Dear Editor and Reviewers:

On behalf of the co-authors, we are very grateful to you for giving us an opportunity to revise our manuscript. We really appreciate your positive and constructive comments together with suggestions on our manuscript entitled 'BrGDGTs-based seasonal paleotemperature reconstruction for the last 15,000 years from a shallow lake on the eastern Tibetan Plateau' (MS No.: cp-2023-32). We have therefore studied reviewers' comments carefully and tried our best to revise our manuscript accordingly. Notably, the changes are highlighted in red in the revised manuscript. Please see below for a point-by-point response to the reviewers' comments and concerns.

Responds to the comment of Reviewer#2:

Hou and coworkers have generated a temperature record for the Tibetan Plateau (TP) covering the last 15.000 years. The record is based on branched GDGTs in Lake Gahai, and is compared with other temperature records from the TP to evaluate spatial patterns in the temperature evolution. They find that there are many distinct temperature patterns on the TP and suggest that people need to study their proxy well before interpreting the record.

The paper is clear and well written., but I have some recommendations that will hopefully take the paper one step further.

General recommendations:

The authors currently only discuss the trends in their record, but they do not discuss absolute values, despite the fact that they spend an entire section of the discussion on considering different calibrations. I would like to read more on how the brGDGT-based temperatures relate to the other temperature records. And see the absolute changes in the record interpreted. For example, is the 10 C temperature difference in the record realistic? And why (not)? And if true, what are the implications for our understanding of the climate during the last deglaciation at the TP?

Response: Thanks for your meaningful comments. Our study reconstructed the mean temperature of Months Above Freezing in Gahai lake using a new Bayesian calibration (Martínez-Sosa et al., 2021). The results of this reconstruction indicate temperatures higher than the annual average temperature and lower than the average temperature of summer months (June to August). The average annual temperature in the Gahai region is 1.2°C, and the average temperature during the summer months is 9.9°C. The temperature we reconstructed using surface sediments is 8.8°C, which aligns with the mentioned conditions.

As for the absolute temperature changes since 15,000 yr, although some influential studies indicate a warming of approximately 6.1-7°C from the deglaciation onset to preindustrial times (Tierney et al., 2020; Osman et al., 2021). However, these results are based on global mean sea surface temperatures. Our reconstructed temperature range is about 10°C, considering the remarkable ‘elevation-dependent warming’ observed in high-altitude regions compared to low-altitude areas (Mountain Research Initiative EDW Working Group, 2015). Thus, this range could be accurate. Nevertheless, we do not rule out the possibility that our temperature reconstruction may exhibit an overestimation. This is a known issue in temperature reconstruction using biomarkers. Aside from potential uncertainties associated with the biomarkers themselves, calibrations may also significantly influence the observed amplitude. We examined temperature variations reconstructed using different calibrations (Fig. S3), with the smallest range being 6°C and the largest being 12°C. Undoubtedly, further efforts are needed to constrain the inherent uncertainties related to biomarker-based temperature reconstructions.

Our preliminary idea is that using regional or global transfer equations for temperature reconstruction may potentially lead to similar issues. Instead, conducting site-specific calibration for temperature reconstruction may help reduce the amplitude of temperature variability.

Reference:

Martínez-Sosa, P., Tierney, J.E., Stefanescu, I.C., Dearing Crampton-Flood, E., Shuman, B.N., Routson, C., 2021. A global Bayesian temperature calibration for lacustrine brGDGTs. Geochimica et Cosmochimica Acta 305, 87-105.

Mountain Initiative EDW Working Group, 2015. Elevation-dependent warming in mountain regions of the world. Nature Climate Change 5, 424-430.

Osman, M.B., Tierney, J.E., Zhu, J., Tardif, R., Hakim, G.J., King, J., Poulsen, C.J., 2021. Globally resolved surface temperatures since the Last Glacial Maximum. Nature 599, 239-244.

Tierney, J.E., Zhu, J., King, J., Malevich, S.B., Hakim, G.J., Poulsen, C.J., 2020. Glacial cooling and climate sensitivity revisited. Nature 584, 569-+.

Comment: As mentioned in the previous comment there is a lot of discussion on which calibration to use, but in the end the currently available and widely-accepted calibrations (i.e., the ones that use both 5-methyl and 6-methyl brGDGTs) are all based on MBT’5me and will thus generate the same record, except for the values on the temperature axis. Instead of discussing all the possible calibrations, including those based on outdated chromatography methods, or on lake systems that are not comparable to the one targeted here (e.g., saline lakes, East African Lakes with limited seasonality), I would rather like to see more discussion on the drivers of brGDGT production in this specific lake. In my opinion it is clear that brGDGTs in lakes are mostly produced in situ, and are sensitive to O2 availability and redox conditions, which in turn is often related to the mixing regime, trophic state, and/or depth of the lake (e.g., Weber et al., 2018 PNAS, van Bree et al., 2020 Biogeosciences, Wu et al., 2021 Chem. Geol). A good understanding of where and when brGDGTs are produced in the lake, and how this is related to temperature, provides support for the selection of the 'right' transfer function.

Response: We thank Reviewer for the meaningful comments and suggestions. We have made revisions to this section based on the reviewers'2# comments, mainly emphasizing the specific status of lake Gahai and elaborating on our utilization of the calibration from Martínez-Sosa et al. (2021).

For a detailed description, please refer to the following introduction.

