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Interactive comment on "Aromatic acids in a Eurasian Arctic ice core: a 3000-year proxy record of biomass burning" *by* Mackenzie M. Grieman et al.

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The referee raised several good points and we appreciate the comments. The manuscript has been modified as described below to take them into account. Referee comments are in italics and our responses are in a normal font.

The end of the discussion section provides evidence that "the similarity in timing between the Siberian biomass burning pulses, the Bond events, and the monsoonal changes likely suggests a link in this region between fires and large-scale climate variability on millennial time scales" (page 11, lines 11-13). This combination of factors is the main strength of the paper, yet the abstract only mentions the similarity between the timing of Bond events with the timing of increased biomass burning in the Akademii

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Discussion paper

Nauk ice core.

This point has been added to the abstract:

". . .The timing of these periods coincides with the episodic pulsing of ice-rafted debris in the North Atlantic known as Bond events and a weakened Asian monsoon, suggesting a link between fires and large-scale climate variability on millennial time scales."

Page 1, Lines 19-21: A more recent paper, Marlon et al., 2016, demonstrates a recent rise in Northern Hemisphere biomass burning after 2000 AD. This compilation in the Marlon et al., 2016 paper is for the entire Northern Hemisphere, verus the synthesis of high latitude Northern Hemisphere charcoal records in Marlon et al., 2008. However, the recent rise in fire activity is driven in part by newly incorporated high latitude records (such as those in Quebec) and the findings from this newer paper should be mentioned at this point. (Marlon J.R., R. Kelly, A-L. Daniau, B. Vannière, M.J. Power, P. Bartlein, P. Higuera, O. Blarquez, S. Brewer, T. Brücher, A. Feurdean, G. Gil Romera, V. Iglesias, S.Y. Maezumi, B. Magi, C.J.C. Mustaphi, and T. Zhihai. "Reconstructions of biomass burning from sediment-charcoal records to improve data-model comparisons." Biogeosciences 13 (2016): 3225-3244. DOI: 10.5194/bg-13-3225-2016)

The newer Marlon et al. paper is now cited in the Introduction:

". . .A synthesis of high latitude Northern Hemisphere charcoal records indicates a gradual decline in burning related to Late Holocene cooling, followed by an increase from 1750-1870 CE and a decline after 1870 CE associated with anthropogenic activity (Marlon et al., 2008). Biomass burning increased during the first half of the 20th century, declined during the second half of the 20th century, and rose sharply after 2000 CE (Marlon et al., 2016). Siberia is the largest forested area in the Northern hemisphere and Siberian wildfires constituted 5 to 20% of global biomass burning carbon emissions from 1998-2002 CE (Soja et al., 2004)... on centennial or millennial time scales with confidence (Marlon et al., 2008, 2016; Power et al., 2008)."

Page 2, Lines 8 and 9: Cite Rhodes et al., 2016 (Rhodes, R. H., X. Faïn, E. J. Brook, J. R. McConnell, M. Sigl, O. Maselli, J. Edwards, C. Buizert, T. Blunier, J. Chappellaz,J. Freitag, 2016. Local artifacts in ice core methane records caused by layered bubble trapping and in-situ production: a multi-site investigation. Climate of the Past, 12, 1061-1077, doi:10.5194/cp-12-1061-2016. http://www.clim-past.net/12/1061/2016/) regarding in situ production of methane in ice cores.

The Rhodes et al. (2016) paper does not appear to be relevant to the text. This paragraph is about the use of methane isotopes to constrain paleo biomass burning emissions. The local artifacts identified by Rhodes et al. (2016) would not affect the interpretation or major conclusions of the earlier studies cited here. No such claims are made in their paper. Consequently, no change was made to the manuscript.

Section 2.1: As you developed an entirely new age scale for this ice core, it is essential to mention in this section why you developed this new age scale and any strengths/weaknesses of this age scale compared to the previously existing depth-age relationship.

The preliminary age scale for the lower part of the ice core (Fritzsche et al., 2010) was originally based on geophysical flow modeling, but unconstrained by chemical correlations. High resolution, continuous flow analysis of multiple elements provided improved dating via identification of volcanic peaks and correlation to other ice cores.

The manuscript was changed as follows:

"The original chronology for the upper 411 m of the core (900-1998 CE) was developed based on annual layer counting of stable water isotopes and volcanic sulfate signals (Opel et al., 2013). A preliminary chronology for the lower part of the ice core (i.e. below 411m) was developed based on an adjusted Nye geophysical flow model (Fritzsche et al., 2010) but unconstrained by chemical correlations. Therefore, an alternative age model was developed and used for this study (Fig. S2). This age model is based on correlation between high resolution multi-element continuous flow measurements of

the Akademii Nauk ice core and other Arctic ice cores (Sigl et al., 2013). This new age scale yields older ages for the lower part of the ice core (below 411 m). The new age scale yields an age of 1100 BCE at 661 m as compared to 694 m for the preliminary age scale."

why were 700 fewer samples run for p-HBA than for VA?

Revision, page 6, line 4: "The instrument was originally optimized to analyze VA. Several samples were analyzed for VA before a method was developed analyze p-HBA."

Page 7, Lines 33-34: Refer the reader back to the supplementary information regarding the age-depth scale.

"The age-depth relationship for Akademii Nauk indicates constant average accumulation rate from 1700-1999 CE (140-0 m depth; Fig. S2)."

Page 8, Lines 8-13: Cite these ecofloristic subdivisions in Table 1.

