

Supplementary Information to

Cosmogenic radiocarbon production and glacial cycles control marine radiocarbon archive variations

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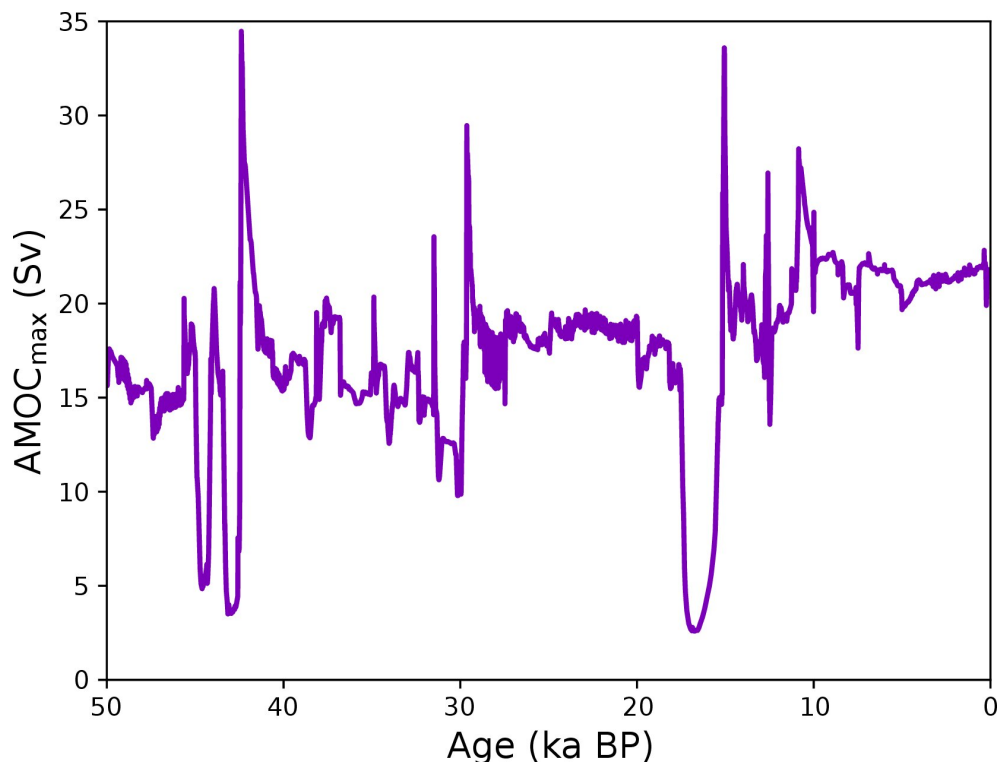


Figure S1. Time series of the meridional overturning circulation in the Atlantic (AMOC). Shown is the maximum of the meridional streamfunction northward of 30°S below 700 m simulated by CLIMBER-X in this study. The long-term average is 17 Sv with a standard deviation of 4 Sv. Most of the AMOC oscillations are unrelated to real Heinrich or Dansgaard-Oeschger events. Except for Heinrich Stadial 1 (HS1, 15.0 - 17.5 ka BP), these events are not captured by the PaleoMIST reconstruction which has a temporal resolution of 2500 years while CLIMBER-X considers interpolated values in between.

