OVERVIEW

The Last Interglacial (LIG) is an important analog for current climate changes, but terrestrial LIG sites are scarce. This manuscript provides a detailed review and paleoclimatic analysis of LIG deposits from lacustrine sediments found in permafrost settings at a series of sites in northern coastal Russia. This is a major synthesis and update, building upon fieldwork conducted over the past 25 years and a remarkably wide-ranging suite of paleoclimatic and paleoecological proxies. (Many prior papers have been published from these sites, this work also serves as a review and synthesis of these papers.) Highlights include new age estimates, new paleoclimatic reconstructions from a wide variety of proxies, and comparisons of the proxy data to paleoclimatic simulations.

This work is also highly valuable given the current geopolitical situation and difficulty of conducting fieldwork in Russia. For at least the next several years, these observations are essentially irreplaceable.

In some ways, this reads as more of a 'Quaternary' paper than a 'paleoclimate' paper, given that the paper includes extensive detail about the stratigraphic sections and ecological interpretations in addition to the paleoclimatic reconstructions. All of the proxies presented provide useful information about local environments and ecosystems, but not all are directly relevant to past climatic interpretations. This paper is very long and very detailed, but its discussion is thorough and all lines of evidence are carefully weighed and integrated.
Thank you for the very encouraging feedback in the overview. We hope that our work will contribute to a better understanding of the MIS 5e interglacial in the Arctic.

I provide below a few comments on the individual proxy-based (and model-based reconstructions), some of which may require revisions to the analyses. These are followed by minor line-by-line comments and see also the attached PDF for recommended edits to make minor grammatical fixes, shorten wording, and sharpen some phrasings.
We have carefully read all the comments and proposed changes in the PDF and have incorporated many of them. Thank you very much.

PROXY-BY-PROXY COMMENTS

Some of the climatic reconstructions are based on the Mutual Climate Range approach (for plants, insects), which is a fairly crude way to derive temperature estimates (Table 2, page 20). But the MCR-based results agree well with each other and other approaches.
Therefore, we believe that even coarser reconstruction approaches, if they are comparable to others, are worth using here.

The pollen-based climatic reconstructions use a modern pollen training dataset that spans the Northern Hemisphere, including Eurasia and North America. I recommend redoing these analyses to remove the North American samples, because they mostly represent different species with somewhat different climatic tolerances from their Eurasian counterparts.
We already used a modern pollen training dataset, including Eurasia and North America, for the pollen-based climate reconstructions (e.g., Andreev et al., 2021). The results show that if we remove the North American pollen spectra from the modern pollen dataset, it does not change the results. Moreover, the North American samples contain the same pollen taxa, although these pollen taxa are produced by different plant species. Basically, the Eurasian and

North American species have similar climatic tolerances, the possible differences are rather insignificant for pollen-based climate reconstructions.

Andreev, A. A., Raschke, E., Biskaborn, B. K., Vyse, S. A., Courtin, J., Böhmer, T., Stoof-Leichsenring, K., Kruse, S., Pestryakova, L. A. and Herzschuh, U. (2021): Late Pleistocene to Holocene vegetation and climate changes in northwestern Chukotka (Far East Russia) deduced from lakes Ilirney and Rauchuagytgyn pollen records, Boreas 50 (3), 652-670. https://doi.org/10.1111/bor.12521

Additionally, the pollen-based climatic reconstructions also do not indicate whether a minimum SCD threshold was used to remove or flag no-analog samples, i.e. fossil samples likely to have no modern analogue. This no-analog analysis and thresholding should be performed.

We have carried out the dissimilarity analysis requested to identify possible non-analog samples. W created plots for the two locations, "Bol'shoy Lyakhovsky Island" and "Oyogos Yar Coast" (Figure S2)

There is only one sample for which no close modern analogs were found (OY7-8B s4 600), but the minimum dissimilarity is still below the 5% threshold that is usually applied to non-analogs.

We added this sentence in the method chapter:

"The dissimilarity analysis shows very high-quality analogs. All samples are below the 5% threshold, which corresponds to "good analogs"; the majority of the samples even have "close analogs" (threshold < 1%). "

The barplot shows the number of analogs found – the higher the bar, the more modern analogs were found for the corresponding sample.

