Referee #1

Wildfires play an important role in the carbon cycle and Earth's energy balance. Despite increasing incidences of tundra wildfires, very few studies on tundra-wildfire carbon emissions exist, and the radiative forcing associated with these emissions is not available. The manuscript of Moubarak et al. attempts to estimate carbon emissions and the resultant radiative forcings from tundra wildfires in the Yukon-Kuskokwim River Delta (YKD), Alaska. While it shows potential scientific significance to the climate community, I find it hard to read overall. It is unclear to me how the authors estimate the carbon emissions and radiative forcing, and the current estimate of radiative forcing is not convincing to me either.

RESPONSE: Thank you for your helpful feedback and the chance to clarify our methodology and importance of our results. Below we have responded to your general and line-specific comments individually.

General comments

1. The manuscript fails to show the total global amounts of carbon emissions from tundra wildfires and how significant they are, for example, compared to those from the boreal forest on a global basis. While the current estimate of emissions from the YKD area within Alaska is essential, it is not clear whether the global emissions are still significant from the global perspective, given that the Tundra ecosystem covers only a small fraction of the earth.

RESPONSE: Given that tundra fires burn less area than boreal fires, with potentially comparable per unit area emissions, they contribute less to global carbon emissions than boreal fires. We will include a statement making this comparison in the discussion, where we cite the relative burned area for tundra and boreal fires in Alaska between the years 2001 and 2018. During this time frame, there was a yearly average of 0.5 Mha of boreal burned area compared to 0.017 Mha of tundra (Scholten et al., 2021). Despite the smaller burned area, tundra fires play an important role in ecosystem function and global climate because they can contribute to permafrost thaw, lack post-fire cooling effects from albedo changes seen in boreal fires, and are increasing in frequency. These factors heighten their importance in climate change. We will highlight these effects with our statement about global emission totals.

Scholten, R.C., S. Veraverbeke, R. Jandt, E.A. Miller, and B.M. Rogers.: ABoVE: Ignitions, Burned Area, and Emissions of Fires in AK, YT, and NWT, 2001-2018, ORNL DAAC, Oak Ridge, Tennessee, USA [data set], https://doi.org/10.3334/ORNLDAAC/1812, 2021.

2. The radiative forcing estimation in the current format looks faulty. First, the radiative forcing is given as a global average. However, the emissions and concentrations used here are the regional mean values. In addition, how do the authors translate the emissions to the concentrations of the gas/aerosol remaining in the atmosphere?

RESPONSE: Calculating global averages is standard practice for radiative forcing modeling of regional wildfires (e.g., Huang et al., 2016, O'Halloran et al., 2012, and Randerson et al., 2006). We will more explicitly state our method's precedent with these citations in the methods section, '2.7: Radiative forcings model'. Our final estimate for radiative forcing from this tundra wildfire season was bounded by estimates of the gaseous radiative forcing from boreal wildfires (Huang et al., 2016, Randerson et al., 2006). Thus our calculation is within reason, especially

given the similar levels of per unit area combustion we show between the fire season we measure and boreal fires. We will more explicitly contextualize our results with this comparison in the discussion by stating that the radiative forcing we calculated for these tundra wildfires is within the range of estimates for the gaseous radiative forcing of boreal fires.

We translated from emissions to atmospheric concentration of gaseous species remaining by converting from a mass emitted (calculated using emissions factors) to a volume as a molar fraction of the atmosphere. This step was crucial in converting from a regional emission to a global value, and we will make it more clear in our methods in response to the reviewer's line-specific suggestions below. Such a conversion was possible and is standard because greenhouse gasses are generally long-lived and globally-mixed, and global averages allow for common comparison.

Huang, S., Liu, H., Dahal, D., Jin, S., Li, S. and Liu, S.: Spatial variations in immediate greenhouse gases and aerosol emissions and resulting radiative forcing from wildfires in interior Alaska, Theoretical and applied climatology, 123, 581-592, https://doi.org/10.1007/s00704-015-1379-0, 2016.

O'Halloran, T. L., Law, B. E., Goulden, M. L., Wang, Z., Barr, J. G., Schaaf, C., Brown, M., Fuentes, J. D., Göckede, M. and Black, A.: Radiative forcing of natural forest disturbances, Global Change Biol., 18, 555-565, https://doi.org/10.1111/j.1365-2486.2011.02577.x, 2012.

Randerson, J. T., Liu, H., Flanner, M. G., Chambers, S. D., Jin, Y., Hess, P. G., Pfister, G., Mack, M. C., Treseder, K. K. and Welp, L. R.: The impact of boreal forest fire on climate warming, Science, 314, 1130-1132, https://doi.org/10.1126/science.1132075, 2006.

Specific comments

Line 57: Is there anything to do with "more variable precipitation" here? How is it related to the "increasing temperature"?