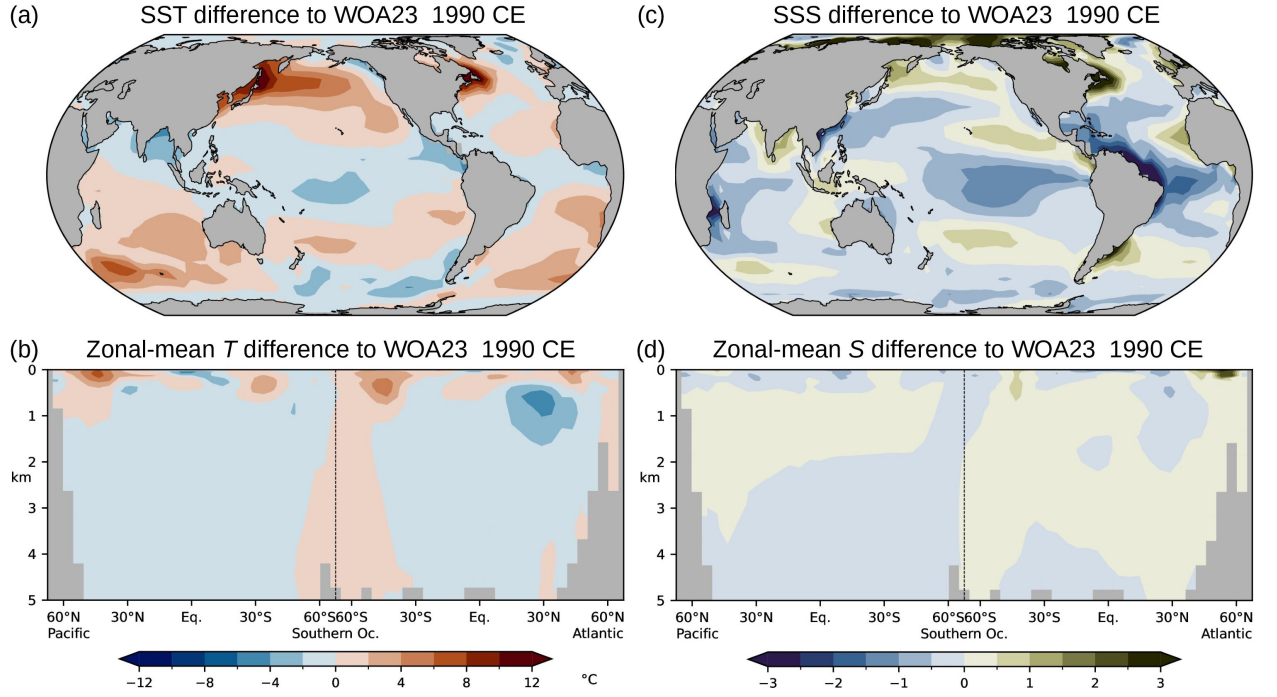


Figure S2. Comparison of simulated and observed temperatures and salinities. Shown are differences with respect to values from World Ocean Atlas 2023 (WOA23, Ref. 1, 2) remapped to the spatial resolution of CLIMBER-X. (a): Sea surface temperature (SST). (b) Zonal-mean temperature (ZMT) in the Atlantic and Pacific. (c) Sea surface salinity (SSS). (d) Zonal-mean salinity (ZMS) in the Atlantic and Pacific. Simulation biases (differences of the mean values, δ) are $\delta_{SST} = 0.43^\circ\text{C}$, $\delta_{ZMT} = -0.23^\circ\text{C}$, $\delta_{SSS} = 0.1$, and $\delta_{ZMS} = 0.01$. Regional simulation uncertainties are summarized in terms of root mean square errors (RMSE) and correlation coefficients (r). For temperature we obtain $RMSE_{SST} = 2.0^\circ\text{C}$, $RMSE_{ZMT} = 1.51^\circ\text{C}$, $r_{SST} = 0.982$, and $r_{ZMT} = 0.979$. Regional salinity uncertainties amount $RMSE_{SSS} = 1.8$, $RMSE_{ZMS} = 0.37$, $r_{SSS} = 0.718$, and $r_{ZMS} = 0.854$.

