Atmospheric CO2 exchanges in coastal ecosystems

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Human activities presently release about 7.7 Gigatons of carbon per year (GtC $year^{-1}$) to the atmosphere, by fossil fuel burning and change in land use (*e.g.* deforestation). It is well established that 3.3 GtC $year^{-1}$ remain in the atmosphere. The ocean behaves as a sink estimated to 2.0 GtC $year^{-1}$ and the terrestrial biosphere is often assumed to trap the remaining 2.4 GtC $year^{-1}$. However, this budget does not consider explicitly the fluxes in the coastal ocean because it is difficult to include this region in global circulation models and because of the lack of field data on the spatial distribution and temporal variability of the partial pressure of CO_2 (pCO_2). The coastal ocean is known to house a large fraction of the oceanic primary production (15 - 30%), a contribution by far larger than its surface area fraction (7%) of the total ocean. The role of the coastal ocean in the global carbon cycle has been the subject of a few major national and international research programmes but it is not yet clear if these regions act as a sink or as a source of atmospheric CO_2. Indeed, the prevailing question is whether coastal ecosystems are net autotrophic or net heterotrophic. The coastal ocean is the site of intense physical and biological processes from which important air-sea gradients of CO_2 can be expected, but the air-sea CO_2 exchanges are still poorly known. The causes of these uncertainties are multiple. Firstly, these regions show high variability in time and in space that is usually not adequately monitored by sparse or incomplete data sets. Secondly, the budgets proposed in literature are based on indirect calculations and use different approaches and a variety of experimentally determined processes that yield different conclusions.
During this talk, we will present field data obtained in European coastal areas, including estuaries, river plume at sea, the continental shelf and the Galician upwelling system.

Estuaries are obligate pathways for the transfer of dissolved and particulate material from the continent to the marine system through rivers. They are extremely dynamic systems usually characterized by strong physico-chemical gradients, enhanced biological activity (both heterotrophic and autotrophic) and intense sedimentation and resuspension.
Profound changes are observed in the speciation of organic and inorganic compounds in response to these factors, particularly in the European estuaries of the North Atlantic system which are additionally subject to macro-tidal forcing. The tidal regime of these estuaries leads to an increased residence time of the fresh water in the estuarine mixing zone and the generation of a turbidity maximum, often with an associated oxygen-deplete zone within which various anaerobic processes may be stimulated. In addition, as a result of supporting the major population centres within their catchments, European estuaries are subject to intense anthropogenic disturbance reflected in elevated loadings of detrital organic matter, nutrients and toxic trace elements. All these features increase the potential for biogenic gas production within estuaries. The pCO_2 of surface water and related atmospheric exchanges have been measured in 10 European estuaries. Averaged fluxes over the entire estuaries are most often in the range 0.1-0.5 $mole.m^{-2}.day^{-1}$. For wide estuaries, net daily fluxes to the atmosphere always amount for several hundred tons of C (up to 790 $tC.day^{-1}$ in the Scheldt estuary). We have computed that European estuaries emit between 30 and 60 millions tons of carbon per year to the atmosphere, i.e. 5 to 10 % of present anthropogenic carbon dioxide emission for Western Europe.

The role of the shelves in the inorganic carbon cycle is uncertain because it results from the integration of production/degradation/export of organic carbon, burial/dissolution of carbonates in the shallow sediment and input of inorganic carbon from rivers and coastal upwellings. The best way to identify these areas as a global source or sink for atmospheric carbon dioxide is to integrate CO_2 fluxes over a complete year, an approach frequently used in open ocean studies.

Until recently, the distribution of surface water pCO_2 has been obtained either over large areas of the continental shelf but with a relatively poor temporal resolution as in the North Sea or with a good temporal resolution but in very specific coastal ecosystems. Furthermore, the air-sea fluxes are not computed in the majority of publications. A recent work carried out during five cruises in the East China Sea suggests that continental shelves constitute a significant sink for atmospheric CO_2 and led the authors to formulate the “continental shelf pump” hypothesis that accounts for a sink in the range 0.5 to 1.0 GtC $year^{-1}$ (Tsunogai, 1999). This range is in good agreement with the value of 0.7 GtC $year^{-1}$ proposed by *Sabine and Mackenzie* (1991) and based on budget calculations. We have monitored the partial pressure of carbon dioxide (pCO_2) over a large surface area of the European Atlantic continental shelf during 13 cruises in the Gulf of Biscay and adjacent areas, and during 5 cruises in the North Sea. Data from the Gulf of Biscay cover all four seasons (9 months of 12) over a period of several years. The studied area is influenced by most coastal particularities (shelf-edge discontinuity, vertical mixing, upwelling, slope current, sediment remineralization, tidal front, river input, eutrophication, *etc*). This is the very first intensive field study of continental shelves, in terms of source/sink for atmospheric CO_2, which allows to integrate fluxes on an annual basis and over a large surface area. European continental shelves are a sink of 90 to 170 million tons of carbon per year, that is an additional appreciable fraction to the presently proposed flux for the open North Atlantic Ocean (about 45%). The air-sea fluxes of CO_2 we obtained are similar to those recently reported in the East China Sea, allowing us to conclude that the coastal ocean plays a considerable role in the global oceanic carbon cycle.