Gahai is a shallow lake in the eastern Tibetan Plateau that is typically completely frozen during winter and spring. Local meteorological data indicate that the average snowfall period lasts for 269 days, with around 50 days of continuous snowfall (Luqu County Local Chronicles Compilation Committee, 2006). The freezing of the lake surface begins in late October each year and gradually thaws starting from May of the following year. As a result, the light transmittance and oxygen content in the lake water are reduced during the freezing season, leading to decreased nutrient levels, which severely hinder the growth of autotrophic microorganisms. Although the bacteria responsible for producing brGDGTs have not been thoroughly characterized, the abundance of heterotrophic bacteria will likely decrease due to the reduced autotrophic biomass during the winter and spring ice-covered period. The weakened light penetration, decreased oxygen levels, and lack of nutrient replenishment during the frozen period significantly impact the growth of autochthonous microorganisms. While the specific bacterial species responsible for brGDGT production are not yet well understood, it is known that these bacteria, as heterotrophic organisms, will also be influenced by the reduction in autotrophic biomass. Furthermore, some research suggests that the production of brGDGTs might be related to factors such as water depth, seasonal alternation of water column mixing and stratification (Loomis et al., 2014; van Bree et al., 2020). During the summer and autumn seasons when the lake ice melts and the water becomes more mobile, the nutrient content increases, resulting in elevated lake biomass, moreover, the oxygen levels at the bottom of Gahai lake are not expected to be too high, which could further contribute to the proliferation of brGDGT-producing bacteria, potentially leading to an increase in the brGDGT-producing bacteria (Weber et al., 2018). Therefore, brGDGTs in Gahai lake may provide records of the average temperature during the ice-free months of the summer and autumn seasons.

Additionally, the presence of the frozen lake surface during winter creates a thermal barrier, impeding the exchange of heat between the lake water and the atmosphere. Consequently, any brGDGTs generated within the lake water during this period lose their ability to accurately reflect atmospheric temperature variations (Sun et al., 2021; Zhang et al., 2022). Thus, they were no longer able to track atmospheric temperature changes during the frozen season.

So, we prefer to use Gahai brGDGTs to reconstruct temperatures during the summer and ice-free seasons. For this purpose, we employed the new Bayesian calibration for the mean temperature of the Months Above Freezing, as proposed by Martínez-Sosa et al. (2021), to derive a warm-biased temperature for Gahai lake.

Reference:

Luqu County Local Chronicles Compilation Committee., 2006. Luqu County Chronicles. Gansu Cultural Publishing House, Lanzhou. pp. 71.

Loomis, S.E., Russell, J.M., Heureux, A.M., D'Andrea, W.J., Sinninghe Damsté, J.S., 2014. Seasonal variability of branched glycerol dialkyl glycerol tetraethers (brGDGTs) in a temperate lake system. Geochimica et Cosmochimica Acta 144, 173-187.

Martínez-Sosa, P., Tierney, J.E., Stefanescu, I.C., Dearing Crampton-Flood, E., Shuman, B.N., Routson, C., 2021. A global Bayesian temperature calibration for lacustrine brGDGTs. Geochimica et Cosmochimica Acta 305, 87-105.

Sun, Z., Hou, X., Ji, K., Yuan, K., Li, C., Wang, M., Hou, J., 2022. Potential winter-season bias of annual temperature variations in monsoonal Tibetan Plateau since the last deglaciation. Quaternary Science Reviews 292.

van Bree, L.G.J., Peterse, F., Baxter, A.J., De Crop, W., van Grinsven, S., Villanueva, L., Verschuren, D., Sinninghe Damsté, J.S., 2020. Seasonal variability and sources of in situ brGDGT production in a permanently stratified African crater lake. Biogeosciences 17, 5443-5463.

Weber, Y., Sinninghe Damste, J.S., Zopfi, J., De Jonge, C., Gilli, A., Schubert, C.J., Lepori, F., Lehmann, M.F., Niemann, H., 2018. Redox-dependent niche differentiation provides evidence for multiple bacterial sources of glycerol tetraether lipids in lakes. Proc Natl Acad Sci U S A 115, 10926-10931.

Zhang, C., Zhao, C., Yu, S.-Y., Yang, X., Cheng, J., Zhang, X., Xue, B., Shen, J., Chen, F., 2022. Seasonal imprint of Holocene temperature reconstruction on the Tibetan Plateau. Earth-Science Reviews 226, 103927.

Comment: Explain the drivers of the current and past climate on the TP. What are the most important wind systems? I tend to see it as influenced by the East Asian Monsoon system, but this is nowhere mentioned. In contrary, there is an out-of-the-blue reference to the Indian Summer Monsoon in L397, but an explanation of its connection to the climate on the TP is not provided.

Response: Thanks for your meaningful comments. We have deleted this sentence "It is possible that these factors impacted the summer temperatures in the Indian Summer Monsoon (ISM) domain via ocean-atmosphere interactions". And we have rephased the part in lines 422-426 as follows "The brGDGTs-based temperature record from Gahai confirms the occurrence of a climate optimum in the mid-Holocene on the northeast Tibetan Plateau, which is consistent with several other pollen and pollen-reconstructed temperature records from the fringe areas of the Asian summer monsoon (Fig. 6), suggesting that it is a reliable representation of Holocene temperature changes in this region.”

Other comments:

Comment: Introduction: The rationale on which exact temperature different proxies represent is not well explained. For example, the chironomid record from Tiancai lake is presented as July temperature. How valid is this? The growing season of chironomids may change over time, especially over glacial/interglacial transitions. Is it always July? The same is true for brGDGTs and pollen. Do they present annual or seasonal (and in that case: ice-free, or summer, or growing season) temperatures? How can we tell, and can we assume that seasonality is constant over time? This is important because climate modelers will want to use these records and it is our responsibility to make sure that they use the right temperatures to warrant low uncertainty on model projections of future climate. For example, the set of aims listed at the end of the introduction raises the question if ice-free season temperatures equal a warm-bias? And why compare the brGDGT record with July temperatures? What is the reason behind that?

