Reviewer #2:

General comment

The manuscript titled "Future prediction of Siberian wildfire and aerosol emissions via the improved fire module of the spatially explicit individual-based dynamic global vegetation model" by Reza Kusuma Nurrohman and colleagues evaluates the implementation of the SPITFIRE fire module into the SEIB dynamic global vegetation model for Siberia. The model is forced with reanalysis data provided by CRU and with global climate model data produced by MirocAR5 for the historical period as well as four emission scenarios until 2100. The manuscript compares simulated and observed fire-related variables and evaluates the impact of wildfires on emissions and tree mortality. The text would benefit from restructuring and enhanced focus on the aspects that really matter. Large parts of the results section are very descriptive, and it is not always self-evident why these results matter and what they imply. It is worthwhile for the authors to revisit the entire text and carefully assess what information is really worth communicating. Additionally, restructuring the results section such that it first evaluates the model during the historical period and then describes future projections afterwards is recommended. Furthermore, adding an overview figure or table that systematically compares and summarizes model performance for the old and new versions of the model is suggested. This is important to convince the reader that the new version is indeed superior. Finally, many of the literature references are outdated and should be replaced with more recent ones. I recommend that the manuscript may be considered for publication in Biogeosciences after major revision. Please find my detailed comments below.

> **Response:**
>
> Thank you for your thorough review of our manuscript, and we appreciate your constructive feedback and insightful suggestions for improvement.
>
> We understand your suggestion regarding the restructuring of the manuscript to enhance its clarity and focus on key aspects. We will carefully reassess the content of the results section to ensure that it effectively communicates the significance of our findings and their implications. Additionally, we acknowledge the importance of prioritizing the evaluation of the model's performance during the historical period before discussing future projections. We will revise the manuscript accordingly to improve its coherence and readability.
>
> Furthermore, we appreciate your recommendation to include an overview figure or table that systematically compares and summarizes the model performance for the old and new versions. This will indeed provide a clearer demonstration of the improvements made in the new version of the model.
>
> Regarding the outdated references, we will thoroughly review the literature and update the references with more recent ones to ensure the accuracy and relevance of our citations.

We are grateful for your suggestion consideration of our manuscript for publication in Biogeosciences after major revision. Your feedback will undoubtedly contribute to enhancing the quality of our work, and we are committed to addressing all your suggestions in our revised manuscript.

Once again, thank you for your time and valuable input.

Detailed Comments

L1 Note that when you are assessing the impact of emission scenarios, you should refer to projections rather than to predictions. Also, but this is completely up to the authors, my personal recommendation is to choose a more catchy title. For instance, you could simply shorten the tile to: "Future projections of Siberian wildfire and aerosol emissions"

Response:

We appreciate your suggestion to use the term "projections" instead of "predictions" when referring to the impact of emission scenarios. We will make sure to adjust the terminology accordingly to accurately reflect the nature of our analyses. Additionally, we are grateful for your recommendation to consider a more catchy title for our manuscript. We have adjusted our manuscript title according to your suggestion.

L17 In statistics, we distinguish between accuracy and precision. You don't want precise values, rather you want accurate values.

Response:

Thank you for your insightful comment regarding the distinction between accuracy and precision in statistics. We have adjusted this word.

L21 Before writing about the future changes, please add a sentence that describes how well the model reproduces historic values.

Response:

We have implemented your recommendation and have incorporated a sentence to address this aspect in our manuscript.

The adjusted sentence now reads as follows:

"The model is able to reproduce historical data well compared to the benchmark datasets, based on the validation results spatially, has the following values: AGB (R^2=0.43, RMSE=21.9 Mg ha^{-1}), burned fraction (R^2=0.75, RMSE=0.01), burned area (R^2=0.609, RMSE=690 ha), dry matter emission (R^2=0.63, RMSE=0.01 Kg DM m^{-2}), GFED4s CO_2 emission (R^2=0.608, RMSE=52.4 Tg), GBEI CO_2 emission (R^2=0.67, RMSE=69.5 Tg). Spatially, the model is able to produce data with the same distribution pattern with a

value of 61.8%. Numerically and on a long-term average, the model is able to produce values with very high accuracy of around 99% compared with the benchmark datasets."

L23 The absolute numbers are not very intuitive. Please provide the relative changes in emissions and trends, instead.

Response:

We have adjusted the text accordingly to provide relative changes in emissions and trends. We have added a percentage increase trend each year of 0.0264 ± 0.01 % year^{-1} (under the same RCP scenarios all emissions have the same increase trend). Under the RCP 8.5, has the highest percentage of increasing trend.

The adjusted sentence (L24) as follows: " Under the Representative Concentration Pathways 8.5 climate scenario, we estimated that the CO_2, CO, $PM_{2.5}$, total particulate matter (TPM), and total particulate carbon (TPC) emissions in Siberia will continue to increase annually until 2100 by 0.0264 ± 0.01 % year^{-1} or individually by 214.4 ± 79.4, 17.16 ± 6.35, 2.8 ± 1.03, 2.1 ± 0.78, and 1.47 ± 0.54 Gg species year^{-1}, respectively."

L38 Please find more recent references here. A good place to start would be the 6th Assessment Report, Working Group I, Chapter 5.

Response:

Thank you for your suggestion. We have read the 6th Assessment Report, Working Group I, Chapter 5, and other recent literature to identify appropriate references for inclusion in this section.

We have adjusted the reference in L41 (revised manuscript) into: "which will cause more emissions from biomass burning (Flannigan et al., 2009; Gauthier et al., 2015) and human activity (Schmoldt et al., 1999; Hantson et al., 2016)."

L43 Currently this sentence reads as if the fact that small fires matter is consistent with a positive trend in fires. This does not make sense to me. Please replace "This finding" with something more explicit.

Response:

We have corrected the word "This finding" to the following: "Increased incidence of wildfire in some regions around the world"

We hope this clarified the meaning of the sentence.

L61 Please use more recent references if you want to provide numbers that represent "current estimates", e.g. Friedlingstein, Pierre, et al. "Global carbon budget 2023." Earth System Science Data 15.12 (2023): 5301-5369.

Response:

Thank you very much for the suggestion, we have checked the publication of Friedlingstein, Pierre, et al. "Global carbon budget 2023." Earth System Science Data 15.12 (2023): 5301-5369.

However, we found it difficult to extract by region (Siberia) to compare with global data. So we have replaced the use of the words "current estimates" and replaced reference [1] with [2 and 3].

[1] Tchebakova, N.M., Monserud, R.A. and Nazimova, D.I. (1994) 'A Siberian vegetation model based on climatic parameters', Canadian Journal of Forest Research, Volume 24,. Available at: https://doi.org/10.1139/x94-208

[2] Kasischke, E.S. (2000) 'Boreal Ecosystems in the Global Carbon Cycle', (Houghton), pp. 19–30. Available at: https://doi.org/10.1007/978-0-387-21629-4_2.

[3] Hantemirov, R. M., Corona, C., Guillet, S., Shiyatov, S. G., Stoffel, M., Osborn, T. J., Melvin, T. M., Gorlanova, L. A., Kukarskih, V. V., Surkov, A. Y., von Arx, G., and Fonti, P.: Current Siberian heating is unprecedented during the past seven millennia, Nat. Commun., 13, 1–8, https://doi.org/10.1038/s41467-022-32629-x, 2022.

So the latest adjusted sentence is as follows (L64):

Boreal vegetation store between 17% of the world's carbon, yet encompasses almost 30% of all terrestrial carbon stocks (Kasischke, 2000; Gauthier et al., 2015), and two-thirds are located in Siberia, Russia (Shvidenko and Nilsson, 2003).

