Response to reviewers' comments

Reviewer 1

The authors touched an interesting topic for the north-east Tibetan plateau, which has a contradictory discussion in literature recently: they want to prove the hypothesis of an early Holocene arid phase. They presented a palynological study including other proxies from a lake sediment core. They sample, analyzed and compared recent as well as fossil pollen samples from the region. Their recent pollen samples come from all important vegetation units available in the region, while the fossil pollen derived from the Gahai lake sediment core situated in about 3,400 m elevation covering the last 14.2 ka. Their sediment core is also used to analyze other proxies (ie. grain sizes, TOC and TN).

For their pollen-data analysis they use standard labor techniques as well as adequate advanced statistic methods which allow a reconstruction of different climate parameters like precipitation and temperature. However, their statistical basis with generally only 100 terrestrial pollen samples counted is quite low. Moreover, the study misses a deeper discussion of recent pollen samples taken close by their lake in order to estimate the amount of long-distance transported pollen taxa to that location. This discussion should have allowed for the rough calculation and discussion of correction factors in order to estimate the amount of recent foreign pollen taxa and use them as a general value for the interpretation of the past. Additionally, the grain size data of their lake sediments are not sufficiently discussed in order to support their (paleo-)climate interpretations based on their palynological study. Some of their arguments in this interpretation are speculative and did not cover all possible climatic influences which could have modify the grain-size distribution in their lake record. For example, the discussion about the possible influence of wind and evaporation in their dry phases needs to be included in order to estimate grain-size variability and lake level changes in their sediment record. In this sense, chapter 5.3 should be rewritten. Furthermore, the authors gave no comments to the radiocarbon age reversals between 191 to 279 cm core depth! In summary I argue for a major revision of the manuscript!

Our Response: Generally, pollen concentration for lake sediment on the Tibetan Plateau is low. Pollen counts for most of the samples are >100 grains (101 out of the total 111 samples). For each sample with less than 100 pollen counts, we counted *Lycopodium spores* higher than 3000 grains, hence, we argue that the counted pollen does represent the ancient vegetation well.

We defined the arboreal pollen taxa as exogenous pollen because they co-occur with drought-tolerant herbaceous taxa (weak dispersal ability) and low pollen concentrations. Quantifying the contribution of exogenous pollen grains to a pollen assemblage is important for the correct interpretation, but it is quite difficult to estimate. We have added discussion about the diffusivity of arboreal pollen in the pollen samples taken close to Gahai Lake. Moreover, we compare our pollen spectra to those from other lakes on the north-eastern Tibetan Plateau to determine their regional consistency. More details are in the responses below.

We cite literature about grain-size analyses to determine the unique characteristics of grain size from the Tibetan Plateau lakes. Furthermore, the grain-size data were classified into more divisions to determine their representativeness. Results show that the temporal changes of the medium silt fraction (16-32 μm) are consistent with those of the whole silt fraction (4-63 μm), and confirm that the silt fraction can be a proxy for lake level and intensity of runoff in this paper. We present more detailed information about grain size in an appendix in the revised version, and we have rewritten the explanation of the grain-size distribution and chapter 5.3.

The lithology between 190 and 280 cm of the GAH is likely non-lacustrine deposits which are probably related to lake sediment collapse or rapid input of terrigenous clastic materials, hence the age between 190 and 280 cm may be unreliable. Here, our research focuses on the vegetation and environmental evolution of the upper 176 cm, which is not affected by the age reversals. We added an explanation of the radiocarbon age reversals in the revised version.

<u>Line 177-180:</u>

"At least 100 terrestrial pollen grains were counted for most samples, except for 10 samples owing to extremely low pollen concentration; and more than 3000 Lycopodium spores were counted for each sample which could reflect the palaeo-vegetation at that time."

Line 359-395:

