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Quantifying the role of ocean biology in glacial-interglacial variations in atmospheric CO_2

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Recent studies have shown a large increase in the radiocarbon age of the ocean during the Last Glacial Maximum (LGM; ∼20,000 years before present), which has been interpreted to imply greater storage of carbon in the ocean as respired CO_2. This increase in the efficiency of the biological carbon pump, as it is conventionally defined, could account for at least some of the known ∼90 ppm lowering of atmospheric CO_2 relative to interglacial periods. Here we present an alternative interpretation based on a novel set of numerical simulations that allows us to more precisely quantify the partitioning of carbon between different reservoirs and the role of ocean biology in glacial-interglacial variations in atmospheric CO_2. The simulations, carried out with an observationally-constrained Earth System Model, produce a lowering of atmospheric CO_2 by ∼67 ppm when preindustrial fields of ocean circulation, temperature, salinity, sea ice, and dust (iron) deposition are replaced by their LGM counterparts. This is a significant fraction of the total observed change, but in our model it is accompanied by a *reduction* in the amount of carbon stored in the ocean as respired CO_2, with the hard tissue pump also decreasing. This is both due to less carbon exported out of the euphotic zone, a consequence of increased sea ice cover in the Southern Ocean overcoming increased export production due to greater iron fertilization, as well as more rapid flushing of the deep ocean from the south due to stronger Antarctic Bottom Water formation. The latter leads to shorter transit times from the surface into the interior, and thus less time for respired carbon to accumulate. However this decrease in the efficiency of the biological carbon pump is more than compensated by a large enhancement in air-sea CO_2 disequilibrium leading to a net increase in carbon storage in the ocean. The higher disequilibrium causes both older radiocarbon ages and significantly reduced dissolved oxygen concentrations in the ocean, consistent with observations. While our simulations indicate a reduction in the efficiency of the biological carbon pump during the LGM, they also demonstrate that ocean biology is critical for producing the background conditions necessary for increased air-sea disequilibrium and thus a lowering of atmospheric CO_2. In fact, we can attribute $2/3^{rd}$ of the atmospheric CO_2 change in our model to ocean biology. Our results suggest that in order to fully account for the role of ocean biology in the sequestration of carbon by the ocean and quantify the efficiency of the biological carbon pump, it is essential to include the impact of biology on the equilibrium and disequilibrium carbon pools.