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A dynamical reconstruction of the pre-industrial and the LGM ocean state constrained by global δ^{18}O data

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Combining ocean general circulation models with observational data via inverse modeling is a powerful means to obtain more reliable estimates of the ocean's state. The Last Glacial Maximum (19-23 ka BP, LGM) was a climatic state substantially different from today and the large-scale ocean circulation patterns during this time remain uncertain. It is furthermore unclear if the sparse data coverage of the LGM is actually sufficient to constrain the ocean circulation by an inverse modeling technique.

We used the adjoint method to estimate the state of the global ocean. For the pre-industrial, this estimate is consistent with the dynamics of the MIT general circulation model (MITgcm) and global temperature, salinity and δ^{18}O data within their respective error bounds. The model uses a cubed-sphere grid with 192 x 32 horizontal grid cells and 15 vertical levels. A water-isotopes module was used to simulate stable water isotopes such that, to our knowledge for the first time, global δ^{18}O data from the whole water-column could be assimilated using the adjoint method. The state estimate based on our 200-year long optimized run shows significant improvements in comparison to the original forward run without data constraint ("first guess"). For example, surface δ^{18}O values in the subtropical gyres in the Atlantic, across the North Atlantic, the Mediterranean Sea and in the Arctic Oceans show a much better agreement with the observations. The same holds true for deep-ocean δ^{18}O values, for example in the Atlantic and the Arctic Oceans.

Two additional state estimates are presented. Firstly, to test the constraint given by the limited data coverage of the LGM an estimate for the pre-industrial ocean is obtained constrained only by data equivalent to available LGM data in terms of data types and data density. Secondly, we reconstruct the state of the LGM ocean using global sea-surface temperature and δ^{18}O data from benthic and planktonic foraminifera from various sources.