L122 Please find more recent reference. The study is 20 years old and much has happened in the last two decades.
Response:

We have adjusted the sentence into the following sentence (L125):

In the Arctic, a rapid warming trend has been observed, and the increase in temperature over the last 20 years of the 20th century was 2 to 3 times higher than the global average, while in the first 20 years of the 21st century, it exceeded four times (Chylek et al., 2022). This enormous increase in temperature in Siberia, affecting the duration and speed of snowmelt and accelerates thawing of carbon-rich permafrost (Natali et al., 2019; Schuur et al., 2015; Nitzbon et al., 2020), which results in drier ground cover, an increased frequency of wildfires, longer fire seasons, and increased ignition sources (Kharuk et al., 2022).

L124 Please don't cite the entire report. Specify the working group and chapter. Also, replace this reference with the most recent assessment report.

Response:

We tried to find a similar statement in the recent assessment report, but we couldn't find it. So, we decided to use another recent reference.

The adjusted sentence is as follows (L130):

These changes may result in a new climate state in which heatwaves as well as the associated the occurrence of wildfires may become routine and more severe (Hantemirov et al., 2022; Landrum and Holland, 2020). Produced emissions from thawing permafrost and from wildfire are likely to feed into the global carbon cycle's feedback on climate change (Schuur et al., 2015), and triggering further warming trends globally (Schimel et al., 2001; Kharuk et al., 2011; Krylov et al., 2014).

L146 The notation suggests that E is a function of nig. What is nig?

Response:

Yes, $E(n_{ig})$ is the expected number of fire ignition event. Ignition event $E(nig)$ is the sum of independent calculations of lightning-caused (n_{il}) and human-caused (n_{ih}) fire ignition events, ignoring stochastic variations (Thonicke et al., 2010).

$$Enig = nih + nil \qquad (6)$$

This is explained in section 2.2.1. Burned area calculation input variables in supplement (L8).

L148 Please consider using a bar rather than an underscore to indicate the mean area.

Response:

Thank you, now it's has been adjusted.

L149 A grid is composed of gridcells. Please replace "grid" with "gridcell".

Response:

it has been adjusted.

L264 Please include an analysis that shows how the inclusion of SPITFIRE affects the model's ability to reproduce the observed patterns during the historical period. So far you only write that the pattern of the new model version is different.

      Response:

Related to the comparison with the benchmark dataset of all of the major variables has been explained in the section 3.1. Improved model validation

Now. we have compared the burned fraction variable between the benchmark data (GFED4s), improved SEIB-DGVM (SPITFIRE), and default SEIB-DGVM. We will add the explanation in the beginning of the section 3.2 Burned Fraction.

Figure Rev1.
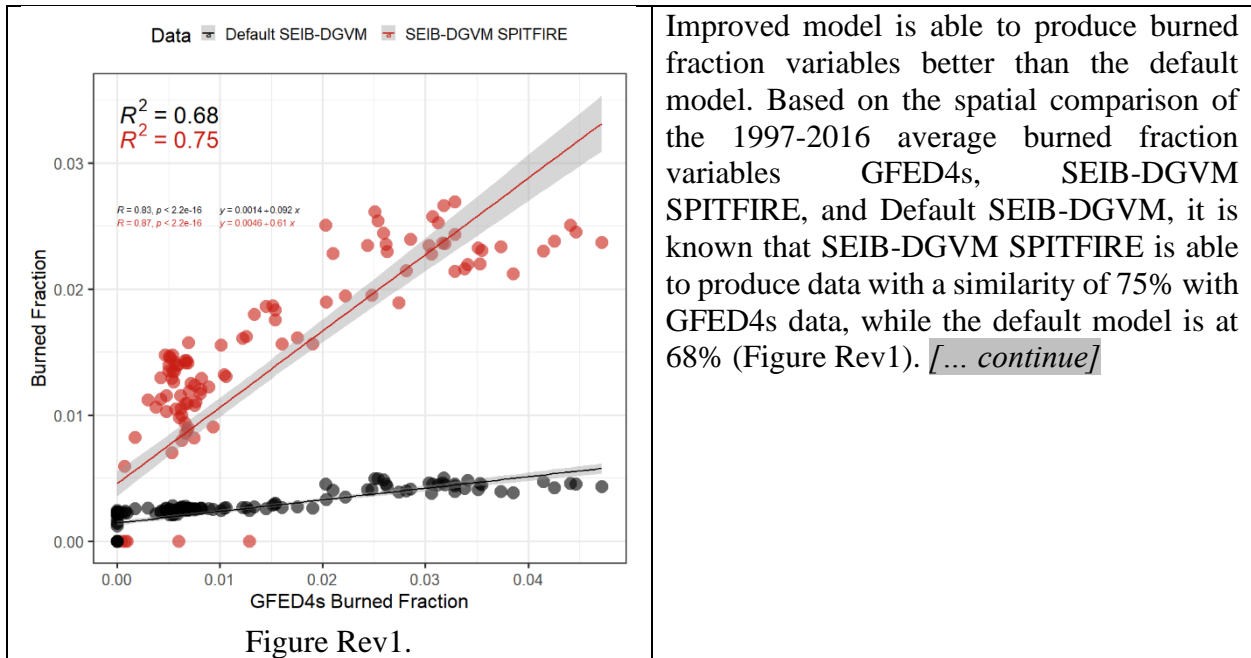
Improved model is able to produce burned fraction variables better than the default model. Based on the spatial comparison of the 1997-2016 average burned fraction variables GFED4s, SEIB-DGVM SPITFIRE, and Default SEIB-DGVM, it is known that SEIB-DGVM SPITFIRE is able to produce data with a similarity of 75% with GFED4s data, while the default model is at 68% (Figure Rev1). *[... continue]*

L275 Do lowest and highest values refer to spatially averaged annual mean values? Please explain.

      Response:

The lowest and highest values in this sentence refer to figure S7. Annual (total) burned area projection (2006-2100). We have adjusted the first sentence to give more explanation about the burned area (L434).

"Overall, under all the scenarios, the **annual total burned area** exhibited the same increasing trend, with the RCP4.5 scenario reaching the **highest value**. Under the RCP4.5 scenario from 2006 to 2100, the burned area has an average value of 1457.6 Ha grid^{-1} year^{-1} and is projected to increase with values of 80.4 to 83.7 x 10^5 hectares (Figure S6.b)."

L284 Does "uniform spatial distribution" mean that the amount of burned biomass is equal across gridcells? Please clarify.

Response:

Uniform spatial distribution -> our intention is to explain that the fire variables (burned fraction, burned area, and burned biomass) have the same distribution pattern, which means that the three variables are confirmed to be mutually integrated because the calculation process comes from the first fire variable, burned fraction. This is consistent with the GFED4s benchmark data, where the burned fraction and dry matter emission variables have the same distribution pattern.

Whereas in the default model, the distribution pattern between the burned fraction (Figure S4.a-d) and burned biomass (Figure 4.a-d) variables are different.

We have adjusted the sentence (highlighted sentences is for this comment adjustment, whole paragraph is also adjusted with **comment L292**) as follows:

"The improved model confirmed uniform spatial distribution patterns for the fire variables: burned fraction (Figure S4.b), burned area (Figure S6.a), and burned biomass (Figure 4.b). All of the improved module fire variables confirmed to be mutually integrated because the calculation process comes from the first fire variable (burned fraction). Compared to the improved model, the spatial distribution pattern of the burned biomass variable from the default model was wider and spread across the entire Siberia region (Figure 4.a). The spatial distribution pattern of burned fraction (S4.a-d) and burned biomass (Figure 4.a) in the default model is different and exhibited a box-like pattern in the center of the map.

