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Lowering of glacial $p\mathrm{CO}_2$ in response to changes in oceanic circulation and marine biogeochemistry

V. Brovkin (1), A. Ganopolski (1), D. Archer (2), and S. Rahmstorf (1)

(1) Potsdam Institute for Climate Impact Research, Germany (victor.brovkin@pik-potsdam.de / Fax: +49 331 2882570)

(2) University of Chicago, U.S.A.

We use a model of intermediate complexity, CLIMBER-2, to investigate what recent improvements in the representation of the physics and biology of the glacial ocean imply for the atmospheric CO_2 concentration. The coupled atmosphere-ocean model is able to reproduce the deep, salty, stagnant water mass inferred from Antarctic deep pore-water data [*Adkins et al., 2002*] and the changing temperature of the entire deep ocean [*Martin et al., 2002*]. When the pH feedback of the sedimentary CaCO_3 cycle is included in the model, we find a drawdown of 43 ppm resulting from this physical circulation change. Fertilizing the Atlantic and Indian sectors of the Southern Ocean north of the polar front leads to a further drawdown of 37 ppm. Other changes to the glacial carbon cycle include a decrease in the amount of carbon stored in the terrestrial biosphere (540 GtC), which increases $p\mathrm{CO}_2$ by 15 ppm, and a change in ocean salinity resulting from a drop in sea level, which increases $p\mathrm{CO}_2$ by another 12 ppm. A decrease in shallow water CaCO_3 deposition draws down $p\mathrm{CO}_2$ by 12 ppm. In total, the model is able to explain more than two thirds (65 ppm) of the glacial to interglacial $p\mathrm{CO}_2$ change, based only on mechanisms that are clearly documented in the proxy data. A good match between simulated and reconstructed distribution of δ^{13}C changes in the deep Atlantic [*Duplessy et al., 1988*] suggests that the model captures the mechanisms of reorganization of biogeochemistry in the Atlantic ocean reasonably well. Additional, poorly documented potential mechanisms to explain the rest of the observed drawdown include changes in the organic carbon:CaCO_3 ratio of sediment rain reaching the sea floor, iron fertilization in the sub-Antarctic Pacific ocean, and changes in terrestrial weathering.