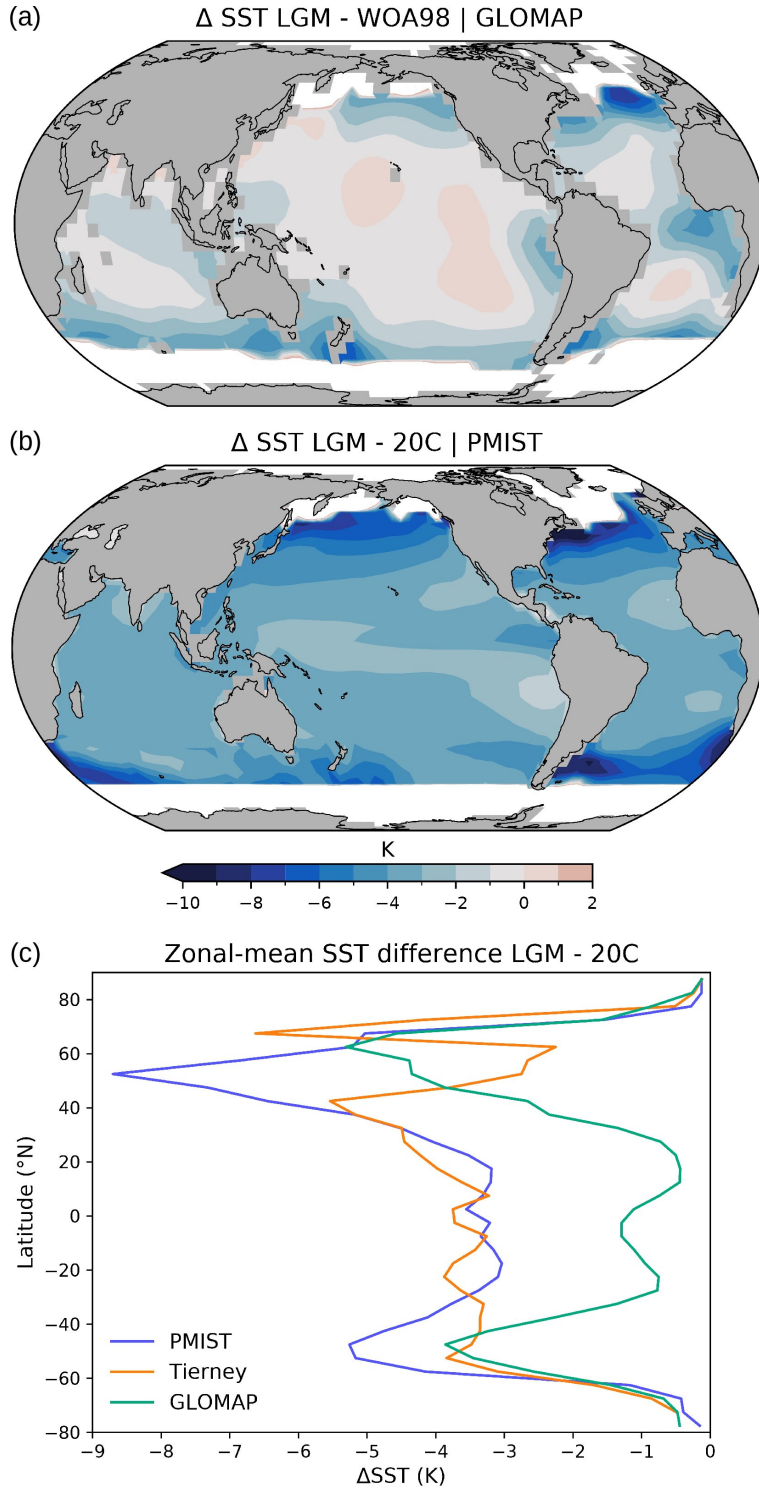


Figure S3. Annual-mean sea surface temperature differences (Δ SST) between the Last Glacial Maximum (LGM, 19 - 23 ka BP) and the 20th century (20C). (a): GLOMAP reconstruction³, reference temperatures are from World Ocean Atlas 1998 (WOA 1998, Ref. 4) . (b): This study. White areas in the top and middle panel indicate the annual-mean maximum sea ice extent at the LGM. (c): Zonally averaged Δ SST values, blue curve: this study. Different to the original publication considering the reference period 0 - 4 cal ka BP, Δ SST values by Ref. 5 have been recalculated relative to WOA 1998 for direct comparison with GLOMAP values. SST and sea ice reconstructions have been remapped to the spatial resolution of CLIMBER-X.

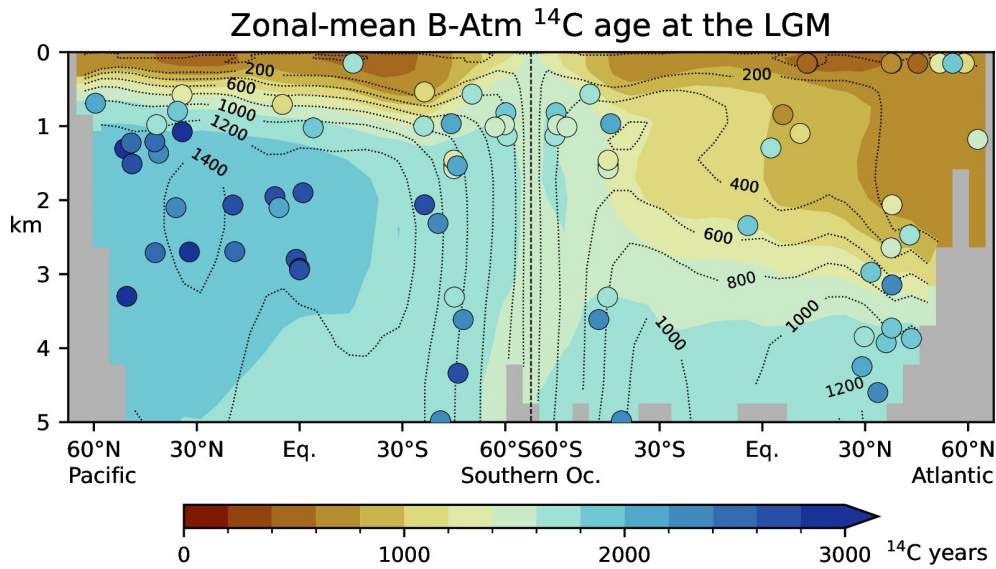


Figure S4. Simulated and reconstructed benthic-atmospheric ^{14}C ages at the Last Glacial Maximum. Shown are values in the Atlantic and Pacific. Shaded areas are zonal-mean results averaged over 19.0 - 21.8 ka BP (this study, simulation IntSH20). Dots are observations between 19.0 and 21.8 ka (compiled by Ref. 6; see further references therein). See Table S1 for numerical uncertainty values. Dotted contour lines and numbers indicate benthic-planktic ^{14}C ages (also simulation IntSH20); contour interval is 200 ^{14}C years.