Under all the RCP scenarios from 2006 to 2100, the burned biomass variable from the default model exhibited a decreasing trend (Figure 4.c). Under the RCP8.5 scenario, from 2006 to 2100, the value decreased from 5.09 to 5.05 kg DM m^{-2}, with an overall mean value of 5.07 kg DM m^{-2}. Meanwhile, the burned fraction product from default model shows an increasing trend (Figure S4.c), this indicates a misalignment in the default model between the burned fraction and burned area variables. On the other hand, the burned fraction (Figure S4.d), burned area (Figure S6.b), and burned biomass (Figure 4.d) variables in the improved model all have an increasing trend, indicating harmony between the three variables. Burned biomass variable under the RCP8.5 scenario from 2006 to 2100, the lowest and highest values were 8.0 and 8.71 kg DM m^{-2}, respectively, with an overall mean value of 8 .52 kg DM m^{-2}. The twenty-year variations and their trends of dry matter emissions up to 2100 are 8.37 ± 0.07 (3.3%), 8.46 ± 0.04 (0.7%), 8.53 ± 0.06 (1.3%), 8.52 ± 0.05 (-0.68%), 8.57 ± 0.08 (1.07%) (Figure S32)."

L290 Do you have any thoughts on what causes the box-like pattern? Also, why does the default model version produce values across the entire domain, while the SPITFIRE model version has many gridcells with no values?

Response:

We suggest the box-like pattern in the default model is caused by the spatial distribution pattern of the aboveground biomass variable (Figure 5.a). Because of the high availability of AGB in that area (box-like area) and the spread of fire (burned fraction) covering that area, the distribution pattern of burned biomass variable also has the same pattern (Figure 4a.a-d).

In the default model, the model produces fire variables that cover the entire domain because the default fire module only considers fuel availability, moisture content, and minimum threshold of fuel availability: 200 g C m^{-2} (Sato et al., 2007). Therefore, if a particular grid has dry fuel above the minimum threshold, a fire will occur, and it can ignite/ spread to neighboring grids.

While in the improved model, we add the fire ignition factors of anthropogenic ignition (population density) and natural ignition (lightning flash) calculation. So that even though the surrounding grid has dry fuel availability, if there is no ignition, the fire does not occur in that area.

Regarding the SPITFIRE module output on some variables that have areas that have no value, originally, they had a value of 0, but I removed it to n.a. because it is to match the data pattern of the two fire benchmark data (GFED4 and GFED4s).

L292 You write that "from 2006 to 2100, the value decreased from 5.09 to 5.05 kg DM m−2 ". Do the values refer to 2006 and 2100? Since there may be considerable variability, it may be better to compare 20 year averages instead, or calculate the trend.

Response:

Yes, the values are referred to 2006 and 2100. We have adjusted this by adding a comparison of the 20-year average and the trend. However, we only discussed the data in the improved model, whereas in the original manuscript the last paragraph discussed the data in the default model.

We have adjusted the wording of this paragraph in accordance with this comment and the previous comment.

The adjusted paragraph and supporting figures are as follows (L446):

"Under all the RCP scenarios from 2006 to 2100, the burned biomass variable from the default model exhibited a decreasing trend (Figure 4.c). Under the RCP8.5 scenario, from 2006 to 2100, the value decreased from 5.09 to 5.05 kg DM m^{-2}, with an overall mean value of 5.07 kg DM m^{-2}. Meanwhile, the burned fraction product from default model shows an increasing trend (Figure S4.c), this indicates a misalignment in the

default model between the burned fraction and burned area variables. On the other hand, the burned fraction (Figure S4.d), burned area (Figure S6.b), and burned biomass (Figure 4.d) variables in the improved model all have an increasing trend, indicating harmony between the three variables. Burned biomass variable under the RCP8.5 scenario from 2006 to 2100, the lowest and highest values were 8.0 and 8.71 kg DM m^{-2}, respectively, with an overall mean value of 8 .52 kg DM m^{-2}. ==The twenty-year variations and their trends of dry matter emissions up to 2100 are 8.37 ± 0.07 (3.3%), 8.46 ± 0.04 (0.7%), 8.53 ± 0.06 (1.3%), 8.52 ± 0.05 (-0.68%), 8.57 ± 0.08 (1.07%) (Figure S32)."==
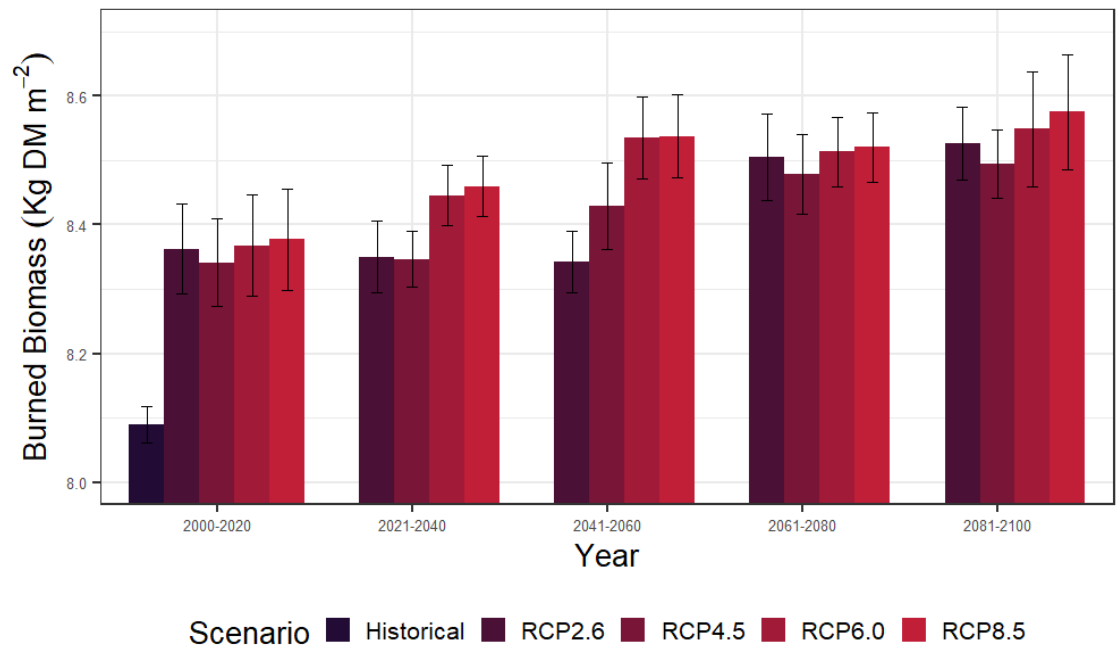

Figure Rev2.

L301 What are "estimation parameters"?

Response:

in this case -estimation parameters- means that the Aboveground biomass estimation process in the default model and improved model uses the same calculation method.

L305 What do you mean by common roots? Please rewrite this sentence.

Response:

In this sentence "common roots" means that the default model and improved model use the same basic aboveground calculation method, but the improved model is adjusted for the impact of fire distribution patterns (based on natural and anthropogenic ignition factors). So even though they use the same aboveground biomass calculation process, they have differences in distribution patterns (Figure 5) and trends in annual average dynamics (Figure S10).

We have adjusted the paragraph in section 3.5 (revised manuscript). as follows (L 459):

The aboveground biomass calculations in the default model and improved model used the same ==estimation process== because the trunk biomass in the SEIB-DGVM included coarse root biomass; therefore, only approximately 2/3 of the trunk biomass was classified as aboveground biomass (Sato et al., 2007). ==However, during the calibration of the aboveground biomass variable with the ESA Biomass CCI benchmark dataset, we made adjustments of the calculation impact of fire and its distribution pattern (based on natural and anthropogenic ignition factors) on the availability of aboveground biomass.==

L307 I am not sure what you are trying to communicate here. You find that a high fire frequency coincides with a low AGB. Do you think this makes sense because fires burn trees and therefore biomass is low? Or is it counter-intuitive because the more biomass, the more fuel load, the higher the probability of fires? How do you interpret your results?