"The grain-size composition of lake sediments can be used to trace the source of clastic particles, aeolian activity, and water-level fluctuations, which reflect the regional climate conditions (Håkanson and Jansson, 1983; Liu et al., 2016). The sources of lacustrine sediments include clastic materials carried by inflow rivers, aeolian inputs, and authigenic chemical deposition, and mean grain size reflects the intensity of transport dynamics (Folk and Ward, 1957; Xiao et al., 2013). There have been many particle-size analyses from lacustrine sediments or loess deposits on the north-eastern Tibetan Plateau. For example, Qiang et al. (2014) analysed the grain size of Genggahai lake and propound that the sand fraction (>63 µm) reflects aeolian activity. Chen et al. (2013) investigated Sugan Lake in the Qaidam basin and argue that changes in the >63 µm fraction reflect the frequencies of dust storms and strong winds. In addition, Wang et al. (2015) analysed a loess deposit from Ledu on the north-eastern Tibetan Plateau and also conclude that a grain-size of 60 µm is locally transported by strong winds during cold climatic intervals. The sand fraction (>63 µm) is also found in modern river sediments although the percentage is typically low. A single extreme rain event under an arid climate could lead to an abrupt sand fraction increase (Ding et al., 2005; Li et al., 2012; Liu et al., 2016; Ota et al., 2017; Zhou et al., 2018). Therefore, the sand fraction is mainly transported by winds and any peak or abnormal increase of the coarse grain size (especially the sand fraction) is likely related to flood events. In our study, a high proportion of the sand fraction (>63 µm) mainly represents aeolian activity intensity.

Particle-size variation can reflect changes in water level or precipitation, taking into account the different lake recharge types, hydrological conditions, and lake sizes. There has been debate about how to interpret the grain-size index because the coarse particle fraction is positively correlated with precipitation and water level in small *lakes dominated by summer rainfall but not in large lakes (Peng et al., 2005; Chen et al., 2021). Gahai Lake is a small, shallow lake and receives most of its precipitation in summer. The coarse particle fraction reflects a humid climate and high lake level owing to strong hydrological dynamics (Håkanson and Jansson, 1983; Peng et al., 2005; Liu et al., 2008). The silt fraction (4–63 μm) in our study 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 silt are combined into the total silt fraction (4–63 μm) for discussion. In addition, the mean grain size is closely related to the sand fraction and poorly reflects the climatic moisture and lake level. Therefore, we speculate that a high silt fraction (4–63 μm) in Gahai Lake reflects an increased lake level, while a high clay fraction (<4 μm) content reflects a low stand."*

Line 402-409:

"In addition, we analysed the non-woodland topsoil samples within 30 km of Gahai Lake (n=22). Results show that arboreal pollen taxa including Pinus, Picea, and Betula are always present (usually at <40%) in the pollen samples, indicating that they have good diffusivity and are easily transported to areas beyond their pollen source (Fig. A3; A4). Therefore, the main arboreal pollen taxa in the GAH core including Pinus, Picea, Betula, and Ulmus are highly diffusive species which may bias the vegetation reconstruction unless their far-distance transport is accounted for."

Line 277-284:

"The age-depth model suggests that the basal age of GAH is about 24 ka BP, with the age of sediments between 191 and 279 cm basically remaining the same, probably because of lake sediment collapse or rapid input of terrigenous clastic materials since the lithology also changes markedly between 190 and 280 cm, confirming that the lake underwent rapid deposition during this phase. The sedimentation rate is relatively stable since 15 ka BP, and our research focuses on the vegetation and environmental evolution since 14.2 ka BP (Fig. 4)."

Specific comments (line by line):

52: Show all records mentioned in your figure 1

Our Response: We have modified Figure 1.

80: "*such arboreal pollen* **amounts**"

Our Response: We have revised this sentence.

<u>Line 80-81:</u>

"Understanding the spatial distribution characteristics of modern pollen and their relationships may be an effective way to identify such arboreal pollen properties."

97: "*Gahai Lake* **recently** *belongs to*"

Our Response: 'Currently' expresses our meaning better.

<u>Line 98-100:</u>

"Gahai Lake currently belongs to the alpine humid climate zone, which is influenced by the West Pacific Subtropical High in summer and controlled by westerlies in winter."

135: Why do you include elevation? What is the meaning of elevation in climatic terms in your region? Is it cold resistance and/or dry resistance for the plants? How is P_{ann} distributed in your region regarding elevation?

Our Response: For the Tibetan Plateau, elevation is an important factor strongly influencing both climate and vegetation distribution, and thus also has an important effect on the pollen distribution and the modern pollen studies on the Tibetan Plateau generally (Lu et al., 2011; Zhang et al., 2012). The percentages of *Picea*, *Abies*, *Betula*, and Cyperaceae are closely related to the elevation range, and *Pinus* is easily transported to high-elevation regions (Li et al., 2012; Shen et al., 2021). The vegetation change is mainly influenced by temperature and precipitation during the Holocene on the eastern Tibetan Plateau but is also affected by treeline expansion or retreat, which is related to elevation, as seen, for example, in Hongyuan peatland (Zhou et al., 2010), ZB08-C1 core (Zhao et al.,

2011), Ximencuo Lake (Herzschuh et al., 2014), and Naleng lake (Kramer et al., 2010). In addition, our study area is located on the eastern Tibetan Plateau, which is an area of concentrated arboreal tree distribution. Therefore, it is necessary to consider the influence of elevation when reconstructing the pollen distribution of the eastern Tibetan Plateau. Pollen diagrams arranged by elevation can be seen in the Appendix.

