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Reply on RC2

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., https://doi.org/10.5194/bg-2021-83-AC2, 2021

We thank Reviewer 2 for these constructive comments and have refined the manuscript as suggested.

SPECIFIC COMMENTS:

Page 2, Line 41: I suggest rephrasing to "and how severe future Arctic wildfire seasons can potentially be".

Done. - This has been revised.

Page 3, Line 68: Suggested rephrasing: "(both starting earlier and ending later)"

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

Section 3, paragraph 3: It is worth also highlighting that the Arctic has been identified as a hot-spot region for the interannual variability of key atmospheric constituents, with wildfire being the major driver of this variability (Fisher et al., 2010; Monks et al., 2012; Voulgarakis et al., 2015).

Done. - We have started paragraph 3 of section 3 with the following sentence: Previous work has identified the Arctic as a regional "hot spot" for interannual variability of key atmospheric constituents, with wildfire being the major driver of this variability (Fisher et al., 2010; Monks et al., 2012; Voulgarakis et al., 2015).

These three citations have also been added to the manuscript's References section.

Page 3, Line 90: Subscript 2 in CO2.

Done. - Thank you for finding this error.

Page 4, Sect. 2: This section contains plenty of useful information and references, but could benefit from better organisation. It features a mixed discussion about different regions, periods, and types of fires (human-driven and natural) in a way that is not well structured and coherent. I suggested some re-organisation of the section so that it flows better.

Done. - This section has been reorganized and shortened so that it (1) introduces the mechanisms of drivers of fires in the Pan-Arctic, (2) contextualises climate and human-driven fire activity for the region in the paleo record, and (3) demonstrates how human activities are still some of the main drivers of fire activity currently. Approximately 10 sentences on climate modeling results have been moved to section 3.1 to consolidate that information into a single section. This revision and re-organization has improved the flow of the section.

Page 4, Lines 114-115: Aren't forest fires and peat fires different kinds of wildfires (and, therefore, wildland fires, which is the broader term)? Also, doesn't the term 'wildland fire' include prescribed fires?

Done. - We have revised this sentence to make it more clear that this review quantifies fires in the Pan-Arctic across wild and human-dominated landscapes and natural and human-caused ignitions: "For this review paper, the definition of open biomass burning in the Arctic will include wildland fires (sometimes referred to as and encompassing of wildfires, forest fires, peat fires, as well as prescribed fires in natural areas) and fires in human-dominated landscapes (i.e., agricultural open burning, prescribed burning in agroforestry, timber, rangelands, etc.), with natural fires (lightning ignitions) and human-caused fires differentiated where possible."

Based on feedback from other reviewers, we have moved this sentence to the third paragraph of the introduction section.

Page 4, Lines 117-118: Fuel condition as well as ignitions depend on climate too. Could rephrase to "Broadly speaking, wildfires are driven by climate and weather conditions influencing flammability, fuels and fuel conditions…"

Done. - We have revised this sentence to: "Broadly speaking, wildfires are driven by climate and weather conditions influencing flammability, fuels, and fuel conditions (Silva and Harrison, 2010; de Groot et al., 2013)."

Page 4, Line 119: Human-caused fires can also be accidental.

Done. - This line has been revised to add accidental.

Page 4, Line 120: Need a space before "Pollen-based".

Done. - The extra space has been removed.

Page 4, Lines 125-127: This sentence is probably not needed, as it is stating something obvious, which is not true just for Arctic fires.

Done. - We have removed this sentence while keeping the definition of fire risk in Supplemental Table 1.

Page 5, Lines 129: Precipitation is also a determinant of fire weather. Also, what about fuel abundance?

Done. - This lines has been revised to: "Ignition from lightning strikes, fire weather (i.e., temperature, humidity, precipitation, and wind), and fuel abundance (build-up) and conditions (moisture) are the typical controlling processes for 'natural' fires, i.e. fires not caused directly by human activity."

Page 5, Line 133: scenario 8.5 -> scenario RCP8.5

Done. - This has been revised.

Fig. 1: Instead of "boreal forest" or "boreal", maybe use "taiga", to be consistent with other parts of the manuscript?

Done. - We thank the reviewer for a keen eye to detail. We have updated Fig.1 to state taiga in Siberia, where it is most commonly used, and maintained the use of boreal for North America and Fennoscandia. We have added a small revision to the figure caption to note this change and complexity of the usage of taiga versus boreal: "Note that taiga is used in northern forest zones completely contained in Russia while boreal is used for the rest of the Pan-Arctic northern forests." .

Page 6, Line 185: Why "in turn"?

Done. - We have removed "in turn" as we do not mean to imply that the previous expansion of grassland ecosystems is related to increased lightning ignitions.

Page 7, Line 203: "predicted to expand by as much as 20 days globally" – under which scenario?