Response:
My point was to convey your first explanation, that the AGB values (in the improved model: especially in some parts of central Siberia) are lower than in the default model because of the high frequency of fires burns biomass.

I have adjusted the whole paragraph in section 3.4 just like the answer in **comment L305 (L464: revised manuscript).**

L314 See comment as for L292.

Response:
We have adjusted the paragraph combined with the previous adjustment as follow (L476):

==The twenty-year variations and their trends of aboveground biomass up to 2100 are 69.09 ± 0.168 (0.13%), 69.04 ± 0.151 (-0.54%), 68.88 ± 0.128 (-0.07%), 68.37 ± 0.226 (-0.76%), 68.36 ± 0.189 (0.63%) (Figure Rev3).==
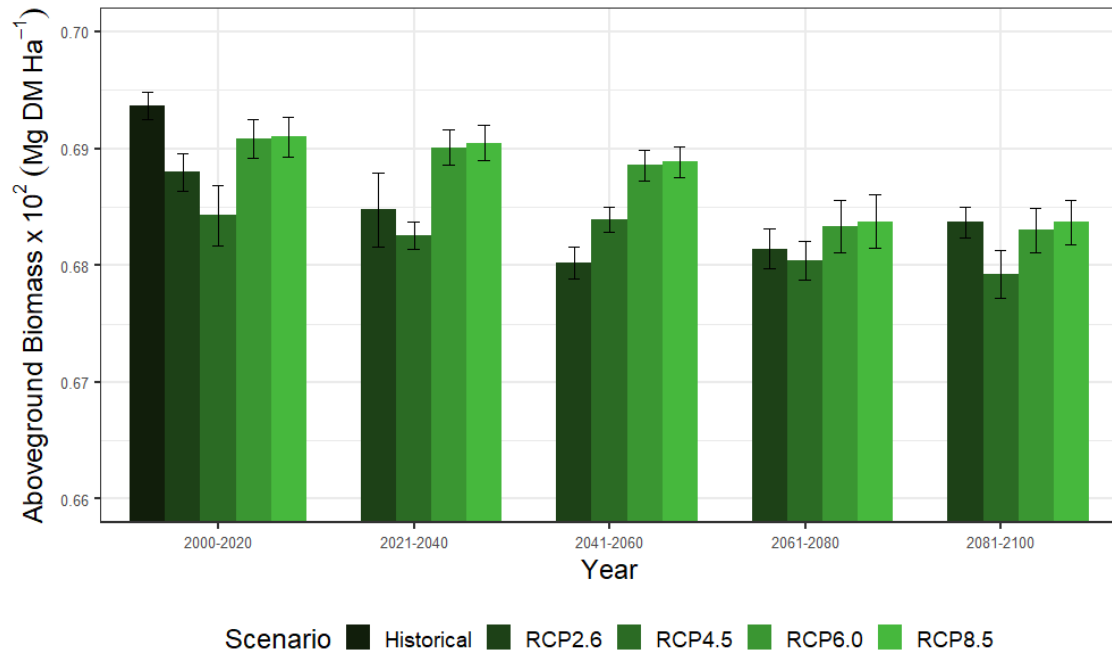
Figure Rev3.

L321 What does "full" refer to in this context?

Response:

"Full" simulation in this context means a complete simulation covering all phases (spinup, historical and future with all four RCPs scenarios) with fire on and fire off simulation, and with 5 repetitions of 5 times to get the average of the random runs values. Random runs: 1) random distribution of different vegetation seeds per gridcel, 2) Tree establishment, and 3) Individual trees that died from fire.

We have adjusted the sentence as follow (L484):

"We conducted complete simulations under fire-on and fire-off modes to compare and assess vegetation dynamics during forest fires. ...."

L322 Why is NPP "the most measurable element of the carbon cycle"? NPP is actually difficult to measure at a canopy scale. The eddy covariance method for instance, measures NEE, from which GPP and ecosystem respiration are then derived. You could also make the case that carbon pools are easier to measure than carbon fluxes.

Response:

1. Running (2022), stated that NPP has been the most easily measured intermediate step because it represents tangible, visible plant biomass, while NEE is the final net exchange of CO_2. NPP has been measured by ecologists and agronomists for centuries, but measurement of NEE was only routinely possible with the development of

automated eddy covariance flux towers in the 1980s, of which more than 500 now operate around the world.

Refference
Running, S.W. (2022) 'GLOBAL ARIDIFICATION AND THE DECLINE OF NPP: A COMMENTARY on Projected increases in global terrestrial net primary productivity loss caused by drought under climate change by Dan Cao, Jiahua Zhang, Jiaqi Han, Tian Zhang, Shanshan Yang, Jingwen Wang, Foyez', Earth's Future, 10(11), pp. 1–3. Available at: https://doi.org/10.1029/2022EF003113.

2. However, we have adjusted the sentences with your suggestion and the reference as follow:

We conducted complete simulations under fire-on and fire-off modes to compare and assess vegetation dynamics during forest fires. Assessing vegetation dynamics can be done by understanding the carbon pools in the certain region or globally, where carbon pools are easier to measure than carbon fluxes. In this study, the net primary production (NPP) is used as a reference variable because is an important metric of the global carbon cycle (Running, 2022) and measures the rate of global plant growth. Based on the comparison of results between the fire-on and fire-off simulations, the NPP variable under all of the RCP scenarios shows a downward trend with some small fluctuations. Under the RCP8.5 scenario, an average loss of 319.3 ± 28.2 g C m^{-2} year^{-1} occurred during 1997–2100 (Figure S23.a).

L325 Please add relative measures here as well, as absolute values alone are not very intuitive.
Response:
We have adjusted the sentence, as follows (L489):

"Under the RCP8.5 scenario, an average loss of 319.3 ± 28.2 g C m^{-2} year^{-1} occurred during 1997–2100 (Figure S23.a). …"

L337 Why does this matter and what do you conclude from this?
Response:
To (internally verify the model) show that both simulations (fire-on and fire-off) individually run well. The comparison between the three tree structure variables (crown area, tree DBH, and tree height) shows a good relationship with an average value of 98%.

(Comparison of tree structure simulation results with observational data is discussed in section 4.2 (L655).)

L349 Why does this matter and what do you conclude from this?

Response:

L349: "We extracted the AGB data in the marked area with coordinates of 130-142°E and 65-80°N (Figure S23) and discovered that the average simulated aboveground biomass in the area was 65.59 g C m^{-2} from 1997 to 2023, compared to 416.4 g C m^{-2} in the one-grid high-AGB areas."

This point is important because it will be discussed in relation to the distribution pattern of the fire variable (and its affected the spatial distribution of other variables, up to the projection of burning biomass emissions).

Further discussion is provided in section 4.1. paragraph 3 (L569), that the low AGB value in the area caused the fire can not to be ignited (due to the AGB value below the fuel load threshold: 200 g C m^{-2} (Sato et al., 2007). Compared to the benchmark data, fire was detected in these areas (GFED4 and GFED4s), and these areas had an average AGB of 2,309.67 g DM m^{-2}.

L360 Does the "annual average spatial distribution" expressed in percentage refer to the correlation coefficient R of annual mean values of individual gridcells? If that is the case, please express your results in terms of fraction (R 2 = 0.79). Please do that consistently throughout the text.

Response:

Yes, it does. We have adjusted this sentence (L360) and the whole paragraph according to your suggestion.

