

Biogeosciences Discuss., author comment AC1
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Reply on RC1

Jessica L. McCarty et al.

Author comment on "Reviews and syntheses: Arctic fire regimes and emissions in the 21st century" by Jessica L. McCarty et al., Biogeosciences Discuss.,
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We thank Reviewer 1 for these constructive comments and specific revisions. To address the overall concern that the outline of the review paper may be confusing, we have revised the introduction of the manuscript to better link the objectives and the paper sections, so that now we identify which sections each of the objectives are being discussed. We moved the policy questions that drove this review to the Supplemental Materials, which still keeps them available to the readers.

Specific comments

Line 36 – the third conclusion is vague: "... transitions... may increase and decrease open biomass burning". Increase and decrease in different biomes? At different times Please clarify.

Done. - This has been clarified and revised to state: "To some extent, shifting agricultural land use, forest-steppe to steppe, tundra-to-taiga, and coniferous-to-deciduous forest transitions in a warmer climate may increase and decrease open biomass burning, depending on land use in addition to climate-driven biome shifts.

Lines 50 – 58. Nice start to the introduction, it's useful to have the aim of the paper stated up front in the introduction in a concise way. Line 52 states what other published reviews have done, but doesn't go on to say how this review differs or what new information is offered. It would be useful to include a sentence on this here.

Done. - The reviewer makes an excellent point and we have revised to state: "In this paper, we review the current understanding of the changing Arctic fire regime, and its impacts on fires emissions, providing a foundation for future systemic Pan-Arctic fire and fire emissions analyses and coordination in the context of the Arctic Council Members, Permanent Participants, Observers, and Working Groups. This review paper is also the first to link emissions with a changing fire regime for the Pan-Arctic."

Line 68 – “both earlier and later”, presumably this means both earlier start and later finish? Please clarify.

Done. - This has been revised to “including earlier springtime fires and fires later in fall”.

Line 114 – I think the definition of open biomass burning would fit better in section 1 where the other definitions are, e.g. in paragraph 3.

Done. - This sentence defining open biomass burning has been moved to start paragraph 3. We thank the reviewer for having such a keen eye for detail.

Line 181 – is this a conclusion of this study based on extrapolation from related literature, or is this part of the findings from Tchebakova et al 2009? Please clarify with a relevant reference.

Done. - Line 181 was linked to the Tchebakova et al. (2009) findings and so we have connected these two sentences to make this more explicit: “Topography plays a crucial role in determining shifting habitats, where drying will dominate on tilted surfaces and bogging will dominate on flat terrain (Tchebakova et al., 2009), such that as the Siberian Arctic tundra is dominated by relatively flat terrain, bogging is predicted to prevail.”

Lines 175-209 – Figure 1 is useful, but the description of it could be clearer. Some of the conclusions in the text are not linked with increased or decreased fire, and it would make this paragraph clearer to explicitly state the direction of change, for example with the change to light-needled *Larix* in conclusion 5 it is not totally clear what the impact on fire risk would be and why. Can you also add an explanation for why boreal to deciduous would decrease fire risk. Is transition to forest-steppe just a result of increases in fire regimes (line 191) or also a cause of change in fire risk? There is some explanation of this in section 7.1 but it can be briefly referred to here.

Done. - Conclusion 5 has been updated to indicate why light-needled *Larix* would maintain a high fire risk: “Permafrost is not predicted to thaw deep enough to sustain dark-needled taiga (*Pinus sibirica*, *Abies sibirica*, and *Picea obovata*), nonetheless light-needled coniferous *Larix* is predicted to continue to dominate in eastern Siberia, maintaining a higher fire risk according to the Russian fire hazard rankings (Melekhov, 1980). The Russian fire hazard ranking systems shows a decrease in fire risk from light needle conifers (Scots pine, larch) to deciduous broad-leaf tree species (birch, aspen, willow) that exist between the temperate and boreal zones, as well as along river valleys. Fire risk is also lower in dark-leaf conifers (Melekhov, 1980). Fire return intervals (FRI) are consistent with Melekhov, with a mean FRI of 36 years (range 17-133) in light coniferous forest compared with a mean FRI of 196 years (range 75-725) in dark-coniferous forest (Soja et al., 2006; Shvidenko and Nilsson, 2000; Furyaev, 1996). *Larix* are a fire-tolerant species, and dark-coniferous species are shade-tolerant secondary-succession cohort (Shugart et al., 1992).”

We have also revised conclusion 6 to strengthen conclusion 5. It now reads “Sixth, forest-steppe and steppe is predicted to dominate over half of Siberia, largely forced by climate and increases in fire regimes (Tchebakova et al., 2009). The forest-steppe that exists at the southernmost extent of the Siberian boreal forest is transitioning to steppe due to: increases in extreme fires that burn the soil organic matter to mineral soil, and repeated

fires and high temperatures that kill regenerating seedlings.”

New citations have been added:

Melekhov, I.S.: Forest Science. Moscow (in Russian), 1980.

