Dear Reviewer #1,

Thanks again 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.

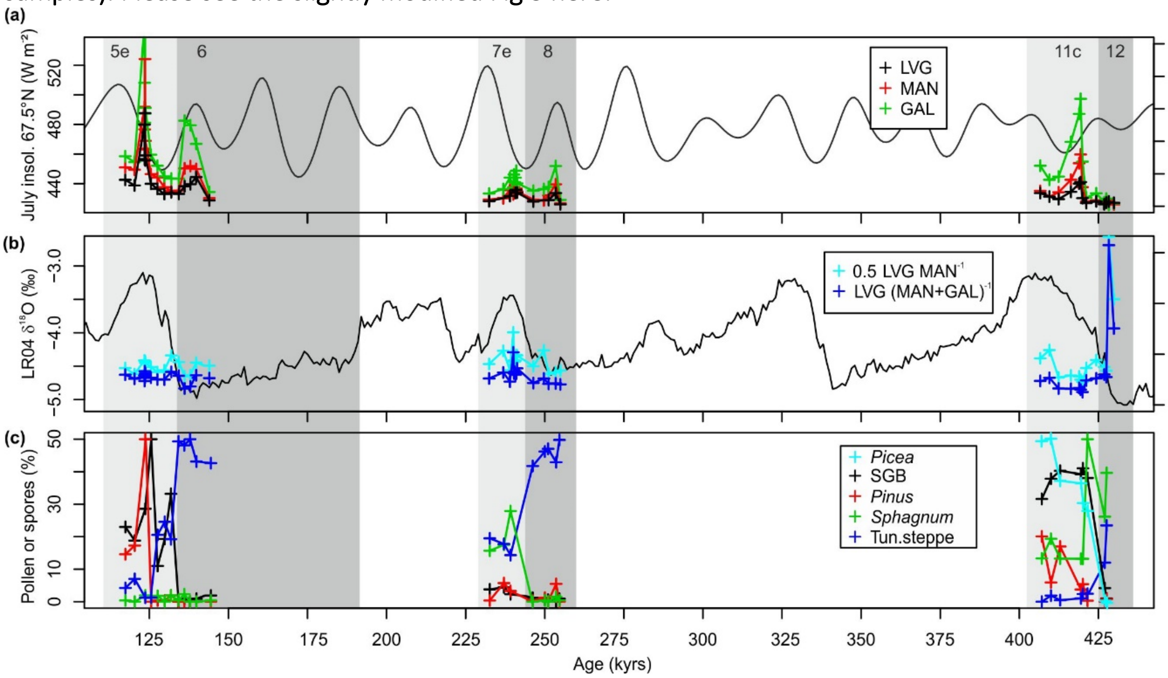
Reviewer: I think some conclusions need more data to support and more discussions needed. For example, for the wildfire reconstruction using the sugar proxies there should be some discussions about the potential of the movement of these indicators in soluble condition since these indicators themselves are soluble. So, peoples would doubt whether these proxies have experienced movement after their deposition. If so, these proxies could not reflect the wildfires in the corresponding layers.
Response: You are right. We have extended the discussion on the proxy behaviour from source to sink (see below and Chap. 4.1.2)

Reviewer: For the wildfire reconstruction from Lake El'gygytgyn sediments, the authors selected three glacial-interglacial cases. Due to the uncertainty of chronology reconstruction, the authors integrated the wildfire proxies into two periods, that is, glacial and interglacial. From my side, I think that such integration indeed could give some information for the glacial-interglacial variations of wildfire. But meanwhile it could mix some useful information and sometimes might result in some wrong conclusions. For example, previous studies also suggested that some wildfire occurs mainly during the transition of glacial-interglacial variations. Under such condition, the integration of wildfire into two parts, the glacial periods and the interglacial periods, would not give the real picture of wildfire pattern.
Response: Thanks for your comment. In this study, we don't aim to provide the full picture of a complete, continuous record of glacial-interglacial fire history and also don't consider a full glacial cycle but only the late glacial part.
We state that better now from the beginning on, e.g. in the title: "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" and introduction: "Here, we *assess (1) how far MAs are useful proxies to study* glacial to interglacial fire histories of the last 430 kyrs using sedimentary MA from Lake El'gygytgyn and *(2) discuss* long-term relationships between low-temperature fires and regional vegetation in the Russian Far East." We also replaced "glacial" by "late glacial" at the places in the text where is was misleading.