The entire adjusted paragraph in section 3.1.1. Fire products (revised manuscript) is as follows (L304):

"We compared the annual average distribution patterns of burned fraction variable (1997-2016) in the SEIB-DGVM SPITFIRE and GFED4s data, and most patterns differed only in eastern Siberia (Figure 7, Figure S10). Compared to the burned fraction variable, burned area GFED4 has a smaller distribution pattern because it does not consider small fires (Figure S9.a). Comparison analysis of burned fraction variables between SEIB-DGVM SPITFIRE and GFED4s showed a linear relationship with a correlation coefficient of R=0.87 (R^2=0.75) (Figure S11.a). Similar to the comparison with GFED4s, the comparison of SEIB-DGVM SPITFIRE output of burned area variables with GFED4 data (1996-2016) shows a linear relationship with a correlation coefficient of R=0.78 (R^2=0.61) (Figure S11.b). Furthermore, in the three regions (west, central and east), the partial comparison of the burned fraction variable with GFED4s showed values of R^2=0.68, R^2=0.51, and R^2=0.58 (Figure S13), while for the burned area variable showed values of R^2=0.51, R^2=0.54, and R^2=0.506 (Figure S14), respectively. The burned fraction correlated better because both the GFED4s and the

model's fire module considered small fires; many scattered fire data with values less than 0.1 and approximately 0.1 were found in both the model's output and the GFED4s data.

The fire products (burned fraction and burned area) in the improved model have the same spatial distribution because they are calculated based on one core variable (Eq. 1). However, the spatial distributions of GFED4s (burned fraction) and GFED4 (burned area) differ for two reasons: first, because GFED4 does not consider small fires (Giglio et al., 2013) while GFED4s does, and second, because GFED4s use the modified burned fraction equation, which is able to calculate the exact fire fraction and fuel load (not uniformized) in a grid cell (Van Der Werf et al., 2017)."

L369 Please quantify how similar the modeled and the observed values are using a statistical metric, such as a correlation coefficient, bias, or RMSE.

> **Response:**
> We have adjusted this sentence by adding RMSE (L322):
>
> "The mean average burned fraction during 1997-2016 was 0.0137 in the simulations, compared to the GFED4s, which recorded the same value of 0.0137 with an RMSE value of 7.2 x 10^{-4}. Furthermore, the mean average burned area of the model in 1996-2016 was 1428.5 ha grid^{-1} year^{-1}, compared to the GFED4 burned area data, which closely recorded value of 1425.1 ha grid^{-1} year^{-1} by an RMSE value of 70.2 ha grid^{-1} year^{-1}. "

L371 Since both values are identical the word "while" does not fit here. Same applies to the next sentence. Please rephrase.

> **Response:**
> We have rephrased the sentences (L322).
>
> "The mean average burned fraction during 1997-2016 was 0.0137 in the simulations, compared to the GFED4s, which recorded the same value of 0.0137 with an RMSE value of 7.2 x 10^{-4}. Furthermore, the mean average burned area of the model in 1996-2016 was 1428.5 ha grid^{-1} year^{-1}, compared to the GFED4 burned area data, which closely recorded value of 1425.1 ha grid^{-1} year^{-1} by an RMSE value of 70.2 ha grid^{-1} year^{-1}. "

L402 Is this total annual rainfall? Is this really rainfall or precipitation, which is the sum of rainfall and snowfall?

> **Response:**
> It's based on the reference, in the previous sentence, they mentioned that its precipitation. I suggested it was mixed (sum) of rainfall and snowfall. Thank you for the detailed review.
>
> I have adjusted the sentence as follow (L352):
>
> Severe wildfires in 2003 were due to low precipitation, as total precipitation reached only 36.0 mm in the Buryatia Republic and 45.7 mm in the Chita Oblast between August 2002 and May 2003 (IFFN, 2003).

L403 This sentence seems to contradict the previous sentence, with two different rainfall values for the same region and time period. Please rewrite.

Response:

It looks like some words were changed during the editing process and we did not notice the discrepancy. Our intention is to compare with the normal condition/ annual average (how much the precipitation in those regions)

we have adjusted as follows (L354):

==“While the 41-year average precipitation between August and May (1981-2022), in the Buryatia Republic was approximately 332.23 mm, and in the Chita Oblast was approximately 119.45 mm. Thus, the low precipitation in 2003 was an anomaly outside of the annual average range.”==

L417 The sentence does not make any sense to me. Why would CO2 emissions be representative for other GHG emissions, simply because most of the mass emitted is CO2? The next sentence on the emission factor gives a better rational. I suggest you delete the first sentence and rewrite this part. Also, I suggest that you remind the reader what the other emissions are.

Response:

Thank you very much for the suggestions,

We have adjusted the initial paragraph to be as follows (L368: revised manuscript):

==‘Emissions from biomass burning contribute significantly to the global budget for residual gases and aerosols that affect the climate. It's estimated that biomass burning contributed up to 50% of global CO and NO_x emissions in the troposphere (Galanter et al., 2000), and the most emitted gas during biomass burning is CO_2 (Ritchie et al., 2020). Since CO_2 emissions are the primary emissions that contribute to climate change, it is critical to assess and monitor them continuously.==

==In this study, out of 33 projected emissions (Table 4 and Table S4), we validated the CO_2 variable that able to represent all projected emissions because all estimated emissions are derived from the same burned dry matter variable, which differs only in the emission factor value of each gaseous emission. “==

L425 What is the difference between the CO2 emission values given here and the ones quoted in the previous sentence? Both are described as annual average values.

Response:

Technically, the first sentence is obtained based on the annual mean data (each source: 1997-2020) ± standard deviation of the three annual extracted data (Table S3). Meanwhile, the second sentence is the mean ± standard deviation of the spatial data (whole data from the 1997-2020) of those three data.

The word "mean" was missing in the second sentence, we corrected it now (L374)..

==“The highest annual average value of CO_2 emissions from 1997 to 2020 is from GFED4 data, followed by SEIB-DGVM SPITFIRE and then the GBEI product, with values of $105.64 \pm 50.69 \times 10^{13}$ g CO_2, $76.41 \pm 0.87 \times 10^{13}$ g CO_2, and $62.4 \pm 26.09 \times 10^{13}$ g CO_2,==

respectively (Table S3). …… However, when comparing the mean of averaged CO_2 emissions all the years from 1997 to 2020 of SEIB-DGVM SPITFIRE, GFED4s, and GBEI, we found that they were similar: 141.1 ± 11.5 Gg CO_2 year^{-1}, 157.2 ± 14.8 Gg CO_2 year^{-1}, and 148.7 ± 7.12 Gg CO_2 year^{-1}, respectively."

L434 Equation 29 is located in the supplementary material. If you want to use this equation in your argument, I suggest you describe it in the text. Otherwise it is difficult to follow your argument, unless one reads the corresponding text in the supplementary material.

Response:
Thank you very much for your suggestion, we will merge sub section **"2.2.8. Trace gas and aerosol emissions"** in the supplement into section **2.2. Improved fire module principles** in the main manuscript.

L454 The low-emission area only contains a few gridcells, so I don't think these values are very meaningful. To my understanding, Figure 11 shows CO2 emissions associated with fires. Why then do some grid cells have negative values? Also, the chosen color legend makes it difficult to determine whether the emissions are low but positive or negative. Finally, the legend says that the figure shows annual average differences 1996-2100. Differences with respect to what?

Response:
Negative value mean being a carbon sink. However, in the revised manuscript we didn't use this low-high emission area classification anymore. We decided to explain and discuss the emission from the total area (there will be no classification for high and low emission area in the next manuscript version).

L501 You arite that the "lighting flash rate affected fire ignition in Siberia by 46%". This sounds as if 46% of the fire ignition was caused by lightning. However, the next sentence suggests that the 46% value refers to a correlation coefficient, which does not translate into the proportion of fires caused by lightning. Please rewrite.