Further details of the ecological environment of the main pollen taxa are given in the results of the revised version.

The mean annual precipitation (MAP) of the study area is 595 mm, about 80% of which falls in the monsoon season (June to September), and mean annual evaporation is 1150.5 mm (Duan et al., 2016).

Lu, H., Wu, N., Liu, K. -B., Zhu, L., Yang, X., Yao, T., Wang, L., Li, Q., Liu, X., Shen, C., Li, X., Tong, G. and Jiang, H.: Modern pollen distributions in Qinghai-Tibetan Plateau and the development of transfer functions for reconstructing Holocene environmental changes. Quat. Sci. Rev. 30, 947–966, doi: 10.1016/j.quascirev.2011.01.008, 2011.

Zhang, D., Sun, A., Han, X. & Dai, R. 2012: The Instruction Significance to Altitudes of Surface Pinus and Abies Pollen from the Middle Reaches of Yarlung Zangbo River. J. Mountain Sci. 30, 478–483 (in Chinese with English abstract).

Shen, C., Liu, K.-B., Tang, L. and Overpeck, J. T.: Modern pollen rain in the Tibetan Plateau. Frontiers of Earth Science 9, 732441, doi: 10.3389/feart.2021.732441, 2021.

Li, Q., Ge, Q. and Tong, G.: Modern pollen-vegetation relationship based on discriminant analysis across an altitudinal transect on Gongga Mountain, eastern Tibetan Plateau. Chinese Sci. Bull. 57, 4600–4608, doi: 10.1007/s11434-012-5236-6, 2012.

Herzschuh, U., Borkowski, J., Schewe, J., Mischke, S., and Tian, F.: Moisture-advection feedback supports strong early-to-mid Holocene monsoon climate on the eastern Tibetan Plateau as inferred from a pollen-based reconstruction. Palaeogeogr. Palaeoclimatol. Palaeoecol. 402, 44–54., doi: 10.1016/j.palaeo.2014.02.022, 2014.

Zhou, W., Yu, S., Burr, G. S., Kukla, G. J., Jull, A. J. T., Xian, F., Xiao, J., Colman, S. M., Yu, H., Liu, H., Liu, Z., and Kong, X.: Postglacial changes in the Asian summer monsoon system: A pollen record from the eastern margin of the Tibetan Plateau. Boreas, 39: 528–539, doi:

10.1111/j.1502-3885.2010.00150.x, 2010.

Zhao, Y., Yu, Z., and Zhao, W.: Holocene vegetation and climate histories in the eastern Tibetan Plateau: controls by insolation-driven temperature or monsoon-derived precipitation changes? Quat. Sci. Rev., 30, 1173-1184, doi: 10.1016/j.quascirev.2011.02.006, 2011.

Kramer, A., Herzschuh, U., Mischke, S., and Zhang, C.: Holocene tree-line shifts and monsoon variability in the Hengduan Mountains (south-eastern Tibetan Plateau) implications from palynological investigations. Palaeogeogr. Palaeoclimatol. Palaeoecol. 286, 23–41, doi: 10.1016/j.palaeo.2009.12.001, 2010.

Duan, Y., Zhao, Y., Wu, Y., He, J., Xu, L., Zhang, X., Ma, L., and Qian, R.: δD values of n-alkanes in sediments from Gahai Lake, Gannan, China: implications for sources of organic matter, J. Paleolimnol. 56, 95–107, doi: 10.1007/s10933-016-9895-1, 2016.

Line 135-145:

"We selected four important climate variables including mean annual precipitation (Pann), mean temperature of the warmest month (Mtwa), mean temperature of the coldest month (Mtco), and mean annual temperature (Tann), together with elevation (Elev) to investigate the relationship between pollen assemblages and the environment because these are important factors influencing the pollen distribution on the Tibetan Plateau (Lu et al., 2011; Herzschuh et al., 2011; Cao et al., 2021; Wang et al., 2022). Modern climatic data were obtained from the Chinese Meteorological Forcing Dataset (CMFD; gridded near-surface meteorological dataset), and each sample is assigned to the nearest pixel of the CMFD using the fields package version 13.3 (Nychka et al., 2021) of R (version 4.0.3; R Core Team, 2021). The detailed processes of obtaining climatic data are presented in Fig. A1."