Soja, A.J., Shugart, H.H., Sukhinin, A., Conard, S., and Stackhouse Jr., P.W.: Satellite-Derived Mean Fire Return Intervals As Indicators Of Change In Siberia (1995–2002), *Mitig Adapt Strat Glob Change* 11, 75–96, <https://doi.org/10.1007/s11027-006-1009-3>, 2006.

Shvidenko, A.Z., and Nilsson, S.: Extent, distribution, and ecological role of fire in Russian forests, in: *Fire, climate change, and carbon cycling in the boreal forest*, edited by Kasischke E.S., and Stocks B.J., Springer, New York, NY, 132-150, https://doi.org/10.1007/978-0-387-21629-4_16, 2000.

Furyaev, V.V.: Pyrological regimes and dynamics of the southern taiga forests in Siberia, in: *Fire in ecosystems of boreal Eurasia*, edited by: Goldammer J.G., and Furyaev V.V., Springer, Dordrecht, Netherlands, 168-185, https://doi.org/10.1007/978-94-015-8737-2_12, 1996.

Shugart, H.H., Leemans, R. and Bonan, G.B.: *A Systems Analysis of the Global Boreal Forest*, Cambridge University Press, New York, USA, 1-565, <https://doi.org/10.1017/CBO9780511565489.022>, 1992.

We also added an explanation for why transition from boreal forests to deciduous forests would decrease fire risk. Line 181-183 now read: “Second, anticipated transitions of boreal forest to deciduous forest stands would decrease fire risk in eastern Canada and small regions of interior Alaska (Terrier et al., 2013; Foster et al., 2019; Mekonnen et al., 2019), as deciduous species are less flammable than coniferous species (Päätaalo, 1998; Krawchuck et al., 2006).” The two citations added are:

Päätaalo, M.-L.: Factors influencing occurrence and impacts of fires in northern European forests, *Silva Fenn.*, 32: 185, <https://doi.org/10.14214/sf.695>, 1998.

Krawchuk, M. A., Cumming, S.G., Flannigan, M.D., and Wein, R.W.: Biotic and abiotic regulation of lightning fire initiation in the mixedwood boreal forest, *Ecology*, 87, 458, <https://doi.org/10.1890/05-1021>, 2006.

Lines 195-209 – I think this would fit better as a separate paragraph. The 8 points in the previous lines clearly relate to Fig 1, but these additional lines are broader. It would also help to break down this very long paragraph.

Done. - This paragraph has been made into two paragraphs, starting at this section after the eight points referring to Fig. 1.

Section 3 – paragraphs 1 and 3 are both about lengthening fire seasons, whereas paragraph 2 is about vegetation shifts. I would swap paragraphs 2 and 3 around for a more logical order.

Done. - These paragraphs have been swapped for a more logical order.

Lines 244-246 – This relates to human management rather than climate change, not sure it fits in this section.

Done. - This line has been moved to the end of Section 2 and now states “Further, suppression of wildfire in Canadian boreal communities has increased their likelihood of flammability, allowing fuels to build up in and near populated places (Parisien et al., 2020), calling into question what other wildland-urban interfaces in the Arctic region may experience increased fire risk and fires due to long term aggressive fire suppression.”

Line 342 – noting the dotted line as stated in the text, it looks like FINN shows a negative trend, not positive.

Done. - We thank the reviewer for catching this and we have revised the text to read “This trend is pronounced in GFED and GFAS, with these two models showing a positive trend (note the dotted line in Fig. 2), and FINN showing a slight decrease in later years even as total MODIS active fire detections increased (bottom panels in Fig. 2).”

Line 367 – is there a reference for the statement that Greenland is a novel fire regime in the Arctic? Table 2 only shows 1 year of data so we cannot tell if it is unusual from this.

Done. - Greenland has experienced two wildland fires, in 2017 and 2019. 2019 is noted in Table 2. We have added a citation and this sentence now reads: “Greenland is a novel fire regime in the Arctic, with two relatively substantial wildfires in 2017 (Evangelidou et al., 2019) and 2019 (Table 2), that accounted for more burned area and emissions than Norway or Finland.

Fig 2 – GFEDv4s data are now available to 2020. Can Fig 2 be extended to 2020 to match the later results?

Not done. - This review article has been performed to be fed in the AMAP short-lived climate forcers assessment, which had to be completed for review by Arctic Council member states by mid-2020. All the modeling, studies, and comparison with observations have been performed for this assessment are inclusive of 2018. Therefore, the time frame of this analysis was aligned accordingly, further extension of the long term emissions to 2020 is therefore out of the scope of this manuscript.

Fig 7 – It would be better to have the global results on the left to match figures 4-6, and the description in the text.

Done. - This figure has been changed to present the global results in the left column and the latitudinal ranges in the right column. A description in the caption and text has been updated.

Technical Corrections

Line 169 – Boike et al showed that
Done. - This has been revised.

Line 402 – because it was produced
Done. - This has been revised.

Line 537 – reword: “it is important to note that”, or “important to note is that”
Done. - This has been revised.

Line 398 – reword: “explicitly considers environmental policies and assesses their impact”
Done. - This has been revised.