Response:

We have rewritten this paragraph as follows (L558):

." This is confirmed by the comparison of the fire variable with the ignition factor variables: the comparison of the burned fraction variable with the lightning flash strikes variable shows a strong correlation of 0.68 (R^2=0.45), and the comparison of the burned fraction variable with the population density variable shows a correlation of 0.24 (R^2=0.06) (Figure S8). "

L505 Replace "Rothermell (1972)" with "(Rothermell, 1972)"

Response:
it has been adjusted.

L525 What is the "burned area parameter"? Do you know how this parameter uncertainty affects the estimated emissions?

> **Response:**
>
> The parameters are mentioned in chapter 2. Methods (Kasischke and Bruhwiler, 2003). The first parameter is (in?) the parameters for calculating the variable is **biomass burning carbon release (Ct)**, namely total burned area (A), average aboveground biomass density (Ba), aboveground vegetation carbon fraction (assumed to be 0.45) (fca), fraction of aboveground vegetation consumed during fires (βa), carbon density (Cg) and fraction of organic mat carbon consumed during fires (βg) (Kasischke and Bruhwiler, 2003).
>
> We have added the section 4.4. Model uncertainty, to discuss more about this matter
>
> We experienced exactly the same thing as described by Kasischke and Bruhwiler, 2003, the input data and parameter adjustments greatly affect the final output, which is the projected emissions from burned biomass. First, the distribution pattern of the fire variable is very influential, because the distribution pattern of emissions for all gases estimated will be the same. Secondly, we also explained in L569 that the reason why the fire could not be ignited in the eastern Siberia area was due to the low AGB level generated by the model in that area and above the minimum threshold fuel load setting. Thus, this range uncertainty is still an opportunity for further model improvement in future studies.
>
> ---
>
> We have added the section 4.4. Model uncertainty, to discuss more about this matter

L536 Replace "and eventually causing" with "and thereby contributing".

> **Response:**
> we have adjusted the sentence according to your suggestion.

L537 The variable that determines the strength of the carbon sink is NBP, which includes disturbances such as wildfires, rather than NPP. Assessing the impact of wildfires on NPP is valid, but, given the focus of this paper on wildfires, I suggest you also write about NBP.

> **Response:**
>
> Thank you very much for the constructive suggestion, we have adjusted by adding the NBP variable in L601:
>
> "By default, both SEIB-DGVM and SEIB-DGVM SPITFIRE defaults do not have NBP output, but the NBP input variable is available. We have added the NBP output and have re-run the simulation using this equation to estimate the NBP:
>
> NBP = NPP - Rh - fire flux (Chapin et al., 2006; Fisher et al., 2014) ''
>
> --

Chapin, F. S., et al. (2006), Reconciling carbon-cycle concepts, terminology and methods, Ecosystems, 9, 1041–1050, doi:10.1007/s10021-005-0105-7.

Fisher, J. B., D. N. Huntzinger, C. R. Schwalm, and S. Sitch (2014), Modeling the terrestrial biosphere, Annu. Rev. Environ. Resour., 39,91–123, doi:10.1146/annurev-environ-012913-093456.

--

We have also obtained the simulation results of NBP under all RCP scenarios, which we will discuss in the new version of the manuscript.

L544 Replace "circumpolar" with "Circumpolar"
  Response:
  Thank you, now has been adjusted.

L541 You may want to mention that wildfires and insect outbreaks are not necessarily independent, e.g. the likelihood of wildfire often increases after insect outbreaks.
  Response:
  Thank you very much for your suggestion, we have adjusted the sentence as follows (L627):

  --

  ”Wildfires and insect outbreaks are not necessarily independent, there is a likelihood of wildfires often increasing or decreasing after insect outbreaks (Meigs et al., 2015, 2016).”

  Meigs, G.W., Campbell, J.L., Zald, H.S.J., Bailey, J.D., Shaw, D.C., Kennedy, R.E., 2015. Does wildfire likelihood increase following insect outbreaks in conifer forests? Ecosphere 6, 1–24. https://doi.org/10.1890/ES15-00037.1

  Meigs, G.W., Zald, H.S.J., Campbell, J.L., Keeton, W.S., Kennedy, R.E., 2016. Do insect outbreaks reduce the severity of subsequent forest fires? Environ. Res. Lett. 11. https://doi.org/10.1088/1748-9326/11/4/045008

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L545 Cite more recent literature, e.g. the IPCC Sixth Assessment Report, Working Group I, Chapter 4.
  Response:

  we have adjusted (added) more recent literature (IPCC Sixth Assessment Report, Working Group I, Chapter 4) for this sentence (L XX):

"Circumpolar northern boreal forests and tundra are likely to continue to warm more than most other terrestrial biomes according to available data from models and observations (Chapin et al., 2005; Foley, 2005; Meehl et al., 2007; Trenberth et al., 2007; Lee et al., 2021)."

L567 For RCP8.5 it should be far more than 2 degrees C. Please provide more accurate numbers here.

Response:

Thank you for your suggestion, now has been adjusted as follows:

By 2100, the air temperature will increase by range 0.3-1.7 (1.0) °C under the RCP2.6 scenario, 1.1-2.6 (1.8)°C under the RCP4.5 scenario, 1.4-3.1 (2.2) °C under the RCP6.0, and 2.6-4.8 (3.7) °C under the RCP8.5 scenarios (IPCC 2021).

L571 Many DGVMs prescribe tree allometry. Is this also the case for SEIB? If yes, then that is why fires have no impact on tree allometry.

Response:

In SEIB-DGVM, the rules of allometry are not entirely prescribed.

For herbaceous PFTs, both below-ground and storage biomass are preserved after a wildfire and used for the recovery of above-ground biomass. During this recovery period, herbaceous PFTs work on producing above-ground biomass while reducing their storage biomass, thus increasing the allocation ratio to above-ground biomass in the post-fire phase.

For woody PFTs, fire only gives the option for individual trees to either die or survive. The surviving trees only lose their foliage biomass. As the foliage is lost, fine root biomass becomes unnecessary, leading to its rapid loss due to its fast turnover rate. In the spring following a fire, surviving trees convert storage resources into foliage and fine root biomass. The new net primary production (NPP) from the newly formed foliage first prioritizes the recovery of leaves and fine roots. Therefore, fires increase the allocation ratio to the foliage and fine roots in surviving woody plants.

L580 A decrease in fire emissions in subsequent years could also be caused by the fact that there is simply less biomass available for burning, since some of the biomass has been burnt during previous years.

Response:

Thank you very much for the suggestions, it has been adjusted (L664).

A decrease in fire emissions in subsequent years could be caused by the fact that there is less biomass available for burning since some of the biomass has been burnt during previous

years. Also, it could indicate the occurrence of postfire vegetation succession in these areas (Figure 11).

L586 It is not clear to me what point you are trying to make. Do you simply want to say that the model is able to account for the effect of fire history on future fires? This is to be expected, and I don't think it deserves a discussion. But I may be missing the point, in which case I suggest you rewrite this paragraph.

Response:

We apologize for the unclear writing structure and thank you very much for the detailed review.

Previously, in this sentence we would like to mention that the improved model (SEIB-DGVM SPITFIRE), has proven to be able to integrate well the new ignition factors (lightning strikes, and population density), which affect the distribution pattern of variable fire and burned biomass emissions. Furthermore, the improved model is also able to simulate well the dynamics of vegetation with variable fire under RCPs scenarios.

Due to the change of use of Figure 11 (classification of low emission and high emission areas), we will not use it in the next version of the manuscript (related to comment L454). We will rewrite this paragraph.

Thank you very much for your suggestions.

L596 You cannot draw the conclusion that a model is accurate, simply because its response is consistent with the change in the perturbation. I would just write that the trend in fire emissions is consistent with the different scenario-dependent trends in radiative forcings.