Line 237-242:

"In addition, elevation is also an important factor influencing the pollen distribution on the eastern Tibetan Plateau. Arboreal pollen taxa including Pinus, Picea, Abies, Betula, Quercus (deciduous, D), and Corylus are mainly distributed in areas below 3900 m a.s.l., while Quercus (E) is concentrated in areas above 3700 m a.s.l. The high percentages of Cyperaceae, Artemisia, and Chenopodiaceae are mainly concentrated in the lower elevations (below 3200 m a.s.l.)."

225-227: Reformulate sentence. How did you define warm and wet? What about Mt_{wa}?

Our Response: We have reformulated this sentence in the revised version. According to the modern pollen dataset, high abundances of arboreal pollen taxa are consistent with precipitation and temperature (Mt_{co}) while having little relation with Mt_{wa}, hence we do not mention the Mt_{wa} in the main text. The details are in the revised version.

<u>Line 229-231:</u>

"High abundances of arboreal pollen taxa including Abies, Quercus (evergreen, E), Corylus, and Carpinus are mainly distributed in regions with Pann higher than 450 mm and Mtco higher than -15 ℃ (Fig. 2; A1)."

228-229: you mean: "*Pinus*, *Picea*, and *Betula* pollen…" That is the influence of wind dispersal of these taxa. With which amount appear these taxa in dry areas? Specify!

Our Response: We have added the details in the revised version.

<u>Line 231-235:</u>

"Pinus (up to 2.3%, mean 0.3%), Picea (up to 25.7%, mean 0.5%), and Betula (up to 5.7%, mean 0.4%) are also widely distributed and appear in extreme dry and cold sampling sites where Pann is lower than 450 mm and Mtco lower than -15 ℃, although their high abundances are restricted to warm and wet areas (Fig. 2; A1)."

260-267: Add information and comments/explanations of the age reversal in the dated samples between 191 and 279 cm depth showing in table 2!

Our Response: The ages between 191 and 279 cm are basically unchanged which is probably related to lake sediment collapse or rapid input of terrigenous clastic materials since the lithology also changes markedly between 190 and 280 cm in the GAH, confirming that the lake underwent rapid deposition during this phase. Our research, however, focuses on the vegetation and environmental evolution of the upper 176 cm, which is not affected by the age reversal. Nevertheless, we

have added an explanation in the revised version.

Line 271-284:

“The AMS 14C ages of GAH exhibit a linear regression with depth, while there is a transient inversion between 191 and 279 cm, which is probably due to increased erosion input to the basin, leading to some old carbon accumulating in the lake. The ages of the upper 20 cm are calculated based on their relationship (Table 2), and the age difference between 14C and 210Pb of the same depth is considered as the reservoir age. We selected two depths (6 cm and 10 cm) to calculate an average to reduce errors and obtained a reservoir age of 483 years. The age-depth model suggests that the basal age of GAH is about 24 ka BP, with the age of sediments between 191 and 279 cm basically remaining the same, probably because of lake sediment collapse or rapid input of terrigenous clastic materials since the lithology also changes markedly between 190 and 280 cm, confirming that the lake underwent rapid deposition during this phase. The sedimentation rate is relatively stable since 15 ka BP, and our research focuses on the vegetation and environmental evolution since 14.2 ka BP (Fig. 4).”

278: “…while *Pinus* pollen amounts increase…”. Also in further sentences: it is not the taxon itself, but the amount of pollen grains of the taxon which increases/decreases!

Our Response: Pollen concentration increased from 53.3 grains/g to 272.3 grains/g after 7.3 ka BP, and number of counted pollen grains also increased from 109 to 535 grains. Arboreal pollen increased from 79 to 372 grains (*Pinus*, 42 to 302 grains), and herbaceous pollen increased from 46 to 151 grains. The pollen proportion of arboreal and herbaceous taxa also changed, with arboreal percentage increasing from 58.4% to 68.6% (*Pinus*, 31.8% to 55.8%) and herbaceous percentage decreasing from 41.6% to 27.3%. Therefore, we believe that not only has the absolute pollen counts changed, but also the percentages of the main pollen taxa.