Response: Thank you for your suggestion. The issue you mentioned is of paramount importance and remains an ongoing challenge yet to be resolved. The method of transferring contemporary knowledge and principles to the study of the past, known as the 'present is the key to the past,' stands as a foundational and paramount methodology within the realm of Earth sciences. This approach involves deducing the conditions, processes, and characteristics of geological events in ancient times based on contemporary understanding and principles.

While the application of current knowledge to the study of the past is viable to a certain extent, it bears the potential for inadvertent deviations from factual precision. Consequently, addressing this issue in the context of the study of lacustrine sediments from the Holocene epoch requires an initial assessment of sedimentary environment stability based on factors such as existing sedimentation rates, chronology, lithological variations, and more. This evaluation helps prevent significant sedimentary discontinuities or other impactful events that could affect the reliability of proxy indicators.

The mentioned study on chironomid record from Tiancai lake, as referenced in Zhang et al., 2017a, explicitly demonstrates that chironomid respond to July temperatures. The chironomid-based transfer function, developed from the region of southwestern China based on a 100-lake calibration training set (Zhang et al., 2017b) was employed to translate the chironomid assemblage data from Tiancai lake into a reconstruction of mean July temperatures. This transfer function, constructed via a weighted averaging partial least squares (WA-PLS) regression in C2 (Juggins, 2005), spans a range of mean July temperature from 4.2 to 20.8 °C, whereas Tiancai lake currently exhibits a modern mean July temperature value of 8.3 °C. This modern process has been applied to the Tiancai lake sediment core, thus enabling the reconstruction of July temperatures over the past 9,000 years. The original authors consider this reconstruction to be reliable.

Similarly, through the examination of modern processes involving global lake and soil, it has been concluded that both brGDGTs and pollen respond to temperature changes. Consequently, these indicators have been employed extensively for temperature reconstructions in Quaternary paleoclimate research, embracing the 'present is the key to the past' principle. However, questions regarding the consistent existence of seasonality remain unresolved. This underscores one of the limitations of paleoclimate reconstruction work, motivating a clear understanding of the indicative significance, sensitivity, and representativeness of relevant proxy indicators. This will help mitigate uncertainties and provide more accurate records for paleoclimate simulation studies.

Finally, temperatures during the non-freezing seasons tend to exceed annual averages yet remain lower than summer temperatures. We are inclined to attribute this to warm-season bias, as opposed to a warm bias. As for why brGDGT-based temperature reconstructions are compared to July temperatures, one prevailing hypothesis addressing the "Holocene temperature conundrum" highlights the possible role of seasonal discrepancies in proxy indicators. These discrepancies could arise from varying climatic implications intrinsic to the proxy indicators themselves. Therefore, a comprehensive understanding of the climatic significance, sensitivity, and representativeness of proxy indicators is pivotal. Undertaking multi-proxy temperature reconstructions within the same study area could shed light on potential seasonal deviations in different temperature series and contribute to unraveling the "Holocene temperature conundrum". Presently, the bulk of studies rely on single temperature proxies. In contrast, we have utilized two distinct temperature proxies, brGDGTs and pollen, from the same borehole to reconstruct Holocene temperature, thus vividly illustrating the existence of seasonal biases in different indicators.

Reference:

Zhang, E., Chang, J., Cao, Y., Sun, W., Shulmeister, J., Tang, H., Langdon, P.G., Yang, X., Shen, J., 2017a. Holocene high-resolution quantitative summer temperature reconstruction based on subfossil chironomids from the southeast margin of the Qinghai-Tibetan Plateau. Quaternary Science Reviews 165, 1-12.

Zhang, E., Chang, J., Cao, Y., Tang, H., Langdon, P., Shulmeister, J., Wang, R., Yang, X., Shen, J., 2017b. A chironomid-based mean July temperature inference model from the south-east margin of the Tibetan Plateau, China. Clim. Past. 13, 185e199.

Juggins, S., 2005. C2 Version 1.5: Software for Ecological and Palaeoecological Data Analysis and Visualisation. University of Newcastle, Newcastle-upon-Tyne, Newcastle, U.K.

Comment: BrGDGTs: it should be explicitly stated in the introduction that brGDGTs are produced in lakes. The introduction only mentions that certain factors can influence their distribution, but this fact must be linked to their producers that are sensitive to e.g., redox conditions (Weber et al., 2018 PNAS), O2 content and/or mixing regime (van Bree et al., 2020 Biogeosciences, Wu et al., 2021 Chem Geol.), and, consequently, also to lake depth due to the different niches that the producers of different brGDGTs occupy. It is the structural offset between brGDGT distributions in lakes and in soils that has led to the lake-specific calibrations (see Tierney and Russell, 2009, Sinninghe Damsté et al., 2009, or Tierney et al., 2010 for the early works).

