Dear anonymous referee #1,

Thank you for the opportunity to revise our manuscript, titled “Projected changes in forest fire season, number of fires and burnt area in Fennoscandia by 2100” (egusphere-2024-741). We appreciate the insightful comments and suggestions provided by the reviewers, which have greatly contributed to improving the quality of our work. We have carefully considered all feedback and have made the necessary revisions. Below, we provide a detailed, point-by-point response to each of the reviewers' comments. Our responses are in blue and the line numbers (L) refer to the manuscript. The cited references are provided at the end of the letter.

We hope that these revisions address all the concerns raised by the reviewers. We believe that these changes have strengthened the manuscript, and we look forward to your favorable consideration of our revised submission.

Thank you once again for your time and valuable feedback.

Sincerely,

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Review of “Projected changes in forest fire season, number of fires and burnt area in Fennoscandia by 2100” by Kinnunen et al.

This is a land modelling study using JSBACH-SPITFIRE for projected changes to northern European forest fires, driven by bias-corrected climate from 3 ESMs from CMIP5 that have been downscaled to higher resolution (Euro CORDEX). The changes to several fire-related variables, such as the fire number, burned area, fire danger index, and length of fire season were all examined for 30 years near end-of-century, in the context of changing temperature, precipitation, winds, and fuel moisture. They found a large range in the results, depending heavily on the driving ESM, but generally finding an increase in both the number of fires and burned area towards the end of the century in the two RCP scenarios examined (RCP4.5 and RCP8.5). Understanding how wildland fires will change in a changing climate is a very important question, and I recommend this paper be published after the following minor revisions.

We thank the reviewer for the very positive view on the relevance of our work. We hope that these changes, presented below, will help the reader better understand the content.

Minor comments:

Line 19: newer --> never

Edited as suggested.

Line 68: rations --> ratios

Edited as suggested.

Line 90: Can you add a line here that explains if anything is done to account for possibly overlapping fires? E.g. if 2 fires within a grid cell grow large enough, could they merge into one fire that may have less burned area than two distinct fires…?

Overlapping fires are not accounted for. We will add sentence: Overlapping fires was not accounted for, but within study area such occurrences are very rare.

Line 91-92: "taken into account" how?

We apologize for being unclear. The modeled burning area has been calculated for the forest area in order to make it more comparable with forest fire observations. We'll reworde the sentence as follows: The analysed burnt area is calculated for forested area.

Line 112: Since land cover changes were not accounted for over the ~150 year period simulated, can you comment on how that would affect your results? Is this region of Europe not expected to have large land cover/vegetation changes? Did it not become more agricultural than forested over time?

Indeed, we did not consider the land cover changes, but used Finnish CORINE and the European CORINE for both past and future. Regarding the past in Finland, the forested area is more than 10 times that of the agricultural fields and the forested area has been relatively constant. There was some decrease in the agricultural land cover between 1950 and 1980, but after that it has been quite stable, especially since ca. 1995. (luke.fi)

Zhou et al. (2021) investigated the recent land cover changes and land transitions from 1992 to 2018 in Norway, Sweden, Finland, and Denmark, as represented by the ESA-CCI-LC and C3S-CDS-LC datasets. According to they findings, the land cover area of forests changes from less than -5% (Sweden) to 4% (Norway) and the changes of the other land cover classes were relatively small as well, compared to the total land area.

Depending on SSP the changes of forested area is forecast to be in between +/-(1%-10%) in most of the Fennoscandia. Denmark and Baltic countries show higher range of variability (Hoffmann et al. 2023). Future land cover changes are out of the scope of this study. Moreover, land cover change does not have strong local legacy effect in the model, because the relatively quickly decomposing carbon in the soil affects the amount of fuel.

We will add the following sentences and the references to the end of first paragraph of the Discussion.

"Land use changes were not accounted for. This does not have much impact on the results as according to Zhou et al (2021) forested area have been relatively constant showing changes of the most prominent land cover class of up to +/-5%. Regarding the future Hoffmann et al. (2023) reported projected land cover changes of up to +/-10% in most of the Fennoscandia."