298: In which direction is your general increasing trend? I can’t see it straight. The four stages are not clear and are not shown in your figure 7.

Our Response: We have rewritten the grain-size results.

<u>Line 315-327:</u>

“The size fractions (volume, %) were classified as clay (<4 μm), silt (fine: 4–16 μm; medium: 16–32 μm; coarse: 32–63 μm – combined into one category for the discussion), and sand (>63 μm), and the specific details are shown in Fig. A2. The grain-size parameters of GAH include mean grain size, which ranges from 17.5 to 60 μm. The combined silt fraction (4–63 μm) accounts for the maximal proportion (58–75%; mean 66%) in general (Fig. 7). The clay fraction (15–33%; mean 23%) forms the highest proportion during 14.2–10.8 ka BP, then decreases significantly and remains stable after 10.8 ka BP (Fig. 7). The silt fraction (57.6–74.7%; mean 63.9%) is lowest during 14.2–10.8 ka BP, then increases and reaches a peak during 7.4–3.8 ka BP, after which the mean value decreases to 65.8% (Fig. 7). The sand fraction correlates with the silt fraction before 10.8 ka BP, while later the variation is anticorrelated. Mean grain size closely correlates with the sand fraction in general (Fig. 7).”

341: “…particles >50 μm” up to which size? But these particles could also be transported by fluvial activity! Discuss!

Our Response: The grain-size particles are between 50 and 1000 μm. From a comparison between the grain-size distribution of core sediment from Qinghai Lake and the distribution of modern dust, loess, and modern lake sediment, the very coarse silt fraction (58 μm) of the core sediment equates to the medium silt fraction (47 μm) of modern dust and loess, suggesting that the very coarse fraction in the lake sediments has mainly been transported via atmospheric circulation, This is discussed in Liu et al. (2016). In addition, the very coarse fraction also exists in modern river sediments, but at a low percentage of only 2.5%. The end-member analyses suggest that the coarse tail of EM1 corresponds to the very coarse fraction (58 μm). Based on the above analysis and given four

grain-size fractions (<2 μm, 2-8 μm, 8-50 μm, >50 μm) of Qinghai Lake, the researchers argue that 50 μm is a more likely boundary to distinguish the riverine and (reworked) eolian components. We have replaced this reference with others following your suggestion.

Liu, X., Vandenberghe, J., An, Z., Li, Y., Jin, Z., Dong, J., and Sun, Y.: Grain size of Lake Qinghai sediments: implications for riverine input and Holocene monsoon variability, Palaeogeogr. Palaeoclimatol. Palaeoecol. 449, 41–51, doi: 10.1016/j.palaeo.2016.02.005, 2016.

346-350: This discussion is not convincing: silt is also easily transported by wind, while high amounts of clay may indicate calm/slow water transport and/or intensive weathering in the catchment. Sand can also be transported by running water. Did you checked the polish features of the quartz grains under the microscope in order to differentiate between aeolian and fluvial transport?

Our Response: We have rewritten this part in the revised version.

We did not check the polish features under the microscope, but we add further evidence in the revised version. Furthermore, the key focus of our paper is the pollen and the studies on particle size are only auxiliary indicators.

Line 359-395:

"The grain-size composition of lake sediments can be used to trace the source of clastic particles, aeolian activity, and water-level fluctuations, which reflect the regional climate conditions (Håkanson and Jansson, 1983; Liu et al., 2016). The sources of lacustrine sediments include clastic materials carried by inflow rivers, aeolian inputs, and authigenic chemical deposition, and mean grain size reflects the intensity of transport dynamics (Folk and Ward, 1957; Xiao et al., 2013). There have been many particle-size analyses from lacustrine sediments or loess deposits on the north-eastern Tibetan Plateau. For example, Qiang et al. (2014) analysed the grain size of Genggahai lake and propound that the sand fraction (>63 μm) reflects aeolian activity. Chen et al. (2013) investigated Sugan Lake in the Qaidam basin and argue that changes in the >63 μm fraction reflect the frequencies of dust storms and strong winds. In addition, Wang et al. (2015) analysed a loess deposit from Ledu on the

north-eastern Tibetan Plateau and also conclude that a grain-size of 60 μm is locally transported by strong winds during cold climatic intervals. The sand fraction (>63 μm) is also found in modern river sediments although the percentage is typically low. A single extreme rain event under an arid climate could lead to an abrupt sand fraction increase (Ding et al., 2005; Li et al., 2012; Liu et al., 2016; Ota et al., 2017; Zhou et al., 2018). Therefore, the sand fraction is mainly transported by winds and any peak or abnormal increase of the coarse grain size (especially the sand fraction) is likely related to flood events. In our study, a high proportion of the sand fraction (>63 μm) mainly represents aeolian activity intensity.