Response: Thanks for your meaningful comments. In the introduction section, we underscored the complexity of the sources of brGDGTs within lakes. Moreover, an increasing body of research indicates that brGDGTs in lakes are primarily of autochthonous origin. In response to reviewer comments, we have clarified that the factors influencing the distribution of brGDGTs are closely tied to their producers. Subsequently, we elaborated on the potential sources of brGDGTs in this study and the environmental conditions under which their producers thrive. The specific revisions made in this section are outlined below:

Line 128-139: "However, the factors that impact the distribution of brGDGTs in lakes are intricate and multidimensional. Notably, the sources of brGDGTs within lakes are intricate, involving contributions from soil as well as autochthonous lake processes. Moreover, an expanding body of research underscores a significant prevalence of autochthonous brGDGTs in lakes (Tierney and Russell, 2009; Tierney et al., 2010; Weber et al., 2015; Wang et al., 2021b). Furthermore, the origins of brGDGT producers remain uncertain and could be influenced by various factors, including lake salinity (Wang et al., 2021b), redox conditions (Weber et al., 2018), oxygen content and/or mixing patterns (Buckles et al., 2014; van Bree et al., 2020; Wu et al., 2021). Additionally, even lake depth plays a role due to distinct ecological niches (Woltering et al., 2012), thereby contributing to the intricate interplay that shapes the distribution of brGDGTs within lakes."

Reference:

Buckles, L.K., Weijers, J.W.H., Verschuren, D., Damste, J.S.S., 2014. Sources of core and intact branched tetraether membrane lipids in the lacustrine environment: Anatomy of Lake Challa and its catchment, equatorial East Africa. Geochimica Et Cosmochimica Acta 140, 106-126.

Tierney, J.E., Russell, J.M., 2009. Distributions of branched GDGTs in a tropical lake system: Implications for lacustrine application of the MBT/CBT paleoproxy. Organic Geochemistry 40, 1032-1036.

Tierney, J.E., Russell, J.M., Eggermont, H., Hopmans, E.C., Verschuren, D., Sinninghe Damsté, J.S., 2010. Environmental controls on branched tetraether lipid

distributions in tropical East African lake sediments. Geochimica et Cosmochimica Acta 74, 4902-4918.
van Bree, L.G.J., Peterse, F., Baxter, A.J., De Crop, W., van Grinsven, S., Villanueva, L., Verschuren, D., Sinninghe Damsté, J.S., 2020. Seasonal variability and sources of in situ brGDGT production in a permanently stratified African crater lake. Biogeosciences 17, 5443-5463.
Wang, H., Liu, W., He, Y., Zhou, A., Zhao, H., Liu, H., Cao, Y., Hu, J., Meng, B., Jiang, J., Kolpakova, M., Krivonogov, S., Liu, Z., 2021. Salinity-controlled isomerization of lacustrine brGDGTs impacts the associated MBT5ME' terrestrial temperature index. Geochimica et Cosmochimica Acta 305, 33-48.
Weber, Y., De Jonge, C., Rijpstra, W.I.C., Hopmans, E.C., Stadnitskaia, A., Schubert, C.J., Lehmann, M.F., Sinninghe Damsté, J.S., Niemann, H., 2015. Identification and carbon isotope composition of a novel branched GDGT isomer in lake sediments: Evidence for lacustrine branched GDGT production. Geochimica et Cosmochimica Acta 154, 118-129.
Weber, Y., Sinninghe Damste, J.S., Zopfi, J., De Jonge, C., Gilli, A., Schubert, C.J., Lepori, F., Lehmann, M.F., Niemann, H., 2018. Redox-dependent niche differentiation provides evidence for multiple bacterial sources of glycerol tetraether lipids in lakes. Proc Natl Acad Sci U S A 115, 10926-10931.
Woltering, M., Werne, J.P., Kish, J.L., Hicks, R., Sinninghe Damsté, J.S., Schouten, S., 2012. Vertical and temporal variability in concentration and distribution of thaumarchaeotal tetraether lipids in Lake Superior and the implications for the application of the TEX86 temperature proxy. Geochimica et Cosmochimica Acta 87, 136-153.
Wu, J., Yang, H., Pancost, R.D., Naafs, B.D.A., Qian, S., Dang, X., Sun, H., Pei, H., Wang, R., Zhao, S., Xie, S., 2021. Variations in dissolved O2 in a Chinese lake drive changes in microbial communities and impact sedimentary GDGT distributions. Chemical Geology 579.

Comment: Calibration chosen. See also my main comment. I suggest to change the argumentation. Rather than applying all calibrations ever published and picking the one that fits best, present a rationale for using the one calibration that is most suitable for this lake /dataset and then apply only that one.

Response: Thanks for your meaningful comments. It's very helpful to us. We have made detailed revisions to this section based on the reviewer's comments, as evidenced in lines 292-372.

"Gahai is a shallow lake in the eastern Tibetan Plateau that is typically completely frozen during winter and spring. Local meteorological data indicate that the average snowfall period lasts for 269 days, with around 50 days of continuous snowfall (Luqu County Local Chronicles Compilation Committee, 2006). The freezing of the lake surface begins in late October each year and gradually thaws starting from May of the following year. As a result, the light transmittance and oxygen content in the lake water are reduced during the freezing season, leading to decreased nutrient levels, which severely hinder the growth of autotrophic microorganisms. Although the bacteria responsible for producing brGDGTs have not been thoroughly characterized, the abundance of heterotrophic bacteria will likely decrease due to the reduced autotrophic biomass during the winter and spring ice-covered period. The weakened light penetration, decreased oxygen levels, and lack of nutrient replenishment during the frozen period significantly impact the growth of autochthonous microorganisms.