The split of samples in two groups was done because we are very confident about the exact position of the shift from late glacial to interglacial conditions, because the pollen data from the same samples suggest a very clear shift from cold, dry tundra-steppe to warmer shrub tundra or interglacial forest, independent of the absolute age uncertainties. We are aware that during glacial-interglacial transitions the fire history can be quite variable as suggested, e.g., by Han et al. (2016), which used a record of much higher sedimentation rates compared to Lake El'gygytgyn, or by Bird and Cali (2002) and Daniau et al. (2013) based on African sediments. As below you have commented also on the relationship between insolation and MA trends in time, we reconsidered this part and discuss now also how far fire has occurred during transitions (see below). However, given the age uncertainties for several hundreds of years, the very low sedimentation rates at Lake El'gygytgyn and that our samples are integrating over several hundreds of years, we prefer here to discuss the general trends evidenced by the late glacial versus interglacial using the boxplots, as a starting point for more detailed reconstructions that require a higher resolution.
We mention that now in the conclusion: "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: In fact, the figure 3 did not give exact information on wildfire pattern at glacial-interglacial scale. There is no clear difference in wildfire between glacial and interglacial periods, except one case of MIS 11c and 12.

Response: In the text, we acknowledge that MA influxes "are consistently higher during interglacials compared to the latter part of their preceding glacials", which doesn't mean that all glacials are equally low. We suspect that the difference didn't become clear visually because we have plotted the biomarker (GAL) with highest influxes on top of those with lower influxes and with rather bold lines. We hope it becomes clearer in a modified Fig 3a that MA influxes are higher during MIS 5e compared to MIS 6 and also in MIS 7e compared to MIS 8 (where just one sample has similarly high influxes as the MIS 7e samples). Please see the slightly modified Fig 3 here:



Reviewer: Specific comments: 1. Lines 68-69. That's good to have an interpretation for fire intensity. But I would like to know the exact factor that controls fire intensity in this study, rather than the factors suggested here including three ones: fire temperatures, combustion efficiencies and fire radiative power. In fact, these factors have no clear relationship between each other. Is temperature more related to fire intensity? Or combustion efficiency is more related to fire intensity? In my view, I think that combustion efficiency is more related with the fire intensity, which has been improved by many previous studies.

Response: According to Keeley (2009), "fire intensity represents the energy released during various phases of a fire" and in a physical sense it is given in W m^{-2}. Depending on the discipline, fire intensities are reported as fire radiative power (e.g. in remote sensing, Rogers et al., 2015) or when studying emissions, combustion efficiencies are reported (van Leeuwen and van der Werf, 2011). All the parameter mentioned (temperature, combustion efficiency, radiative power) are positively related to each other, as higher burning temperatures combust organic matter more efficiently and also release more energy (see e.g. carbon combustion continuum in several studies, for example, Conedera et al. (2009).

We have now rephrased this part and also added that during each fire several phases of fire intensity can happen, with an average low or high fire intensity characterizing a fire regime that integrates over longer time and larger spatial scales. "While a single fire has several phases of varying fire intensities, fire regimes define larger temporal and spatial scale properties of several fire events with regimes of low fire intensity generally referring to low fire temperatures, low combustion efficiencies and low fire radiative power as typical for smoldering and in contrast to flaming fires (Keeley, 2009;Conedera et al., 2009;van Leeuwen and van der Werf, 2011)."

