Dear John Dodson,

Thanks for your review. Please find below our response to each of the issues that you have raised together with links on how we considered your suggestions.

Reviewer: Actually, it does not cover all of the last 430 kyr and is really a record from MIS stages 5e to 12. Perhaps the title should reflect this.
Response: You are right. We have modified the title that is becomes clearer: "Relationships between low-temperature fires, climate and vegetation during three late glacials and interglacials of the last 430 kyrs in northeastern Siberia reconstructed from monosaccharide anhydrides in Lake El'gygytgyn sediments"

Reviewer: The manuscript and interpretations make a number of assumptions that could be better spelled out. Interpretation of the deeper time record is based on knowledge of contemporary ecosystems in Siberia. Hence assumption number one is that present ecology is a good analogue for the past. Yet we know from the pollen record that the boundary conditions may be different.
Response: You are right that past boundary conditions were very different in the past and we are specifically testing how fire-vegetation relationships during several late glacial to interglacial periods (with different boundary conditions represented by the pollen data) have changed with insolation and global ice volume (LR04 record). Thereby, it is one of the major goals of using El'gygytgyn sediments (that comprise proxy records from different interglacials) to test if the modern fire regime – ecosystem association also holds on long time scales, the reason for the MA-pollen correlation analysis. In the discussion and interpretation, we mainly assume that known physico-chemical processes during burning would be transferable also to previous interglacials. These processes are those that determine the MA emission ratios and the physical properties of the modern ecosystems, such as a more open canopy in larch versus spruce forest and certain fire adaptive traits, which are thought to be typical for high latitude biomes.
We have phrased that now more prominently in the abstract: "Combined with pollen and non-pollen palynomorph records from the same samples, we assess *how far the modern* relationships between fire, climate, and vegetation *also persisted during the past*, on centennial to orbital time scales." and in the discussion: "One additional biomass source could be dense moss–lichen mats within the summergreen boreal forest, assuming that past ecosystem properties were similar as today".

Reviewer: I am not aware that the molecular proxies have been tested in the field or lab. So assumption 2 is that the only source of the key compounds is from low-temperature fires….
Response: A comprehensive review paper came out recently that summarizes the state-of-knowledge on anhydrosugars (MAs) in the earth system (Suciu et al., 2019), discussing all relevant processes from source to sink and confirming assumption 2. We acknowledge this review paper throughout the revised manuscript and we added concerning your question:
"A recent review of Suciu et al. (2019) attributes the dominant low temperature production to depolymerization, fragmentation and inter- and intramolecular transglycosylation during pyrolysis, while a minor fraction of MAs can attach to charcoal during higher temperatures, when smoldering overlaps or follows flaming conditions."

Reviewer: The fire record could be readily strengthened if there was some accompanying micro-charcoal record from the sediments. Does such data exist?
Response: Thanks for this remark. We are currently analysing charcoal from pollen slides but so far we have microcharcoal data only from the new pollen samples of sediment core PG1351 (MIS 5e-8), but microcharcoal analysis was not included in the previously published pollen data of MIS 11-12 from the ICDP 5011-1 core (Melles et al., 2012). Our main objective is to test the potential of MAs for fire reconstructions on long timescales and we are aware that MAs and charcoal might have partially different sources, transport and degradation pathways (Clark, 1988;Dietze et al., 2019). Hence, we don't

expect identical trends from both proxies and we will discuss a charcoal- versus MA-based fire history in more detail in a next study when we have more data available for both, MAs and charcoal.
We mention this now in the concluding sentence: "Further research will continue exploring lake-sedimentary MAs *in higher resolution together with further sedimentary fire proxies such as charcoal to study* low-intensity fire–climate–vegetation feedbacks in space and time and potential ways of post-depositional degradation in even older interglacials, with CO2 levels similar to those expected in the future".