Done. - We have deleted this sentence here as it is repeated, with the designated scenarios, in lines 214-218: "By the end of the century, wildland fire risk is expected to increase, with length of fire seasons - measured in terms of daily severe fire weather occurrence - predicted to expand by as much as 20 days for high northern latitudes using the A1B (roughly corresponding to RCP6.0), A2 (~ RCP8.5), and B1 (~RCP4.5) scenarios (Flannigan et al., 2013)."

Page 9, Line 270: I suggest rephrasing to "and a decrease in its regeneration cycle"

Done. - This has been rephrased.

Page 10, Lines 298-299: I am not sure it will be clear to the reader after reading this paragraph why "Therefore… the springtime burning of northern grasslands, peatlands, and croplands - often human-caused - means these emissions are more likely to be transported to the Arctic than summertime forest fires". Please clarify.

Done. - This has been clarified to "Therefore, while boreal forest fires emit more SLCFs than grasslands and cropland fires, the springtime burning of northern grasslands, peatlands, and croplands - often human-caused - means these emissions are more likely to be transported to the Arctic during favourable transport conditions in March, April, and May than summertime forest fires." Please note that earlier in this paragraph, we explain this mechanism, and now are reinforcing this documented mechanism.

Page 11, Line 335: I would suggest "Note, however" rather than "Note also".

Done. - This has been revised to "Note, however…".

Page 11, Line 340: Certainly there is a sharper trend in >60N, but I would not say that the following statement is supported by the figure: "More fire is now taking place north of 60° N than in the temperate zone of 45° to 50° N". Also, FINN does not show an increasing trend anywhere.

Done. - We have revised this statement to say: "Fire emissions are increasing more north of 60° N compared to the temperate zone of 45° to 50° N, where large amounts of human-caused burning and wildfires throughout North America, Europe, and Eurasia occur (Fig. 2)." As we are comparing emission estimates and not direct fire counts or burned area, focusing on the trend is a more appropriate finding.

Further, how the trend in FINN data is described has been revised. 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)."

Page 11, Lines 344-346: 2008 appears both in highest and in lowest!

Done. - We thank the reviewer for catching that error. The lowest years should be 2007 and 2013, while 2008 was one of the highest. This sentence now reads: "The lowest annual average BC emission from the five global fire emissions models are 2007 and 2013, both with 0.27 Tg.."

Page 11, Line 352: Please subscript 4 in CH4.

Done. - Thank you for finding that error. It has been subscripted.

Page 12, Lines 366-367: "fires in temperate zones of the CONUS tend to emit double the emissions of boreal ecosystems" – would be useful to the readers to comment on why this happens.

Done. - It should be noted that while Canada and CONUS reported similar official statistics for burned area, fires in temperate zones of the CONUS tend to emit double the emissions of boreal ecosystems (Table 2) due to higher fuel loadings, emission factors, and combustion completeness (Suppl. Table 2).

Page 12, last paragraph of section: Focusing on BC deposition effects in Greenland is nice, but maybe this section requires some mention of findings from other regions regarding this mechanism? Otherwise the focus on Greenland seems a bit disproportional.

Done. - In this paragraph, we wanted to explore the new novel fire regime in the Arctic that Greenland represents. We have tried to emphasize that, as well as citing literature on BC deposition from North American fires to situate the Greenlandic sources of BC deposition.

Page 12, Lines 372: on deposition -> on BC deposition

Done. - This has been revised to state "on BC deposition".

Page 12, Lines 386-387: "while the average instantaneous BOA (Bottom Of the Atmosphere) radiative forcing over Greenland at noon on 31 August 2017 (post-fire) was between 0.03 and 0.04 Wm-2, with locally occurring maxima up to 0.77 Wm-2" – does this refer to the atmospheric effect of aerosols (not the surface albedo effect)? Please clarify.

Done. - We have clarified the sentence by adding the following: "The maximum albedo change due to BC and BrC deposition from the Greenland fires was -0.007 at maximum, while the average instantaneous BOA (Bottom Of the Atmosphere) radiative forcing over Greenland at noon on 31 August 2017 (post-fire) was between 0.03 and 0.04 Wm-2, with locally occurring maxima up to 0.77 Wm-2. Here, the BOA included both the aerosol effects of BC and BrC in the atmosphere and deposited on the snow. The albedo effect (a decrease) was very low (0.007), practically unmeasurable."

Section 5: There are some bits where GFAS emissions are referred to as "wildfire emissions". Given that they also include e.g. agricultural fire emissions, I would suggest referring to them as "biomass burning emissions".