While the specific bacterial species responsible for brGDGT production are not yet well understood, it is known that these bacteria, as heterotrophic organisms, will also be influenced by the reduction in autotrophic biomass. Furthermore, some research suggests that the production of brGDGTs might be related to factors such as water depth, seasonal alternation of water column mixing and stratification (Loomis et al., 2014; van Bree et al., 2020). During the summer and autumn seasons when the lake ice melts and the water becomes more mobile, the nutrient content increases, resulting in elevated lake biomass, moreover, the oxygen levels at the bottom of Gahai lake are not expected to be too high, which could further contribute to the proliferation of brGDGT-producing bacteria, potentially leading to an increase in the brGDGT-producing bacteria (Weber et al., 2018). Therefore, brGDGTs in Gahai lake may provide records of the average temperature during the ice-free months of the summer and autumn seasons.

Additionally, the presence of the frozen lake surface during winter creates a thermal barrier, impeding the exchange of heat between the lake water and the atmosphere. Consequently, any brGDGTs generated within the lake water during this period lose their ability to accurately reflect atmospheric temperature variations (Sun et al., 2021; Zhang et al., 2022). Thus, they were no longer able to track atmospheric temperature changes during the frozen season. So, we prefer to use Gahai brGDGTs to reconstruct temperatures during the summer and ice-free seasons. For this purpose, we employed the new Bayesian calibration for the mean temperature of the Months Above Freezing, as proposed by Martínez-Sosa et al. (2021), to derive a warm-biased temperature for Gahai lake.

To assess the accuracy of this calibration approach, we compared the fractional abundances of summed tetra-, penta-, and hexamethylated brGDGTs in Gahai lake sediments with other datasets (Fig. 4). These datasets include lake sediments from the Tibetan Plateau (Günther et al., 2014; Wang et al., 2016), East Africa (Russell et al., 2018), and global lakes (Martínez-Sosa et al., 2021). The distribution pattern of Gahai core sediments is distinctly remarkable compared to that of other lake sediments within the Tibetan Plateau, even though they share a common regional origin (Fig. 4). However, its resemblance to the global distribution of brGDGTs in lake sediments is evident. Notably, the calibration developed by Martínez-Sosa et al. (2021) is based on brGDGTs from a global lake dataset.

Using calibration of Martínez-Sosa's et al. (2021), we reconstructed the surface sediment temperature of Gahai lake, resulting in a temperature estimate of 9.4°C. This reconstructed temperature closely matches the ice-free season temperature recorded by meteorological stations in the Gahai region (8.8°C for May to September). Furthermore, considering the significant contribution of autochthonous brGDGTs in Gahai lake, we also attempted to reconstruct the Holocene paleotemperature record using previously published lake-specific brGDGTs-temperature calibrations (e.g., Dang et al., 2018; Günther et al., 2014; Martínez-Sosa et al., 2021; Russell et al., 2018; Sun et al., 2011; Wang et al., 2016). As illustrated in Fig. S3, most of these calibrations showed qualitatively similar patterns of temperature change when applied to the sediment core from Gahai lake. However, the magnitudes of temperature fluctuations varied considerably and were found to be unsuitable for application in Gahai lake due to several key reasons. Firstly, the fractional abundances of summed tetra-, penta-, and hexamethylated brGDGTs in Gahai lake were inconsistent with those found in the reference datasets (Fig. 4). Secondly, the analytical technique used for distinguishing 5- and 6-methyl isomers, which was a crucial aspect of some calibration studies (Günther et al., 2014; Wang et al., 2016), was not employed in those studies, resulting in their exclusion from our analysis. Thirdly, although the brGDGTs fractions in Gahai lake are resembled those of East African lakes, the annual mean temperature reconstructed using this calibration significantly differed from the temperature data recorded at the Langmu Temple station. Moreover, even though the paleotemperature reconstruction for Gahai lake based on the warm-season temperature calibration by Dang et al. (2018) showed similarity to the calibration by Martínez-Sosa et al. (2021). However, it is worth noting that the calibration by Dang et al. (2018) was established based on an investigation of 35 Chinese alkaline lakes, which may not be directly applicable to the freshwater environment of Gahai lake. Similarly, despite the salinity correction, the calibration reported by Wang et al. (2021) was not considered suitable for our study.

Given these limitations, we ultimately opted to use the new Bayesian calibration for the mean temperature of the Months Above Freezing, as proposed by Martínez-Sosa et al. (2021), to reconstruct a warm-biased temperature record for Gahai lake.”

Reference:

Luqu County Local Chronicles Compilation Committee., 2006. Luqu County Chronicles. Gansu Cultural Publishing House, Lanzhou. pp. 71.

Dang, X., Ding, W., Yang, H., Pancost, R.D., Naafs, B.D.A., Xue, J., Lin, X., Lu, J., Xie, S., 2018. Different temperature dependence of the bacterial brGDGT isomers in 35 Chinese lake sediments compared to that in soils. Organic Geochemistry 119, 72-79.

Günther, F., Thiele, A., Gleixner, G., Xu, B., Yao, T., Schouten, S., 2014. Distribution of bacterial and archaeal ether lipids in soils and surface sediments of Tibetan lakes: Implications for GDGT-based proxies in saline high mountain lakes. Organic Geochemistry 67, 19-30.

