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Supporting Online Material for

The Deep Ocean During the Last Interglacial Period

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Supporting Online Material

Model description and experimental set-up

We use two different Earth System models of intermediate complexity: CLIMBER-2 and LOVECLIM.

CLIMBER-2 is a coarse-resolution fully coupled atmosphere-ocean-vegetation model designed for long-term simulations. It is composed of a 2.5-dimensional statistical-dynamical atmosphere, with spatial resolution of 10 degrees (latitude) and 7 sectors (longitude, approximately 51 degrees). The ocean model is composed of three zonally averaged basins (Atlantic, Indian, Pacific) on a 2.5 degrees latitudinal grid, with 20 uneven vertical layers. The Arctic and Antarctic oceans are parts of these three oceanic basins. The vegetation model is the VECODE dynamical terrestrial vegetation model (Brovkin et al., 1997) which computes plant fractions for trees and herbaceous (plus desert) from several atmospheric variables in each land grid-cell. The model is able to capture the main features of the modern climate (Petoukhov et al., 2000) as well as those of the LGM (Ganopolski et al., 1998) and compares favourably with paleoclimatic simulations with general circulation models (Kageyama et al., 2001).

In the version used here, LOVECLIM consists of three components coupled together: atmosphere, ocean, and vegetation. The atmosphere part is a global model at T21 resolution based on quasi-geostrophic equations, with additional parameterisations for the diabatic heating due to radiative fluxes, the release of latent heat, and the exchange of sensible heat with the surface (Opsteegh et al., 1998). The ocean is the CLIO three-dimensional, free surface, general circulation model coupled with a thermodynamical and dynamical sea-ice model (Goosse and Fichefet, 1999). The vegetation model is the same as the one included in CLIMBER-2, i.e. VECODE. LOVECLIM has been validated for the present-day climate (Driesschaert, 2005) and used to study the Last Glacial Maximum (Roche et al., 2006). In the present set-up it is similar to the ECBilt – CLIO version 3 coupled model used for last millenium and Holocene climate simulations (Goosse et al., 2005; Renssen et al. , 2005).

Both models are integrated under fixed 126ka B.P. insolation (Berger and Loutre, 1992) from the pre-industrial climate, used as control. The atmospheric CO_2 concentration is kept constant to allow for an easy comparison with the control sate. Models are integrated for 4,000 years, after which equilibrium is attained.

Results for the global climate

As a summary of the simulated LIG climate, Figure SI1 shows the LIG-CTRL temperature anomaly in Surface Air Temperature (SAT) for boreal summer (July) and winter (January). Although the resolutions of the two models are very different, the results are qualitatively identical. They mainly show the direct response to the orbital forcing, that is cooler winters and warmer summers, in response to increased seasonal cycle in insolation. This increased seasonal cycle is larger over the continents than over the oceans due to the larger thermal capacity of the latter. In two regions, the response is not a direct response to the insolation forcing. 1) The Arctic undergoes a year-round warming due to the reduction of summer sea-ice directly forced by the insolation and the large thermal inertia of the ocean. 2) The summer warming in the southern part of the Sahara desert is smaller than to the north or the south of this region. This is due to a change in land surface, with a colonisation of the desert by grasslands, as is observed during the Holocene. Hence the LIG climate obtained in both models favourably compares to both what is inferred from the data and from other simulations (e.g. Kaspar et al., 2005; Groll et al. 2005).

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Supporting Online Material figure captions

Fig. S1

Global January and July temperature anomalies (LIG – modern) simulated by CLIMBER-2 (in °C) and LOVECLIM. Fields are averaged over the last 100 years of the simulations. The upper panels are from CLIMBER-2, the lower ones from LOVECLIM. The left-hand column is for January, the right-hand one is for July.

Fig. S2

Annual mean temperature anomalies (LIG – modern) simulated by CLIMBER-2 in the Atlantic. Field is averaged over the last 100 years of the simulation.

