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Interactive comment on "Climate reconstructions based on GDGT and pollen surface datasets from Mongolia and Siberia: calibrations and applicability to extremely cold-dry environments over the Late Holocene" *by* Lucas Dugerdil et al.

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1 Responses to the comments of Reviewer 3 (Anonymous Referee)

1.1 General comments:

This paper presented valuable data sets of pollen assemblage and bacterial branched GDGTs from Mongolia and Siberia that are both extremely dry and cold regions.

Regional or local calibrations for temperature and precipitation reconstruction were developed based on the relationship of pollen assemblages and the distribution of brGDGTs with climatic parameters. The authors then used two sediment profiles published in other studies to validate their proposed calibrations and posited that the calibrations were applicable to the cold and dry regions, as stated in the title. This study is valuable in terms of the scarcity of pollen assemblage and bacterial brGDGT data from Mongolian and Siberian soils. This paper is generally well written. But the phrases or wording in this paper need to be improved, as can be seen below.

I also have some concerns that need to be clearly addressed. First, the authors have mentioned 7-methylbrGDGTs that were not widely present in soils. So I am not so convinced that the compounds they identify in these soils are 7-methyl brGDGTs since they do not provide any useful information to support this. This, however, needs to be accurate.

Response: We do agree that the method has to be accurately described and especially when it concerns quite recent proxy improvement such as 7-methyl brGDGT detection. To identify the 7-methyl brGDGT compound we have followed the approach described by Ding et al., (2016) for the peak identification for the Cameroon lake chromatograms. It is principally based on the m/z and relative retention time of each compound. About the slight proportion of 7-methyl brGDGTs in the Mongolian soil, it appears that we obtained an average of 4.6 % in Mongolian soil against 6.2% for Chinese lakes and 4.3% in Cameroon lakes (Ding et al., 2016). We observe same order of magnitudes.

Applied changes: The sentence L.255 in the method has been modified as follow : " Each compound was identified and manually integrated according to its m/z and relative retention time following the integration descriptions from Liu et al., (2012b) and DeJonge et al., (2014b) for 5- and 6-methyl brGDGT and Ding et al., (2016) for 7-methyl brGDGTs." Then, in the result part we have appended this observation (L. 366) " Even if the 7-methyl brGDGTs appear to have weak significance in the brGDGT variance explanation (Fig. 5.A), the surface samples 7-methyl average fractional abundance around 4.6% is following the normal order of magnitude (4.3% in Cameroon lakes and 6.2% for Chinese lakes, Ding et al., 2016). "

Second,the paper discussed two types of environmental indicators: pollen and brGDGTs, thus providing abundant information. However, in other words, the paper is rather complex and unfocused. I would write pollen and brGDGTs in two separate papers. The combination of them into one paper results in insufficient discussions. For example, I do not see many discussions about the pollen and mechanisms behind the environmental control on brGDGTs and pollen in such extremely cold and dry regions. The response of pollen and brGDGTs to precipitation and temperature was dependent on biochemical mechanisms. The model or calibrations developed by statistical methods should be consistent with these mechanisms.

Response: We can understand that this article appears to be complex because it is going into technical issues of two different proxy methodologies. The strength of this study is precisely to promote an interdisciplinary approach. It is addressed to two different communities: the organist geochemist and the palynologist. These two scientific communities are working to the same goal (the past environment and climate understanding) with tools slightly different but based on same hypothesis and methods. The topic of this article is precisely comparing the two calibration processes on the same dataset. It is the first time that this pollen-GDGTs interdisciplinary approach is proposed and tested on the same calibration. This article addresses a review of biases of both proxy and solutions to take them into account. This approach aims to help geochemists and palynologists researchers to have a clearer idea of the

benefits and flaws of each proxy.

By the way, we thank the three referees (coming from the two different communities) for all of their accurate comments which improve the readability of this article: language corrections, better method description, archaeal communities description, acronym definition, significant figure reducing, etc. For the discussion on mechanisms controlling the pollen and brGDGT distribution, we agree that this question is a critical issue, but it is not exactly the topic of this article since we are presenting mathematical calibrations and not pollen estimation production (such as PPE approach, Ge et al., 2017; Li et al., 2017) or brGDGT producing community (since we are not working on the archaeal soil communities in this article). This topic will be the object of a subsequent detailed article (Dugerdil et al., in prep.). As described in the introduction, this article applies a black box mathematical models without consideration to ecophysical mechanism in a first step. Then, the models are validated by such mechanisms.