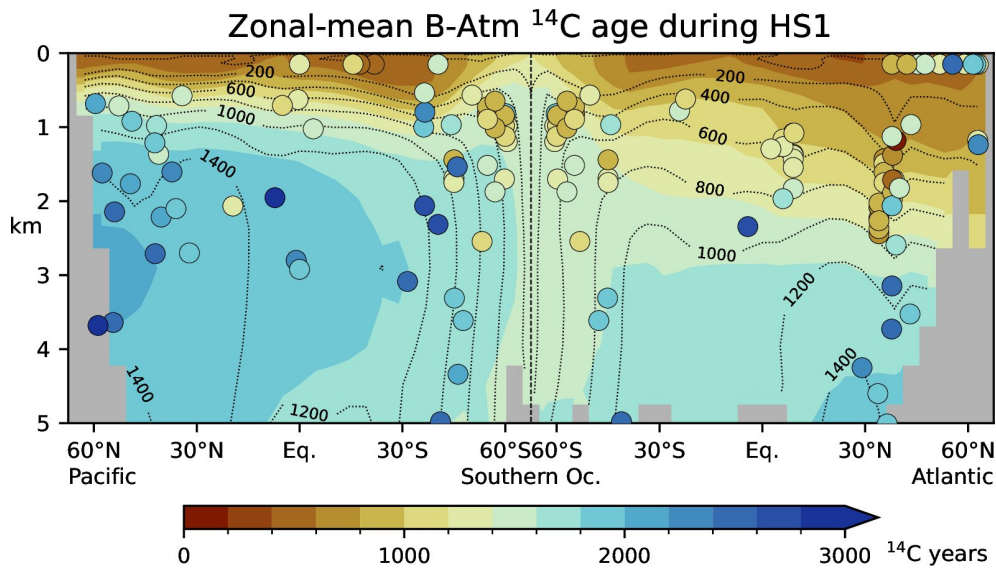


Figure S5. Simulated and reconstructed benthic-atmospheric ^{14}C ages during Heinrich Stadial 1. Shown are values in the Atlantic and Pacific. Shaded areas are zonal-mean results averaged over 15.0 - 17.5 ka BP (this study, simulation IntSH20). Dots are observations between 15.0 - 17.5 ka (compiled by Ref. 6; see further references therein). See Table S1 for numerical uncertainty values. Dotted contour lines and numbers indicate benthic-planktic ^{14}C ages (also simulation IntSH20); contour interval is 200 ^{14}C years.

Table S1 | Uncertainty of ^{14}C simulation results with respect to observations

Variable	Figure	δ	RMSE	r
$\Delta^{14}\text{C}$ near corals, CLIMBER-X	2a	-7	40	0.912
$\Delta^{14}\text{C}$ nears, LSG	2b	-25	45	0.922
MRA ~1950 CE	3a	25	127	0.609
MRA ~1990 CE	3b	-108	439	0.682
MRA during the LGM	3c	-379	653	0.416
B-Atm ^{14}C age ~1950 CE, IntSH20	4a	92	185	0.991
B-Atm ^{14}C age ~1950 CE, SpinHist	4b	82	189	0.990
B-Atm ^{14}C age ~1990 CE, IntSH20	4d	85	207	0.997
B-Atm ^{14}C age ~1990 CE, SpinHist	4e	82	184	0.998
B-Atm ^{14}C Age at the LGM	S4	-483	649	0.753
B-Atm ^{14}C Age during HS1	S5	-192	535	0.520

Biases (= the difference in means, δ) and root-mean square errors (RMSE) are in ^{14}C years, except for $\Delta^{14}\text{C}$ where uncertainties are reported in ‰; r is the Pearson correlation coefficient. Uncertainty values for Figures S4 and S5 are illustrative rather than exact as zonally averaged model results are compared with observations at different longitudes.

Supplementary References

1. Locarnini, R. A. *et al.* World Ocean Atlas 2023, Volume 1: Temperature.
<https://doi.org/10.25923/54bh-1613> (2024).
2. Reagan, J. R. *et al.* World Ocean Atlas 2023, Volume 2: Salinity.
<https://doi.org/10.25923/70qt-9574> (2024).
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4. Levitus, S. NODC Standard Product: World Ocean Atlas 1998 (7 disc set). (2012).
5. Tierney, J. E. *et al.* Glacial cooling and climate sensitivity revisited. *Nature* **584**, 569–573 (2020).
6. Skinner, L. *et al.* Rejuvenating the ocean: mean ocean radiocarbon, CO₂ release, and radiocarbon budget closure across the last deglaciation. *Climate of the Past* **19**, 2177–2202 (2023).