It's exciting to see that sedaDNA analyses were performed at a core in this site, but it's not clear what is added by these analyses. No attempt is made to make a paleoclimatic inference based on the sedaDNA data (this is probably wise). Grouping the aeDNA results into functional groups is reasonable (Figure 7, p. 21) but misses a lot of the interesting ecological detail. Recommend adding a figure that shows the stratigraphic occurrences of the taxa described in the text on p21, at maximum feasible taxonomic resolution.

Even though we refrain from paleoclimatic reconstructions, comparisons among pollen, macrofossils, and *sed*aDNA have shown that the three proxies contain complementary information and only together provide the most accurate picture. This is highlighted by our sedaDNA results challenging the previous northern distribution limits reconstructed, for example, for *Larix* and *Picea*, thus adding value of this proxy to the overall manuscript.

We hope the following clarification strengthens our approach and addresses your concerns (added to page 22, L22-29):

"We refrain from paleoclimatic inferences as *sed*aDNA (compared to traditional proxies like pollen assemblages) provides only qualitative or semi-quantitative assemblage information, is rather local in the origin of the signals, and the lack of taxonomic resolution to species level in many taxa hampers the accurate inference of past temperatures. However, the northern distribution limit of *Larix* is clearly spatially linked to the 10–12.5°C isotherm (based on its modern ecology (MacDonald et al. 2008)), and the co-occurrence of *Picea* (likely *P. obovata*) suggests an active layer depth of at least 1.5–2 m (Tchebakova et al. 2009). Thus, our results align with other proxy reconstructions presented in this study, supporting the interpretation of warmer-than-present temperatures during the Last Interglacial (LIG)."

Tchebakova et al 2009 Environ. Res. Lett. 4 045013; DOI 10.1088/1748-9326/4/4/045013

MacDonald et al. 2008 Phil. Trans. R. Soc. B 363, 2285–2299; doi:10.1098/rstb.2007.2200

We appreciate your suggestion regarding the inclusion of a figure showing the stratigraphic occurrences of taxa at the highest feasible taxonomic resolution. We would like to note that Zimmermann et al. (2017) has previously published such figures open-access. Given this, we focused our presentation on functional groupings to emphasize broader ecological patterns while avoiding redundancy.

We added the following sentence to the caption of Figure 7:

"For detailed stratigraphic co-occurrences of all taxa at the highest feasible taxonomic resolution, see Zimmermann et al. (2017)."

Similarly, the ostracode and mollusk analyses (pp12-13) are interesting but do not contribute to the paleoclimatic reconstructions shown here. Delete or move to supplementary information?

We believe that both proxies provide important information for paleoenvironmental reconstruction during the MIS 5e interglacial. In particular, the thermokarst landscapes with lakes would not have been possible without the greatly elevated paleotemperatures during this period. Furthermore, the ostracods and bivalves as proxies provide basic information that is important for the clumped isotope studies.

We suggest highlighting that the reviewer may have misunderstood or missed our use of these specimens. The ostracod and bivalve analyses were used for paleoclimate reconstruction; some temperature information and water oxygen isotope compositions were derived from these specimens. using clumped isotopes.

Paleoclimatic simulations often include a spin-up period, during which the model is in a transient state that is artificially influenced by the starting conditions. Was this spin-up period removed prior to calculating climatological means from the simulations?

The model spin-up procedure, as part of the PMIP4 protocol, recommends spin-ups similar to those of the PIcontrol simulations for all participating models. Details about the spin-up procedures employed by the different modeling groups are discussed where the simulations were discussed in separate, special papers (e.g., for HadGEM (https://cp.copernicus.org/articles/16/1429/2020/), ACCESS (https://cp.copernicus.org/articles/17/869/2021/), EC-Earth (https://gmd.copernicus.org/articles/14/1147/2021/) or AWI-CM). However, there is no conclusive overview. However, for all models with available details, we can confirm that the modeling groups did not submit their spin-up simulation results to the ESGF, so the spin-up data was not included in the analysis. We assume that none of the modeling groups submitted spin-up data to the ESGF labeled as PMIP4 simulations.