Applied changes: To refer to the importance of such works the sentence " In any cases, a better understanding of the archaeal community responses to ecophysiological parameters variations will considerably improve the brGDGT calibration process (Xie et al., 2015; Dang et al., 2016; De Jonge et al., 2019). " has been added (L. 440), we also precised that " the effects of frozen soils on soil archaeal communities and GDGT production are thought to be important (Kusch et al., 2019) since the archaeal community seems to be shifting with abrupt temperature modifications (De Jonge et al., 2019)." (L. 453).

Third, the authors developed calibrations based on brGDGTs in Mongolian soils; however, no paleo sequences or loess-like sediments can be used in this region to assess the applicability of these calibrations. So I questioned the value of these calibrations.

Response: This comment has been formulate by the referee 2 too. We applied the calibration to two more sequences one in Baikal area (Dulikha, Bezrukova et al., 2005; Binney, 2017) and one in the Chinese Altai (NRX, Rao et al., 2020). Please report to the answer addressed to referee 2. Moreover, this calibration study is a preliminary work for the brGDGT-inferred climate reconstruction made on Mongolian lakes, a region poorly documented by molecular biomarkers records. Then, the MP could be an efficient analogue for other cold semi-arid areas in central Asia (in Altai, Tian Shan, Qilian Shan, Sayan range...) because of the similitude in vegetation (Erds et al., 2018, Klinge et al., 2018) and in climate history (Zhang 2021). The NRX sequence (added following the advice of Referee 2) from the Altai mountains is a good example (Rao et al., 2020).

Applied changes: For the applied change, please report to the referee 2 answer. To sum-up, we have added a new paleo-sequence from the Chinese Altai range which is closer from the surface data set presented in this study into the discussion. Also the rebuttal figures 1, 2 and 3 have been modified with this new paleo-sequence.

Link to Referee 2 response and applied changes: For the time being, we found a recently brGDGT paleosequence (NRX) with open access data from (Rao et al., 2020). This sequence is perfect for our calibration validation test : the peat core come from Altai mountains, with an elevation (around 1700 m a.s.l) close to the NMSDB average elevation and with same range of climate parameters, is only 200 km away from the D3L6 sequence as the crow flies. Therefore in the revised manuscript, we were able to compare the brGDGT calibration on two paleo-sequences (NRX and XRD) and to compare the brGDGT and the pollen signal for Altai mountains (NRX and D3L6). The location of the new paleo-sequences have been added to Rebuttal Figs. 2 and 3 and the results are displayed in Rebuttal Fig. 1.

Fourthly, different types of sediments were used in this paper, e.g., muds, soils, and moss. I learn from previous studies that brGDGTs might have different sources in different sediments. So we can see calibrations specific for each environment have been proposed over the last decade. I am very confused about the use of all these sediments in the development of a calibration. Other concerns are listed below for your consideration.

Response: We do agree that the type of environment determines the composition in brGDGT fractional abundances. This observation is particularly true for deep lake / marine environment / surface soil samples differentiation. However, if the in-situ production of brGDGT is strongly enhanced in wide and deep lakes, it seems not to be the case for the two temporary pond mud samples from the surface data-set. Following Pearson et al., (2011a) only the samples with BIT index < 0.4 are really following a lake brGDGT signals. On the Rebuttal Fig. 4, we can see that our 2 pond muds samples really follow a soil produced brGDGT signal. About the IIIa/IIa ratio, Cao et al., (2020) find values below 0.86 for soil and values above 1.15 for northern arid Chinese lake sediment. This ratio (Xiao et al., 2016; Martin et al., 2019a) is used to indicate the brGDGT origin. Here too (Rebuttal. Fig. 4) the IIIa/IIa ratio indicates that these two samples are controlled by brGDGT-soil production. The other sediment samples (MMNT5C11 and MMNT5C12) are not used into the calibration dataset, they are just displayed to make comparison with the surface database. In Mongolia, we do think that the surface sample type heterogeneity (soil, moss, pond mud) is not impacting the calibration reliability because the area is very arid. Even a small climate/environment change in precipitation amount can convert a lake into pond or into wet meadow including moss polster. Thus, the archive type is also varying in between these types of environment. Calibrations specific for each environment are most interesting at the global scale but not at the local scale where the surface dataset should be representative of the local variability. Finally, we do think that the bias induced by this samples heterogeneity is smaller than the bias induced by tiny dataset.