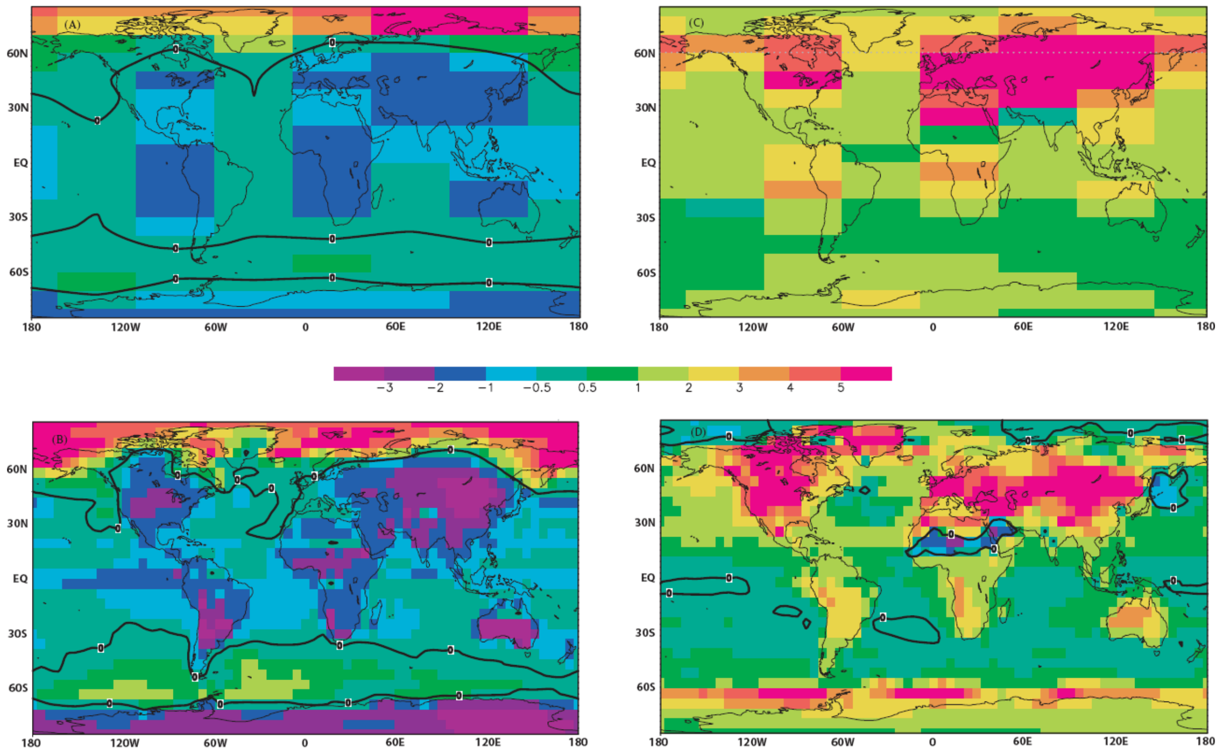