Lines 117-122: Is a 20% cloud-to-ground fraction applied everywhere in the model domain? If so, do you have a reference for that factor? At higher latitudes, the cloud-to-ground fraction is likely greater than 20%. It could also be a function of cloud-base height.

We thank referee for this insightful comment. The FMI lightning data is cloud to ground, i.e. no need for modification. The LIS/OTD data was modified offline by a latitude dependent factor to obtain cloud to ground lightnings (see below for more details) and used in the south east part of the domain.

Can you comment on how lightning frequency and distribution are expected to change in the RCP4.5 and RCP8.5 scenarios and how this might affect your results (e.g. lines 201-204) in this paper?

This is indeed an interesting point. There is some discussion in the lines 256-260. As far as we understand, there is no consensus on the change. We will add to the Discussion a sentence based on foundings by Rädler et al., who concluded that due to rising instability, in the RCP4.5 and RCP8.5 scenarios, all model members predict relative changes in lightning frequency between 5% and 40% in Northern Europe until 2100.

Line 120: ODT --> OTD

Corrected as suggested. Same correction is in lines 119 and 122

Line 121: Is the latitude-dependent correction factor applied to the LIS/OTD data a correction to the total lightning flashrate from that dataset? Or do you just mean a latitude-based cloud-to-ground fraction applied to this dataset? If the latter, I wouldn't call it a "correction" since the total flashrate from this dataset is correct. If the former, I can't find this correction in that Lasslop et al (2014) reference. Can you be more clear here about what was done?

The latitude-dependent relation between total flashes and cloud-to-ground flashes is presented in Pierce, 1970 article. It is applied to the LIS/OTD data a correction to the total lightning rate from that dataset.

We added Pierce, 1970 to the references and corrected the sentence: In addition, a latitude-dependent relation between total flashes and cloud-to-ground flashes was applied to correct the latitude bias in the LIS/OTD data, as described in Pierce (1970).

Line 136: simulate --> simulated

Corrected as suggested.

Figure 1: the 6 locations are difficult to see (black font on dark background colour). Could you please put them on panel (c) instead? Or else, change the font colour to white to better see them.

We will change the font colour to white.

Lines 208-209 (and repeated at lines 268-269): It says the simulations underestimate the number of fires, but then given the uncertainties, those numbers agree with each other. For example, 1355 is within the observed range of 1691 +/- 799, no?

We thank you for the critical comment regarding the conclusions of the number of fires in Finland. We are not able to present accurate limits for the uncertainty because we don't have an estimate of the uncertainty of the annual averages. We only have the average and standard deviation of a few years for the measurements and a few more years of values from the model. We definitely agree that the modeled values are in the range of the measured annual averages. We rewrite the sentence: The simulated values of the average number of fires in Finland from 1355 ± 509 to 1568 ± 556 match the values 1691 ± 799 observed in the PRONTO data (Table 2). Moreover, we'll change the order of the tables as well as the sentences referring to them respectively. This will improve the readability of the text.

Lines 218-219 (and repeated at lines 271-273): Similarly, the burnt area ranges overlap, so I don't think it's correct to say that the simulations overestimate, when they are within the range given (5.84 +/- 3.93 km^2).

We agree and rewrite the sentences as follows: The burnt area in the simulations ranged from 7.33 km^2 ± 3.77 km^2 to 10.73 km^2 ± 5.86 km^2 in Finland. Compared to the PRONTO data (5.84 km^2 ±

3.93 km2), the simulations slightly overestimate the burnt area, but the dispersion interval covers the averages of the modeled values (Table 4).

Lines 241 & 266: newertheless --> nevertheless

Corrected as suggested.

Lines 259-260: this statement sounds too definitive for being based on one lightning parameterization being implemented in one model (EMAC). Given the high variability and uncertainties associated with both lightning and fire modelling, I suggest you change this sentence to: “The risk of lightning-ignited fires **may vary** from a 62% decrease to a 38% increase under RCP 6.0 in the polar regions from the 2010s to the 2090s**, according to one study** (Pérez-Invernón et al., 2023).

We will change the sentence as suggested. We'll add a another sentence and reference in to this context as shown above.

Table 1: this is a big table filled with numbers that is already well-represented by Figure 3. Therefore, I suggest Table 1 be moved to the appendix or supplement.