Applied changes: To made this more clear the label of Fig. 4 and Fig. 6 have been changed from " Lacustrine " to " Pond mud ". The sentence (L.281) has been precised with " A cross-validation test was performed for all the brGDGT calibrations (from this study and from the literature) using an independent set of six lacustrine samples from the lake *MMNT5C12* top-core. " We also have added the Rebuttal Fig. 4 in Supplementary information S1. And the following sentences have been introduced into the manuscript " The GDGT input origin could be traced using the BIT index (Branched and Isoprenoid Tetraether index, Hopmans et al., 2004; Pearson et al., 2011a) and the III_a/II_a ratio (Xiao et al., 2016, Martin et al., 2019a, Cao et al., 2020). " (L. 68) and " About the pond mud samples, the BIT and III_a/II_a ratio (Supplementary Fig. 4) show that a coherent soil origin is leading the brGDGT input instead of a lacustrine one (Pearsonet al., 2011; Martin et al., 2019a; Cao et al., 2020). " (L. 376). To clarify the SSM method we also added " The SSM has been applied on the total surface dataset (including the pond muds validated by the Supplementary Fig. S1 " (L. 394)

1.2 Specific comments:

Line 34 '?' Question mark. References needed here.

Response and applied changes: The Braconnot et al., 2021a reference was miss-indexed into the bibliography index. The error has been corrected.

Line 46 Change 'leads' to 'lead'

Line 57 Redundant. Pls delete 'and agree well'.

Line 63 'Damsté et al., 2000' should be 'Sinninghe Damsté et al., 2000'

Response and applied changes: Texts and reference modified accordingly.

Line 69 'Salvador-Castel et al., 2019 in press' Pls list this reference in the reference list.

Response and applied changes: The published version of the article has been actualized in the reference list.

Line 71-72 'bacterial community structure (Xie et al., 2015), the bacterial group response(Knappy et al., 2011) and the GDGT occurrences in different bacterial communities (Liu et al., 2012b) to. All these references are related to archaea that completely differ from bacteria. They are archaeal community and archaeal group, not bacterial community.

Response and applied changes: Text modified accordingly. Each occurrence of " bacterial " in the text have been change by " archaeal " (L. 67, 75, 76, 107, 438 and 454).

Line 75 MBT and CBT need to be defined since they appear for the first time.

Response and applied changes: The text has been modified following the comment of Referee 2.

Line 76-77, 78 'reacts' better use 'respond'. Add brGDGTs after '5-methyl', add '-' after '5,6'

Response and applied changes: Text modified accordingly.

Line 78 Add brGDGTs after'6-methyl'.

Response and applied changes: Text modified accordingly.

Line 84 'Ri/b' should be defined upon its first occurrence in the text.

Response and applied changes: The text has been modified following the comment of Referee 2.

Line130-135 Mud from ponds generally contains GDGT distribution that differs markedly from neighboring soils. The calibration for pond-like sediments is also different from that of soils. I cannot agree with the incorporation of mud sediments in developing calibrations for soil environments.

Response and applied changes: Since this comment is similar to the last general comment, we invite you to consider our response in the end of part 1.1.

Line 171 'precipitations' changed to 'precipitation'.

Response and applied changes: Text modified accordingly here and in the Fig.1

caption.

Line 224 APCI needs to be explained for the wide readership of the journal. What is'LGLTPE-ENS de Lyon'?

Response and applied changes: The APCI acronym has been deciphered. The laboratory of analysis (LGLTPE-ENS de Lyon) has been precised too.

