Correction of the manuscript entitled

"Climate changes during the Lateglacial in South Europe: new insights based on pollen and brGDGTs of Lake Matese in Italy"

By Mary Robles et al.

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We thank the reviewers for their attentive reading and their accurate comments. As detailed in the point-by-point reply below, we have addressed their recommendations.

Responses to the comments of Reviewer 1

General comments:

The manuscript by Robles et al. is generally well written and its subject well-suited for publication in 'Climate of the Past'. The authors present reconstructions of temperature and precipitation changes in southern Italy based on biomarker proxy data and the application of statistical methods on palynological data. The data helps to increase the resolution on the spatial extend of prominent climate fluctuations in Europe and the Mediterranean during the deglacial and will therefore be of interest to the paleoclimate research community.

As the title suggests, both pollen and terrestrial biomarker data are equally important for the reconstruction of deglacial climate change at Lake Matese. However, it appears as if the authors are not quite sure what to make of the biomarker-based mean annual air temperature curve (brGDGT MAAT) as it diverges from other data records. They therefore highlight the need for proxy calibration that is more specific to certain sites or environments, and quite rightly so as this is a general issue. However, MAAT strictly speaking reflects soil temperature. Temperature and export of soil material towards the lake can be influenced by a range of local, catchment-specific factors (soil exposure, preferential erosion) that the authors should discus alongside fluctuation in pollen record and Ti and based on their detailed knowledge of the lake's catchment and local conditions. See below for more detailed comments.

The presentation and discussion of the radiocarbon data used for dating the core could be streamlined. I suggest shifting chapter "4.2 Age-depth model" and chapter "5.1 Validation of age-depth model" into chapter "3.2 Chronology and age-depth model". Establishing the age of the core should be part of the methodology unless, e.g., findings from the radiocarbon data support paleoenvironmental interpretations.
Overall, and I recommend publication of the manuscript following minor revisions.

Response: We thank the Reviewer 1 for these positive and interesting comments. Our responses and changes applied are presented below.

Specific comments:

line 176: "with a maximum at Campitello Matese (1400 m a.s.l.)" – What is the maximum precipitation, then? This needs a rainfall value.
Response: The rainfall value has been added in the text line 178: "…with a maximum **of 2167 mm** at Campitello Matese"

lines 180/181: "The precipitation is less important in the southeastern part of the massif" – What does "less important" mean here?
Response: The sentence has been deleted.

lines 256/257: "A simplified pollen diagram was constructed with the R package" – I assume, this diagram is incorporated in Figure 2? Please, refer to the figure. For readers used to looking at extensive plots of palynological data it could be emphasised here that variations of individual species are not the focus of this study. However, the complete data should be provided, e.g., as supplementary material.
Response: The figure 2 has been referred line 256: "A simplified pollen diagram was constructed **(Fig. 2)** with the R package Rioja". The aim of our study is the reconstruction of the climate changes during the Lateglacial. In this frame, and as mentioned by the reviewer, interpretation of individual species variations is beyond the scope of this manuscript. Moreover, a detailed description of the vegetation changes at Matese during the Lateglacial and the Holocene is a central issue in themselves and their study (based on the complete pollen diagram) will be the focus of a future dedicated manuscript.
The text has been modified as follows line 257: "**This study presents the main pollen taxa and is not focused on variations of individual species**."

lines 321/322: "The analytical reproducibility was assessed based on a sediment internal standard." – Which compound was used as standard? How was 'reproducibility' assessed without duplicate analyses or duplicate extractions? Or do the authors mean analytical precision?
Response: We added more information in the text line 323: "The analytical reproducibility was assessed **by regularly processing a lab-internal sediment sample (Vaux Marsh; 45°57'21.1"N, 5°35'32.42"E). Analytical precision is based on duplicate injections of one sample of each Matese core lithological types (n=4). Respective analytical 1-sigma standard deviations are then applied to each measurement within one lithology."**

lines 387/388: "most of the 14C dates (Table 3) are not included in the age-depth model" – It would be good to know why exactly most of the radiocarbon dates were omitted rather than being referred to the good match of the pollen curves and tephra dates. In chapter 5.1, the authors speculate that root penetration may be the cause for biased 14C ages. It would be good to bring this point forward.
Response: **Because most of the ^{14}C are rejected in our study, we made the choice to discuss this point in the discussion part. However,** we agree with the reviewer1 and we added a sentence to do the link with the discussion section line 393: "**The organic matter extracted from sediment was essentially composed of rootlets, that explains the rejuvenation of the ^{14}C ages".**

