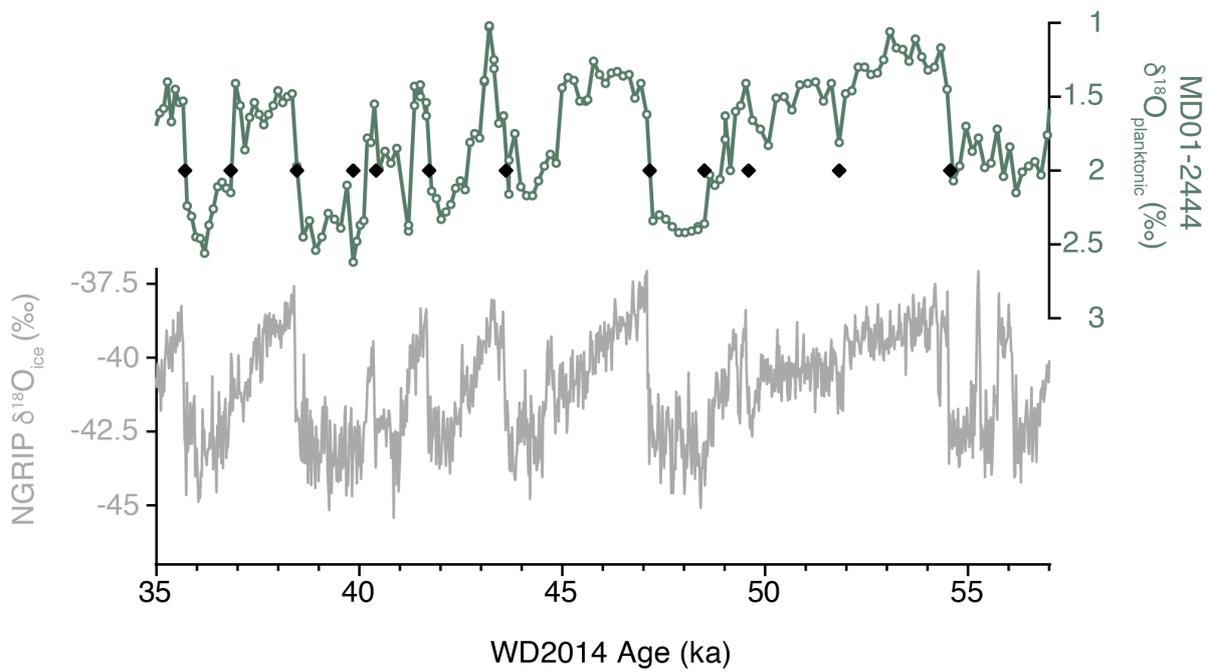Supplementary information for

Fast and slow components of interstadial warming in the North Atlantic during the last glacial

V. Margari, L. C. Skinner, L. Menviel, E. Capron, R. H. Rhodes, M. J. Mleneck-Vautravers[2],
M. M. Ezat, B. Martrat, J. O. Grimalt, D. A. Hodell, & P. C. Tzedakis