Also, for the paleoclimatic simulations: On P13, L23-27, I can't quite follow this description of the calculation of the anomalies, which seems to repeat the subtraction used to calculate the anomalies, when it should only be performed once.

In general, we follow the procedure suggested in the IPCC AR6 and also applied, e.g. by Otto-Bliesner et al., where we use the climate change signal from the PMIP models, which are calculated with reference to the pre-industrial simulations of the models to determine their paleoclimate. In order to derive absolute values for the LIG from these climate change signals, we have to add the observed pre-industrial to the climate change signals.

The calculations are admittedly complicated, which stems mainly from the fact that the database for the observed pre-industrial climate is only available as an anomaly itself, and not

as absolute values, which requires using another dataset that delivers the mean climate of the reference period used in the anomaly calculation for the pre-industrial climate. We have altered the text in the manuscript to describe the process more clearly, and added a formula in the supplement that shows how the absolute model values for comparison with the proxy data were derived.

LINE-BY-LINE COMMENTS

P2L2-4: Long sentence, awk
We've changed that to two sentences.
"Fossil proxy records in Last Interglacial (LIG, ca. 130-115 ka) lacustrine thermokarst deposits now preserved in permafrost can provide insights into terrestrial Arctic environments during a period when northern hemisphere climate conditions were warmer than today. This period might be considered a potential analog for a near-future warmer Arctic."

P2L31-33: Model results are presented as anomalies but all proxy-based reconstructions earlier in this paragraph are presented as absolute values, making it difficult to compare the model-based and proxy-based results.
We have included the absolute values derived from the models in the abstract to allow easy comparison.

P2L36: Again, proxy-model mismatch is highlighted here, but the exact magnitude and nature of the mismatch is unclear.
This was fixed by adding the absolute temperature values derived from the models as well as the present-day values for comparison to modern conditions.

P2L36: What does 'more systematic' mean?
"More systematic" means a reconstruction approach for the paleoproxies that is as comparable as possible.

P3L7: 'promote' is present tense but prior sentences in past tense. Check for verb tense consistency throughout ms.
Thank you very much. We have corrected this error.

P3L19-20: Add ref(s) here to support LIG as analog for future, e.g. (Burke et al. 2018; Gulev et al. 2021; Otto-Bliesner et al. n.d., 2)
Thank you very much. We have added the quotations.
"The globally warmer-than-today Last Interglacial (LIG, ca. 130-115 ka) (Wilcox et al., 2020) is commonly seen as a potential analog for future climate warming (Burke et al., 2018; Gulev et al., 2021; Otto-Bliesner et al., 2013)."

P3L26-27: reduced ice sheet – reduced by how much?
This is meant as a general statement and should not be supported by specific data here.

P3L35: A data-model mismatch is invoked here as if already introduced to the reader, but so far no data-model mismatch has been described. Instead, the paper describes data-model agreement earlier in the paragraph.
Thank you for this comment. We state that there is a general agreement from modelling studies and proxies analyzed for the LIG earlier in the introduction. What we refer to here are

mismatches on a local scale, like shown in our study. However, since this is not the focus here, the sentence was moved to the discussion about the mismatch between MTWA from models and from proxies in section 5.3.

P4L9: 'were conducted'… by who? Unclear if this is introducing work by the authors or reviewing the broader literature.
The references are listed one line below:
"Both the southern coast of Bol'shoy Lyakhovsky Island near the Zimov'e River mouth and the Oyogos Yar mainland coast near the Kondrat'eva River mouth have been studied for LIG pollen, plant macrofossils, fossil insect remains including beetles and chironomids, lacustrine invertebrates such as ostracods, cladocera, and mollusks, and testate amoebae and sedimentary ancient DNA (Andreev et al., 2004, 2011; Ilyashuk et al., 2006; Kienast et al., 2008, 2011; Wetterich et al., 2009; Schneider, 2010; Zimmermann et al., 2017). However, only scarce chronological control is available (Andreev et al., 2004; Opel et al., 2017) for lacustrine deposits, which are locally named the Krest-Yuryakh stratum (Tumskoy and Kuznetsova, 2022) and commonly interpreted as deposits of the LIG, i.e., MIS 5e (Eemian)."