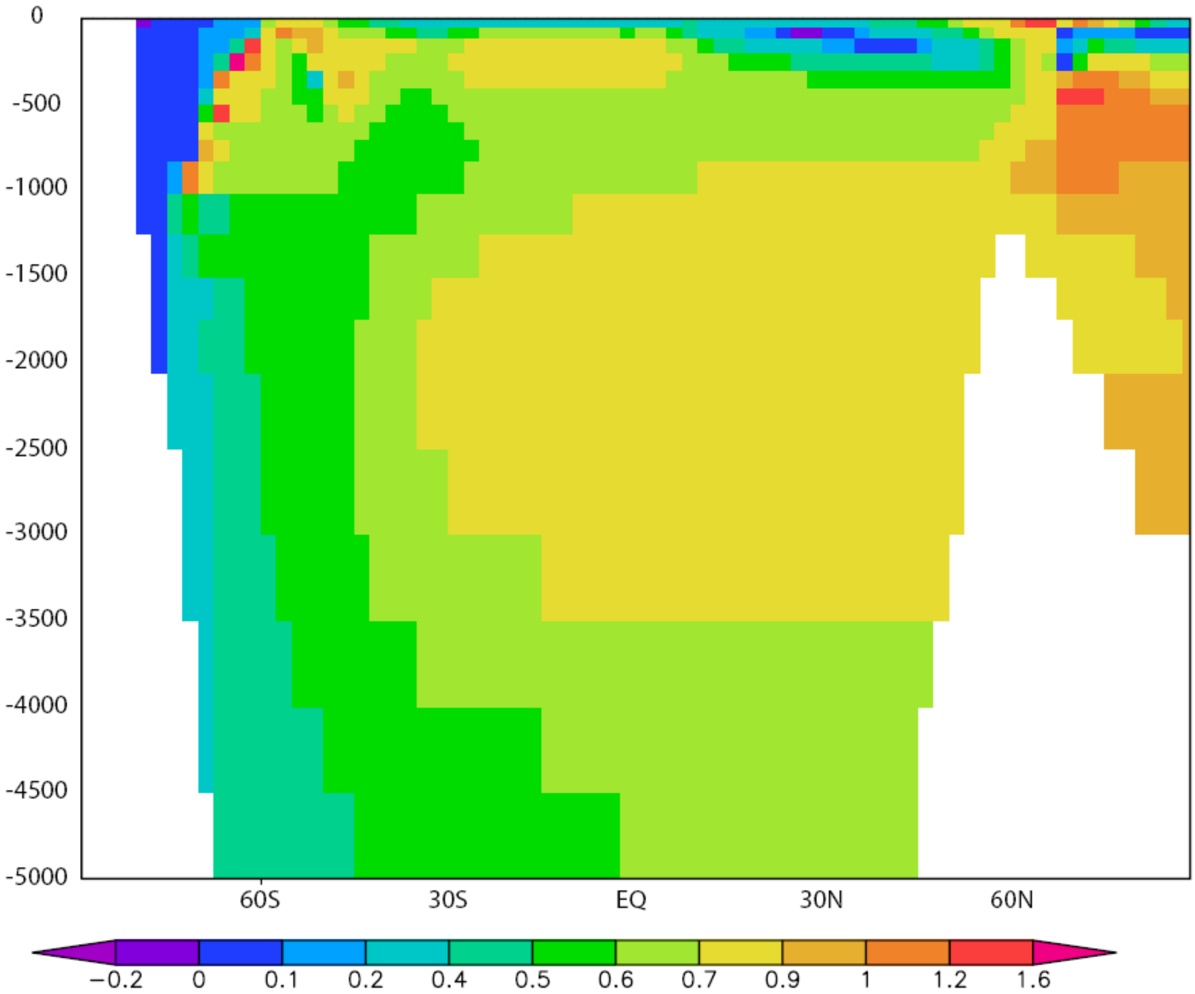