Particle-size variation can reflect changes in water level or precipitation, taking into account the different lake recharge types, hydrological conditions, and lake sizes. There has been debate about how to interpret the grain-size index because the coarse particle fraction is positively correlated with precipitation and water level in small lakes dominated by summer rainfall but not in large lakes (Peng et al., 2005; Chen et al., 2021). Gahai Lake is a small, shallow lake and receives most of its precipitation in summer. The coarse particle fraction reflects a humid climate and high lake level owing to strong hydrological dynamics (Håkanson and Jansson, 1983; Peng et al., 2005; Liu et al., 2008). The silt fraction (4–63 μm) in our study 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 silt are combined into the total silt fraction (4–63 μm) for discussion. In addition, the mean grain size is closely related to the sand fraction and poorly reflects the climatic moisture and lake level. Therefore, we speculate that a high silt fraction (4–63 μm) in Gahai Lake reflects an increased lake level, while a high clay fraction (<4 μm) content reflects a low stand.”

357-359: What amount of these pollen taxa appear in your recent pollen samples close to your lake and/or in the top sample of your core? May be, you can use these values as correction factors! Moreover, these taxa might indicate phases with higher wind speed as well! Compare the pollen data closer with your grain size data!

Our Response: Thanks for the suggestion. We have analysed the diffusivity of the main arboreal pollen species and topsoil samples near Gahai Lake (*n*=22) and include the detailed information in the revised version. We agree the main arboreal pollen taxa including *Pinus*, *Picea*, and *Ulmus* before 7.4 ka BP in the GAH core are highly diffusive species which may bias the interpretation of the source of arboreal pollen.

Thanks for the suggestion. We believe the comparison between pollen and grain-size data is more appropriately placed in the discussion (5.3) and have rewritten this part.

<u>Line 402-409:</u>

"In addition, we analysed the non-woodland topsoil samples within 30 km of Gahai Lake (n=22). Results show that arboreal pollen taxa including Pinus, Picea, and Betula are always present (usually at <40%) in the pollen samples, indicating that they have good diffusivity and are easily transported to areas beyond their pollen source (Fig. A3; A4). Therefore, the main arboreal pollen taxa in the GAH core including Pinus, Picea, Betula, and Ulmus are highly diffusive species which may bias the vegetation reconstruction unless their far-distance transport is accounted for."

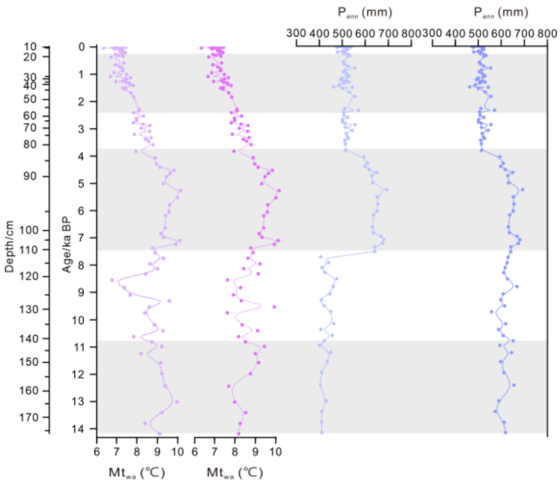
373-378: You suggested an extremely arid climate between 14.2 to 7.4 ka: but your grain size data do not support that strongly, even the P_{ann} reconstruction is contrary (figure 7). Why don't you show the light blue (excluding arboreal taxa) curve for the whole core? Comment on this!

Our Response:

Thanks for the suggestion. We have rewritten the discussion about the grain-size data. We believe that arboreal pollen before 7.4 ka BP is mainly transported from a long distance, which is discussed in the revised version (Discussion 5.2). Therefore, we reconstructed precipitation based on the fossil pollen records either including (dark curve) or excluding (light curve) arboreal pollen taxa which can provide an approximate range of P_{ann} and Mt_{wa} during this period.

The former inclusive reconstruction overestimates precipitation compared to the exclusive reconstruction, and we have added details to the discussion.