RESPONSE: By mentioning more variable precipitation in the context of increasing temperature, we meant to highlight the more frequent co-occurrence of hot and dry conditions, which provides context for the climate and environmental drivers of increasing wildfires in the following paragraph. We will add the phrase "hence more frequently pairing hot and dry conditions" to make this explicit.

Line 164: How do the authors "maximize" physical separation of the unburned sites?

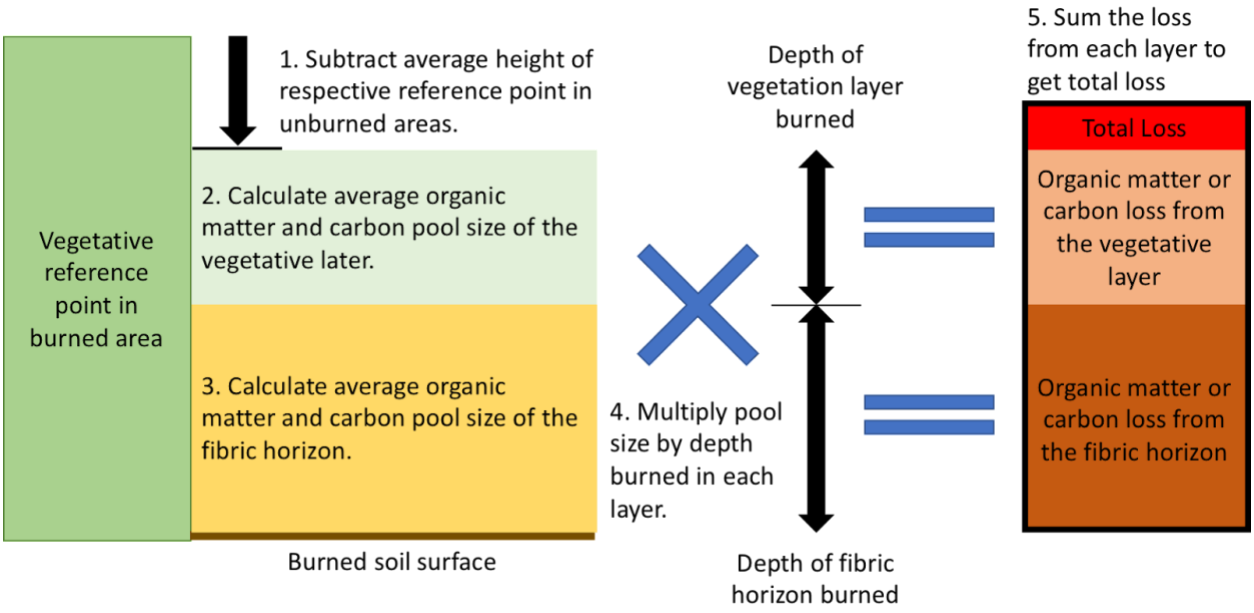
RESPONSE: We will remove the word "maximize" since it implies a formal optimization. Instead, we will cite the minimum distance of 1 kilometer between unburned sites.

Line 190-191: How do the authors calculate the organic matter combustion and carbon loss? I cannot get any hint from Fig. A4. Can they provide an equation and/or diagram to help readers understand this?

RESPONSE: Referencing Fig. A4 here was a typo, since it was meant to illustrate the trend in tussock burn depth measurements. We will move our reference of the figure to a later sentence

in the paragraph where we discuss our exclusion of tussock measurements because their burn depths correlated negatively with fire severity.

We also will add a schematic to the appendix to illustrate our calculation of organic matter and carbon loss at each burn depth transect. This figure will be referenced after text that describes how organic matter and carbon loss were calculated. Below is a sample of what that appendix figure will look like.



Line 192: Can the authors explain the reasons for the unexpected behaviors of tussock measurements?

REPONSE: Given the limited sample size of tussocks on the landscape and the lack of an explicit experimental design for this specific purpose, we cannot make definitive statements regarding the behavior of tussock measurements. We will suggest that tussocks may alter burn dynamics locally, while emphasizing that no conclusions can be drawn from our current dataset.

Line 246-248: How about the uncertainty associated with the emission factor?

RESPONSE: Since Akagi et al. (2011) combines measurements of emissions factors for each gaseous species from multiple studies with different designs, such as laboratory, field, and airborne, uncertainty is introduced into the emissions factor by the measurement technique. Post-emission chemical reactions from the released gaseous species cause the concentrations of specific gasses to vary after emission. As a result, how the gasses are measured might affect the emission factor. We will summarize this uncertainty in the methods.

Akagi et al. (2011) provides an estimate of natural variation for most emissions factors, which we do not include in our model. We also will highlight this in the uncertainty section of our discussion by stating future models might incorporate the natural variation of each emission factor to bound their estimates.

