TRANSIENT, ACCELERATED, AND EQUILIBRIUM SIMULATIONS OF THE LAST 30kyr WITH GENIE-1

D.J. Lunt (1), M.S. Williamson (2), P.J. Valdes (1), T.M. Lenton (2)

(1) BRIDGE (Bristol Reasearch Initiative for the Dynamic Global Environment, University of Bristol, UK
(2) University of East Anglia, UK

d.j.lunt@bristol.ac.uk
www.bridge.bris.ac.uk

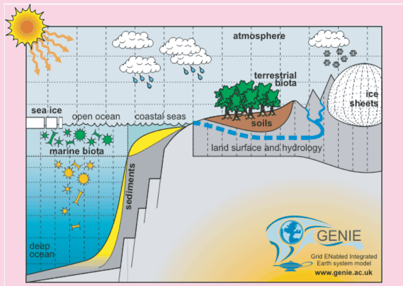
(1) INTRODUCTION

General Circulation Models (GCMs) have for many years been used to simulate paleoclimates. Typically, 'snapshot' equilibrium simulations of selected time-periods are carried out; that is, the boundary conditions do not vary with time. This is due to the computational expense of carrying out multi-millennial transient simulations.

One of the assumptions behind this methodology is that the Earth-system which is being represented is in equilibrium, or close to equilibrium, with its boundary conditions, at the time periods being considered. Here, we test this assumtion by comparing 30kyr transient simulations with equilibrium simulations, in particular of the Last Glacial Maximum (LGM, 21kyrBP), mid-Holocene (6kyrBP) and pre-industrial.

In order to overcome model speed limitations, some previous workers have employed an 'acceleration' technique for transient paleo simulations, in which the boundary conditions are accelerated by some factor, to compress the simulation. We assess the error this introduces in an AOGCM by carrying out an ensemble of transient simulations with different acceleration factors, and comparing them to an un-accelerated transient simulation.

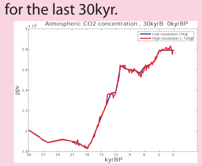
The tool we use is GENIE, an Earth system Model of Intermediate Complexity (EMIC). The 'flavour' of the model, GENIE-1, which we use consists of an energy-moisture balance atmosphere, a 3-dimensional frictional geostrophic ocean, dynamic and thermodynamic seaice, and a physical land-surface. The ice-sheet height and extent and the atmospheric CO2 concentration are both prescribed.

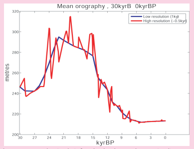


Schematic of the GENIE model, in its most comprehensive 'flavour'. Here we use the atmosphere, ocean, and land-surface components, with prescribed ice-sheets and atmospheric CO2.

(2) BOUNDARY CONDITIONS

We produce high-resolution and low-resolution timeseries for the last 30kyr.





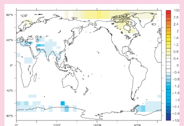
Prescribed boundary. conditions of CO2 (left) and icesheet orography (right), for the high-resolution (red) and low-resolution (blue) simulations

For the ice-sheets, we use the Peltier ice-sheet reconstructions for the time period 21kyr to present. We also make use of a 30kyr snapshot reconstruction from the STAGE3 project. To obtain a higher resolution timeseries, we interpolate using the Vostok d18O record.

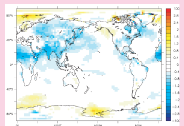
For the CO2, we use the Vostok record for the low resolution timeseries, and the DOME-C record for the high resolution timeseries

(3) VALIDATION OF SNAPSHOTS

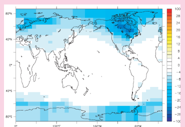
Initially, we carry out snapshot simulations every 3000 years. Here we compare our LGM and mid-Holocene results (anomalies form pre-industrial) with those from HadSM3.