Reviewer: An anonymous review asks the question about how mobile these compounds may be down a sediment profile. This is potentially a serious matter which could make the whole interpretation flawed. It may be ameliorated if the compounds become bound to say clay particles but it needs to be tested. One wonders whether these proxies
may be affected by diagenesis. The authors allude to this in their discussion (lines 280-285, and 340+). Thus, we assume any diagenetic effect is small compared to the magnitude of the changes in abundance of the key compounds. It would be useful if this was made more explicit...
Response: We have now strongly extended the discussion of potential sources, transport and degradation pathways based on the current knowledge of potential source areas, catchment and lake configuration and previously studied processes (e.g. after Suciu et al. (2019) and further studies of the El'gygytgyn expedition team members). For example, we now discuss that the MAs we detect in El'gygytgyn lake sediments might be those that have attached to particles during the production, transport or deposition (and mention this now also in the abstract already) given that all degradation processes are quick (hours to weeks) and are mainly affecting the dissolved MAs. An in-situ production of MAs by diagenesis has been described as "theoretically impossible" (Suciu et al., 2019).
We have added in the abstract: "We find that MAs *attached to particulates* were well-preserved…" and please see the extended chapter 4.1.2. In chapter 4.3.2, we also added: "El'gygytgyn MA ratios are also about two to ten times lower than those previously reported for other lake systems (Kirchgeorg et al., 2014;Schüpbach et al., 2015;Callegaro et al., 2018;Dietze et al., 2019), *suggesting that long-term post-depositional degradation could have altered MA ratios, but the direction of diagenetic decomposition was opposite to what we find, i.e. no MAN and GAL in Miocene and older deposits (Fabbri et al., 2009;Marynowski et al., 2018;Suciu et al., 2019)"*.

Reviewer: In lines 200-210 mention is made that the pollen records have been harmonized. What does this mean and how was it done?
Response: As we use pollen data from two different pollen experts, the original pollen names were slightly different and partly describing pollen types in different taxonomic detail. We harmonized the pollen type names by aggregating on a higher taxonomic level (e.g. Betula alba-type and Betula nana-type pollen summed up to "Betula".
In the text, we now have specified: "Existing pollen data (Melles et al., 2012) from the same depths as MA samples of late MIS 12 and 11c were harmonized with the new pollen samples of core PG1351, *i.e. pollen types were aggregated to the highest taxonomic level identified by the two pollen experts,* to compare the same taxa in percentages."

Reviewer: There is an obvious question about how these ancient fire regimes relate to fire in the present day. There is potentially a lot to say here about any differences in natural and anthropogenic fires regimes.
Response: You are right that modern fire regimes might be strongly affected by human fire management, which we know very well from the boreal forests in general (Molinari et al., 2018;Bowman et al., 2011) and that is also the reason to analyse natural processes and fire-vegetation feedbacks in periods when humans have clearly not affected them. However, while it is certainly of strong interest to discuss the human alteration of natural fire-vegetation feedbacks in eastern Siberia, we still have a poor understanding on how humans have affected, for example, the Siberian summergreen boreal forest, as existing data is limited or site-specific (Mollicone et al., 2006;Kukavskaya et al., 2013). Yet, our data is

not suited to answer this question as we are lacking, for example, modern and Holocene lake sediment samples for comparison.
However, based on your comment, we have specified the last sentence in the abstract "extend our knowledge on long-term *natura*l fire–climate–vegetation feedbacks in the high northern latitudes" and added a motivation/explanation in the conclusion on why it is valuable to reconstruct explicitly the natural processes from previous warm periods: "Although limited in samples, we can deduce first fire–climate–vegetation relationships in north-eastern Siberia on long timescales, *which can guide towards a natural, process-based land management of the future*."

References used in this response letter

Bowman, D. M., Balch, J., Artaxo, P., Bond, W. J., Cochrane, M. A., D'Antonio, C. M., Defries, R., Johnston, F. H., Keeley, J. E., Krawchuk, M. A., Kull, C. A., Mack, M., Moritz, M. A., Pyne, S., Roos, C. I., Scott, A. C., Sodhi, N. S., Swetnam, T. W., and Whittaker, R.: The human dimension of fire regimes on Earth, J Biogeogr, 38, 2223-2236, 10.1111/j.1365-2699.2011.02595.x, 2011.