Reviewer: 2. Line 127, the authors selected three cases of the glacial-interglacial periods for wildfire reconstruction. I would like to know the reason for such selection.
Response: To assess the suitability of MAs as fire proxies in high-latitude lake sediments on long time scales, we have selected three glacial-interglacial periods that differ in terms of biome configuration and climate, including two of them (MIS 5e and 11c) that are generally referred to as potential analogues for future climate change.
We have fully rephrased this part and now write: "We selected three late glacial-to-interglacial periods, i.e. marine isotope stages (MIS) 12–11c, 8–7e, and 6–5e, which reflect varying interglacial biome types and climate conditions, as reconstructed using the pollen records from El'gygytgyn sediments (Melles et al., 2012;Tarasov et al., 2013)."

Reviewer: In fact, a continuous record of three glacial-interglacial intervals would give more robust evidences for the wildfire-climate relationship, I think. Please give some explanations.
Response: In this study, we aim to test how far MAs are useful proxies on long time scales in Arctic lake sediments and to see if we can deduce some first fire-vegetation-climate relationships. Given the amount of time to prepare and analyse a sample in the lab, a continuous record over several glacial-interglacial intervals was beyond the scope of this study. Here, we focus on comparing interglacials and their preceding late glacial period that have previously been identified as being different concerning their climate and vegetation configurations.
Yet, we added in the conclusion: "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."

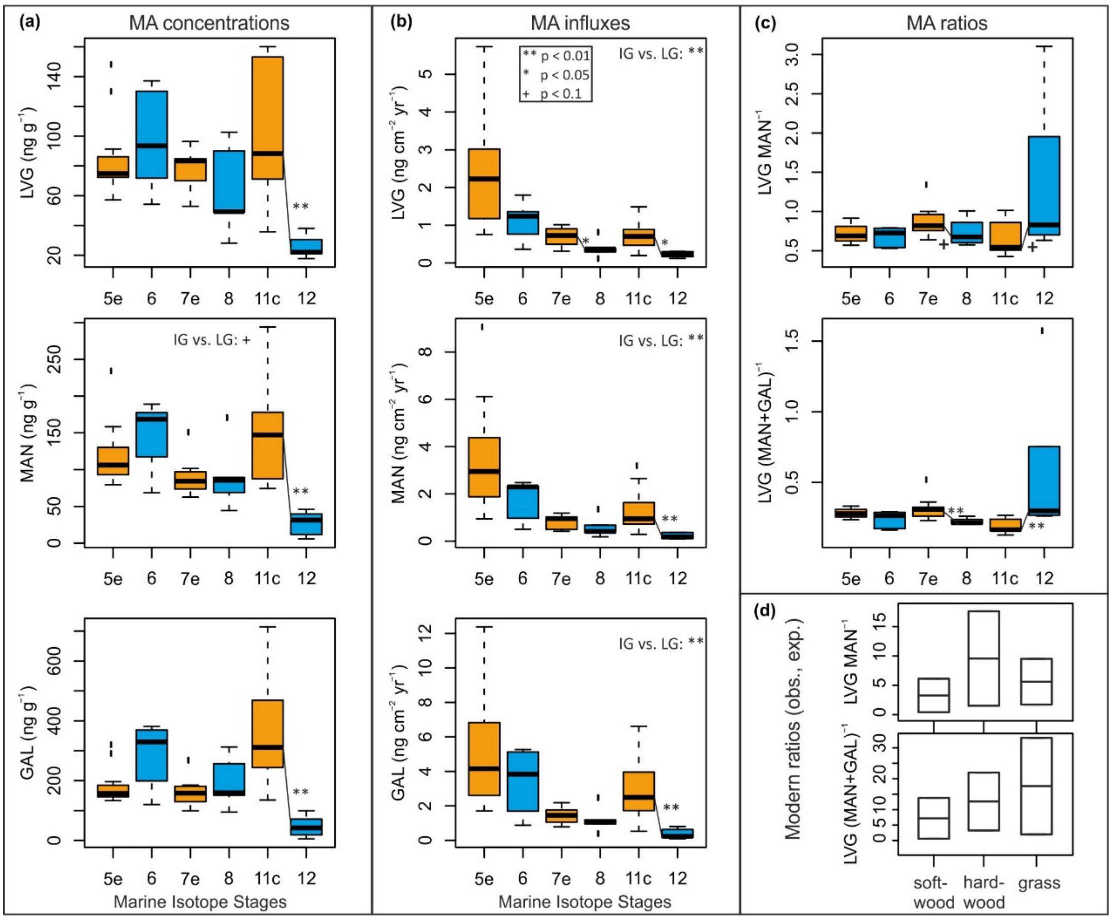
Reviewer: 3. Lines 139-140, please add a parentheses.
Response: As the part in the parentheses did not become clear, we have reordered it to: "(for interglacial astronomical and GHG characteristics see Yin and Berger (2012) and Table 1)".