Loomis, S.E., Russell, J.M., Heureux, A.M., D'Andrea, W.J., Sinninghe Damsté, J.S., 2014. Seasonal variability of branched glycerol dialkyl glycerol tetraethers (brGDGTs) in a temperate lake system. Geochimica et Cosmochimica Acta 144, 173-187.
Martínez-Sosa, P., Tierney, J.E., Stefanescu, I.C., Dearing Crampton-Flood, E., Shuman, B.N., Routson, C., 2021. A global Bayesian temperature calibration for lacustrine brGDGTs. Geochimica et Cosmochimica Acta 305, 87-105.
Russell, J.M., Hopmans, E.C., Loomis, S.E., Liang, J., Sinninghe Damsté, J.S., 2018. Distributions of 5- and 6-methyl branched glycerol dialkyl glycerol tetraethers (brGDGTs) in East African lake sediment: Effects of temperature, pH, and new lacustrine paleotemperature calibrations. Organic Geochemistry 117, 56-69.
Sun, Q., Chu, G., Liu, M., Xie, M., Li, S., Ling, Y., Wang, X., Shi, L., Jia, G., Lü, H., 2011. Distributions and temperature dependence of branched glycerol dialkyl glycerol tetraethers in recent lacustrine sediments from China and Nepal. Journal of Geophysical Research 116.
Sun, X., Zhao, C., Zhang, C., Feng, X., Yan, T., Yang, X., Shen, J., 2021. Seasonality in Holocene Temperature Reconstructions in Southwestern China. Paleoceanography and Paleoclimatology 36.
van Bree, L.G.J., Peterse, F., Baxter, A.J., De Crop, W., van Grinsven, S., Villanueva, L., Verschuren, D., Sinninghe Damsté, J.S., 2020. Seasonal variability and sources of in situ brGDGT production in a permanently stratified African crater lake. Biogeosciences 17, 5443-5463.
Wang, H., Liu, W., He, Y., Zhou, A., Zhao, H., Liu, H., Cao, Y., Hu, J., Meng, B., Jiang, J., Kolpakova, M., Krivonogov, S., Liu, Z., 2021. Salinity-controlled isomerization of lacustrine brGDGTs impacts the associated MBT5ME' terrestrial temperature index. Geochimica et Cosmochimica Acta 305, 33-48.
Wang, M., Liang, J., Hou, J., Hu, L., 2016. Distribution of GDGTs in lake surface sediments on the Tibetan Plateau and its influencing factors. Science China Earth Sciences 59, 961-974.
Weber, Y., Sinninghe Damste, J.S., Zopfi, J., De Jonge, C., Gilli, A., Schubert, C.J., Lepori, F., Lehmann, M.F., Niemann, H., 2018. Redox-dependent niche differentiation provides evidence for multiple bacterial sources of glycerol tetraether lipids in lakes. Proc Natl Acad Sci U S A 115, 10926-10931.
Zhang, C., Zhao, C., Yu, S.-Y., Yang, X., Cheng, J., Zhang, X., Xue, B., Shen, J., Chen, F., 2022. Seasonal imprint of Holocene temperature reconstruction on the Tibetan Plateau. Earth-Science Reviews 226, 103927.

Comment: The authors present their record as "warm-biased temperature record". I find this not so informative, as it is not clear why it has a bias and where it comes from. I suggest to specify the bias further so outsides know what the record represents and how they can use it in future studies.

Response: Thank you for your suggestion. In this study, we have reconstructed the mean temperature of Months Above Freezing. We have already replaced 'warm-biased' with 'the mean temperature of Months Above Freezing' in certain sections.

Comment: Questions I had while reading the paper: how is it so clear that the record contains a warm bias? In the end, the calibration from Martinez-Sosa et al 2021 is used, but this transfer function uses mean air temperature for months above freezing (MAF). In other words, the record that is presented is a record of MAF, and thus by default warmer than MAT. If there are any further offsets or structural biases from MAF then they have to be identified and explained in the text.

Response: Thank you for your suggestions. As you mentioned, we have employed the calibration proposed by Martinez-Sosa et al. (2021) in this study to reconstruct temperatures during the ice-free seasons. Without a doubt, temperatures during ice-free seasons are higher than the annual average temperatures. Therefore, we believe that the reconstructed records in this paper contain a certain warm bias.

As detailed in the section about study site, Gahai lake is located on the eastern edge of the Tibetan Plateau, with consistently low temperatures throughout the year. The maximum depth of the lake does not exceed two meters. From October to April in the next year, the lake is predominantly covered by ice. Consequently, the sediment cores likely record the average temperatures during the ice-free months. Furthermore, Gahai lake is presently an open lake, with its waters flowing northwestward through the Tao River and eventually into the Yellow River. Thus, we have reason to believe that the lake's water level has not exceeded two meters since the Holocene. Given the shallowness of the lake in such a cold region, we posit that brGDGTs in the lake sediment are more likely to grow during the warmer seasons, while the complete freezing of the lake during ice-cover periods restricts the growth of brGDGT producers.

Comment: How can brGDGTs represent both annual mean air temperature and a warm-biased temperature (L35-36 in the abstract)?

Response: Thank you for your reminder. Here, we are referring to instances where brGDGTs are utilized for various interpretations in different studies. For example, in some articles, brGDGTs are considered to reflect annual average temperatures, while in others, they are believed to indicate warm-biased temperatures. This might have caused ambiguity in our original statement. Thus, we have rephrased the sentence for clarity.

“The results demonstrate that brGDGTs have been employed to reconstruct various temperatures in different studies, including annual average temperature and warm-biased temperature.” Please see lines 35-37.

