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Modelled equilibrium LGM seawater temperatures inconsistent with plankton biodiversity

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The Last Glacial Maximum (23,000 – 19,000 years ago; LGM) is the most recent time when Earth's climate was fundamentally different from today. The LGM hence remains a prime target to evaluate climate models outside current boundary conditions. Evaluation of paleoclimate simulations is usually done using proxy-based reconstructions. However, such reconstructions are indirect and associated with marked uncertainty, which often renders model-data comparison equivocal. Here we take a different approach and use macro-ecological patterns preserved in fossil marine zooplankton to evaluate simulations of LGM near-surface ocean temperature.

We utilise the distance-decay pattern in planktonic foraminifera to evaluate modelled temperature gradients. Distance decay emerges because of differences in habitat preferences among species that cause the compositional similarity between assemblages to decrease the further apart they are from each other in environmental space. Distance decay is a fundamental concept in ecology and is observed in many different taxa and ecosystems, including planktonic foraminifera that show a monotonous decrease in similarity with increasing difference in temperature. Because the ecological niches of planktonic foraminifera are unlikely to have changed since the LGM, the distance-decay relationship based on simulated LGM temperatures and LGM assemblages should in principle be identical to the modern distance decay pattern. Thus we can use fossil planktonic foraminifera species assemblages to evaluate climate model simulations based on ecological principles.

Our analysis is based on an extended new LGM planktonic foraminifera database (2,085 assemblages from 647 unique sites) and a suite of 10 simulations from state-of-the-art climate

models (PMIP3 and 4). We find markedly different planktonic foraminifera distributions during the LGM, primarily due to the equatorward expansion of polar assemblages at the expense of transitional assemblages. The distance-decay pattern that emerges when the LGM assemblages are combined with simulated ocean temperatures is different from the modern pattern. All simulations suggest large thermal gradients between regions where the planktonic foraminifera indicate no, or only weak, gradients. This pattern arises from the pronounced shift to polar species assemblages in the North Atlantic where the simulations predict only moderate cooling. In general, the models predict spatially rather uniform cooling, whereas the microfossil evidence suggests more pronounced regional differences in the temperature change. The difference between reconstructions and the simulations reaches up to 10 K in the North Atlantic.

Importantly, simulations with a reduced AMOC and hence lower North Atlantic near sea surface temperatures, yield a distance-decay pattern that is much more similar to the modern pattern. The planktonic foraminifera assemblages thus question the view of the LGM ocean as an equilibrium response to external forcing.