Reviewer: 4. Line 154, "that cover the time period", which time period?
Response: Thanks. We added that we refer to the period "125 to 3600 kyrs".

Reviewer: 5. Lines 203-204, the subhead "2.2 Analyses of source areas". I don't think that we could fully ignore the river input and only consider the atmospheric deposition for source analyses. So, the discussion about the source areas should include the local river inputs.
Response: You are right. We are discussing also fluvial transport in Chap. 4.1.2 and here we write now: "MAs can be transported attached to aerosols in the atmosphere (Sang et al., 2016;Schreuder et al., 2018) and/or via fluvial transport from the catchment (Suciu et al., 2019). To discuss potential source areas of *aeolian-derived* MAs, we calculated exemplary backward trajectory ensembles…"
and we start the discussion now by stating: "*Here, we discuss the potential local and regional to extra-regional MA source areas, transport pathways and post-depositional degradation in El'gygytgyn lake sediments.*" And mention catchment sources also in the discussion (chap. 4.2), e.g. "…MA influxes tend to increase with higher amounts of tree and shrub versus tundra-steppe pollen (Figs. 3c, 4b) – *potentially allowing also fires to occur in the El'gygytgyn catchment during warmer than present interglacials (MIS 5e, 11c)*".

Reviewer: 6. Lines 236-239, This could in general work on the condition that you have known that there were clear wildfire changes between glacial and interglacial periods. But, in fact, in your records of three glacial-interglacial periods, I merely find that the last one (MIS 11c-12) could present a clear increasing trend in MA from MIS12 to 11 (although it is not a full glacial-interglacial cycle), however, for the other two cases, there are no clear wildfire variation pattern at the glacial-interglacial intervals. So, I am not convinced of your conclusion that more low-temperature fires occurred during interglacial periods.

Response: To test how far the proposed trends are different, we have now added a non-parametric Wilcoxon rank sum test suitable for small and non-normally distributed sample sets and now mark the respective $p > 0.1$, 0.05 and 0.001 in fig.2 and provide the test statistics in the supplementary data. We find strong evidence that also based on this distribution test, late glacial samples had lower mean MA influxes compared to interglacial samples, although the p-values partly suggested that more scrutiny is needed in future studies using more samples. In addition, we are choosing a more careful phrasing to not overinterpret the data, as we are aware that our sample size is not very high causing some uncertainties to the statistics.
In the figure 2 caption we have added: "*Lines between interglacial (IG) and preceding late glacial (LG) boxplots indicate different mean values for the two periods according to a non-parametric Wilcoxon test, with stars and + indicating respective p-values. IG vs. LG in a subplot marks different means when all interglacial samples are compared to all late glacial samples (see supplement for detailed p-values).*" Fig. 2 modified:



Reviewer: 7. Lines 265-275, For those with $p > 0.05$, I don't think that there are relationships between these two proxies. So, in these cases you couldn't get some relationships for these proxies, especially when there are only very small numbers of samples.
Response: It is common practice to not interpret data with $p > 0.05$ as being related, but the p-value strongly depends on sample sizes. Hence, we are providing a very careful evaluation of these data sets *sensu* Wasserstein et al. (2019).
In the discussion, we now discuss the relationships more as tendencies (same as for the differences between interglacials and glacials, above).