Correspondence to: v.margari@ucl.ac.uk and p.c.tzedakis@ucl.ac.uk

Supplementary Fig. 1. **MD01-2444 Age model**. Alignment of abrupt transitions in the planktonic $\delta^{18}O$ record to warming and cooling events in the NGRIP $\delta^{18}O_{ice}$ record[1], on the WD2014 timescale[2]. Tie points are indicated by diamonds.
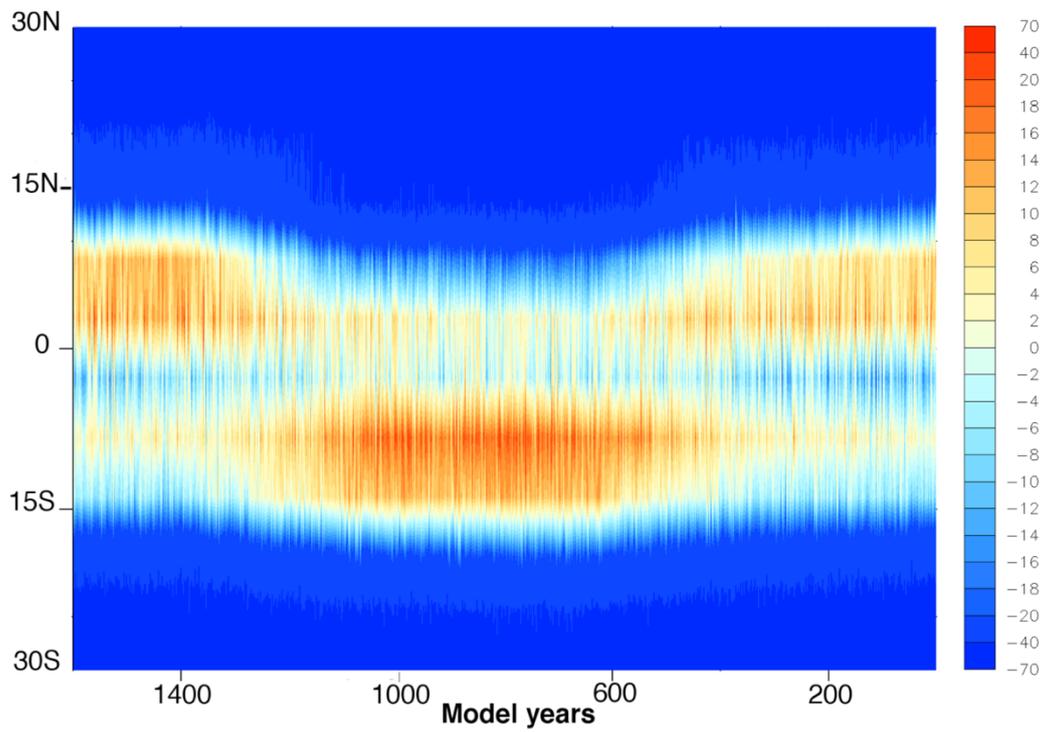
Supplementary Fig. 2. Hovmoeller diagram of precipitation anomalies (cm yr^{-1}) zonally averaged over the Atlantic. Anomalies are with respect to the mean precipitation zonally averaged over the Atlantic and over 15°S-10°N for the first 20 years of the simulation (40.00-40.02 ka).
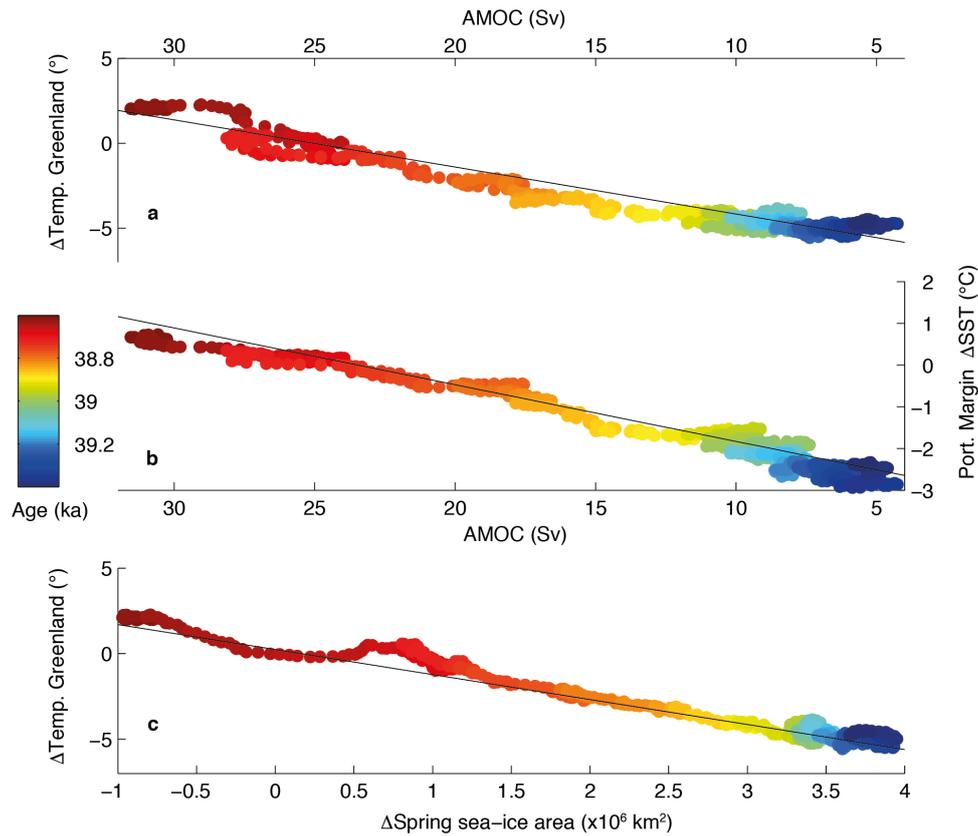
Supplementary Fig. 3. Relationships between different climate variables during the AMOC recovery phase (39.4-38.6 ka) from the HS4 experiment with LOVECLIM. a, AMOC changes (Sv) and annual mean Greenland air temperature (°C). **b,** AMOC