Line 226-230 I found from the Result part (figure 4) that the authors have identified a series of 7-methyl brGDGTs, which were not widely seen in soils and lakes. Please provide the details as to how these compounds were identified and assigned in the text so that reviewers can assess whether they are identified in a right way.

Responses and changes listed following the first general comment of Referee 1.

Line 261 and Figure 3 captions What are 'AP' and 'NAP'? Please define this term prior to use.

Response and applied changes: AP is the acronym of Arboreal Pollen while NAP is for Non-Arboreal Pollen. They are explained on lines 290 and 291.

Line 279-280 Please show the determination coefficients and p values for the correlations Table 1 It is a little bit confusing to see so many abbreviations in the table. Please provide notes below the table.

Response and applied changes: The determination coefficient is already given in the column R^2 selected. The MAT and WAPLS methods modeled in *Rioja* package from R give no p-value. The labels in the table have been changed following your recommendations: the spatial range of the database and the climate parameters deciphered.

Line 312 '74.6%' I think this maybe the average abundance of each compound for all the soil samples. Please specify.

Response and applied changes: It is the average abundance of each compound for sediment samples. To make this clearer the sentence (L. 343) has been changed in " In the MMNT5C12 sediments, isoGDGTs are dominated by $GDGT_0$ and crenarcheol (74.6% and 9.8% in relative abundances, respectively, in Fig. 4.A, grey boxplots). These compounds previously considered as lake-produced (Schouten et al., 2012) exist in moss samples (32.7% and 31.3%, green boxplots) and in soils (57.4 % and 26.7%, orange boxplots). "

Line 316 diverge from surface soil samples? Please make it clear.

Response and applied changes: We have changed " surface " by " soil " (L. 348).

Line 316-317 The same iGDGT distribution between soil and lake sediments does not necessarily indicates a significant contribution of GDGTs to the lake. GDGT-0 dominates over crenarchaeol in these soils, probably reflecting a high alkalinity of the soils or a dominance of methanogenic Euryarchaeota due to the anoxic environments in the moss. In contrast, the dominance of GDGT-0 over crenarchaeol in lake sediments might indicate that abundant methanogenic Euryarchaeota inhabit the anoxic lake sediments yet few Thaumarchaeota live in the lake.

Response and applied changes: We do agree that the recent archaeal community studies and their relation to brGDGT production could help us to mitigate our discussion of isoGDGT production origin. Following your observation and making reference to Li et al., (2018a) and Besseling et al., (2018). We changed the paragraph into (L. 350-355) " IsoGDGT patterns in lake sediments do not really diverge from soil samples which can lead to postulate that the *in-situ* production of isoGDGTs in shallow and temporary lakes like MMNT5C12 is reduced (Fig. 4.A). At least, it may show that the archaeal community both in lake and in soils is dominated by methanogenic *Euryarchaeota* more than *Thaumarchaeota* (Zheng et al., 2015; Li et al., 2018a; Besseling et al., 2018). Then, it appears (Fig. 4.A) that the isoGDGT produced in soils are dominated by crenarcheol in accordance with studies on high alkalinity of the soil (Li et al., 2018a) linked to the impact of aridity (Zheng et al., 2015). "

Line 317 'soil-produced' changed to 'produced in soils'

Response and applied changes: Text modified accordingly.

Line 318 '[crenarcheol]' What does the bracket indicate? Please specify in the text.

Response and applied changes: The bracket are used to express molecular concentration. To make it more clear we have change the sentence (L. 354) by " the crenarcheol concentration " instead of " [crenarcheol] ".

Line 319 What does 'reaction' mean?

Response and applied changes: " reaction " is used for " response ". Text changed accordingly.

Line 327 Reduce ’22.77%’ to one significant figure.

Response and applied changes: Change into " 22.8% "

Line 341 ‘methyled and cyclized’ changed to ‘methylated and cyclized’

Line 349 Add ‘-‘ after ‘5 and 6’.

Line 376 Add ‘brGDGTs’ after ‘6-methyl’.

Line 396 O2

Response and applied changes: Texts modified accordingly.