Reviewer: 8. These proxies for wildfire reconstruction used in this study are soluble sugar materials. So, people would like to know if there is possibility that MA would move downward and thus influence

their indications for wildfire reconstruction? I think such discussions could not be missed in Section 4.1.
Response: We are discussing that now in Chap. 4.1.2 and write: "Assuming that dissolved MAs degrade within days or weeks in oxic, turbulent water (Norwood et al., 2013), the MAs recorded from previous warm periods may rather derive from MAs in particulate phase, which probably did not migrate post-depositionally."

Reviewer: 9. Lines 342-343, Please rethink about the sources and pathway of Mas since river input may be another source.
Response: Yes, we have added more discussion on potential local sources and pathways and depositional processes. Please see chap. 4.1.2 and our response above.

Reviewer: 10. Lines 354-355, I am not sure about the explanation for MA to indicate a background wildfire. I would like to suggest this might be associated (mainly) with the local biofuel availability as well.
Response: We assume that local fires might have contributed MAs only during warmer interglacials (as already today vegetation is sparse to allow fires to occur, see discussion at the beginning of chap 4.1.2). Yet, in this sentence we refer to the presence of MAs in glacial sediments – when it is even more unlikely that fires happened in an even colder and drier climate with sparse tundra steppe vegetation. To not be misleading, we have rephrased the sentences and now write "Accordingly, our rank correlation analysis shows that MA influxes tend to increase with higher amounts of tree and shrub versus tundra-steppe pollen (Figs. 3c, 4b) – *potentially allowing also fires to occur in the El'gygytgyn catchment during warmer than present interglacials (MIS 5e, 11c). In contrast, during glacials,* low temperatures and CO_2 levels limit biomass (fuel availability) and fire spread, which has be shown in previous mid- to high-latitude reconstructions and model simulations (Thonicke et al., 2005;Krawchuk and Moritz, 2011;Daniau et al., 2012;Martin Calvo et al., 2014;Kappenberg et al., 2019). Thus, El'gygytgyn's glacial MA influxes represent a background signal from remote source areas, when fires associated with high-productivity biomes have shifted southwards."

Reviewer: 11. Lines 357-360, In fact, I do not find there is a clear relationship of low-temperature wildfire with maximum summer insolation. There is only one case in MIS 8, while for others more evidences suggest that this is not the case. I think that you should be more precise.
Response: You are right, there is actually no relationship between insolation and MA influxes. We have correlated (Kendall's τ) now the MA concentrations and influxes with the summer insolation (67.5°) at the same time (basically assuming the age uncertainties are low) and found τ around 0 (-0.17 to 0.05) – but more data and a more sophisticated statistical approach would be needed to test that considering potential age and source area uncertainties, which is beyond the scope of this study.
We have rephrased this part now: "We *did not find evidence* for more biomass burning close to the lake in times of high summer insolation, *as suggested by previous* mid- to high latitude studies (Daniau et al., 2012;Remy et al., 2017;Dietze et al., 2018;Kappenberg et al., 2019). *MA influxes rather peaked during transitions from high to low summer insolation and during MIS 8 maximum insolation*, despite pollen data suggesting rather low tree and shrub presence *during MIS 8* (Fig. 3a, c). In addition, lower mean MA influxes during MIS 11c compared to MIS 5e (Fig. 2b) *might be linked* to the rather moderate summer insolation during MIS 11 compared to *a more pronounced insolation cycle* during MIS 5e (Yin and Berger, 2012). Indirectly, high latitude summer insolation could have driven biomass productivity and fires *in the source areas*, for example, by *altering* the length of the growing season,…".

Reviewer: 12. Line 396, a small error "is not adapted to is but able to survive fires"
Response: We have corrected it.

Reviewer: 13. Line 495. A error "CO2".
Response: We have corrected it to "CO_2".

Reviewer: 14. I am not expert to pollen. So, I also would like to know the meaning of the pollen and spores (such as drought or wet?). So, could you please add a brief explain the indications of the pollens and spores in Figure 3. This would facilitate people to know the climate condition.