lines 409/410: "At the transition with phase 4, a significant decrease in the precipitation parameters is recorded." – It would be worth pointing out that this coincides with the maximum amount of *Artemisia* pollen and a peak in Ti. Is there a causal relationship or could catchment processes be responsible for this? Notably, the brGDGT-derived parameters show some fluctuations there, as well.
Response: Actually, we still have a high percentage of *Artemisia* and a high Titanium content, suggesting high erosion rates, at the beginning of the Holocene (Part 4, 11,700-11,260 cal BP). Similar during the Younger Dryas, high erosion rates are certainly favorized by an open vegetation in the catchment of Lake Matese. Climate reconstructions based on pollen show an increase of PANN and MTCO from 11,260 cal BP whereas the annual temperatures reconstructed with pollen and brGDGTs increase at 11,500 cal BP.

lines 540-546: "Lake Matese is located at an altitude of 1012 m a.s.l. and the strong seasonal variability may have influenced the brGDGT distribution. Moreover, the Lake Matese climate reconstructions are based on several global lacustrine calibration datasets, which may not be well adapted to reconstruct paleotemperatures in the Mediterranean region. According to Dugerdil et al. (2021a), local calibrations perform better to reconstruct more reliable absolute values. Unfortunately, at date, only a few global lacustrine calibrations are available, and a local calibration dataset for the Mediterranean region is still missing" – It is highly likely that site-specific factors hamper the application of more general calibrations. However, these factors are currently not discussed. For example, brGDGT-derived temperature values strictly speaking, reflect soil temperatures and are not necessarily linearly related to air temperature. This is particularly true for high-altitude settings where thin soils exposed to sunshine may warm up significantly beyond the actual air temperature while soil temperatures in shaded areas, e.g., under forest vegetation are closer to the temperature of the air. In an attempt to develop a local brGDGT calibration for the Lake Ohrid Basin (Albania, North Macedonia), I determined brGDGT-based MAAT values along a west-facing 1000m altitude transect where all values from forested areas show an excellent correlation with altitude. However, the by far highest value came from a thin, rocky soil exposed on a plateau above the current tree line (unpublished data). Thus, one might speculate that, at Lake Matese, the effect of shading from enhanced tree cover may be responsible for the missing difference in brGDGT-derived MAAT values between Phases 2 and Phase 3. Changing supply of brGDGTs from different parts of the lake catchment may also be responsible for this, e.g., enhanced supply from areas where the soils were not consolidated by tree cover and more susceptible to erosion in Phase 3 or from areas facing different directions (North vs. South). For example, the sediments of Lake Ohrid recorded much higher brGDGT-based MAAT values prior to the major expansion phase of the lake. This may be explained by the associated drowning of wetlands, some of which were likely to include peatbogs without tree cover and dark soils supplying brGDGT that would bias calculated MAATs towards higher values (Panagiotopoulos et al., 2020). Some anecdotal observation of my own: on a sunny day in the field, the water in a dark pool in a peatbog at ~1800m altitude in Albania exceeded 30 degrees C.

I therefore suggest that, with the benefit of detailed knowledge of Lake Matese's catchment, the authors discuss possible mechanisms that may modify brGDGT-derived MAAT values one way or other rather than pointing out shortfalls of specific proxies and calibrations. As with many other proxies (e.g., C/N, bulk d13Corg), brGDGTs probably produce correct values of the soil temperature at their specific source, it's just a matter of knowing the dynamics of different sources and local factors in order to interpret their variability correctly. Some of this discussion is already presented, e.g. in Chapter 5.3.2, lines 658-660.
Response: We thank the reviewer for his interesting suggestions. We completed the discussion line 664 : "**By contrast**, brGDGTs are produced in the lake or in the catchment area (Russell et al., 2018; Martin et al., 2019) and thus are local contributors. Moreover, the YD is characterized by high erosion rates in the catchment (Fig. 4), which could favor greater soil-derived brGDGTs and induce a warm bias in temperatures (Martínez-Sosa et al., 2021). Indeed, **the distribution of brGDGTs differ according to sample type and could differ between lake sediments and catchment soils (Loomis et al., 2011, 2014; Buckles et al., 2014; Russell et al., 2018; Martin et al., 2019; Martínez-Sosa et al., 2021; Raberg et al., 2022). Soil sediments generally exhibit less hexamethylated brGDGTs and more tetramethylated brGDGTs than lake sediments (Loomis et al., 2011, 2014; Buckles et al., 2014; Russell et al., 2018; Martin et al., 2019; Martínez-Sosa et al., 2021). However, an increase of tetramethylated brGDGTs is mainly associated with an increase in temperatures in soils and lake sediments (Russell et al., 2018). At Matese, the YD is characterized by a decrease in hexamethylated brGDGTs and a slight increase in tetramethylated brGDGTs. These differences may have affected the annual temperature reconstructions by inducing a warm bias in temperatures during the YD. Furthermore, soil-derived brGDGTs may also be affected by changes in pH, moisture, soil compounds and vegetation in the catchment of Lake Matese (Davtian et al., 2016; Martin et al., 2019; Liang et al., 2019; Dugerdil et al., 2021a). Furthermore soil samples without vegetation cover are more sensitive to seasonal changes than that of soil samples with grass and forest cover (Liang et al., 2019). Therefore, soils with vegetation cover allow a better reconstruction of global temperatures (Liang et al., 2019). Since at Matese, the YD is characterized by an open vegetation, soil-derived brGDGTs could also have been affected by seasonal temperature changes due to a sparse vegetation and this effect is superimposed to changes in the sources of brGDGTs in lake sediments"**

