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The combustion of fossil fuels has increased the atmospheric content of the greenhouse gas CO_2 ever since the onset (about 1780 AD) of industrialisation. During the past decade, investigations have been made towards understanding and quantifying the natural biogeochemical carbon cycle and its perturbations by mankind. In such studies the carbon exchange between the single compartments of the oceanic and terrestrial environments has been envisioned to take place mainly as CO_2 via the atmosphere. The coastal and marginal seas, here treated as distinct compartments, provide a second link between terrestrial and marine compartments. The direct impacts of both the natural terrestrial ecosystems and mankind, of which 37% live within 100 km of the coastline, are buffered or at least smoothed by the coastal seas before they reach the oceanic systems [1-3].

The relevance of marginal and coastal seas to the global carbon budget is reflected by their high biological activity [1, 4]. Although these seas cover less than 10% of the global sea surface, the primary productivity in coastal seas is estimated to be up to 30% of the marine productivity. A large part of this primary production is recycled within the euphotic zone by the bacteria and grazers of the planktonic foodweb. Yet some part (10-50%) of the fixed carbon will settle out to the bottom sediments, but then it is mostly (>90%) decomposed at the sediment/water interface, yielding an increase of dissolved inorganic carbon (DIC) in bottom waters. The subsequent outflow of such DIC-enriched subsurface waters into the oceans would then provide a net export of DIC from the coastal seas and constitutes the "continental shelf pump" hypothesis [5].

The primary production, export and transport of dissolved inorganic and organic carbon (DIC, DOC) by water masses as well as the CO_2 air-sea exchange are the major terms in carbon budgeting over the annual cycle, with implications up to decadal time scales. The small portion of organic matter escaping respiration and being preserved (burial) is trivial at an annual time frame, but for budgeting over much longer periods (>100 years) this burial in coastal sediments may become significant. Over even longer, geological, time scales (>10,000 y) it constitutes a major sink of carbon from the biosphere, and eventually the origin of refractory kerogen as well as recoverable reserves of petroleum. While recognising the significance of longer time scales, the proposed project most notably aims at annual budgets, which are deemed most relevant for policy decisions over time scales in the order of one to about 100 years.

During the last two years an international carbon cycle program has been established for the North Sea with participants from the Netherlands, Belgium and Germany and major funding by the Dutch Organisation for Scientific Research (NWO). The aim of the study has been to assess simultaneously all relevant parameters of the carbon and nutrient cycle during all four seasons covering a dense 97 stations grid across the entire North Sea. The cruises were carried out in August/September 2001 (summer), November 2001 (autumn), February/March 2002 (winter) and May 2002 (spring).
First results of the partial pressure difference between the atmosphere and the sea surface (ΔpCO_2) indicate the North Sea as an overall sink for atmospheric CO_2. During the summer, a clear distinction between the shallower, well-mixed southern part of the North Sea and the deeper, stratified northern part is evident from the ΔpCO_2 distribution. In the northern part the surface waters are undersaturated with respect to CO_2 as a consequence of biological CO_2 drawdown and export of organic matter to the deeper layers. In contrast, the southern part does not allow the escape of organic matter to any deeper layer. The remineralisation thus occurs in the euphotic zone and counteracts the CO_2 drawdown. As a result no net CO_2 drawdown is possible and the warming of the surface waters during summer increase the pCO_2.

During autumn and winter the surface system heads toward equilibration and only slight super- or undersaturation is visible in February. During spring, which is the time of highest primary productivity the entire North Sea is strongly undersaturated because of the strong CO_2 uptake by biological activity.

The $NO_{3/2}$ and DIC profiles from a central station of the North Sea clearly indicate the seasonal cycle. The wintry mixed layer shows the higher and homogeneous concentrations of DIC. The onset of the spring bloom then starts to decrease the DIC in the surface waters. The export of organic matter to the deeper layers with subsequent remineralisation increases the DIC. Lowest DIC concentrations in the surface waters and highest DIC concentrations in the subsurface waters are observed during summer, when both processes, surface layer production and subsurface remineralisation show the highest extent. During autumn the water column is homogenised by the deepening of the mixed layer until the winter situation is reached again. From the first view, the sum of nitrate and nitrite ($NO_{3/2}$) shows a similar behaviour. However, $NO_{3/2}$ is depleted in the surface layer during spring and summer and does not show any enrichment in the subsurface layer. These observations point to a strong decoupling of carbon and nitrogen cycles.

A first carbon budget indicates the North Sea as an autotrophic region with a CO_2 uptake from the atmosphere of approximately 1.3 mol C m^{-2} y^{-1} [7], which thus is of a similar magnitude as the CO_2 uptake in the Baltic Sea. This budget however has established the CO_2 air-sea exchange as a closing term and future budgeting will include the above ΔpCO_2 observations to assess direct CO_2 air to sea fluxes.
The North Sea water is renewed once to twice per year most notably by water from the North Atlantic Ocean. The major control mechanism of the biological activity in the North Sea is thus the continuous nutrient inputs from the North Atlantic Ocean. For the CO_2 export from the North Sea to the Atlantic Ocean this means that the water is enriched by CO_2 during its 6-12 month travel through the North Sea. Since almost no burial occurs in the North Sea [8], the North Sea acts as a strong continental shelf pump for atmospheric CO_2 by increasing the CO_2 concentrations in the Atlantic waters while they are bypassing through the North Sea (bypass-pump) [7].

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