Line 417‘react’ Not properly used word.

Response and applied changes: Word changed in " response ".

Line 442 ‘affects’ changed to ‘affect’.

Line 502 extreme

Figure 10 captions ‘foe each cores’ ‘for each core’.

Line 567 drier

Response and applied changes: Texts modified accordingly.

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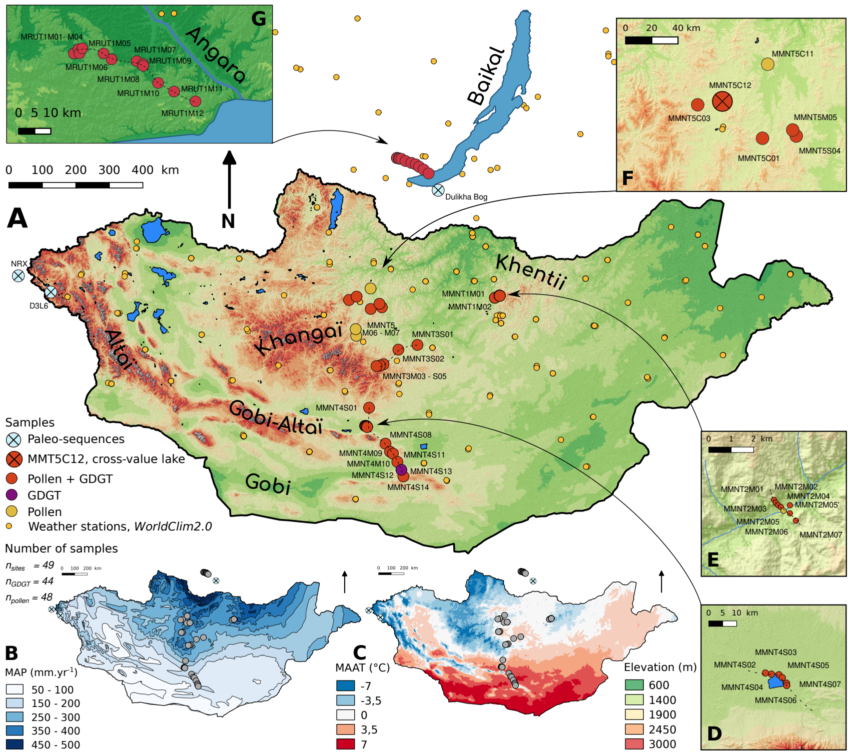

Fig. 1. A : Topographic map of Mongolia (from ASTER data) with the location of surface samples and weather stations considered in the present study.

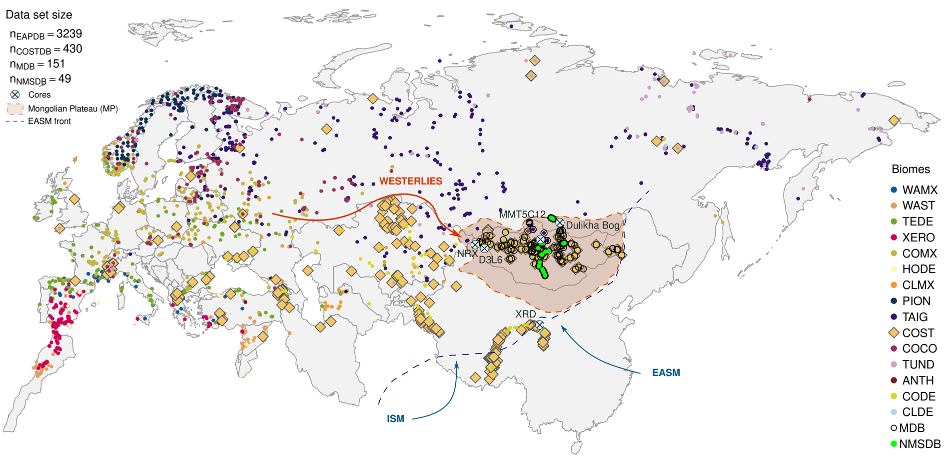

Fig. 2. Eurasian map of all the pollen surface samples included in the database.