Response: We have added climate conditions for the tundra-steppe taxa that clearly represent the dry cold glacial climate but Sphagnum peatland extent does not only reflect more precipitation but can also be a response to warming and thawing of permafrost, so we would not like to link it one-to-one just to climate: "Tun.steppe (i.e. tundra and steppe taxa reflecting cold and dry glacial conditions): sum of Poaceae, *Artemisia*, Chenopodiaceae, Caryophyllaceae, Cichoriaceae, and *Thalictrum* pollen; summergreen boreal forest taxa (SGB): sum of *Larix*, *Populus,* and *Alnus* pollen; *Pinus* s/g. *Haploxylon*-type pollen (with SGB and *Pinus* spreading during interglacials); and the *Sphagnum* spore abundance (representative for peatlands)."

References used in the response letter

Bird, M. I., and Cali, J. A.: A revised high-resolution oxygen-isotope chronology for ODP-668B: implications for Quaternary biomass burning in Africa, Global and Planetary Change, 33, 73-76, https://doi.org/10.1016/S0921-8181(02)00062-0, 2002.

Conedera, M., Tinner, W., Neff, C., Meurer, M., Dickens, A. F., and Krebs, P.: Reconstructing past fire regimes: methods, applications, and relevance to fire management and conservation, Quaternary Science Reviews, 28, 555-576, http://dx.doi.org/10.1016/j.quascirev.2008.11.005, 2009.

Daniau, A.-L., Sánchez Goñi, M. F., Martinez, P., Urrego, D. H., Bout-Roumazeilles, V., Desprat, S., and Marlon, J. R.: Orbital-scale climate forcing of grassland burning in southern Africa, Proceedings of the National Academy of Sciences, 110, 5069-5073, 10.1073/pnas.1214292110, 2013.

Daniau, A. L., Bartlein, P. J., Harrison, S. P., Prentice, I. C., Brewer, S., Friedlingstein, P., Harrison-Prentice, T. I., Inoue, J., Izumi, K., Marlon, J. R., Mooney, S., Power, M. J., Stevenson, J., Tinner, W., Andrič, M., Atanassova, J., Behling, H., Black, M., Blarquez, O., Brown, K. J., Carcaillet, C., Colhoun, E. A., Colombaroli, D., Davis, B. A. S., D'Costa, D., Dodson, J., Dupont, L., Eshetu, Z., Gavin, D. G., Genries, A., Haberle, S., Hallett, D. J., Hope, G., Horn, S. P., Kassa, T. G., Katamura, F., Kennedy, L. M., Kershaw, P., Krivonogov, S., Long, C., Magri, D., Marinova, E., McKenzie, G. M., Moreno, P. I., Moss, P., Neumann, F. H., Norström, E., Paitre, C., Rius, D., Roberts, N., Robinson, G. S., Sasaki, N., Scott, L., Takahara, H., Terwilliger, V., Thevenon, F., Turner, R., Valsecchi, V. G., Vannière, B., Walsh, M., Williams, N., and Zhang, Y.: Predictability of biomass burning in response to climate changes, Global Biogeochemical Cycles, 26, GB4007, 10.1029/2011GB004249, 2012.

Dietze, E., Theuerkauf, M., Bloom, K., Brauer, A., Dörfler, W., Feeser, I., Feurdean, A., Gedminienė, L., Giesecke, T., Jahns, S., Karpińska-Kołaczek, M., Kołaczek, P., Lamentowicz, M., Latałowa, M., Marcisz, K., Obremska, M., Pędziszewska, A., Poska, A., Rehfeld, K., Stančikaitė, M., Stivrins, N., Święta-Musznicka, J., Szal, M., Vassiljev, J., Veski, S., Wacnik, A., Weisbrodt, D., Wiethold, J., Vannière, B., and Słowiński, M.: Holocene fire activity during low-natural flammability periods reveals scale-dependent cultural human-fire relationships in Europe, Quaternary Science Reviews, 201, 44-56, https://doi.org/10.1016/j.quascirev.2018.10.005, 2018.

