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# A particle filter method to estimate the state of the ocean during the Last Glacial Maximum

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Combining ocean general circulation models with proxy data via data assimilation is a powerful means to obtain more reliable estimates of the past ocean's state as well as of model parameters. 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. At present, only a few attempts on using data assimilation to estimate the ocean's state during the LGM exist and it is unclear which data assimilation methods are suitable for this application where data is comparatively sparse and uncertain.

We present a new particle filter method that combines ensemble runs of an ocean general circulation model with (pseudo-) proxy data to estimate several parameters of the atmospheric forcing used to drive the model. The method is based on the Bayesian framework and explores the multi-dimensional probability density function (pdf) of the parameters in an efficient way without the requirement of a Gaussian assumption. The method uses a tempering approach, in which the accuracy of the data is increased in each iteration to avoid ensemble collapse. A few iterations of model simulations and re-sampling steps are needed for convergence. The method yields an approximation of the pdf and therefore an estimate of the parameters and their uncertainties. The resulting model ensemble provides an estimate of the state of the global ocean and its uncertainty.

We employ the MIT general circulation model (MITgcm) in a global configuration that uses a cubed-sphere grid with 192 x 32 horizontal grid cells and 15 vertical levels. A water-isotopes module incorporated in the model is used to simulate stable water isotopes such that global oxygen-isotope data from the whole water-column can be assimilated.

To validate the method we carried-out an experiment with pseudo-proxy data sampled at MARGO locations from a target model run. The method is capable of efficiently estimating 6 parameters (the mean air temperature and mean precipitation over the Atlantic, the Pacific and the Indian Ocean) and their uncertainties using less than 10 iterations. The Atlantic Meridional Overturning Circulation (AMOC) of our target run yields a maximum of 18.7 Sv which is successfully reconstructed in the experiment: We obtain 28 model simulations for which all parameters lay within one standard deviation of the estimated parameters, the respective max. AMOC values range from 18.2 to 19.1 Sv with a mean of 18.7 Sv. Pro's and con's of the particle filter method will be discussed.

We will apply the method to estimate the state of the global ocean during the LGM. To that end, we use the seasonal MARGO sea-surface temperature reconstruction and a global collection of oxygen-isotope data from benthic and planktonic foraminifera from different sources. We will present results from these experiments and discuss climatic implications of our findings.