The Glacial Ocean Circulation in a Coupled Climate Model: Comparison with Paleoproxy Records

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Abstract: We propose to investigate using geochemical tracers the ocean's circulation at the Last Glacial Maximum in a coupled ocean–atmosphere–ice model. To achieve this goal, we will develop and test a novel technique to incorporate paleoceanographic tracers in coupled general circulation models. In this initial "proof of concept" study, our focus will be on evaluating and validating a state-of-the-art simulation, with regard to ventilation rates and pathways, of the last glacial period against paleoproxy records (e.g., radiocarbon and isotopes of neodymium) from marine sediments. Our intention is to use the results of this preliminary investigation in support of a full NSF proposal.

can be written as a linear matrix equation:

$$\frac{dc}{dt} = A(t)c, \qquad (1)$$

where, c is the vector of tracer concentrations at the grid points of the GCM. The matrix $A(t)$ is the "transport matrix" which results from discretization of the advection-diffusion operator and includes the effects of advection, diffusion, sub-grid scale processes, and surface boundary conditions. Note that c is merely a vector representation of a discretized 3-dimensional tracer field. These equation are readily generalized to include time-dependent, linear (as for radioactive decay) or nonlinear (as for biological tracers) sources and sinks, as well as flux BCs. The matrix formulation of the tracer equation has some very useful properties that allow for very efficient simulation of any passive tracer. In particular, the problem of finding the steady state distribution of a tracer such as radiocarbon reduces to finding the solution to a set of linear algebraic equations, $Ac = b$ (Fig. 1). This may be done quite conveniently with software such as MATLAB.

While the idea underlying eq. 1 is not new, it has not been ex- ploited in the past. This is largely because it would be quite time consuming to directly code the advection-diffusion equation, including various parameterizations, for an arbitrary ocean geometry in the form of eq. 1. Recognizing this, Khatiwala et al[8] have developed an efficient *empirical* procedure to estimate the elements of A for any GCM.

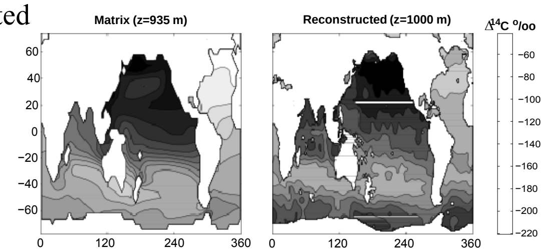

Figure 1: Equilibrium distribution of (natural) $\Delta^{14}C$ in an ocean GCM forced by present day climatalogical fluxes. The tracer field is computed using the matrix method. For comparison, we also show a reconstruction of the $\Delta^{14}C$ field based on *Levitus* T/S (S. Peacock, personal communication).

We propose to apply the technique described above to compute the transport matrix of the circulation of a coupled AOGCM configured to simulate the climate at the LGM. (See below.) Once the matrix for the LGM circulation is known, the AOGCM can be dispensed with, and any tracer can be efficiently and conveniently simulated by integrating eq. 1. In this pilot study, we will focus on simulating radiocarbon and neodymium isotope ratios[9], two well established tracers of past ocean circulation with relatively simple boundary conditions. One aspect of particular interest to us is whether changes in the flux of aeolian dust during the glacial, as seen in Antarctic ice cores, may be responsible for the observed signal of Nd isotope ratios in marine sediments. Such an effect may complicate the straightforward interpretation of these tracers as proxies of ocean ventilation. Our tracer simulation method is well suited to addressing issues such as this. In the future we also intend to incorporate other tracers, including paleonutrient proxies such as $\delta^{13}C$ and Cd/Ca[10]. (We have a related project underway to develop a simple carbon system model for paleoclimate research.)

AOGCM Simulation of the Last Glacial

Integrating a coupled AOGCM to equilibrium is not a simple proposition. Conveniently for us, a state-of-the-art LGM simulation has recently been performed using the NCAR Community Climate System Model (CCSM)[7], and the results are available to us. Thus, we do not propose to carry out such a calculation ourselves. The main stumbling block is that the matrix method has only been implemented in the Lamont and MIT ocean GCMs. There are two solutions to this problem. One is to implement the matrix method in the ocean component of the NCAR-CCSM. This would be time consuming. We favor an alternative approach. We propose to *diagnose* the fluxes between the ocean and atmosphere from the output of the coupled run, and use these boundary conditions to force a similarly configured ocean GCM[11]. (We will use the MIT model.) While this strategy is by no means guaranteed to work (in the sense of being able to reproduce the circulation in the coupled model), its success would open up a very fruitful new approach to performing accurate ocean simulations over long time scales, without the expense of a fully coupled run.

Objectives

To summarize, specific objectives of this proposal are as follows:

1) Diagnose forcing fields (SST, SSS, heat flux, evaporation, precipitation, and sea ice concentration) from the output of the NCAR-CCSM simulation at the LGM.

2) Force the MIT ocean model with the derived LGM boundary conditions and integrate it to a steady state. This is the one (relatively) expensive step in our procedure, but one well within our reach. To accelerate the adjustment to equilbrium, we will follow a conventional "robust diagnostic" approach in which temperature and salinity are restored (for the first several decades of the integration) to those in the coupled run.

3) Compute the transport matrix for the LGM circulation. This will be done at monthly mean resolution which should adequately resolve the seasonal cycle.

4) Simulate radiocarbon and Nd isotopes, and compare with records preserved in marine sediments.

We note that systematic model assessment and validation of the kind we propose to undertake requires an adequate observational data set. To facilitate this, Rutberg and Khatiwala are submitting a separate proposal to the Climate Center to compile a database of key paleocirculation proxy data. That parallel effort is an essential aspect of our long-term goal to build upon Lamont's traditional strengths in climate modeling and paleoceanography.

References

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Budget

1. We seek funds for a summer undergraduate intern to work on this project. Funds are requested for 8 weeks at $10 per hour, 35 hours per week. Amount: $2800. (A Columbia Applied Math major has previously worked with one us (SK) on tracer modeling and has extensive experience with the MIT GCM. She has expressed interest in continuing this research.)

2. We also request funds for a fast dual-processor workstation running Linux for performing the calculations and analyzing the output ($2500) and a large disk drive for storing model output ($500).

Total funds requested: $5800.