Revised Table 1 caption:

"Table 1. Fractions of air mass back trajectories originating from or intersecting various ecofloristic zones and geographic regions (% rounded to nearest integer). Ecofloristic zones are defined by Food and Agriculture Organization (Fig. S7; http://cdiac.ornl.gov/epubs/ndp/global_carbon/carbon_documentation.html; Ruesch and Gibbs, 2008)."

Page 8, Lines 13-14: Why did you start the back-trajectories at 100 m above ground level?

We were curious about the influence of shallow atmospheric boundary layers or topographically influence flow on the results of the trajectories. To investigate whether such effect influenced the trajectories, we ran the trajectories at several heights from the surface to 1000 m above the surface. There was little difference in the results. Given that aerosols are deposited by both wet and dry deposition, we felt it reasonable to use

a height above surface, but still within the boundary layer.

Page 9, Lines 14-24: To what do you ascribe the difference between the Akademii Nauk and Kamchatka Peninsula VA and p-HBA concentrations in the 20th century? Figure 7 highlights this offset and readers are left wondering if this difference may reflect local or regional difference in biomass burning.

The increase in Kamchatka Peninsula VA and p-HBA in the 20th century is after 1970, except for a peak at 1949. There were no Akademii Nauk samples available for analysis from 1975-1983 or after 1988. It is therefore not possible to determine if the two ice core records are different in the late 20th century.

The text was revised to read: "VA and p-HBA remain elevated late in the 20th century in the ice core from the Kamchatka Peninsula. It is not possible to determine if Akademii Nauk VA and p-HBA also increase during this period due to limited Akademii Nauk sample availability after 1970."

Page 10, Line 11-17: While describing all of the possible interactions between the PDO and Indian Ocean monsoon is beyond the scope of this paper, mentioning that these two phenomenon interact and are not completely separate from one another demonstrates that the cited papers are not in conflict with one another.

Revision: "...drought conditions. They link Asian drought to monsoon failures during the 16th and 17th centuries. This variability may also be related to the PDO, given that the PDO can modulate the summer monsoon (Chen et al., 2013; Krishnamurthy and Krishnamurthy, 2014)."

Citations added to the manuscript: Chen,W., Feng, J., and Wu, R.: Roles of ENSO and PDO in the Link of the East Asian Winter Monsoon to the following Summer Monsoon, Journal of Climate, 26, 622–635, doi:10.1175/JCLI-D-12-00021.1, 2013.

Krishnamurthy, L. and Krishnamurthy, V.: Influence of PDO on South Asian summer monsoon and monsoon–ENSO relation, Climate Dynamics, 42, 2397–2410,

doi:10.1007/s00382-013-1856-z, 2014.

While the points outlined within the conclusion section are valuable, they are weaker than the finding of the connections between North Atlantic and Central Asian climate resulting in increased fire activity and then recorded in a Siberian ice core. I suggest rewriting the conclusions to emphasize the climatic aspects of this work rather than concentrating (as in the current form) on the use of VA and p-HBA as biomass burning proxies.

Revision, page 11, line 26: "Regional millennial-scale Siberian wildfire activity is not well-established due to a paucity of proxy records in the region. Siberian biomass burning may be linked to North Atlantic climate variability and the Asian monsoon. Regional records of Siberian precipitation changes would help to uncover how Bond Events may have affected climate in Siberia. More and longer records of the Arctic Oscillation and PDO are needed to reveal a relationship between Siberian biomass burning and atmospheric circulation. This study demonstrates that ice core records of organic compounds that are uniquely derived from biomass burning, such as aromatic acids, have the potential to add to our understanding of regional-scale trends in biomass burning and their relationship to climate."

Figure 8: Why do you use the Pages 2K temperature reconstruction if this record does not encompass the entire time period that you are examining? If you are absolutely convinced that this temperature reconstruction must be used, then also incorporate other high latitude Northern Hemisphere temperature reconstructions that extend back through the entire record.

Revision: The Marcott et al. (2013) reconstruction will also be included in Figure 8.

Revised caption: "30-year medians of domain areas of PAGES 2k temperature reconstructions (blue; PAGES 2k Consortium, 2013) and 20-year means of zonal 30-90°N stacked temperature reconstruction (black; Marcott et al., 2013),"

Added citation in manuscript, page 10, line 18: Climate reconstructions based on Northern Hemisphere proxy records show a long-term cooling trend over the past 2,000 years (Fig. 8; PAGES 2k Consortium, 2013; Hegerl et al., 2006; Ljungqvist et al., 2010; Mann et al., 2008; Marcott et al., 2013; Moberg et al., 2005)

Abstract, line 13: Define "it" (ie. "this sudy", "or results", etc.)

Revision: "This study clearly demonstrates that coherent aromatic acid signals are recorded in polar ice cores that can be used as proxies for past trends in biomass burning."

Page 2, line 3: Replace "difference" with "different" and use another adjective rather than repeating "very different" twice in the same short sentence.

Revision: "These records cover very different age ranges at varied temporal resolutions."

Page 9, Line 7: Define "this" (ie. "This result").

Revision: "The Akademii Nauk aromatic acid record suggests that high biomass burning emissions were sustained for multi-century periods during the last 3,000 years of the Holocene. This result perhaps indicates that the fires were widespread, but of relatively low intensity, consistent with the fact that low intensity ground fires are the principle mode of burning in Eurasian boreal forests today."

Page 11 Lines 11-14. You repeat the same sentence twice.

The extra sentence has been deleted.

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