



## **Long-term role of the coastal ocean in the carbon cycle, land-to-ocean transfer, and atmosphere-ocean CO<sub>2</sub> exchange**

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There are major differences of opinion concerning the global role of the coastal ocean (shelves, banks, estuaries, bays) in the carbon cycle and air-sea CO<sub>2</sub> exchange as reflected in the views of its (i) being a major site of post-glacial carbonate mineral accumulation that has a strong bearing on the air-sea CO<sub>2</sub> exchange, (ii) having no effect on the post-glacial rise of atmospheric CO<sub>2</sub>, (iii) making a small contribution to the global CO<sub>2</sub> balance, and (iv) being an important site of organic carbon and carbonate storage and CO<sub>2</sub> air-sea exchange during the expansion of the coastal zone since the post-glacial rise in sea level. Using several models developed by our group, we show that transport of materials from the continents to the shallow coastal ocean (area of  $25 \times 10^6$  to  $29 \times 10^6$  km<sup>2</sup>) has varied since the Last Glacial Maximum (LGM; about 18,000 years b.p.) owing to the following factors: (1) growth of the coastal ocean area due to the rising sea level; (2) increase in the continental land surface due to ice melting; (3) increase in riverine flow; and (4) changes in the chemical and biogeochemical weathering rates of minerals and organic matter on land due to temperature change. The global mean temperature increase of 4° to 5°C and, to a lesser extent, the growth of the weatherable land surface by 9% have increased the global CO<sub>2</sub> uptake in weathering by 50%, from about  $14 \times 10^{12}$  to  $22 \times 10^{12}$  mol C/yr from the LGM to late pre-industrial time, leading to increased carbon fluxes to the coastal ocean. The

natural nutrient fluxes of N and P from land to the coastal ocean, driving the global carbon cycle through primary production, depend in part on the C:N:P Redfield ratios in the upcycle reservoirs of the land plants and soil organic matter and the rate of denitrification on land that reduces the N transport to the coastal ocean. These C:N:P ratios are modified in the downcycle reservoirs of marine plankton and the organic matter stored in sediments. Since the LGM the global coastal ocean has been a source of atmospheric CO<sub>2</sub> from the remineralization of organic matter produced *in situ* as well as imported from land and due to calcification by benthic and pelagic organisms. The source strength is mainly related to the proximal coastal zone and shoal water regions (e.g., reefs) of carbonate formation, areas of the coastal waters that generally have high specific area CO<sub>2</sub> fluxes. The rising atmospheric CO<sub>2</sub> of the Industrial Age has invaded on average the upper approximately 500 m of the oceanic water column. The increasing CO<sub>2</sub> concentrations exert a counter-pressure on the CO<sub>2</sub> flux from global coastal waters to the atmosphere with the result, based on modeling, that the CO<sub>2</sub> flux direction will be reversed soon, making the coastal ocean a CO<sub>2</sub> sink. The timing of this flux reversal depends mainly on the integrated CO<sub>2</sub> flux from the proximal coastal zone, as the distal coastal area by itself already appears to be a sink of atmospheric CO<sub>2</sub>. Projections of future atmospheric CO<sub>2</sub> rise at a time scale of 1 to 3 centuries indicate that carbonate production and accumulation in the coastal zone may be significantly reduced because of decreasing pH and carbonate saturation state due to absorption of atmospheric CO<sub>2</sub> by coastal zone waters and their acidification. This trend is projected to occur despite greater inputs of nutrient N and P from land, due to application of inorganic fertilizers in agriculture and the weathering of soil humus, which would increase primary production in the coastal ocean. The enhanced remineralization of organic matter from increasing land inputs of organic carbon and *in situ* production, which is expected to increase due to higher inputs of nutrient N and P from land, will lead to increased dissolution of shoal water carbonates and production of alkalinity, but the alkalinity produced will be insufficient to buffer coastal zone waters against rising atmospheric CO<sub>2</sub> and consequent decreases in pH and carbonate saturation state. The continuation of this trend is primarily driven by the CO<sub>2</sub> emissions from fossil fuel burning, and the total C mass in the proven reserves of fossil fuels as of the year 2004 is approximately equal to the atmospheric C content as CO<sub>2</sub>. If the anthropogenic flux of CO<sub>2</sub> continues until depletion of conventional fossil fuel resources in 2300, near surface, shoal water carbonate sediments will have a different composition than that in late pre-industrial time, mainly lacking in highly soluble high magnesian calcites.