Han, Y. M., Peteet, D. M., Arimoto, R., Cao, J. J., An, Z. S., Sritrairat, S., and Yan, B. Z.: Climate and Fuel Controls on North American Paleofires: Smoldering to Flaming in the Late-glacial-Holocene Transition, Scientific Reports, 6, 20719, 10.1038/srep20719, 2016.

Kappenberg, A., Lehndorff, E., Pickarski, N., Litt, T., and Amelung, W.: Solar controls of fire events during the past 600,000 years, Quaternary Science Reviews, 208, 97-104, https://doi.org/10.1016/j.quascirev.2019.02.008, 2019.

Keeley, J. E.: Fire intensity, fire severity and burn severity: a brief review and suggested usage, International Journal of Wildland Fire, 18, 116-126, https://doi.org/10.1071/WF07049, 2009.

Krawchuk, M. A., and Moritz, M. A.: Constraints on global fire activity vary across a resource gradient, Ecology, 92, 121-132, 10.1890/09-1843.1, 2011.

Martin Calvo, M., Prentice, I. C., and Harrison, S. P.: Climate versus carbon dioxide controls on biomass burning: a model analysis of the glacial–interglacial contrast, Biogeosciences, 11, 6017-6027, 10.5194/bg-11-6017-2014, 2014.

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.

Norwood, M. J., Louchouarn, P., Kuo, L. J., and Harvey, O. R.: Characterization and biodegradation of water-soluble biomarkers and organic carbon extracted from low temperature chars, Organic Geochemistry, 56, 111-119, 10.1016/j.orggeochem.2012.12.008, 2013.

Remy, C. C., Hély, C., Blarquez, O., Magnan, G., Bergeron, Y., Lavoie, M., and Ali, A. A.: Different regional climatic drivers of Holocene large wildfires in boreal forests of northeastern America, Environmental Research Letters, 12, 035005, 10.1088/1748-9326/aa5aff, 2017.

Sang, X. F., Gensch, I., Kammer, B., Khan, A., Kleist, E., Laumer, W., Schlag, P., Schmitt, S. H., Wildt, J., Zhao, R., Mungall, E. L., Abbatt, J. P. D., and Kiendler-Scharr, A.: Chemical stability of levoglucosan: An isotopic perspective, Geophysical Research Letters, 43, 5419-5424, 10.1002/2016GL069179, 2016.

Schreuder, L. T., Hopmans, E. C., Stuut, J.-B. W., Sinninghe Damsté, J. S., and Schouten, S.: Transport and deposition of the fire biomarker levoglucosan across the tropical North Atlantic Ocean, Geochimica et Cosmochimica Acta, https://doi.org/10.1016/j.gca.2018.02.020, 2018.

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.

Tarasov, P. E., Andreev, A. A., Anderson, P. M., Lozhkin, A. V., Leipe, C., Haltia, E., Nowaczyk, N. R., Wennrich, V., Brigham-Grette, J., and Melles, M.: A pollen-based biome reconstruction over the last 3.562 million years in the Far East Russian Arctic - new insights into climate-vegetation relationships at the regional scale, Clim. Past, 9, 2759-2775, 10.5194/cp-9-2759-2013, 2013.

Thonicke, K., Prentice, I. C., and Hewitt, C.: Modeling glacial-interglacial changes in global fire regimes and trace gas emissions, Global Biogeochemical Cycles, 19, 10.1029/2004gb002278, 2005.

van Leeuwen, T. T., and van der Werf, G. R.: Spatial and temporal variability in the ratio of trace gases emitted from biomass burning, Atmos. Chem. Phys., 11, 3611-3629, 10.5194/acp-11-3611-2011, 2011.

Wasserstein, R. L., Schirm, A. L., and Lazar, N. A.: Moving to a World Beyond “p<0.05”, The American Statistician, 73, 1-19, 10.1080/00031305.2019.1583913, 2019.

Yin, Q. Z., and Berger, A.: Individual contribution of insolation and CO2 to the interglacial climates of the past 800,000 years, Clim Dyn, 38, 709-724, 10.1007/s00382-011-1013-5, 2012.