Southern Ocean activation of two modes of CO_2 storage during the ice ages

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In the effort to identify the causes of the glacial/interglacial cycles in atmospheric CO_2, the coupled biogeochemistry and circulation of the Southern Ocean have long been recognized as potentially important. Paleoceanographic reconstructions increasingly support such a role for the Southern Ocean in past CO_2 changes. I will make the case for this focusing on recent and new data on the $^{15}N/^{14}N$ of organic matter bound in the fossils of diatoms, planktonic foraminifera, and deep sea corals from both the Antarctic and Subantarctic Zones of the Southern Ocean. In the Antarctic, the data point to ice age reductions in the exchange of water between the surface and the underlying ocean, leading to more complete consumption of the nitrate supply. In the Subantarctic, dust-borne iron fertilization appears to have been an important process, enhancing export production and thus leading to more complete nitrate consumption in this zone as well. With this combination of Antarctic and Subantarctic physical and biological changes, the full (~90 ppm) ice age CO_2 decline is achievable.

For the most part, the geochemical "knobs" for lowering ice age CO_2 had been identified and characterized by the end of the 1980s. Subsequent work has largely focused on which physical and biological changes might have turned those knobs. In this context, the incapacity of reduced Antarctic overturning alone to achieve the full amplitude of ice age CO_2 drawdown has much to do with (a) the apparent observational constraint that Antarctic export production was reduced during ice ages and (b) the model-based finding that reducing Antarctic oveturning increases the efficiency of both the ocean's "soft tissue pump" and its "carbonate pump" (the former lowering CO_2 but the latter raising it).

If the paleoceanographic observations are interpreted as above, the key question becomes why the Southern Ocean underwent these changes, the ice age reduction in Antarctic overturning in particular. This point is underscored by the common result in climate model simulations that Antarctic overturning decreases under global warming. I will address this question in part by drawing a comparison to data from the subarctic North Pacific. I interpret the existing data to require a mechanism for reduced Antarctic overturning that involves more atmospheric than oceanic processes.