Partially done. - The reviewer is correct that GFAS includes all types of fire emissions, not just wildfires. To make this more clear, we have revised Section 5 to describe the GFAS data and why it is referred to as wildfire emissions in this review. In particular, the GFAS data hosting site refers to emissions database as 'wildfire and biomass burning' emissions (https://www.ecmwf.int/en/forecasts/dataset/global-fire-assimilation-system). Further, CAMS and ECMWF branded science outreach refers to GFAS emissions as 'wildfire emissions' (see an example from Twitter here: https://twitter.com/m_parrington/status/1402532919890096128?s=20). The pertinent sentences in the first paragraph of Section 5 now reads: "The GFAS wildfire and biomass burning emissions include all open biomass burning activity, with no differentiation between human-caused ignitions and natural sources, like lightning, but attempt to remove spurious fire emissions from industrial, volcanic, and geothermal sources (Rémy et al., 2017). Data was clipped to Pan-Arctic extents at 50°N, 60°N, and 65°N. The GFAS emissions data, referred to as wildfire emissions in this review due to inability to differentiate fire types in the emissions data, has a spatial resolution of 0.1°, so it was aggregated to 0.5° for comparison with GAINS."

Page 13, Line 411: Maybe "replicate" is too strong a word?

Done. - This has been revised so "replicate" is now "represent".

Page 14, Line 427: phenomena -> phenomenon

Done. - This has been revised.

Page 14, Line 450: black -> black carbon

Done. - This has been revised to add the missing word.

Page 15, Lines 464-466: Suggest rephrasing to "…and fires from grasslands, forests, and agricultural lands in southern Siberia (Kukavskaya et al., 2016) and the Russian Far East (Hayasaka et al., 2020) are most common during the spring months of March, April, and May."

Done. - This has been revised.

Page 15, Line 491: Maybe instead of "in practical terms" the authors meant to write "in theory"?

Done. - This has been revised: "To date, the effectiveness of this campaign is unclear, but in theory it should reduce fire risk."

Page 16, Line 515: is important -> they are important

Done. - This has been revised to "fires are important".

Page 17, Lines 533-535: This sentence may need to be rephrased as it does not read very clearly.

Done. - This sentence has been revised to: "Future Arctic fire regimes will be influenced by shifting vegetation types (Tchebakova et al., 2009; Sizov et al., 2021), with both climate change and subsequent fire seasons, i.e., fire disturbance, determining the species and locations of future vegetation on Arctic and boreal landscapes (Foster et al., 2019)."

Page 18, Lines 569-571: There has also been an important body of recent laboratory work on how organic soils burn and how peat fires spread, e.g. Christensen et al. (2020), Santoso et al. (2021), Huang et al. (2019), Huang et al. (2017), Huang et al. (2015), Prat-Guitart (2016), Yuan et al. (2021), amongst others.

Done. - A sentence has been added to this section noting improved understanding of peat burn processes from laboratory experiments: "Recent laboratory work on fire mechanisms of organic soils and how peat fires spread improves the understanding of these processes (for example, Huang et al., 2017; Huang et al., 2015; Prat-Guitart, 2016; Huang et al., 2019; Christensen et al., 2020; Santoso et al., 2021; Yuan et al., 2021), though a need for Pan-Arctic field observations persists."

These references have been added to the paper:

Santoso, M.A., Cui, W., Amin, H.M., Christensen, E.G., Nugroho, Y.S. and Rein, G.: Laboratory study on the suppression of smouldering peat wildfires: effects of flow rate and wetting agent, Int J Wildland Fire, 30, 378-390, https://doi.org/10.1071/WF20117, 2021.

Christensen, E.G., Fernandez-Anez, N. and Rein, G.: Influence of soil conditions on the multidimensional spread of smouldering combustion in shallow layers, Combust Flame, 214, 361-370, https://doi.org/10.1016/j.combustflame.2019.11.001, 2020.

Huang, X. and Rein, G.: Upward-and-downward spread of smoldering peat fire, Proc Combust Inst, 37, 4025-4033, https://doi.org/10.1016/j.proci.2018.05.125, 2019.

Huang, X., and Rein, G.: Downward spread of smouldering peat fire: the role of moisture, density and oxygen supply. Int J Wildland Fire., 26, 907-918, https://doi.org/10.1071/WF16198, 2017.

Huang, X., and Rein, G.: Computational study of critical moisture and depth of burn in peat fires, Int J Wildland Fire, 24, 798-808, https://doi.org/10.1071/WF14178, 2015.

Prat-Guitart, N., Rein, G., Hadden, R.M., Belcher, C.M. and Yearsley, J.M.: Propagation probability and spread rates of self-sustained smouldering fires under controlled moisture content and bulk density conditions, Int J Wildland Fire, 25, 456-465, https://doi.org/10.1071/WF15103, 2016.

