Geophysical Research Abstracts
Vol. 13, EGU2011-9886, 2011
EGU General Assembly 2011

Twin experiments towards more robust simulations of past ocean circulation

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Simulation of paleoclimates and paleocean is often done in an ad-hoc fashion. The reliability of model results is often judged from observations of limited quantity. Accordingly it is highly uncertain how valid or robust the reconstructed atmosphere or ocean is as a whole. In this study we test the robustness of our numerical ocean model with an inverse modeling approach to secure comparatively strong reliability of the model results.

The ocean model that we used is the Massachusetts Institute of Technology ocean general circulation model (MITgcm) with a cubed-sphere grid system that avoids converging grid lines and pole singularities. We used this model (as a forward model) to generate three kinds of model oceans with different formation rate of North Atlantic Deep Water (NADW): one corresponds to the modern state, one has weaker, and the third one has stronger NADW formation than the modern ocean. Then we extracted model temperature and/or salinity from the latter two model results, and made them artificial targets for the following twin experiments.

We employed a quadratic cost function based on the misfit between the control case and each target. An optimal ocean state that gives the minimum of the cost function was searched by adjusting the independent control variables of the control run, such as initial conditions (e.g. temperature), boundary conditions (e.g. surface winds, heat flux), or internal parameters (e.g. vertical diffusivity). Then we examined how well the target ocean was reconstructed through the inverse (adjoint) method. The results of our twin experiments showed that our model can reproduce the global ocean circulation including the magnitude of NADW formation that is satisfactorily similar to the control case, even from spatially sparse target information. This indicates the robustness and usefulness of the model for future experiments aiming at, for example, the last glacial maximum (LGM).