line 559: "Molecular biomarkers are considered as indicators of annual temperatures like brGDGTs (this study) or alkenones […]" – brGDGTs can only be produced by soil bacteria when the soil is not frozen, i.e. there may be some bias towards the warmer seasons, particularly in high-altitude settings. Alkenone-based SSTs are not annual average values, either as marine haptophytes do not thrive year-round. Alkenones are mainly produced during the chlorophyll maxima in spring and early summer before the nutrients of the seawater are depleted. In the Mediterranean, nutrient loads will also vary with climate and, thus, change the growing season for alkenone-producing haptophytes. Alkenone-based SSTs are generally highly accurate, with very low analytical error and much stronger calibrations than

GDGTs. Changes in the main growing season and in ocean circulation will have to be considered for a correct interpretation of alkenone-based SST values.
Response: We completed the text line 564: "**Depending on the production and deposition settings,** molecular biomarkers are considered as indicators **of annual or seasonal** temperatures like brGDGTs or alkenones **(Sbaffi et al., 2004; Sicre et al., 2013; Zhang et al., 2013; Max et al., 2020; Martínez-Sosa et al., 2021; this study). »**

lines 649-651: "At Matese, a decrease of temperatures is evidenced by the pollen-based reconstructions, but it is less clear from the brGDGT-based reconstructions." – This is where factors such as the effect of shading, exposure or changes in source area could be discussed.
Response: We agree and completed the discussion line 664 (see the previous answer for lines 540-546).

line 653/654: "The basin size of the Lake Matese is larger than 5 hectares, which suggest a signal of regional vegetation rather than local […]" – I would have thought that the size of the pollen catchment strongly depends on local topography, i.e. altitude and the surrounding morphology. The majority of pollen grains settles close to the source. Thus, if a lake basin is situated at elevated altitude and surrounded by mountains, I would expect a local pollen signal rather than regional. The relatively narrow range of species present in the Matese record would support this. Perhaps, the authors could elaborate on this?
Response: We thank the reviewer for his comment. Even if the site is located in mountains, pollen can be dispersed by wind over long distances, as it is the case for *Pinus*, *Picea* or *Quercus* for example (Bell and Fletcher, 2016; Zhang et al., 2021; Robles et al., 2022), the provenance of pollen therefore depends mainly of wind speeds and directions. In the Matese Mountains, we also studied modern pollen-vegetation relationships and it was possible to see the presence of pollen of the regional vegetation mainly for trees, such as *Pinus* or *Quercus-ilex*-type which were not present in the catchment of the Lake Matese. We still have to work on this issue and this study is ongoing.

Bell, B. A. and Fletcher, W. J.: Modern surface pollen assemblages from the Middle and High Atlas, Morocco: insights into pollen representation and transport, Grana, 55, 286–301, https://doi.org/10.1080/00173134.2015.1108996, 2016.

Robles, M., Peyron, O., Brugiapaglia, E., Ménot, G., Dugerdil, L., Ollivier, V., Ansanay-Alex, S., Develle, A.-L., Tozalakyan, P., Meliksetian, K., Sahakyan, K., Sahakyan, L., Perello, B., Badalyan, R., Colombié, C., and Joannin, S.: Impact of climate changes on vegetation and human societies during the Holocene in the South Caucasus (Vanevan, Armenia): A multiproxy approach including pollen, NPPs and brGDGTs, Quaternary Science Reviews, 277, 107297, https://doi.org/10.1016/j.quascirev.2021.107297, 2022.