(A)
(B)
(C)
(D)
60N
30N
EQ
30S
60S
180
120W
60W
0
60E
120E
180
−3
−2
−1
−0.5
0.5
1
2
3
4
5

Figure S1



0
-500
-1000
-1500
-2000
-2500
-3000
-3500
-4000
-4500
-5000
60S
30S
EQ
30N
60N
−0.2
0
0.1
0.2
0.4
0.5
0.6
0.7
0.9
1
1.2
1.6

Figure S2

Table S1

Comparison of the oxygen isotope composition of benthic foraminifera from Holocene and LIG levels in the Nordic Seas, Atlantic and Southern Ocean cores.

Core	Latitude	Longitude	Water depth (m)	Holocene benthic $\delta^{18}O$ (permil)	Holocene benthic sigma $\delta^{18}O$ (permil)	LIG benthic $\delta^{18}O$ (permil)	LIG benthic sigma $\delta^{18}O$ (permil)	LIG - Modern $\delta^{18}O$ (permil)	Foram	
Nordic Seas										
V27-60	72,18	8,58	2525	4,47	0,05	4,33	0,08	-0,14	Cibicides	Gif data
K11	71,78	1,60	2900	4,42	0,04	4,36	0,03	-0,06	Cibicides	Gif data
V28-38	69,38	-4,40	3411	4,46	0,02	4,23	0,07	-0,23	Cibicides	Gif data
HM 57-7	68,72	-15,33	1620	4,55	0,03	4,35	0,12	-0,20	Cibicides	Fronval, 1997
23065-2	68,50	0,82	2802	4,47	0,07	4,35	0,07	-0,12	Cibicides	Vogelsang, 1990 thesis
V 27-86	66,60	1,12	2900	4,57	0,08	4,37	0,03	-0,20	Cibicides	Gif data
MD 95-2009/NA81-10	63,22	-4,00	1027	4,55	0,08	4,45	0,05	-0,10	Cibicides	Gif data
Atlantic										
V 28-14	65,31	-31,17	1855	3,22	0,11	3,07	0,24	-0,15	Cibicides	Shackleton, pers. Comm
MD 95-2014/SU 90-33	60,57	-22,07	2397	3,58	0,06	3,40	0,06	-0,18	Cibicides	Gif data
SU 90-33	60,56	-22,07	2370	3,58	0,06	3,49	0,02	-0,09	Cibicides	Gif data
ENAM 97-09	55,47	-18,14	2452	3,28	0,13	3,21	0,03	-0,08	Cibicides	Gif data
NA 87-25	55,20	-14,74	2320	3,21	0,11	3,19	0,15	-0,03	Cibicides	Gif data
MD 95-2003	55,15	-14,75	2365	3,19	0,05	3,09	0,00	-0,11	Cibicides	Gif data
NA 87-26	54,81	-14,79	2300	3,15	0,05	3,11	0,10	-0,04	Cibicides	Gif data
V29-191/NA 87-26	54,44	-18,39	2370	3,15	0,05	3,11	0,14	-0,04	Cibicides	Gif data
SU 90-38	54,08	-21,07	2900	3,29	0,07	3,24	0,11	-0,05	Cibicides	Gif data
M 23414	53,89	-22,64	2196	3,47	0,18	3,30	0,15	-0,17	Cibicides	Jung data Kiel
M 23415	53,31	-21,86	2472	3,29	0,11	3,20	0,09	-0,09	Cibicides	Jung data Kiel
NEAP 18K/M23418	52,77	-30,34	3275	3,39	0,04	3,27	0,06	-0,12	Cibicides	Chapman &

