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# A multi-variable box model approach to the ocean carbon cycle during the last glacial

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The canonical question of which physical, chemical or biological mechanisms were responsible for oceanic uptake of atmospheric $CO_2$ during the last glacial is yet unanswered. Insight from paleo-proxies has led to a multitude of hypotheses but none so far have been convincingly supported in three dimensional numerical modelling experiments. The processes that influence the $CO_2$ uptake and export production are inter-related and too complex to solve conceptually while complex numerical models are time consuming and expensive to run which severely limits the combinations of mechanisms that can be explored. Instead, an intermediate inverse box model approach of the soft tissue pump is used here in which the whole parameter space is explored. The realitistic glacial circulation and biological production states are derived from the solutions using data proxies of glacial export and atmospheric $CO_2$ decrease. We find that circulation patterns which explain glacial observations include reduced Antarctic Bottom Water formation and high latitude upwelling and mixing of deep water and to a lesser extent reduced equatorial upwelling. The proposed mechanism of $CO_2$ uptake by an increase of eddies in the Southern Ocean, leading to a reduced residual circulation, is not supported. Regarding biological mechanisms, an increase in the nutrient utilization in either the equatorial regions or the northern polar latitudes can reduce atmospheric $CO_2$ and satisfy proxies of glacial export production. Consistent with previous studies, $CO_2$ is drawn down more easily through increased productivity in the Antarctic region than the sub-Antarctic, but that violates observations of lower export production there. The glacial states are more sensitive to changes in the circulation and less sensitive to changes in nutrient utilization rates than the interglacial states.