Zhang, N., Ge, Y., Li, Y., Li, B., Zhang, R., Zhang, Z., Fan, B., Zhang, W., and Ding, G.: Modern pollen-vegetation relationships in the Taihang Mountains: Towards the quantitative reconstruction of land-cover changes in the North China Plain, Ecological Indicators, 129, 107928, https://doi.org/10.1016/j.ecolind.2021.107928, 2021.

lines 658-660: "high erosion rates in the catchment […] could favour greater soil-derived brGDGTs and induce a warm bias in temperatures […]" – This is almost certainly the case. Similarly, the minimum in brGTGD-derived MAAT during the BA may be caused by the erosion of soil strata carrying a cooler climate signal following hydrological changes in the catchment. Does it coincide with a peak in Ti, for example?
Response: During the B/A, the erosion rates are much less important in comparison with the YD (see Fig. 2, Unit 3). We decided to complete mainly the text in the YD part to explain the differences between GDGT and pollen climate reconstructions.

lines 672/673: "In terms of precipitation, the marine cores located south of latitude 42°N record a slight temperature increase based on pollen" – How is the temperature change linked to precipitation here?

Response: We agree and modified the text line 710: "In terms of precipitation, the marine **sequences** located south of latitude 42°N record a slight increase **for proxies** based on pollen (Fig. 9GH; Combourieu-Nebout et al., 2013) and on $\delta^{18}O$ *G. bulloides* data (Fig. 9FI; Sicre et al., 2013)."

lines 688/689: "in northern sites an ~~abrupt~~ increase of precipitation is recorded" – This is certainly true for the data by Li et al. (2021). However, the record from Corchia cave appears very low resolution, so "abrupt" probably does not apply here.
Response: We agree and deleted the term "abrupt" in the text.

lines 699/700: "their reconstructions are also influenced by a record from Bulgaria which can could potentially have biased the signal of Southern Europe" – I fail to see the causal relationship here. How would a data record from Bulgaria "bias" proxy data from Southern Europe?
Response: The text was modified to clarify our proposals line 725: "Climate reconstructions **for East-Central Southern Europe** from Heiri et al., (2014) are not consistent with our results probably because while two of their **chironomid records are located in North Italy and one in Bulgaria none consider Southern Italy."**

Technical comments/corrections:

line 49: Replace "wet" with "wetter".
lines 54, 720, 749, 757: Replace "On the contrary" with "By contrast".
line 72: Replace "bec**o**me" with "bec**a**me".
lines 98/90: Replace "in **the** Southwestern Europe and Mediterranean area" with "in Southwestern Europe and the Mediterranean area."
line 91: Replace "North**-W**est" with "Northwest".
line 126: Replace "reconstruction" with "reconstruct**ing**".
line 127: Replace "somewhat unknown" with "elusive".
line 142: Replace "study" with "studies".
line 171: Surely, the lake does not have a volume of merely 15 mm^3? That would be drop.
line 182: Insert "the" before "mountains".
line 195: Replace "Coring" with "Core".
line 142: Replace "master" with "composite".
line 225: Replace "based on radiocarbon dates and correlated tephra ages" with "based on **one** radiocarbon **date** and correlated tephra ages". Clarifying this here means that the readers won't have false expectations with regard to the radiocarbon dating.
line 252: Replace "counts" with "concentrates".
line 261: Replace "more" with "greater".
line 272: Delete "The" before "WAPLS".
line 281: Insert 'p' in "bootstrap**p**ing".
line 282: Replace "applied on" with "applied to".
line 327: Introduce the abbreviation "CBT" (cyclisation of branched tetraethers).
line 337: Insert '±' before "0.040 for CBT" and other values.
line 346: Replace "geochemistry" with "XRF" for specification.
line 347: Insert 'the' before "Matese core".
line 349: Replace "macroscopic" with "macroscopic**ally**".
line 419: Replace "dotted" with "dashed".
line 670: Delete 's' in "appear**s**".
line 710/711: Replace "in" with "for" in "not reconstructed in this region".
line 714: Replace "into" with "in" before "the Mediterranean".
line 715: Insert comma after "latitude 42°N".
line 735: Replace "South Central" with "Central Southern".

Response: All the corrections have been done in the manuscript.

Figures:

If possible, add small symbols to the data points in all proxy records so that the reader can get a better idea of the resolution of these records.
Response: We thank the reviewer for his relevant comment. Unfortunately, we just used digitized curves because we do not have access to the raw data for most proxy records and thus it is not possible in the majority of cases to add symbols to the data points.

Figure 3: Replace "Gray bands are 95% confidence intervals" with "The gr**e**y band is the 95% confidence interval" (I can see one grey band, only).
Response: We replaced the sentence.