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Loisel, J., Gallego-Sala, A.V., Amesbury, M.J., Magnan, G., Anshari, G., Beilman, D.W., Benavides, J.C., Blewett, J., Camill, P., Charman, D.J. and Chawchai, S.: Expert assessment of future vulnerability of the global peatland carbon sink, Nat. Clim. Chang., 11, 70–77, https://doi.org/10.1038/s41558-020-00944-0, 2021.

Lasslop, G., Coppola, A.I., Voulgarakis, A., Yue, C. and Veraverbeke, S.: Influence of Fire on the Carbon Cycle and Climate, Curr Clim Change Rep, 5, 112–123, https://doi.org/10.1007/s40641-019-00128-9, 2019.

Page 18, Line 580: Here it is worth mentioning that peat fires and related feedbacks are not typically represented in current Earth system models, which limits predictability of the future. Suitable references could be Loisel et al. (2020) and Lasslop et al. (2019).

Done. - We have added a sentence in this paragraph: "Current Earth system models do not typically characterize well or include peat fires and related feedbacks (Lasslop et al., 2019; Loisel et al., 2020), further limiting our ability to predict future emissions from peatland burning."

Page 20, Lines 687-688: What does "agreement was less than 10%" mean?

Done. - We have revised this sentence to clarify what 10% means: "Agreement of burned area within Siberian forests between official Russian statistics and four satellite-based burned area products was less than 10% (Kukavskaya et al., 2013)."

Page 22, Lines 700-702: it is worth mentioning whether there is any explanation of why GWIS may be giving such contrasting performance when compared to ground-truth information compared in neighbouring locations such as Norway and Sweden.

Done. - We have added to this section a possible explanation but also clarification: "The work of the SLCF EG was unable to determine exact reasons for why this mismatch occurs, though previous work has shown that satellite-based fire observations are more likely to align with official records as fire sizes increase (Fusco et al., 2019). Both Norway and Finland reported the lowest fire activity and burned area (Table 2). Future open biomass burning emissions will need improved satellite fire detection methodologies for the Arctic and boreal regions and shorter latency in ground reports and statistics from official agencies. Further, verifying and relating satellite detections of fires to ground-level verification will require a concerted effort and likely lead to a better understanding of how and why these two fire data sources do not presently align."

Conclusions: It would be good to highlight how important it will be to improve our understanding of the future of Arctic wildfires and emissions, for being able to better predict the future of Earth system processes, both at high latitudes and globally.

Done. - This has been added to the first paragraph in Conclusions: "Improving our understanding of the future of Arctic fires and fire emissions will also allow us to better predict future Earth system processes - both at high latitudes and globally."

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Voulgarakis, A., Marlier, M. E., Faluvegi, G., Shindell, D. T., Tsigaridis, K., and Mangeon, S. (2015), Interannual variability of tropospheric trace gases and aerosols: the role of biomass burning emissions, J. Geophys. Res.-Atmos., 120, 7157–7173, https://doi.org/10.1002/2014JD022926.

Santoso Muhammad A., Cui Wuquan, Amin Hafiz M. F., Christensen Eirik G., Nugroho Yulianto S., Rein Guillermo (2021), Laboratory study on the suppression of smouldering peat wildfires: effects of flow rate and wetting agent. International Journal of Wildland Fire, https://doi.org/10.1071/WF20117.

Eirik G Christensen, Nieves Fernandez-Anez, Guillermo Rein (2020), Influence of soil conditions on the multidimensional spread of smouldering combustion in shallow layers, Combustion and Flame, 214, 361-370, https://doi.org/10.1016/j.combustflame.2019.11.001.

Huang Xinyan, Guillermo Rein (2019), Upward-and-downward spread of smoldering peat fire, Proceedings of the Combustion Institute, 37, 3, 4025-4033, https://doi.org/10.1016/j.proci.2018.05.125.

Huang Xinyan, Rein Guillermo (2017), Downward spread of smouldering peat fire: the role of moisture, density and oxygen supply. International Journal of Wildland Fire 26, 907-918, https://doi.org/10.1071/WF16198

Huang Xinyan, Rein Guillermo (2015), Computational study of critical moisture and depth of burn in peat fires. International Journal of Wildland Fire 24, 798-808, https://doi.org/10.1071/WF14178

Prat-Guitart Nuria, Rein Guillermo, Hadden Rory M., Belcher Claire M., Yearsley Jon M. (2016), Propagation probability and spread rates of self-sustained smouldering fires under controlled moisture content and bulk density conditions. International Journal of Wildland Fire 25, 456-465, https://doi.org/10.1071/WF15103.

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Lasslop, G., Coppola, A.I., Voulgarakis, A. et al. (2019), Influence of Fire on the Carbon Cycle and Climate. Curr Clim Change Rep 5, 112–123, https://doi.org/10.1007/s40641-019-00128-9.

Done. - These references have been added as mentioned in the responses above.