Response:

Apologize for the previous incorrect sentence and thank you very much for the given suggestion. Now the sentence has been adjusted (L691):

Therefore, its indicated that the trend in fire emissions is consistent with the different scenario-dependent trends in radiative forcings.

L599 The projected increase depends on your emission sceanrio, and currently ranges between 1.5 and 6.0 degrees C by 2100 compared to 1850-1900 mean value (IPCC, AR6, WGI, Chapter 4)

Response:

Thank you very much for you suggestions, we have adjusted the mentioned sentence (L693).

Overall, based on the RCPs climate scenario data used (MirocAR5), the emission scenario projected an increase in global mean surface temperature in the range of 1.0-3.7 (0.3~4.8) ºC (IPCC, 2014), and currently ranges between 1.5 and 6.0 ºC by 2100 compared to 1850-1900 mean value (Lee et al., 2021)

Tables

Table 2: Replace RCP80 with RCP8.5 and use a consistent notation in table in text (e.g. RCP8.5rather than RCP85)

Response:

Thank you very much for the suggestions, all of the related notation has been adjusted accordingly.

Table 4: Replace "Baseline" with "Historical". Note the meaning of +/- (1 or 2 standard deviations?)

Response:

Thank you very much for the suggestions, all of the related notation has been adjusted accordingly. It was 2 standard deviations.

"Table 4. Twenty-year average (± 2 standard deviation) of projected emissions of CO_2, CO, $PM_{2.5}$, TPM, and TPC species from forest fires in Siberia (2023-2100). The emissions of the remaining 28 species are listed in Table S4 in the Supplement."

Figures

Figure 3 Move the text in the Figure caption into the main text as you are describing the figure.

Response:

Thank you for the suggestions, now has been adjusted.

"SEIB-DGVM code modification are described in the section 2.2., and annual average ignition factor variables (population density and lightning flash rate) are used constantly throughout all phases to compare the improved fire regime module product with the default, previous fire module, and we run both models with the same protocols (Figure S3 in the Supplement)[*]. Simulations were run in three phases (spin-up, historical and future) and the simulation was run with the fire mode on and fire mode off to compare and assess the vegetation products during fire, and also each phase was replicated 5 times to minimize bias due to random variables in the tree morality[1]. Verification stage is to ensure the new input data can be read, produced, and processed properly[3]. After verifying that the new module

was incorporated seamlessly, we validated the model outputs (fire, vegetation and emissions variables) by using GFED4, GFED4s, ESA Biomass CCI and GBEI benchmark datasets[4]. To determine the impact of fire and climate on forest structure and their interactions, we ran the simulations with 5 climate scenarios (baseline, RCP8.5, RCP6.0, RCP4.5, and RCP2.6) using the same configuration as the fire-on simulation (Figure 3)."

Figure 4 and 5 All panels look very similar. If you want to work out the differences, then I suggest you provide a different type of plot.

Response:

We combined the distribution pattern map image and the graph (figure S9 and S10) into the main text. We still display one distribution pattern map to be able to see the spatial distribution pattern of the data. The adjusted figure 4 and 5 as follows:
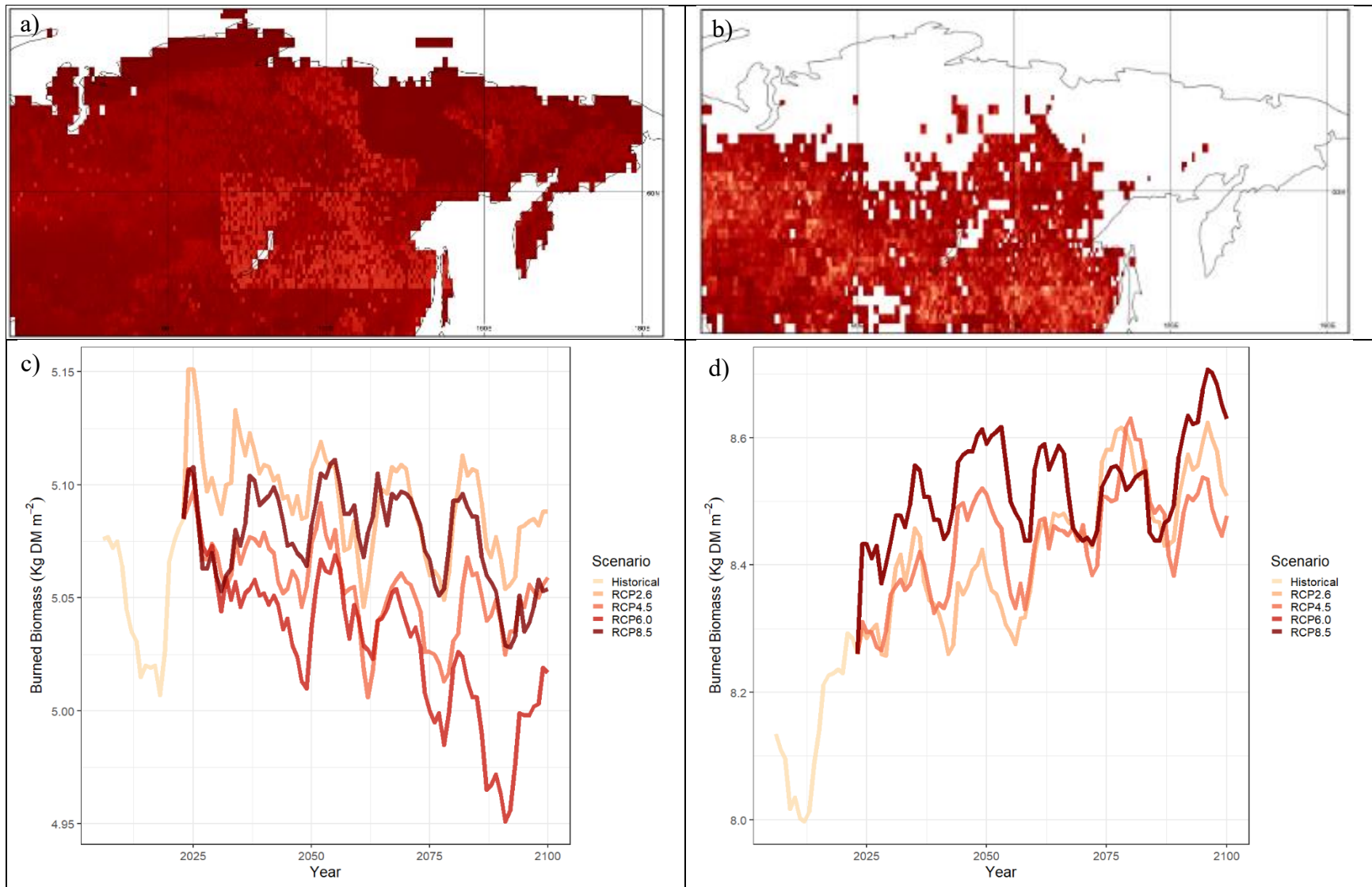
Figure 4. Distribution pattern map and graph of annual average burned biomass (2006-2100). Default SEIB-DGVM (a and c), SEIB-DGVM SPITFIRE (b and d).
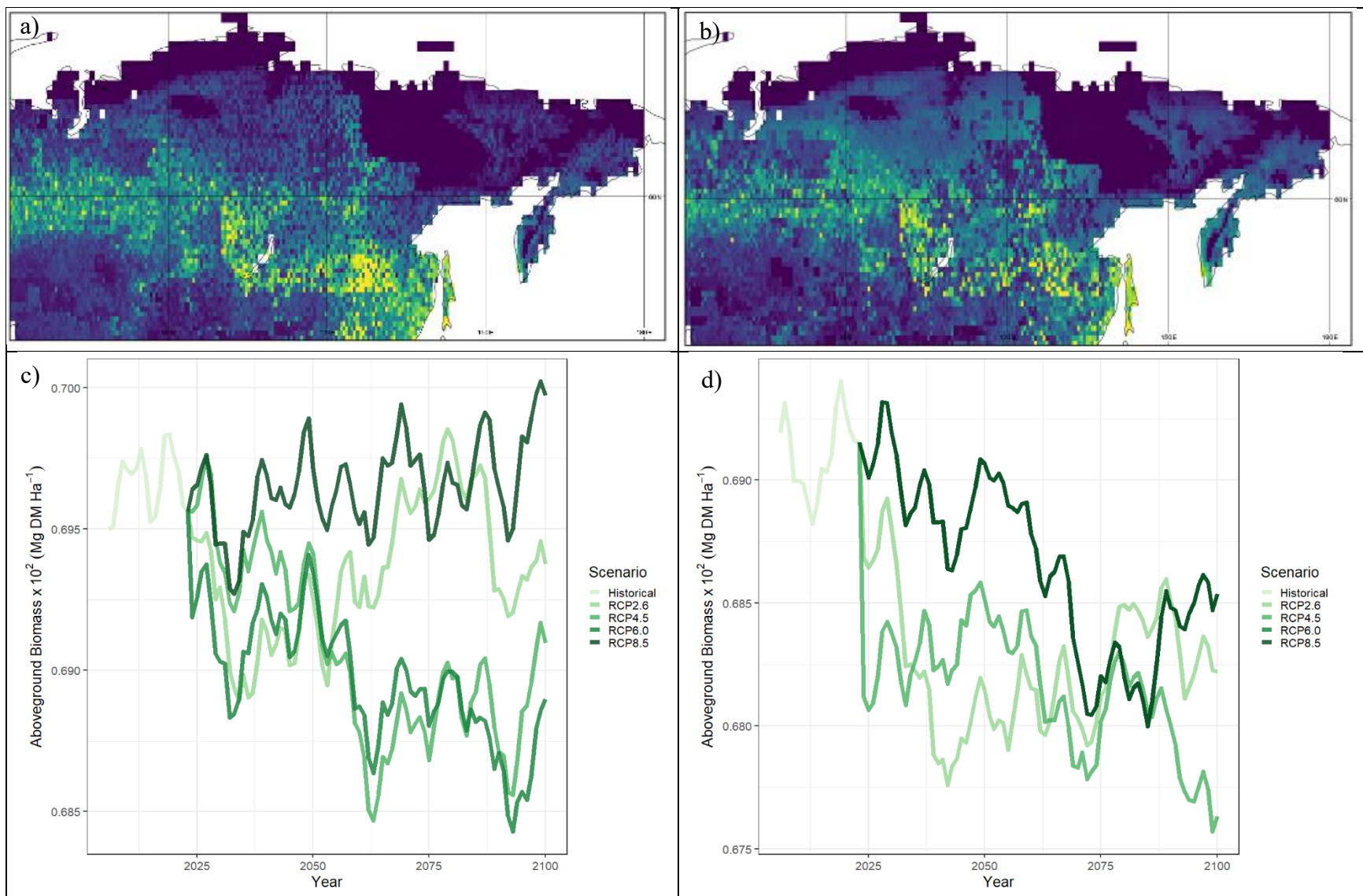
Figure 5. Distribution pattern map and graph of annual average aboveground biomass (2006-2100). Default SEIB-DGVM (a and c), SEIB-DGVM SPITFIRE (b and d).