Answer: We moved the table 1 to the appendix as suggested. The numbering of other tables will be changed.

Tables 2 & 4, and Figure A14: How come the smaller time frame (2011-2018) was not used for the models too? The different time ranges mean that you are not comparing the same thing from models to the observations. The additional years from the simulations may be responsible for the differences.

As we have used scenarios rather than observed weather data, the model do not represent a real year. We have used an average of 30 years to smooth out the annual variability and gotten more reliable climate than a few years of data. That's why we've always used an average of 30 years. We cannot use the reference period because it does not match the PRONTO data years. Unfortunately, the time period for PRONTO data is short. Below are the values for the shorter period even though we do not change it in the article.

Number of fire

Source 2011-2018	Average	Std	Max	Min
PRONTO data	1691.0	799.0	3365.0	652.0
RCP 4.5 CNRM-CM5	1308.0	177.0	1640.0	1081.0
RCP 8.5 CNRM-CM5	1434.0	357.0	1940.0	785.0
RCP 4.5 MIROC5	1655.0	438.0	2384.0	1067.0
RCP 8.5 MIROC5	1689.0	443.0	2416.0	1002.0
RCP 4.5 CanESM2	1417.0	385.0	2063.0	982.0
RCP 8.5 CanESM2	1565.0	372.0	2054.0	800.0

Source	Average	Std	Max	Min
PRONTO data	1691	799	3365	652
RCP 4.5 CNRM-CM5	1419	331	2362	909
RCP 8.5 CNRM-CM5	1414	372	2363	785
RCP 4.5 MIROC5	1534	448	2384	710
RCP 8.5 MIROC5	1568	556	3409	692
RCP 4.5 CanESM2	1355	509	2655	410
RCP 8.5 CanESM2	1419	436	2167	429

Burnt area

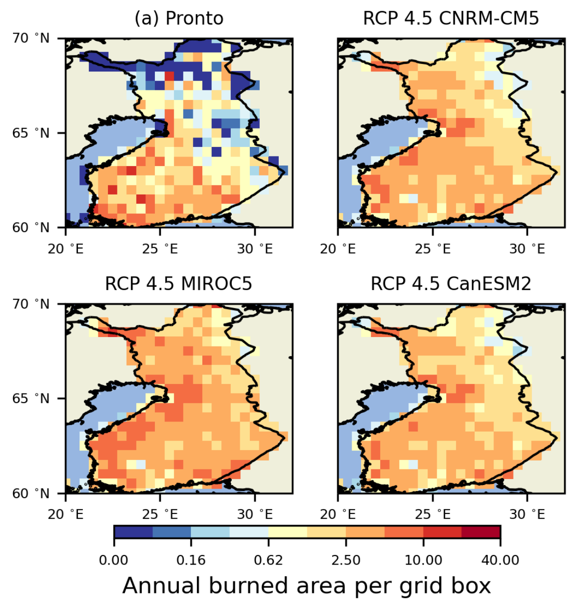
Source 2011-2018	Average	Std	Max	Min
PRONTO data	5.84	3.93	14.09	1.18
RCP 4.5 CNRM-CM5	6.45	1.91	9.54	4.38
RCP 8.5 CNRM-CM5	9.51	5.1	17.83	2.82
RCP 4.5 MIROC5	10.07	3.92	17.83	5.4
RCP 8.5 MIROC5	12.35	4.79	19.32	4.29
RCP 4.5 CanESM2	8.72	4.07	15.28	3.72
RCP 8.5 CanESM2	7.96	2.53	12.16	3.77

Source	Average [km^2]	Std [km^2]	Max [km^2]	Min [km^2]
PRONTO data	5.84	3.93	14.09	1.18
RCP 4.5 CNRM-CM5	7.68	3.10	14.93	3.01
RCP 8.5 CNRM-CM5	7.80	3.95	17.83	2.82
RCP 4.5 MIROC5	9.94	4.77	21.74	3.48
RCP 8.5 MIROC5	10.73	5.86	29.3	3.70
RCP 4.5 CanESM2	7.53	4.60	19.27	0.92
RCP 8.5 CanESM2	7.33	3.77	19.10	1.02