Akagi, S. K., Yokelson, R. J., Wiedinmyer, C., Alvarado, M. J., Reid, J. S., Karl, T., Crounse, J. D. and Wennberg, P. O.: Emission factors for open and domestic biomass burning for use in atmospheric models, Atmospheric Chemistry and Physics, 11, 4039-4072, https://doi.org/10.5194/acp-11-4039-2011, 2011.

Line 277-283. How do the authors get the atmospheric concentrations of CH4 and N2O from the fire emissions?

RESPONSE: While we mentioned briefly on line 250 (original submission) in our general description of the radiative forcings model that we converted the mass of the gaseous species emitted to volumes as molar fractions of the atmosphere, we will rearrange our text to make this methodology clearer for the gaseous species to which it was applied. First, we will remove that original sentence on line 250 (original submission). Then, for CH_4 and N_2O, we will add a sentence in section 2.8 stating that the concentration of both gasses was calculated by converting the initial mass emitted to a volume as a molar fraction of the atmosphere. We also originally labeled C_0 in equation 3 as an "initial pulse mass of the gas." Here we will change "mass" to "concentration." For CO_2, we will add a similar sentence describing the conversion of mass to atmospheric concentration in section 2.9. Finally, the same method was also used for CO when calculating the concentration of tropospheric ozone. Therefore, we will add the same description for CO in section 2.10.

Line 294. Again, how do the authors estimate the CO2 concentration from the fire emissions?

RESPONSE: See response to line 277-283.

Line 318. Although ozone precursors can affect CH4 formation, how are aerosols related to CH4?

RESPONSE: Our original text on this line was misleading. While aerosols are not explicitly related to CH4 formation, we chose to model them using methods similar to those we used for ozone precursors for the sake of consistency in GWP-derived radiative forcings calculations. We will change the text to reflect this methodological choice by stating:

> "We derived the radiative forcings for ozone precursors based on CH_4 because the radiative forcing of ozone precursors is through their effect on methane over the long-term (Collins et al., 2013). To remain consistent with our methodology for ozone precursors, we derive the radiative forcings for aerosols from CH_4 as well."

Collins, W. J., Fry, M. M., Yu, H., Fuglestvedt, J. S., Shindell, D. T. and West, J. J.: Global and regional temperature-change potentials for near-term climate forcers, Atmospheric Chemistry and Physics, 13, 2471-2485, https://doi.org/10.5194/acp-13-2471-2013, 2013.

Line 340. Why is R20 used here? So only accounts for the cumulative radiative forcing at the 20-year time zone?

RESPONSE: Our original text did not fully explain our assumptions for our aerosol calculations. We will rearrange the paragraph and add text to clarify. R20 is used because the total radiative forcing of aerosols likely happens within the first year of the fire event, as aerosols

exit the atmosphere on a time scale of weeks. Therefore, the cumulative radiative forcing of aerosols every year after the fire event is constant. We chose to use the GWP of the aerosols at year 20 to calculate the radiative forcing and assumed this value was the same across all years. We will change the text to state that:

> "The radiative effect of aerosol emissions happens within a year of the fire event, as fire aerosols are typically removed from the atmosphere via wet and dry deposition within a matter of weeks (Bond et al., 2011, Quinn et al., 2008). We assumed that the cumulative radiative forcing of aerosols at any year after the fire event would be constant and equal to the radiative forcing of aerosols in the year of the fire event."

Bond, T. C., Zarzycki, C., Flanner, M. G. and Koch, D. M.: Quantifying immediate radiative forcing by black carbon and organic matter with the Specific Forcing Pulse, Atmospheric Chemistry and Physics, 11, 1505-1525, https://doi.org/10.5194/acp-11-1505-2011, 2011.

Quinn, P. K., Bates, T. S., Baum, E., Doubleday, N., Fiore, A. M., Flanner, M., Fridlind, A., Garrett, T. J., Koch, D. and Menon, S.: Short-lived pollutants in the Arctic: their climate impact and possible mitigation strategies, Atmospheric Chemistry and Physics, 8, 1723-1735, https://doi.org/10.5194/acp-8-1723-2008, 2008.

Line 350: what is the "gls" function?

RESPONSE: To make clear the "gls" function is defined by the nlme package, we will rearrange the sentence to say, "we used the nlme function "gls" to fit a linear model." We will also clarify that the model was fit using the generalized least squares method.

Line 359: what is the "lme" function?

RESPONSE: Similarly, to emphasize the "lme" function came from the nlme package, we will add the phrase "defined in the nlme package." We will also clarify that the model is fit using the restricted maximum likelihood method.

Line 396: what is "SEM"?

RESPONSE: SEM stands for standard error of the mean, and the text will be changed to reflect this definition.