										Shackleton, 1999, geology, 27, 795-798
SU 90-39	52,56	-21,94	3955	3,40	0,05	3,25	0,08	-0,15	Cibicides	Gif data
M 23416	51,94	-20,00	3616	3,35	0,07	3,14	0,10	-0,21	Cibicides	Jung data Kiel
SU 90-44	50,02	-17,10	4279	3,29		3,19	0,05	-0,10	Cibicides	Gif data
SU 90-11	44,06	-40,02	3645	3,45	0,10	3,22	0,06	-0,23	Cibicides	Gif data
CHN 82-24-4	42,19	-34,36	3427	3,29	0,04	3,17	0,06	-0,13	Cibicides	Boyle & Keigwin, EPSL 76 135-150 1985/86
MD 03-2697	42,16	-9,69	2164	3,09	0,11	3,01	0,10	-0,08	Cibicides	Gif data
CHN 82-31-11 PC	42,00	-32,00	3209	3,20	0,23	3,08		-0,12	Cibicides	Boyle & Keigwin, Science, 218, 784-787, 1982
CH 69-K09 T	41,75	-47,34	4100	3,46	0,09	3,24	0,12	-0,22	Cibicides	Gif data
V 30-97	41,00	-34,22	3371	3,16		2,96	0,08	-0,20	Cibicides	Mix & Fairbanks, EPSL 73, 231-243, 1985
MD 95-2037	37,09	-32,03	2159	2,96	0,10	2,87	0,07	-0,09	Cibicides	Gif data
CHO 288-54	17,41	-77,65	1020	2,89	0,08	2,62	0,09	-0,27	Cibicides	Gif data
V 22-197	14,28	-20,14	3167	3,28	0,14	3,29	0,04	0,01	Cibicides	Shackleton, pers. Comm
V 25-59	1,61	-35,31	3824	3,20	0,10	3,07	0,05	-0,13	Cibicides	Mix & Fairbanks, EPSL 73, 231-243, 1985
RC 13-228	-22,33	11,20	3204	3,20	0,04	3,13	0,13	-0,07	Cibicides	Shackleton, pers. Comm
Southern Ocean										
MD94-101	-42,5	79,417	2920	3,38	0,06	3,46	0,09	0,08	Cibicides	Gif data
MD94-102	-43,5	79,833	3205	3,48	0,02	3,41	0,11	-0,07	Cibicides	Gif data
MD84-527	-43,817	51,317	3269	3,46	0,15	3,55	0,12	0,09	Cibicides	Gif data
MD88-770	-46,017	96,45	3290	3,68	0,06	3,65	0,12	-0,03	Cibicides	Gif data
MD88-769	-46,067	90,1	3420	3,69	0,02	3,55	0,11	-0,14	Cibicides	Gif data
MD 00-2374	-46,04	96,48	3250	3,44	0,06	3,38	0,05	-0,06	Cibicides	Gif data
MD84-528	-46,167	53,067	3408	3,66	0,12	3,61	0,08	-0,05	Cibicides	Gif data
MD02-2488	-46,49	88,02	3420	3,56	0,06	3,46	0,07	-0,10	Cibicides	Gif data
MD80-304	-51,067	67,733	1930	3,63	0,01	3,56	0,10	-0,06	Cibicides	Gif data

References for Table S1

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Table S2:

Data-model comparison for the Norwegian Sea, the Atlantic Ocean and the Southern Ocean. First column: mean LIG-modern benthic $\delta^{18}O$ anomaly; second column: standard deviation on the anomalies computed from all measurements; third column: error estimate for the average anomaly. Fourth and fifth column: mean LIG-modern benthic $\delta^{18}O$ anomaly, corrected for the ice volume change effect, and associated error estimate. Last four columns: mean temperature and salinity anomalies computed assuming a constant density (see text) and associated error estimates. The CLIMBER model results in $\delta^{18}O$, temperature and salinity and the LOVECLIM results for temperature and salinity are given for comparison. The salinity simulated by the models has been corrected for the global LIG to present-day change in mean salinity due to higher sea-level.

	LIG -Modern $\delta^{18}O$ anomaly (permil)	statistical error for individual core (permil)	statistical error for water mass (permil)	mean $\delta^{18}O$ anomaly (permil)	error on $\delta^{18}O$ anomaly (permil)	mean LIG deep water T anomaly (°C)	mean LIG deep water S anomaly (psu)	error on deep water T anomaly (°C)	error on deep water S anomaly (psu)
Norwegian Sea	-0.15	0.06	0.02	-0.11	0.04	0.58	0.07	0.20	0.03
Atlantic Ocean	-0.11	0.07	0.01	-0.07	0.03	0.37	0.04	0.20	0.02
Southern Ocean	-0.04	0.08	0.03	0.01	0.04	0.05	0.00	0.20	0.02
CLIMBER-2									
Norwegian Sea				-0.16		0.58	0.037		
Atlantic Ocean				-0.12		0.47	0.04		
Southern Ocean				-0.06		0.27	-0.006		
LOVECLIM									
Norwegian Sea						0.68	0.05		
Atlantic Ocean						0.46	0.09		
Southern Ocean						0.06	0.003		