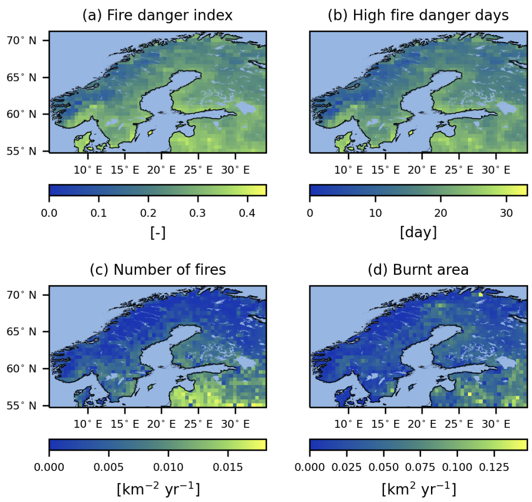
We have added a sentence to line 205: For the models, the 30-year average (1991-2020) is more reliable than the shorter PRONTO period (2011-2018), as the forcing data don't represent the conditions in any given year.

Figure A9: It would be helpful if the observations of these same variables were mapped up in a similar way for comparison to these multi-model avg results.

There is no observations of FDI and number of high and extreme high FDI days. We have plotted observations and modeled number of fires in the Figure A14. The plot with burnt area will not give any extra information (shown below, left hand side).



End of the century



It makes sense to take the multimodel average over the reference period because the model values are basically the same on average during that period. However, because they differ at the end of the century, by averaging out the models we would miss the information about these differences. The same figure as A9, plotted for the end of the century, is shown above (right hand side). For example, while the number of very high or extremely high fire danger days increases 5.3 as a multimodel average, it changes from 3.5 to 12 days when calculated separately.

We will keep the original presentation of the results.

Figure A13: important to note the limitation of panel (c) that future lightning was kept the same as present lightning. Therefore, this panel only shows changes in the future due to the changing human ignition rate. So the title of panel (c) should be “human ignition rate change”, no?

We will not change the caption of figure A13, but we reworded the sentence in lines 197-199 as follows: The average total ignition rate of 2071–2100 in the eastern part of the model domain decreases, and in the western part of the model domain, it increases compared to the reference period 1981–2010 due to the change in human ignition rate.

References:

Hoffmann, P., Reinhart, V., Rechid, D., de Noblet-Ducoudré, N., Davin, E. L., Asmus, C., Bechtel, B., Böhner, J., Katragkou, E., and Luyssaert, S.: High-resolution land use and land cover dataset for regional climate modelling: historical and future changes in Europe, Earth Syst. Sci. Data, 15, 3819–3852, https://doi.org/10.5194/essd-15-3819-2023, 2023.

Pierce, E. (1970), Latitudinal Variation of Lightning Parameters, Journal of Applied Meteorology , 9, 194–195.

Rädler, A.T., Groenemeijer, P.H., Faust, E. et al. Frequency of severe thunderstorms across Europe expected to increase in the 21st century due to rising instability. npj Clim Atmos Sci 2, 30 (2019). https://doi.org/10.1038/s41612-019-0083-7

Na Zhou, Xiangping Hu, Ingvild Byskov, Jan Sandstad Næss, Qiaosheng Wu, Wenwu Zhao, Francesco Cherubini (2021), Overview of recent land cover changes, forest harvest areas, and soil erosion trends in Nordic countries, Geography and Sustainability, Volume 2, Issue 3, Pages 163-174, ISSN 2666-6839, https://doi.org/10.1016/j.geosus.2021.07.001. (https://www.sciencedirect.com/science/article/pii/S2666683921000341)

website luke.fi

agricultural land:
https://statdb.luke.fi/PxWeb/pxweb/fi/LUKE/LUKE__02%20Maatalous__04%20Tuotanto__22%20Kaytossa%20oleva%20maatalousmaa/03_Peltoala_1910_ja_1920-.px/
and forested land:
https://statdb.luke.fi/PxWeb/pxweb/fi/LUKE/LUKE__04%20Metsa__06%20Metsavarat/1.01_Metsatalousmaa.px/