Figure 5: For better comparability with Figures 9 and 10, please insert the climate stages OD, B/A, YD and EH into the plots, at least the ones at the bottom.
Response: The climate stages OD, B/A, YD and EH have been added in the Figure 5 and Figure 8 (Annual temperature based on brGDGTs).

Reference used in this review:
Panagiotopoulos et al. (2020): Insights into the evolution of the young Lake Ohrid ecosystem and vegetation succession from a southern European refugium during the Early Pleistocene, *Quaternary Science Reviews*, 227, 106044, doi.org/10.1016/j.quascirev.2019.106044.

Responses to the comments of Reviewer 2

General comments

"Climate changes during the Lateglacial in South Europe: new insights based on pollen and brGDGTs of Lake Matese in Italy" by Mary Robles and colleagues is a nicely crafted paper that uses multiproxy techniques to reconstruct palaeoclimate climate conditions in southern Italy during the Late Glacial period. These records are compared and contrasted with other regional reconstructions. The discussion is rich and the figures are of good quality. I fully support the manuscript's publication in Climate of the Past.
Response: We thank Reviewer 2 for the interesting comments. Our responses and changes are presented below.

Some minor suggestions

Lines 81-83: The chironomid-based synthesis of Heiri et al. (2014) suggests that temperature variations during the Lateglacial tend to be more pronounced in Western Europe (British Isles, Norway) than in Southwestern Europe, Central and Southeastern regions. Why?
Response: We added a sentence in the introduction section line 85: "**These regional differences would be attributed to the changing position of the North Atlantic sea-ice and the Polar Frontal Jet Stream (Renssen and Isarin, 2001).**"

Line 87: "cooler" is vague. How much cooler?
Response: The differences in terms of temperature values depend on the proxies considered or on the climate models justifying the citation of the different papers. We added line 90: "Studies suggest that (1) the OD was cooler than the YD in Southern and Central Europe in comparison with Northern Europe (**~1-3 °C**; Heiri et al., 2014; Moreno et al., 2014)".

Line 89: Idem with "warmer". It would be good to put some numbers on these statements.
Response: See the response below. We added line 91 "the Allerød period was warmer than the Bølling in Southwestern Europe and the Mediterranean area **(~1°C**; Moreno et al., 2014)".

Lines 125-126: "…for reconstruction environmental parameters."
Response: The sentence has been modified by "… for **reconstructing** environmental parameters".

Line 369: 4.2 Age-depth model: There is no discussion on why there is such a marked offset between the radiocarbon and tephra chronologies. Given the disparity, this point needs to be addressed.
Response: We thank the reviewer for his comments. **Because most of the ^{14}C are rejected in our study, the age model is in our study a very important point which need to be discussed;** therefore the discussion of the age-depth model is presented in the discussion section. However, we agree with the reviewer and added a sentence in the results section to do the link with the discussion section line 393: "**The organic matter extracted from sediment was essentially composed of rootlets, that explains the rejuvenation of the ^{14}C ages."**

Figure 7: No error envelopes?
Response: The analytic reproducibility has been calculated and it is presented in the Material and methods section line 337: "The analytic reproducibility corresponds to ±0.040 for CBT, ±0.0167 for MBT, ±0.0206 for MBT'_{5me}". The values are low for the different ratio presented in this paper.

Lines 511-512: "…hypothesized that the dated organic matter may have originated from penetrating roots of plants growing during sedimentary Unit 5's deposition (Fig. 4)." If there is evidence of bioturbation, could this not affect the different proxy reconstructions?
Response: This is, in fact, essentially of fine rootlets and there is no evidence of bioturbation. We changed the text in the results section line 357: "This part is mostly composed by roots and **fine rootlets"** and line 393:" **The organic matter extracted from sediment was essentially composed of rootlets, that explains the rejuvenation of the ^{14}C ages" and in the discussion section line 516: "**it is hypothesized that the dated organic matter may have **partly** originated from penetrating **rootlets** of plants growing during sedimentary Unit 5's deposition (Fig. 4)".

Line 694-695: "In Italy (Fig. 9), climate reconstructions do not show latitudinaldifferences in terms of temperature." Is it possible to make this statement given the different proxy reconstructions used at different latitudes? The authors could consider converting the different series in figure 9 into z-scores to test amplitudes and rates of change on a common scale.
Response: We thank the reviewer for his relevant comments. Unfortunately, we do not have the raw data for most proxy records (we digitalized them) and thus it is not possible to test amplitudes and rates of change on a common scale.