After 7.4 ka BP, arboreal pollen mainly comes from within the catchment and the pollen data (dark and light curves) are the same, hence we believe that the reconstructions of them are the same and it is not necessary to show the light curves (excluding arboreal taxa) alongside the dark curves. The comparison of the light and dark curves is shown below.



Reconstructions of P_{ann} and Mt_{wa} for Gahai Lake based on the fossil pollen record either including (darker lines) or excluding (lighter lines) arboreal pollen taxa since 14.2 ka BP.

379-446: In general, the whole chapter 5.3 needs a deeper discussion: ie. you are assuming arid conditions between 14.2 to 10.8 ka but weak aeolian activity, why? High clay amounts could also speak for a deeper lake! Do you have former strand lines around your lake? Again, why don’t you show the light blue curve in figure 7 for the whole profile?

Our Response: Because the silt fraction (4-63 µm) represents moister climate and the sand fraction (>63 µm) suggests aeolian activity as is explained in the revised version. High sand fraction in the lake sediments reflects intense aeolian activity and we have amended the revised version (Discussion 5.2). In addition, we have rewritten section 5.3.

No other strand lines exist around Gahai Lake.

The P_{ann} reconstruction based on the pollen record has not excluded arboreal

pollen before 7.4 ka BP but we consider the reconstructions to be biased due to the likely exogeneous nature of the arboreal pollen. Hence, we also reconstruct P_{ann} after removing the arboreal pollen (the light blue curve) for the early period. After 7.4 ka BP, however, the arboreal pollen mainly originated from within the lake basin rather than being exogeneous, and the P_{ann} reconstruction (blue curve) is thus based on all pollen taxa. Therefore, we do not have a light curve after 7.4 ka BP.

401-404: You argue for a cold and arid climate, but meanwhile your water level is supposed to have increased and your P_{ann} still shows high amounts between 10.8 to 7.4 ka! How could the supposed enhance wind strength you mentioned could have reduced the water level of your lake due to enhanced evaporation? Discuss!

Our Response: Thanks for the suggestion. We have rewritten this part in the revised version. The significant increase of the silt fraction with small fluctuations of the sand fraction suggest that the water level rose slightly and aeolian activity intensified during the early Holocene.

As given in the explanation above, the P_{ann} reconstruction based on pollen (including arboreal pollen; blue curve) is likely to be overestimated in the early part because the arboreal pollen is probably exogenous. To correct this bias, we reconstruct P_{ann} based on assemblages excluding the arboreal pollen (light blue curve).

We apologise for giving the wrong explanation about the relationship between aeolian activity and enhanced evaporation, and we have rewritten this part in the revised version.

<u>Line 452-456:</u>

"The silt fraction significantly increases while the clay fraction decreases sharply with small fluctuations in the sand fraction, indicating a slight rise in the water level and intense aeolian activity during the early Holocene (Fig. 7). Therefore, we infer that the vegetation of Gahai Basin was covered by alpine steppe under dry climatic conditions during the early Holocene."

405-408: Why could the silt fraction after 7.4 ka be indicative for a lake high stand? Why not for more wind? Your P_{ann} after 7.4 ka first is still high as before, but goes down at about 4 ka. Explain!

Our Response: Thanks for the suggestion. We have explained above that the silt fraction is used as a proxy of lake-level change, and its significant increase suggests a high lake level between 7.4 and 3.8 ka BP. The P_{ann} reconstruction is based on pollen assemblages in which the arboreal pollen taxa have changed from long-distance transport (exogeneous) to within catchment taxa. Reconstructed P_{ann} (mean 634 mm) increases compared to the former stage. Hence, we infer a climate that was warm and wet and which reached an optimum between 7.4 and 3.8 ka BP.

436-437: Again, explain the grain size- distribution and your "weaker water dynamics"! What do you mean with weaker? And why only sand is indicative for aeolian activity. What about the occurrence of single extreme rain events under an arid climate? They could also bring sand into your lake!

Our Response: Thanks for the suggestion. We have rewritten this part in the revised version. The grain-size distribution and its representation are detailed in the revised version (Discussion 5.2). The silt fraction represents the lake level and moisture, and we have changed "weaker water dynamics" to "lower lake level". The silt fraction decreases significantly compared with the previous stage, thus the lake level most likely decreased (weaker water dynamics) between 2.3 and 0.24 ka BP.