P9L5: Italicize Rumex and all other genus and species names.
Thank you very much. We have corrected all the taxonomic names that were not yet in italics.

P6 Figure 1: Recommend replacing the 1-16 site labels with the site codes used in Figure 2. Right now there is no easy way to look between Figures 1 & 2 and understand which sites are which. Or, add the numeric codes in Fig. 1 to Fig. 2.
Due to a lack of space, the site codes from Figure 2 cannot be entered in Figure 1. Therefore, we decided to write the numbers from Figure 1 in parentheses before the site codes in Figure 2.

P7 Figure 2: What is a 'taberal' deposit?
We have added this explanation to the caption for Figure 2:
"Taberal deposits means thawed and refrozen permafrost deposits."

P16 Table 1: A couple of the numbers are using commas instead periods to indicate decimal places.
Thank you. This has been corrected.

P18L21: 'relatively' – relative to what?
We changed the sentence to "Based on the quite high percentage of *Larix* pollen, …"

P19L2: avoid 'optimum' when referring to a peak in temperature. Any given temperature will be optimum for some species and suboptimal or adverse for others.
It is not about a specific peak temperature, but rather about the general shift of the tree line during the peak LIG.

P22L6: Is Morychus viridis a steppe species? This is implied but unclear.
Yes, *M. viridis* lives today on a specific type of short grass steppe – hemicryophytous steppe (Berman et al., 2001).
Berman, D. I., Alfimov, A.V., Mazhitova, G. G., Grishkan I. B., Yurtsev, B. A., 2001. Cold steppe in north-eastern Asia. Dal'nauka, Vladivostok, 183. (in Russian)….

P22L8: Which 'other Pleistocene samples' – those at the site, worldwide, or other domain? Unclear.

It concerns other samples from our study area. The sentence has been modified to clarify this point:
Several identified thermophilous steppe species … are absent in other Pleistocene samples from our sites (Andreev et al., 2004, 2009; Kiselev and Nazarov, 2009),

P26L15: Should A. Kossler be invited to be a co-author, given their intellectual contribution in identifying molluscs and the large interdisciplinary team?
A. Kossler was co-author of the cited paper by Kienast et al. (2011). While preparing the manuscript, we have tried to contact Anette Kossler several times, unfortunately without success.

P28L13-14: agreement with each other? Agreement with the proxy data?
We have completed the sentence: "The PMIP models show the highest agreement with each other over the sea and the lowest agreement over the continental grid cells."

P33-34, Table 7:
*Recommend moving the ERA reanalysis data to the top row for each region, so that this modern reference is clearly established as the basis of comparison for all the paleoestimates.
Done
*Also note that the ERA reference is for 1990-2019, which already includes >1-2C of anthropogenic warming. Consider also adding a row with a temperature estimate for the early 20th century or pre-industrial period.
Thank you for this suggestion. We have added the PIobs values to the table.
*For numbers with a +/- uncertainty estimate, does this represent one or two standard deviations? Clarify in table legend.
We have added a description of the uncertainties to tables 6 and 7.

P34, Fig. 12: Recommend a standard order of first showing the modern values, then the paleoclimatic simulations, then the proxy results. This ordering will better clarify the distinction between paleoclimatic simulations vs. proxy data. Among the proxy results, I suggest moving the clumped isotopes to the bottom of the order, because they represent different variables than the other proxies.
We have changed the order of the data sets such that the data from Bol'shoy Lyakhovsky now come before the data from Oyogos Yar and the clumped isotope data are at the bottom. The further internal order (modern, simulation, proxy) should be retained.

P37L7-10: Another reason why pollen is unlikely to be an important source of aeDNA is a mass effect: the total biomass of airborne pollen rain is very low to all local aeDNA sources, so any pollen-sourced aeDNA is swamped out.
Yes, that is correct. We have added the following sentence:
"Moreover, the relatively low biomass contribution of pollen, combined with its limited endogenous chloroplast DNA content, likely results in the dilution or loss of any *sed*aDNA signal derived from pollen (Also et al., 2024)."

REFERENCES CITED

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