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Simulation of glacial ocean biogeochemical tracer and isotope distributions based on the PMIP3 suite of climate models

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In the present climate system, buoyancy forced convection at high-latitudes together with internal mixing results in a vigorous overturning circulation whose major component is North Atlantic Deep Water. One of the key questions of climate science is whether this "mode" of circulation persisted during glacial periods, and in particular at the Last Glacial Maximum (LGM; 21000 years before present). Resolving this question is both important for advancing our understanding of the climate system, as well as a critical test of numerical models' ability to reliably simulate different climates. The observational evidence, based on interpreting geochemical tracers archived in sediments, is conflicting, as are simulations carried out with state-of-the-art climate models (e.g., as part of the PMIP3 suite), which, due to the computational cost involved, do not by and large include biogeochemical and isotope tracers that can be directly compared with proxy data. Here, we apply geochemical observations to evaluate the ability of several realisations of an ocean model driven by atmospheric forcing from the PMIP3 suite of climate models to simulate global ocean circulation during the LGM. This results in a wide range of circulation states that are then used to simulate biogeochemical tracer and isotope (^{13}C, ^{14}C and Pa/Th) distributions using an efficient, "offline" computational scheme known as the transport matrix method (TMM). One of the key advantages of this approach is the use of a uniform set of biogeochemical and isotope parameterizations across all the different circulations based on the PMIP3 models. We compare these simulated distributions to both modern observations and data from LGM ocean sediments to identify similarities and discrepancies between model and data. We find, for example, that when the ocean model is forced with wind stress from the PMIP3 models the radiocarbon age of the deep ocean is systematically younger compared with reconstructions. Changes in glacial circulation, characterized using ventilation tracers, are then analyzed in terms of forcing factors such as wind stress, surface heat and freshwater budgets, and sea ice to improve our understanding of the physical reasons for the changes.