The sand fraction is indicative of aeolian activity, which is explained in the revised version (Discussion 5.2). We agree that extreme rain events under an arid climate could lead to a sand fraction increase, which would generate an abnormally high value or peak in the proportion of coarse grains. Zhou et al. (2018), for example, identified extreme flood events based on grain-size analysis

in Kanas Lake (northwest China), and show that high-intensity floods are closely related to the peak of coarse grains (40-100 μm) under warmer and wetter climate. Li et al. (2012) reconstructed historical flood events from sedimentary records in Taihu Lake (eastern China), and 15 flood events could be identified from the peaks of the sand fraction (> 64 μm) during the past 150 years. Ota et al. (2017) investigated flood history from rock magnetism, grain-size distribution and sediment geochemistry in Nakaumi Lake (western Japan), suggesting that the abnormally high values of the C/N ratio and coarse grain-size (62.5-74.3 μm) are consistent with flood event deposits. However, the sand fraction is generally transported by strong winds and can therefore be used as a proxy for aeolian activity as is explained in detail in the revised version. The sand fraction generally represents aeolian activity, although peaks or an abnormal increase in coarse grain size (especially sand fraction) is likely related to flood events.

Li, Y., Yu, G., Shen, H., Hu, S., Yao, S., Yin, G.: Study on Lacustrine Sediments Responsing to Climatic Precipitation and Flood Discharge in Lake Taihu Catchment, China, Acta Sediment. Sin., 30, 1099–1105, 2012. (in Chinese with English abstract)

Ota, Y., Kawahata, H., Sato, T., Seto, K.: Flooding history of Lake Nakaumi, western Japan, inferred from sediment records spanning the past 700 years. J. Quaternary Sci., 32, 1063–1074. doi: 10.1002/jqs.2982, 2017.

Zhou, J., Wu, J., Zeng, H.: Extreme Flood Events over the Past 300 Years Inferred from Lake Sedimentary Grain Sizes in the Altay Mountains, Northwestern China, Chin. Geogra. Sci., 28, 773–783. doi: 10.1007/sl1769-018-0968-0, 2018.

441: What about other “introduced” taxa due to human activity?

Our Response: We have added other “introduced” taxa (Poaceae, Ranunculaceae) in the revised version.

<u>Line 504-507:</u>

“According to earlier topsoil studies, Ranunculaceae and Poaceae are important indicators of grazing activities on the north-east Tibetan Plateau, with pollen

percentages changing significantly in the overgrazed sites (Wei et al., 2018; Duan et al., 2021)..”

445: Why is the increased silt fraction indicative for increased surface erosion. What transport mechanism? Wind? Fluvial?

Our Response: Because the percentage of the silt fraction is an indicator of the transport dynamics associated with riverine runoff, where a high value suggests enhanced erosion intensity within the catchment and thus strong water dynamics.

445: A figure with the compared other sites you mentioned in chapter 5.4 and their main proxies should be shown.

Our Response: Accept. We have added a figure that shows the sites mentioned in chapter 5.4 and added the main proxies of these records in the revised version.

Technical comments:

Figure 1: Show all other lake sites. Use other color/sign for your recent pollen samples in Fig. 1a, light blue crosses are hard to identify. There are so many recent samples in some regions that they are hard to identify individually. May be add a figure in another scale to show the detailed distribution of the recent pollen samples. Add the modern pollen samples in Fig. 1b and show the vegetation units, not only elevation (or add recent pollen samples and vegetation units of your catchment in an extra map)

Our Response: First, we have added the mentioned records in figure 1a. Second, we have changed the colour of the modern sites from light blue to black. Third, the discussion of the modern sample sites is intended to provide some key pollen characteristics and provide some basis for subsequent discussion of the GAH core rather than the focus in this paper. In addition, the pollen dataset has too many samples and has several concentrated areas, hence we cannot add figures owing to space limitations. Fourth, we have added a vegetation map in figure 1.

Figure 2: please enlarge it!

Our Response: Agreed, we have enlarged figure 2.

Figure 5: please enlarge it and add a depth scale!

Our Response: Agreed, we have enlarged and added the depth scale in figure 5.

Figure 7: please enlarge it and add a depth scale! The scale for the light blue curve partly is out of range of the scale on top! Why do you show the light blue curve only for the time before 7.4 ka? Show it for the whole record!

Our Response: Agreed, we have enlarged and added the depth scale in figure 7. We are so sorry for this careless mistake, and have added the 300mm to ensure the light blue curve was within the range of the scale.

Thanks for the suggestion, and the reason for not showing the whole curve is explained in detail above.