Comment: L169: add number of soils sampled and indicate the depth interval, and also plot them on the triplot (Fig. 4). Actually, it is quite clear that such a triplot does not really separate brGDGTs in lake sediments from soils on a global scale – it seems best suited to identify in situ production in the marine coastal zone (Sinninghe Damsté, 2016). However, lakes tend to have more hexamethylated brGDGTs (in particular IIIa), so directly comparing the relative abundances of brGDGTs and soils with a bar-plot could be more informative (see e.g., Fig. 11 in Martinez-Sosa et al., 2021). It can also help to do Principle Component Analysis (PCA) on the lake sediment record, and then passively add the soils to see where they plot. The sample distribution in the PCA can further help to identify the main changes in brGDGT distributions through time and possibly connect this to likely environmental drivers (and finally temperature).

Response: Thanks for your suggestions. Four catchment soil samples were collected from around the lake. As per your suggestion, we have explicitly mentioned this number (four catchment soils) in the manuscript and plot them on the triplot (see Fig. 1). In addition, we also compared the relative abundance of brGDGTs in soils and core sediment samples with a bar-plot in Fig 2 here, which is also presented in Supplementary Fig. S2.

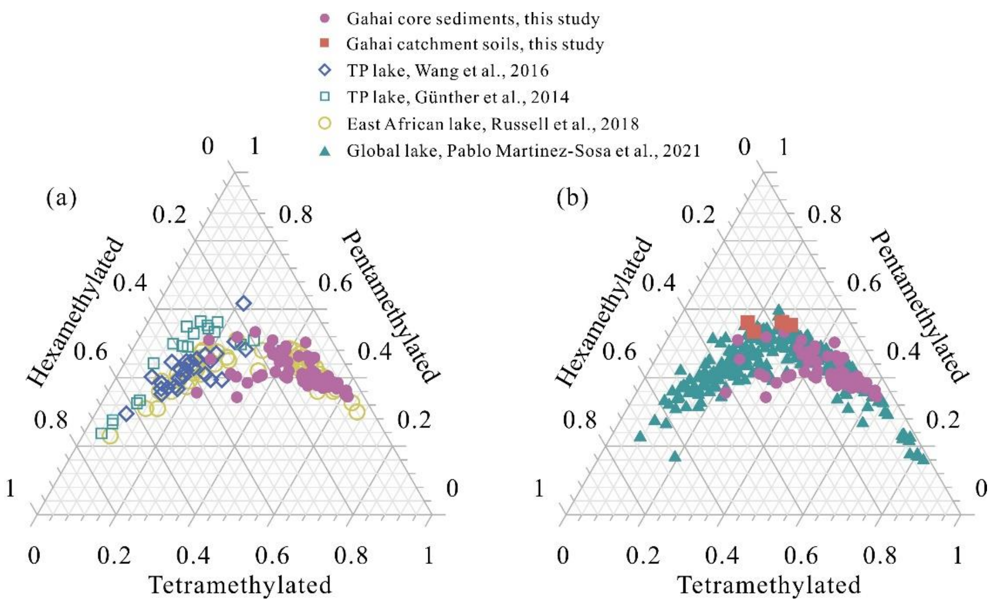

Fig. 1 Comparison of the fractional abundances of tetramethylated, pentamethylated, and hexamethylated bGDGTs in sediment core samples and catchment soils from Gahai with lake surface sediments from the Tibetan Plateau (Günther et al., 2014; Wang et al., 2016), East Africa (Russell et al., 2018), and worldwide (Martínez-Sosa et al., 2021).

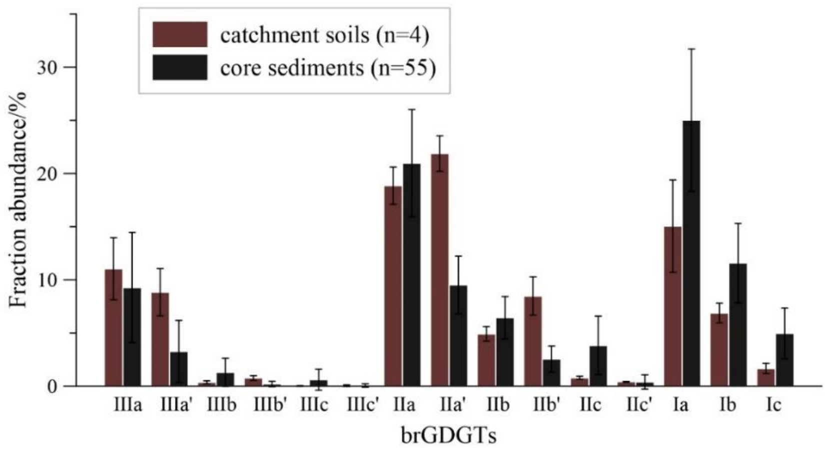

Fig. 2 Mean fractional abundances and standard deviations of brGDGTs from downcore sediments and catchment soil samples in Gahai lake.

Comment: The methods can do with a bit more information on the lithology and the age model. In the Discussion the oldest 5000 years are suddenly discarded (L308), as these sediments could represent a slump, but no evidence is provided.

Response: We are very grateful to you for your meaningful comments. We have included this part in the text, please see line 187-213.

"The chronology of the upper 20 cm of the sediment core is based on measurements of ^{210}Pb and ^{137}Cs, at a 1-cm interval. The chronology for the deeper part of the core is provided by accelerator mass spectrometry (AMS) ^{14}C measurements of 13 bulk sediment samples, which were conducted by Beta Analytic Inc. (Miami, USA) (Fig. 2) (Wang et al., 2022).

The ^{210}Pb age model was constructed using the constant rate of supply (CRS) model and the ^{137}Cs peak was used as supplement (Appleby, 2002). The calculated age of ^{210}Pb using CRS model aligned well with the ^{137}Cs peak at 6 cm. Overall, the CRS model was deemed suitable for determining the age of Gahai lake.