changes (Sv) and Portuguese Margin SST (°C). **c,** changes in Northern Hemisphere spring sea-ice area (10^6 km^2) and annual mean Greenland air temperature (°C). Anomalies are calculated from the values at the beginning of the experiment (40 ka).
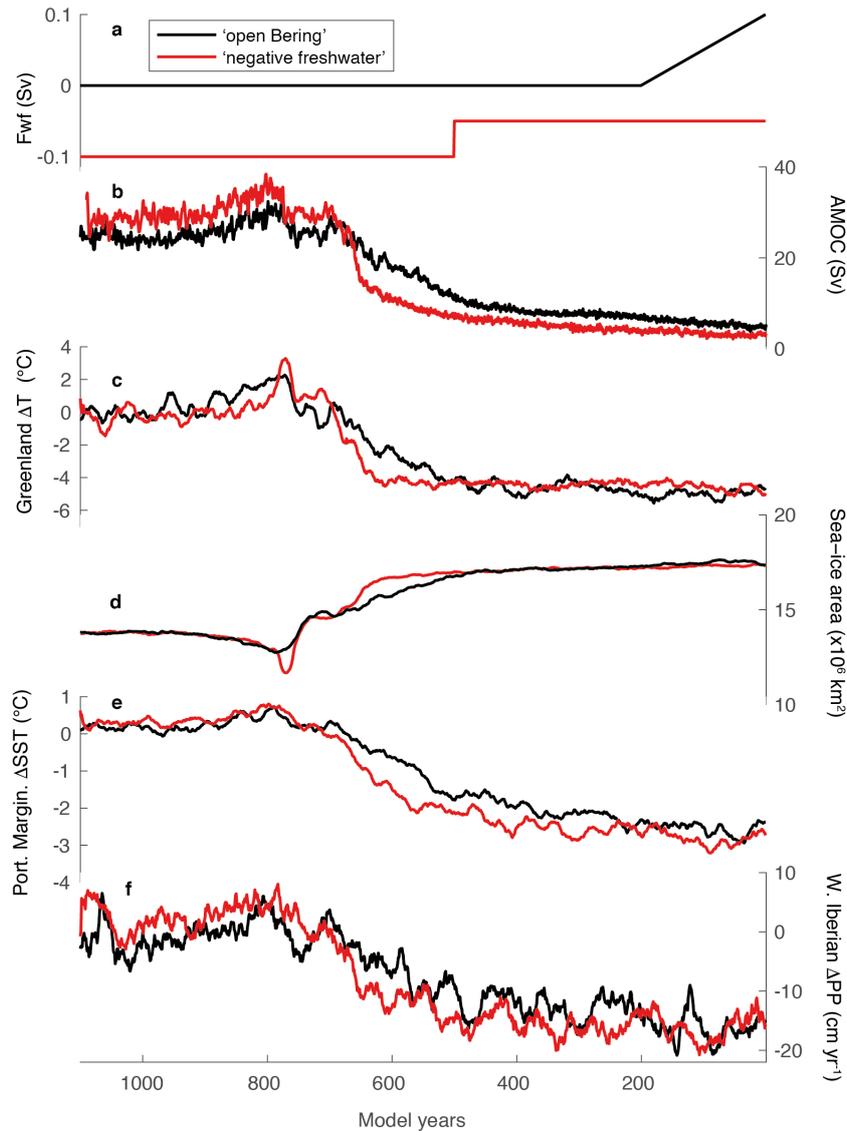
Supplementary Fig. 4. Comparison of AMOC recovery and associated climate changes in 'open Bering' and 'negative freshwater' HS4 experiments performed with the Earth system model of intermediate complexity LOVECLIM. a, freshwater input (Sv). **b,** monthly AMOC (Sv) with a 21-month smoothing. **c,** annual mean Greenland air temperature anomalies (°C). **d,** the annual mean sea-ice area integrated over the high northern latitudes (10^6 km^2). **f**, Portuguese Margin SST (°C, 15°W-8°W, 37°N-43°N). **f,** precipitation over western Iberia (cm yr^{-1}, 10°W-5°W, 36°N-43°N). A 21-year smoothing has been applied to timeseries in **c-f**.