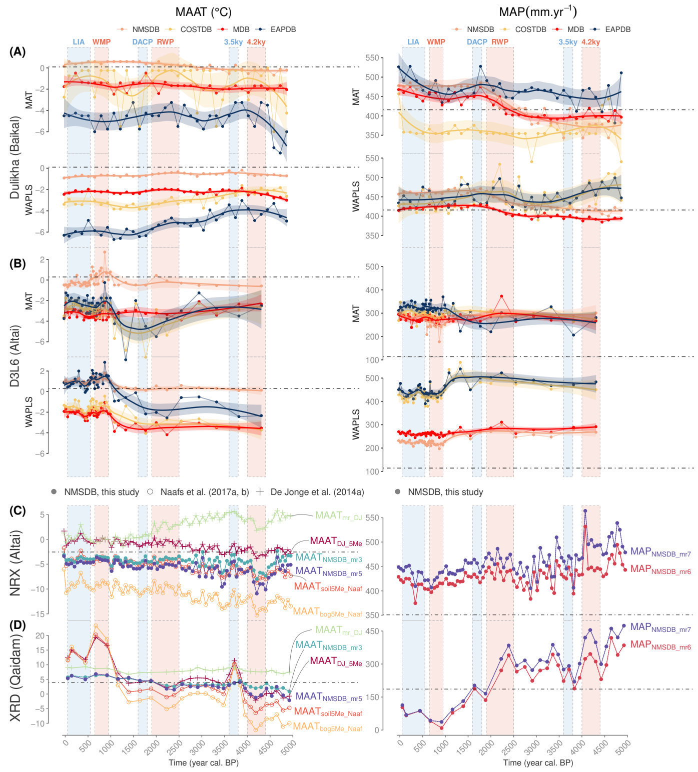

Fig. 3. ACA climate reconstruction for the 5000 year cal BP.

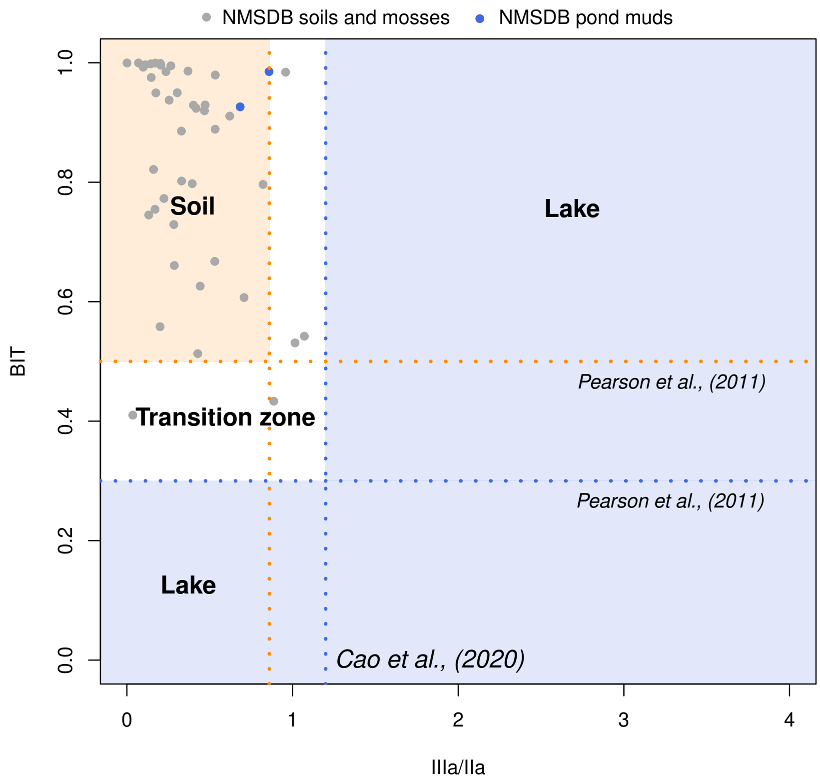

Fig. 4. brGDGT origin plot. The thresholds derived from Pearson et al. (2011) for the BIT index and from Cao et al. (2020) for the IIIa/IIa ratio.