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The efficiency of the biological pump in the Southern Ocean and its role in controlling past atmospheric CO_2 concentrations

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In the high-latitude Southern Ocean, nutrient- and CO_2-rich deep waters outcrop in the surface ocean and exchange CO_2 with the atmosphere. The efficiency of the biological pump, that is, the degree to which the major nutrients (N, P) are consumed by phytoplankton, is given by the ratio of nutrient uptake and export relative to the nutrient supply to the surface. By measuring the stable nitrogen isotope composition of the organic matter bound within the mineral structure of (micro-)fossils, we can reconstruct past nitrate consumption in the Southern Ocean and thus the efficiency of the global biological pump.

Over the relatively climatically stable Holocene period, a compilation of N isotope records measured on diatoms, foraminifera, and corals from all basins of the Southern Ocean indicates that nitrate consumption declined (surface nitrate concentrations increased) while export production increased or remained constant. Together, these data point to an acceleration of Southern Ocean overturning, which would have weakened the ocean's biological pump and thus may explain the 20ppm Holocene CO_2 rise that has long been a mystery.

On longer timescales, two diatom-bound N isotope records from the Pacific and Indian Antarctic Ocean indicate a pervasive coupling between nitrate consumption and Antarctic climate back to the penultimate ice age ($\sim$150'000 years ago). Nitrate consumption was effectively complete (surface nitrate was exhausted over the course of the summer) during the peaks of the last two ice ages, while productivity was reduced, indicating that the gross nutrient supply to the surface ocean must have been diminished. These changes would have increased the efficiency of the biological pump and thus contributed to the decline in atmospheric CO_2 entering into ice ages.