Callegaro, A., Matsubara Pereira, F., Battistel, D., Kehrwald, N. M., Bird, B. W., Kirchgeorg, T., and Barbante, C.: Fire, vegetation and Holocene climate in the south-eastern Tibetan Plateau: a multi-biomarker reconstruction from Paru Co, Clim. Past Discuss., 2018, 1-33, 10.5194/cp-2018-19, 2018.

Clark, J. S.: Particle motion and the theory of charcoal analysis: Source area, transport, deposition, and sampling, Quaternary Research, 30, 67-80, http://dx.doi.org/10.1016/0033-5894(88)90088-9, 1988.

Dietze, E., Brykała, D., Schreuder, L. T., Jażdżewski, K., Blarquez, O., Brauer, A., Dietze, M., Obremska, M., Ott, F., Pieńczewska, A., Schouten, S., Hopmans, E. C., and Słowiński, M.: Human-induced fire regime shifts during 19th century industrialization: A robust fire regime reconstruction using northern Polish lake sediments, PLOS ONE, 14, e0222011, 10.1371/journal.pone.0222011, 2019.

Fabbri, D., Torri, C., Simoneit, B. R. T., Marynowski, L., Rushdi, A. I., and Fabiańska, M. J.: Levoglucosan and other cellulose and lignin markers in emissions from burning of Miocene lignites, Atmospheric Environment, 43, 2286-2295, 10.1016/j.atmosenv.2009.01.030, 2009.

Kirchgeorg, T., Schüpbach, S., Kehrwald, N., McWethy, D. B., and Barbante, C.: Method for the determination of specific molecular markers of biomass burning in lake sediments, Organic Geochemistry, 71, 1-6, http://dx.doi.org/10.1016/j.orggeochem.2014.02.014, 2014.

Kukavskaya, E. A., Buryak, L. V., Ivanova, G. A., Conard, S. G., Kalenskaya, O. P., Zhila, S. V., and McRae, D. J.: Influence of logging on the effects of wildfire in Siberia, Environmental Research Letters, 8, 045034, 10.1088/1748-9326/8/4/045034, 2013.

Marynowski, L., Bucha, M., Smolarek, J., Wendorff, M., and Simoneit, B. R. T.: Occurrence and significance of mono-, di- and anhydrosaccharide biomolecules in Mesozoic and Cenozoic lignites and fossil wood, Organic Geochemistry, 116, 13-22, https://doi.org/10.1016/j.orggeochem.2017.11.008, 2018.

Melles, M., Brigham-Grette, J., Minyuk, P. S., Nowaczyk, N. R., Wennrich, V., DeConto, R. M., Anderson, P. M., Andreev, A. A., Coletti, A., Cook, T. L., Haltia-Hovi, E., Kukkonen, M., Lozhkin, A. V., Rosén, P., Tarasov, P., Vogel, H., and Wagner, B.: 2.8 Million Years of Arctic Climate Change from Lake El'gygytgyn, NE Russia, Science, 337, 315-320, 10.1126/science.1222135, 2012.

Molinari, C., Lehsten, V., Blarquez, O., Carcaillet, C., Davis, B. A. S., Kaplan, J. O., Clear, J., and Bradshaw, R. H. W.: The climate, the fuel and the land use: Long-term regional variability of biomass burning in boreal forests, Global Change Biology, 24, 4929-4945, 10.1111/gcb.14380, 2018.

Mollicone, D., Eva, H. D., and Achard, F.: Human role in Russian wild fires, Nature, 440, 436-437, 10.1038/440436a, 2006.

Schüpbach, S., Kirchgeorg, T., Colombaroli, D., Beffa, G., Radaelli, M., Kehrwald, N. M., and Barbante, C.: Combining charcoal sediment and molecular markers to infer a Holocene fire history in the Maya Lowlands of Petén, Guatemala, Quaternary Science Reviews, 115, 123-131, http://dx.doi.org/10.1016/j.quascirev.2015.03.004, 2015.

Suciu, L. G., Masiello, C. A., and Griffin, R. J.: Anhydrosugars as tracers in the Earth system, Biogeochemistry, 146, 209-256, 10.1007/s10533-019-00622-0, 2019.