Supplementary Table 1

Demarcation of stadial sections

	HS4		HS5	
	Onset (ka)	End (ka)	Onset (ka)	End (ka)
Mid-point of abrupt transition in $\delta^{18}O_{planktonic}$	40.15	38.50	48.58	47.18
Breakfit/Rampfit[3,4] $\delta^{18}O_{planktonic}$	40.20	38.50	48.80	47.20
Breakfit/Rampfit[3,4] XRF Zr/Sr	40.00	38.50	48.60	47.40

Supplementary Table 2

Estimates of duration of cooling and warming phases within HS4 and HS5

	HS4		HS5	
	Duration of cooling phase (yr)	Duration of warming phase (yr)	Duration of cooling phase (yr)	Duration of warming phase (yr)
Alkenone SST above mean stadial value*	200	500	150	500
XRF Zr/Sr Rampfit[3]	295	829	266	1348**

* The initial cooling and final warming phases represents the intervals during which alkenone SST are above mean stadial values of 12.1°C for HS4 and 12.5°C for HS5.

** The value is an overestimate as the Rampfit model takes the decrease in Zr/Sr at the time of the IRD peak as the start of the warming phase.

Supplementary Table 3

Summary of changes associated with the AMOC recovery in the HS4 'open Bering' experiment with LOVECLIM. The three phases are indicated in Fig. 6 of the main text.

Model years/ *model age (ka)*	Duration (yrs)	ΔAMOC (Sv)	ΔTemp. Greenland (°C)	ΔSea-ice area West (x10^{12} m^2) / (%)	ΔSea-ice area East (x10^{12} m^2) / (%)	ΔHeat Flux West (W m^{-2})	ΔHeat Flux East (W m^{-2})	ΔSST Portuguese Margin (°C)
600-1080 / *39.40-38.92*	480	6	0.4	0.2 / (*-6*)	-0.6 / (*-17*)	-10	40	0.9
1080-1300 / *38.92-38.70*	220	17.2	4.6	-1.6 /(*-44*)	-0.6 / (*-17*)	80	53	2
1350-1380 / *38.65-38.62*	30	6.2	2.5	-0.5 / (*-14*)	-0.7 / (*-19*)	40	60	0.5

Supplementary Methods and Notes

To examine the rates of change in different climate variables during the AMOC recovery, another experiment ('negative freshwater') with LOVECLIM was performed under similar HS4 background conditions, but with a closed Bering Strait throughout and different freshwater forcing: a meltwater pulse of 0.15 Sv was applied for 1000 years, followed by 200 years without any forcing. The recovery phase was induced by a negative freshwater flux of 0.05 Sv for 200 years and of 0.1 Sv after that. The recovery phases of the 'open Bering' and 'negative freshwater' experiments are shown in Supplementary Fig. 4. Similar to the 'open Bering' experiment, the 'negative freshwater' experiment first simulates a slow AMOC reinvigoration (+10 Sv) in ~500 years, with little warming over Greenland and a small SST increase off the Portuguese Margin. This is followed by a more abrupt (~100 years) AMOC increase (+18 Sv), sea-ice loss in the Nordic Seas and warming over Greenland (+ 5.6°C). An overshoot in AMOC occurs after another 80 years (+5 Sv) slightly preceded by a major loss of sea-ice and a 2.3°C increase in Greenland temperature.

Supplementary References

1. NGRIP Ice Core Project Members. High-resolution record of Northern Hemisphere climate extending into the last interglacial period. *Nature* **431**, 147-151 (2004).

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3. Mudelsee, M. Ramp function regression: a tool for quantifying climate transitions. *Comput. Geosci.* **26,** 293-307 (2000).

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