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Climate of the Past
Discussions

Interactive comment on "Rapid waxing and waning of Beringian ice sheet reconcile glacial climate records from around North Pacific" *by* Zhongshi Zhang et al.

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Dear Julie,

Thanks for the review. Although we are not surprised that you suggest rejecting our paper, we are happy to have a chance to discuss with you. We would like to use this chance to show our respects to your important contributions, the sediments from Lake El'gygytgyn, in understanding past climate evolution over Beringia.

Please allow us to ask you three questions.

1) How to resolve the conflicts in the perennial lake-ice explanation? Let us take two

stages, MIS3b, MIS10c. The Lake El'gygytgyn records show different sedimentological facies in these two stages, glacial facies in MIS10c, but interglacial facies in MIS3b. However, summer insolation, greenhouse gas levels, and the total NH ice volume (indicated from the benthic d18O) are very similar in these stages, indicating similar surface temperatures over NE Siberia-Beringia. With similar climate conditions, why did the glacial facies appear in MIS10c, but the interglacial facies in MIS3b. This conflict should be resolved if the lake-ice explanation is reasonable. The lake-ice explanation highly depends on the assumption that no gaps exist in these sediments in glacial facies. However, this is not the case, bringing uncertainties in the lake-ice explanation. (Please also see our reply below.)

We appreciate that you admit that ice sheet can develop on the East Siberian continental shelf, at least during some stages, for example MIS6. You also suggest that a wetter condition in MIS6 (than in LGM) is the key for understanding the larger ice sheet during MIS6. This suggestion already includes one conflict. Very similar external climate forcing should cause similar precipitation in MIS6 and LGM over Beringia. Our second question is related to this wetter condition explanation.

2) How to resolve the conflicts between MIS6 and MIS4? MIS6 and MIS4 have similar low summer insolation, while the greenhouse gas levels are higher in MIS4. These climate forcings lead to a wetter condition over Beringia in MIS4 than MIS6. Did the ice sheet develop over the continental shelf in MIS4? If the answer is no, it means precipitation is not the major controller for the ice sheet growth over NE Siberia-Beringia. If the answer is yes, to some extent it falls in conflict with the ice-free Wrangel Island.

The following conclusion is taken from a recent study (Bakker et al., 2020). "In most of the examined PMIP LGM simulations, Siberia receives less precipitation; however, we do not find indications that the buildup of a Siberian ice sheet was hampered by the absence of precipitation." From modelling side, we already know that the precipitation is not the key forcing for understanding glaciations over Beringia.

3) Why is a good simulation of LGM Laurentide-Eurasia-only ice sheet a pre-condition for understanding climate over Beringia? One example is the simulation from Abe-Ouchi et al., 2013. This simulation well reproduces the Laurentide-Eurasia-only ice sheet in LGM. However, this simulation shows that NE Siberia-Beringia is totally ice-free during the past four glacial-interglacial cycles, without any mountain glaciers or ice on the continental shelf, in conflict with direct evidence. This simulation is a good example that does not support your suggestion.

We have to admit that the interpretations of direct glacial or climate evidence from NE Siberia-Beringia are highly controversial. Please allow us to point out the uncertainties in the perennial lake-ice explanation in Lake El'gygytgyn. Lacking absolute age controls and based on a tuned age model, it is difficult or uncertain to identify gaps within these sediments in glacial facies. When we review the high-resolution magnetic susceptibility stratigraphy from core PG1351, we at least can find gaps at $\sim$310 cm (tuned in MIS4), $\sim$680 cm (tuned in MIS6c-b), $\sim$900 cm (tuned in MIS6e). In Site 5011-1, the sediments in glacial facies include turbidites (Sauerbrey et al., 2013). In a permanent frozen land and lake, what process causes these gaps and mass movements? It is obvious that these gaps and mass movements bring uncertainties in the lake-ice explanation, but often neglected. The second example is the evidence you listed in the review, the mammoths' fossils on Wrangel Island from 48 ka to nearly 3400 years ago (Vartanyan et al., 1993). The explanation of this evidence depends on the temporal resolution in age controls. Wrangel Island is in the marginal of the BerIS. On Wrangel Island, ice cover lasts only 1-2 kys. When the Beringian ice sheet reaches its peak, it will melt rapidly, and Wrangel Island exposes. Without age controls in a high temporal resolution, it is difficult to know whether there are small gaps with mammoths' fossils missing on the island. Therefore, it remains uncertain to use ice-free Wrangel Island to indicate the nonexistence of the BerIS. It is possible that Wrangel Island is ice-free, while a substantial BerIS remains on the NE Siberian-Beringian continents. As we wrote in the paper, "partly due to poor age controls, it remains highly controversial whether the glacial evidence points towards a pre-LGM ice sheet over NE Siberia-

Beringia or local activities of ice domes/sheets on continental shelves and mountain glaciers on continents."

Did a BerIS once exist? To answer the question, we should put each piece of evidence (not only the direct glacial evidence) into one framework, without conflicts. Since the direct evidence cannot really answer the question, we turn our eyes to investigate the continuous climate records with precise age controls.

Our simulations indicate that the Laurentide-Eurasian ice sheets alone (even the ICE6G reconstructed) fail in explaining these paleoclimate records from around the North Pacific, whereas the fast waxing and waning of the BerIS success. This is the added value of our study. The physical mechanism behind is the interactions between ice sheets and mid-latitude climates, which are revealed in Fig 4.

It is easy, but quite unfair, to use modelling uncertainties to reject a modelling study. When compared to the map (Figure 63.2) from Glushkova, 2011, and the map (Figure 33.1) from Kaufman et al., 2011, our simulated BerIS is reasonable. However, simulations always include unavoidable uncertainties. These uncertainties should be improved and further constrained with more models in future. "Although the above uncertainties in the ice sheet modelling should be revisited in future studies to archive more realistic simulations for past ice sheet evolutions, these uncertainties do not influence the main logic in this study." Our purpose is not to unequivocally resolve the ice sheet limits, but to find which ice sheet scenario can well reconcile climate evidence from around the North Pacific.

In summary, there are many conflicts in the current interpretations of direct glacial evidence over NE Siberia-Beringia and the mainstream concept of Laurentide-Eurasia-only ice sheets. "The reconciliation cannot be achieved through the growth of ice domes on the NE Siberian continental shelf or mountain glaciers on the NE Siberian continent, since the small-scale glaciations across NE Siberia-Beringia cannot cause strong climate feedbacks to match the paleoclimate records from around the North

Pacific.

It is now too early and simplified to reject the possibility of the BerIS, before these conflicts are well resolved in the concept of Laurentide-Eurasia-only ice sheets together with mountain glaciers over NE Siberia-Beringia.

If you have more criticisms or comments, please let us know.

Regards

Zhongshi on behalf of all co-authors

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