Modelling ocean circulation, climate and oxygen isotopes in the ocean over the last 120,000 years

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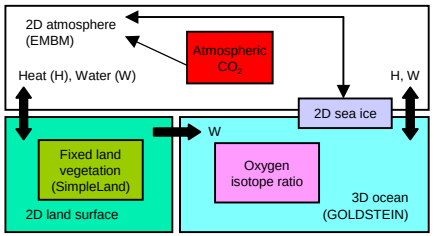
Abstract

A new Earth System Model of Intermediate Complexity, GENIE-1 (Lenton et al. 2006), is used to simulate the most recent glacial-interglacial (G-IG) cycle by prescribing orbital forcing, time evolution of ice sheet extent and orography (based on latest reconstructions), and atmospheric CO_2 concentration (from ice cores). The model features a 3-D ocean component in realistic geometry and topography, a 2-D Energy Moisture Balance atmosphere, thermodynamic sea ice, and a simple land scheme with fixed vegetation. A series of experiments are designed to investigate both model sensitivity and uncertainty in the amplitude, frequency and location of prescribed melt water pulses (MWPs) attributed to Heinrich Events. Associated with each MWP is a flux into the ocean of glacial oxygen isotope ratio that serves as a tracer of the melt water. Modelling forward from 120,000 years before present, benthic oxygen isotope records are simulated that can be directly compared with measurements taken from IMAGES and ODP sediment cores at four key locations. The experiments are a first step towards more complete modelling of climate and biogeochemical cycles over G-IG cycles.



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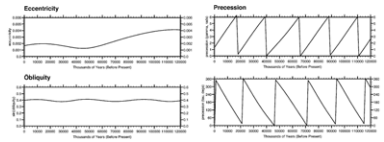
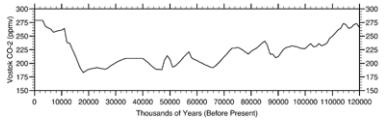
Model Experiment: "Background" boundary conditions

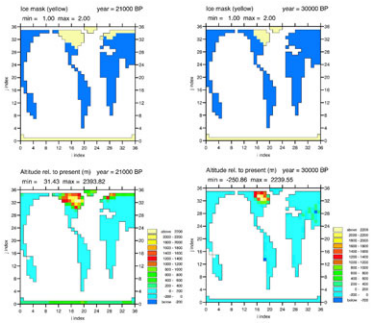
(1) Orbital forcing (Berger 1976)



(2) Vostok Atmospheric CO_2 (Petit *el al.* 1999)



(3) Reconstructed ice sheet extent and orography [Peltier (1994) 0-21 ky BP, tuned with Vostok $\delta^{18}O$, 21-120 ky BP] - examples at 21 ky BP and 30 ky BP on the model grid



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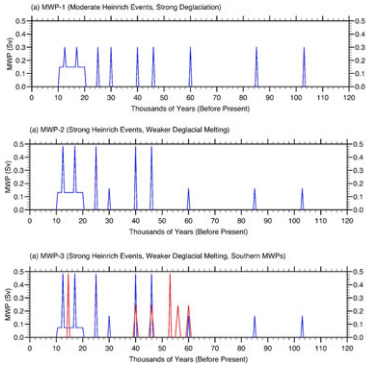
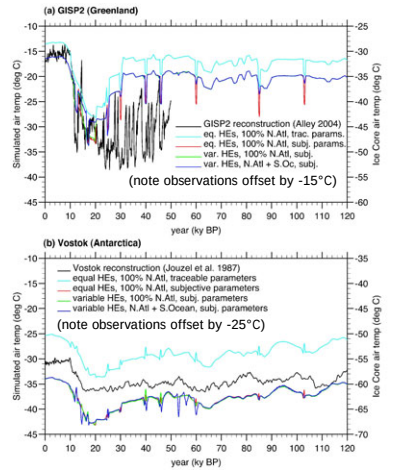
Model Experiment: Meltwater Pulses (MWPs)

MWPs specified into North Atlantic (blue spikes below) or Southern Ocean (red spikes below), based on proxy evidence for:

- Heinrich Events (Hemming 2004)
- Millennial Antarctic variability (Kanfoush *et al.* 2000)



Simulated air temperature versus reconstructions in Greenland (Alley 2004) & Antarctica (Jouzel *et al.* 1987)



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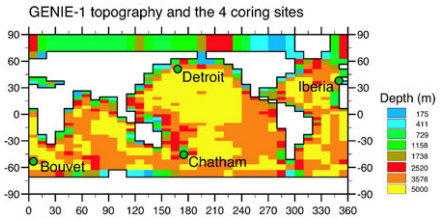
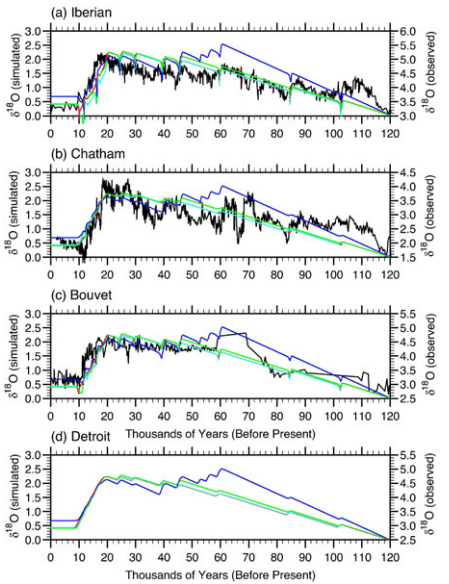
Simulated benthic $\delta^{18}O$ at selected coring sites

- Iberian Margin (IMAGES MD95-2042, Shackleton *et al.* 2000)
- Bouvet Island (ODP site 1094, Kanfoush *et al.* 2002)
- Chatham Rise (IMAGES MD97-2120, Pahnke *et al.* 2003)
- Detroit Seamount (ODP site 883, Kiefer *et al.* 2001)



How do the four experiments compare with the data?

Here simulated water $\delta^{18}O$ is plotted alongside the measurements of $\delta^{18}O$ in calcite (black lines, where available)



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Summary

- Calcite $\delta^{18}O$ measurements in cores around the World Ocean reveal glacial-interglacial (G-IG) changes in both ice sheets and climate, strongly influenced by Meltwater Pulses (MWPs), highly uncertain in location, timing & magnitude
- Low resolution EMIC forced by a range of MWPs (and changing boundary conditions) simulates themohaline circulation and climate over last 120 ky
- A limited number of experiments undertaken, as 120 ky simulations with even the low resolution EMIC presently take several days to complete
- Results are sensitive to model parameter set - "subjective" parameter set of Lenton *et al.* (2006) gives closer agreement to high latitude temperature reconstructions, and is subsequently used in MWP sensitivity experiments
- Marginally better agreement between simulated and core-measured $\delta^{18}O$ obtained with scenario MWP-3, which comprises variable Heinrich Events plus MWPs around Antarctica
- These results support the assertion of Rohling *et al.* (2004) that Antarctic ice sheets contributed substantially to glacial sea-level variability
- Much work lies ahead:
  - in the physical model, to incorporate changing winds (improving atmospheric moisture transport) and to better represent high latitude processes (particularly sea-ice)
  - in the isotopic modelling, to incorporate $^{16}O/^{18}O$ fractionation caused by physical (evaporation/condensation) and biological (calcification) processes

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