Geophysical Research Abstracts
Vol. 13, EGU2011-7259-1, 2011
EGU General Assembly 2011

Reconstruction of the LGM ocean circulation from data with the adjoint method

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Understanding the behavior of the Earth's climate system under different conditions in the past is the basis for robust predictions of future climate. It is believed that the ocean circulation plays a very important role in the climate system, because it can greatly affect climate by dynamic-thermodynamical (as a medium of heat transport) and biogeochemical processes (by modifying the marine carbon cycle). In this context, studying the period of the Last Glacial Maximum (LGM) is particularly promising, as it represents a climate state that is very different from today. Furthermore the LGM, compared to other paleoperiods, is characterized by a relatively good paleo-data coverage. Unfortunately, the ocean circulation during the LGM is still uncertain, with a range of climate models estimating both a stronger and a weaker formation rate of North Atlantic Deep Water (NADW) as compared to the present rate. Here, we present a project aiming at reducing this uncertainty by combining proxy data with a numerical ocean model using variational techniques.

Our approach, the so-called adjoint method, employs a quadratic cost function of model-data differences weighted by their prior error estimates. We seek an optimal state estimate at the global minimum of the cost function by varying the independent control variables such as initial conditions (e.g. temperature), boundary conditions (e.g. surface winds, heat flux), or internal parameters (e.g. vertical diffusivity). The adjoint or dual model computes the gradient of the cost function with respect to these control variables and thus provides the information required by gradient descent algorithms. The gradients themselves provide valuable information about the sensitivity of the system to perturbations in the control variables.

We use the Massachusetts Institute of Technology ocean general circulation model (MITgcm) with a cubed-sphere grid system that avoids converging grid lines and pole singularities. This model code is tailored to be used with a source-to-source compiler to generate exact and efficient adjoint model code. We have carried out a feasibility study on the reconstruction of the LGM ocean circulation from sparse paleoceanographic data. As the first step, we used artificial data (temperature and salinity) sampled from simulations with the MITgcm to mimic real geological data. We found that the adjoint method with the MITgcm has the potential of providing estimates of past ocean circulations from sparse data, and that the availability of salinity(-like) data rather than the sparsity of data points appears to be the limiting factor.