Reservoir age, as highlighted by Hou et al. (2012), is a crucial factor affecting the age determination of lake sediment cores on the TP. Therefore, it was necessary to establish the reservoir age of Gahai lake before undertaking paleoclimate reconstruction. The linear extrapolation relationship between the ^{14}C ages and depth to the sediment-water interface is often used to estimate the reservoir age. The ^{14}C age of 13 samples exhibits a good linear relationship with sediments depth in Gahai lake. Extrapolation of this 13 ^{14}C ages down to the depth of 6 cm yielded a ^{14}C age of 461 yr BP, while the reliable ^{210}Pb age at 6 cm is -27 yr BP. Consequently, the difference between the two ages, which amounts to 488 yr, was taken as the reservoir age. Additionally, it's worth noting that independent estimations of the ^{14}C calibration age and ^{210}Pb age around 10 cm in Gahai lake was obtained, resulting in values of 497 yr BP and 18 yr BP, respectively.

The difference of 479 yr between these two ages can also be considered as the reservoir age. These two methods of estimating reservoir age of Gahai lake show very close, which are mutually supportive. So, the average of 483 yr was adopted as the reservoir age. All original ^{14}C dates were corrected by subtracting the reservoir age (483 yr) and calibrating them to calendar ages using Calib 8.1. The age-depth model (Fig. 2) was constructed using the Bacon program with the ^{14}C ages and ^{210}Pb ages (Blaauw and Andres Christen, 2011) and was reported by Wang et al. (2022)."

Regarding the lithology, especially the sudden exclusion of the oldest 5000 years, we believe that the corresponding time interval (from 191 cm) may have undergone rapid sedimentation or alternatively slumping. There are several reasons for this:

1. We can observe that the ages around 191 cm, 229 cm and 279 cm are relatively close (15070 a, 14870 a, 15500 a, respectively), which suggests the possibility of rapid sedimentation.
2. By examining the grain size distribution, we can notice significant fluctuations in the silt fraction (4-63 μm) starting from 191 cm (Fig. 3). The silt fraction in Gahai is driven by the medium silt (16-32 μm) fraction, while the fine and coarse silt fractions remain almost unchanged during the Holocene, hence the fine, medium, and coarse silts are combined into the total silt fraction (4-63 μm) for discussion (Wang et al., 2022). This could indicate the occurrence of specific events.

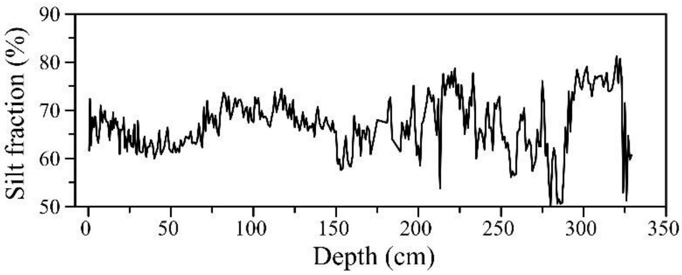

Fig. 3 Silt fraction (4-63 μm) distribution.

3. During this stage, the concentration of brGDGTsis notably low, which hinders our ability to conduct thorough analysis. Similarly, the pollen concentration during this time period is also quite low, and the data are insufficient for statistical analyses (Wang et al., 2022).

Therefore, we only present the research results from the past 15,000 years.

Reference:

Appleby, P.G., 2002. Chronostratigraphic techniques in recent sediments. In: Tracking Environmental Change Using Lake Sediments. Springer, pp. 171–203.

Blaauw, M., Andres Christen, J., 2011. Flexible Paleoclimate Age-Depth Models Using an Autoregressive Gamma Process. Bayesian Analysis 6, 457-474.

Hou, J.Z., D'Andrea, W.J., Liu, Z.H., 2012. The influence of ^{14}C reservoir age on interpretation of paleolimnological records from the Tibetan Plateau. Quaternary Science Reviews 48, 67-79.

Wang, N., Liu, L., Hou, X., Zhang, Y., Wei, H., Cao, X., 2022. Palynological evidence reveals an arid early Holocene for the northeast Tibetan Plateau. Climate of the

Past 18, 2381-2399.

Comment: Interpretation of the temperature record by vegetation change in the area, and thus heat capacity (L333): Note that this process is mostly valid for soils, for which this has been described, but that the vast majority (if not all) of the brGDGTs in the lake record will be produced in situ. Assuming that the lake has always contained water during the studied interval, the heat capacity would not have changed.

Response: Thank you very much for your suggestion, and we have removed this statement.

Remediation effects: Since this anthropogenic spike only represents a few datapoints I would be careful not to overinterpret the data. Especially stating that remediation effects have an effect and that brGDGTs now record temperature again based on only the surface sediment would be overstating it for me. Please tone down and substantially reduce the discussion on this part of the record.

Response: Thank you for your reminder. In accordance with your suggestion, we have reduced the discussion in this section.

Minor comments:

Comment: Check the order of references. By first name, then by year.

Response: Thank you for your suggestions, we have made individual revisions throughout the manuscript.

Comment: Often use of ‘significant’ without providing p-value.

Response: Thank you for your reminder, we have thoroughly checked and made corresponding revisions to each of them.

Comment: Damsté et al should be Sinninghe Damsté et al.

Response: Thank you very much for your reminder. We have conducted a thorough review and made all the necessary modifications.

Comment: Provide information on the detection limit used for GDGT quantification.

Response: Thank you for your suggestion. During the sample testing process, the detection limit for GDGTs testing is 0.0004 ppm.