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Constraining glacial ocean carbon cycle – A multi-model study

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The ocean contained a larger carbon content at the Last Glacial Maximum (LGM, ~21kyr before present) compared to the late Holocene, making a considerable contribution to the deglacial atmospheric CO_2 rise of about 90 ppm. Yet, there's no consensus on the mechanisms controlling the glacial-interglacial changes in oceanic carbon storage due to uncertainties and sparseness of proxy data. Numerical simulations have been widely used to quantify the impact of key factors, such as changes in sea surface temperatures, ocean circulation and biological production, on glacial ocean carbon sequestration. However, the robustness of these findings is subject to further testing due to the differences in process representation, parameterization, model architecture, or external forcing employed by models.

Towards further constraining the LGM ocean carbon cycle, we conducted a multi-model comparison with three comprehensive Earth System Models (Alfred Wegener Institute Earth System Model, AWI-ESM; Community Earth System Model, CESM; Max Planck Institute Earth System Model, MPI-ESM) and one Earth system Model of Intermediate Complexity (CLIMBER-X). We carried out three coordinated experiments with each model: 1) PI (the pre-industrial control simulation), 2) LGM-PMIP (following PMIP4 LGM protocol) and 3) LGM-LowCO2 (as LGM-PMIP, but with boosted alkalinity inventory to lower atmospheric CO_2 to about 190 ppm. All experiments were conducted with the prognostic CO_2 for the carbon cycle, considering only the atmosphere and ocean reservoirs, and prescribed CO_2 for radiative forcing.

All models consistently show that applying the PMIP4 LGM boundary conditions alone leads to only a 5-40 ppm decrease in atmospheric CO_2. Globally, the glacial CO_2 drawdown in LGM-PMIP is mainly controlled by the enhanced solubility pump. The spatial distribution of the increased glacial DIC depends on the ocean circulation state in each model. In MPI-ESM and CLIMBER-X, the

shallower and weaker AMOC facilitates carbon storage in the deep Atlantic. An LGM atmospheric CO_2 of 190 ppm can be achieved by boosting alkalinity by 5-8% in scenario LGM-LowCO2. In all models, boosting LGM alkalinity inventory increases DIC in the bottom water. However, comparison to proxy data reveals that the models lack respired carbon, particularly in the deep Pacific. This suggests a need to enhance the glacial biological carbon pump in the models.