Sources and sinks of carbon dioxide in the surface oceans

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The ocean plays an important role in the global carbon cycle as it contains a vast reservoir of carbon, rapidly exchanges carbon with the atmosphere, and takes up from the atmosphere an amount equivalent to approximately 30% of anthropogenically-released carbon. Over the past four decades, we have collected an extensive database of surface water pCO_2 measured from research ships and other volunteer observing ships. This data set has been used to determine the primary source and sink regions for CO_2 in the oceans. The results show that Atlantic Ocean as a whole, which has 23.5% of the global ocean area, is the strongest CO_2 sink (41%). The high latitude northern North Atlantic region including the Greenland-Iceland-Norwegian Seas is a major sink. This is probably due to a combination of two factors: (1) the intense summer time photosynthesis; and (2) low CO_2 concentrations in subsurface waters resulting from recent ventilation of the North Atlantic subsurface waters. The Pacific Ocean as a whole has the smallest sink flux (18% of the total) in spite of its larger oceanic area (49%). This is because the mid-latitude sink flux (about 1.1 Pg C yr^{-1}) is nearly compensated by the large equatorial source flux of about 0.7 Pg C yr^{-1}. If the equatorial source flux were totally eliminated, as occurs during strong El Niño events, the Pacific would become a major CO_2 sink, comparable to the entire North and South Atlantic Oceans. The southern Indian Ocean is one of the most intense sink areas in spite of its small area (15% of the total). This may be attributed primarily to the cooling of tropical waters flowing southward in the western South Indian Ocean. The annual net sea-air CO_2 flux has been computed using the NCEP/NCAR 41-year mean monthly wind speeds. An annual net uptake flux of CO_2 by the global oceans has been estimated to be 1.6 ± 0.4 Pg C yr^{-1} using the wind speed dependence of the CO_2 gas transfer velocity of Wanninkhof (1992). Time-series measurements of CO_2 fluxes in the equatorial Pacific over the past three decades suggest that decadal changes in CO_2 out-gassing of CO_2 may be related to decadal changes in shallow meridional overturning circulation.

How the coupling of the C, N and O cycles determines atmospheric CO_2 and O_2 concentrations

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Geochemical evidence suggests that the deep ocean remained anoxic for several hundred million years after the establishment of oxygenic photosynthesis. In this paper we examine the possibility that this extraordinary delay was caused by a geochemical "bottleneck" imposed by feedbacks between carbon burial, net oxygen evolution, and the evolution of the nitrogen cycle in the Proterozoic oceans. Whereas under anoxic conditions oceanic ammonium would have been relatively stable, as oxygen concentrations rose, nitrification and subsequent denitrification would have rapidly removed fixed inorganic nitrogen from the oceans. Denitrification would have imposed a strong constraint on the further rise of free oxygen by depriving oxygenic photoautotrophs of an essential nutrient. To examine the dynamic interactions between oxygen and nitrogen cycling, we developed a simple box model that incorporates the basic features of oxygen, nitrogen and carbon biogeochemistry, ocean circulation and ocean-atmosphere gas-exchange.

Model simulations, initiated under anaerobic conditions with no free oxygen in the atmosphere or ocean, are characterized by an initially reduced deep ocean with abundant ammonium, followed by a low-nitrogen phase where neither form of fixed nitrogen is stable, and a fully oxidized phase with abundant nitrate. We infer that, in the process of oxidizing the early Proterozoic ocean, the system had to go through an extended nitrogen-limited phase during which time export production was severely attenuated. Our studies suggest that the presence of shallow seas with increased organic matter burial was a critical factor determining the concentration of oxygen in the ocean and atmosphere, while the phosphate concentration played a key role in determining the rate of oxygenation of the deep ocean.