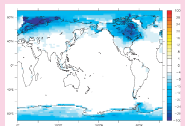
GENIE-1: 6kyrBP - pre-industrial



HadSM3: 6kyrBP - pre-industrial



GENIE-1: 21kyrBP - pre-industrial
(-4.7 K global annual mean)

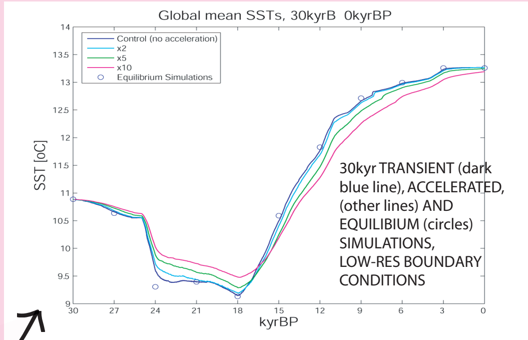


HadSM3: 21kyrBP - pre-industrial
(-3.7 K) global annual mean

The LGM anomalies are very similar. The largest difference is over the Fennoscandian icesheet becasue we have a constant land-sea mask. For the Holocene, HadSM3 exhibits significant cooling in the tropics, particularly over Saharan Africa and South Asia, linked to an intensification of the African and Asian monsoons. The change in these regions is much weaker in our model because our simplified atmosphere does not contain the necessary dynamics to have a realistic monsoon.

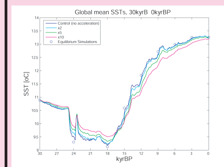
(4) TRANSIENT SIMULATIONS

We carry out 30,000 year transient simulations, using the boundary conditions shown in box (2). As well as the control, we carry out 3 additional simulations with varying degrees of acceleration (for example by squeezing the 30kyr of boundary conditions into 3kyr of simulation).



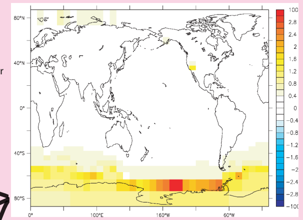
30kyr TRANSIENT (dark blue line), ACCELERATED, (other lines) AND EQUILIBRIUM (circles) SIMULATIONS, LOW-RES BOUNDARY CONDITIONS

The unaccelerated transient simulation (blue line) is nearly always close to equilibrium (circles) In particular, the LGM, mid-Holocene and pre-Industrial are all very close to equilibrium. This is good news for model-data comparisons, such as in the PMIP2 project, where the model is calculating an equilibrium solution.
As expected, the greater the acceleration, the greater the error relative to the non-accelerated simulation. The accelerated simulations behave in a damped fashion relative to the non-accelerated simulation, with a decrease in magnitude of temporal temperature gradient. The maximum errors in global-annual mean surface temperature occur after and during periods of relatively rapid change in the boumdary conditions, in particular the ongoing deglaciation between 15kyrBP and 9kyrBP and the sharp increase in land-ice fraction between 24 and 23kyrBP.



This plot is the same as above, but for the high-resolution boundary conditions. This shows that even with faster-varying boundary conditions, the model still stays very close to equilibrium throughout the 30kyr.

This plot shows the difference between the x10 accelerated run, and control, at the time of the LGM. It is the Southern Ocean which is producing the damping in the system in the accelerated simulations. In this region, the local surface temperature errors are of the order of 1 or 2K, being too warm during the cooling LGM and too cold during the warming mid-Holocene. This is the region with the greatest thermal inertia, due to the deep mixed-layer, and it reflects the slowly varying temperature of the deep ocean. Consequently, Antarctica also has a significant temperature error in the accelerated simulations. In contrast, the surface temperature in the Northern Hemisphere is in fact very well simulated in the accelerated simulations.



x10 ACCELERATION - CONTROL (LGM)

(5) CONCLUSIONS

In our model, the time period from 30kyrBP to pre-industrial is in very close equilibrium with the ice-sheet, CO2, and orbital boundary conditions, even with high temporal resolution (~0.4kyr) ice-sheets and (~120 years) CO2 This implies that the method of comparing equilibrium simulations with paleo data is not flawed in this respect (good news for PMIP-2!).

We find that the Southern Ocean and Antarctica are the regions most sensitive to the technique of bioundary -condition acceleration. However, the Northern Hemisphere is relatively insensitive to the acceleration. This implies that when comparing an accelerated AOGCM simulation to paleodata, the Northern Hemisphere comparison is likely to be more robust than the Southern Hemisphere comparison.

This work neglects the effects of some shorter-timescale transient events such as Heinrich events. See poster by Marsh et al next door!

Future work to include dynamic vegetation, ice-sheets and biogeochemistry (GENIE-fy and QUEST projects).