Figure 6 Replace "Principle component" with "Principal component". Why do you need to do a PCA here? This would deserve description in the main text, if it is really worthwhile. As I mention above, please verify whether SEIB prescribes allometric relationships, which would explain why the impact of fires is small on allometry. I am not sure whether this analysis is worth including.

Response:

This PCA was not discussed in the main manuscript because in that figure, PCA was used only for color grading. In the next manuscript, we did not use color grading again for the plots.

Regarding the tree allometry in SEIB-DGVM, we have explained in the answer to comment L571.

*"In SEIB-DGVM, the rules of allometry are not entirely prescribed.*

For herbaceous PFTs, both below-ground and storage biomass are preserved after a wildfire and used for the recovery of above-ground biomass. During this recovery period, herbaceous PFTs work on producing above-ground biomass while reducing their storage biomass, thus increasing the allocation ratio to above-ground biomass in the post-fire phase.

For woody PFTs, fire only gives the option for individual trees to either die or survive. The surviving trees only lose their foliage biomass. As the foliage is lost, fine root biomass becomes unnecessary, leading to its rapid loss due to its fast turnover rate. In the spring following a fire, surviving trees convert storage resources into foliage and fine root biomass. The new net primary production (NPP) from the newly formed foliage first prioritizes the recovery of leaves and fine roots. Therefore, fires increase the allocation ratio to the foliage and fine roots in surviving woody plants."

Figure S16 Does this figure show that the model tends to overestimate AGB between 25 and 75 Mg ha−1 ? I would also add a diagonal 1:1 line so the reader sees where the dots should ideally be located. What do the colors of the dots represent? Please replace the horizontal axis label Ha with ha.

Response:

We have updated the plot for comparison of AGB data as follows:
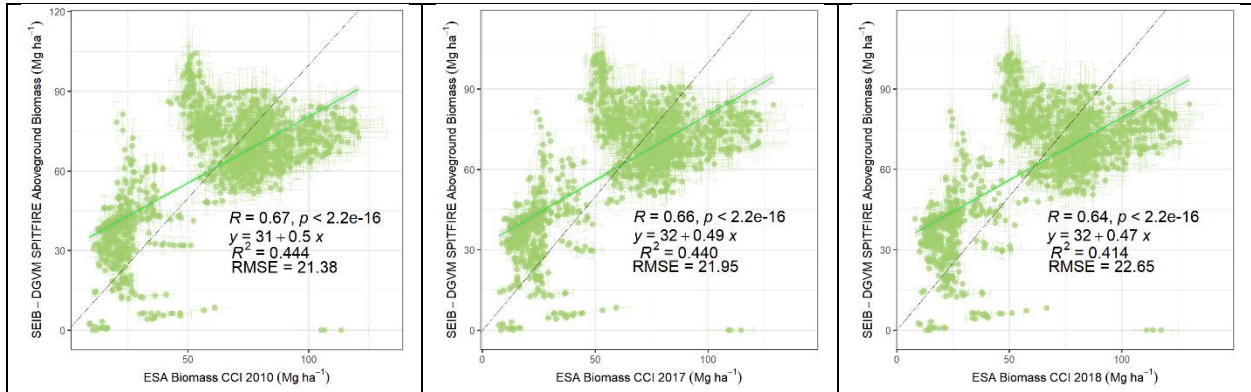
Based on the previous plot and this plot (latitude averaged) shows that the model tends to overestimate around 21 Mg ha^{-1}. However, based on the grid-wide annual average, the model and benchmark data show similar values **(L330)**: In 2010, 2017, and 2018, the simulations predicted 63.714 ± 64.89 Mg DM ha^{-1} year^{-1}, 64.141 ± 65.54 Mg DM ha^{-1} year^{-1}, and 64.313 ± 65.61 Mg DM ha^{-1} year^{-1}, respectively, while the ESA Biomass CCI data showed 64.027 ± 56.95 Mg DM ha^{-1} year^{-1}, 64.548 ± 54.69 Mg DM ha^{-1} year^{-1}, and 65.05 ± 55.78 Mg DM ha^{-1} year^{-1}, respectively, for the same years.

Figure 8 Why does SEIB-DGVM has uncertainty bars but GFED4s does not? Also, explain the meaining of the uncertainty bar in the Figure caption. Is this +/- SD across multiple years?

Response:

Apologies for the previous plot we didn't include the uncertainty for the GFED4s data. Now we have added as your suggestions for both plots.
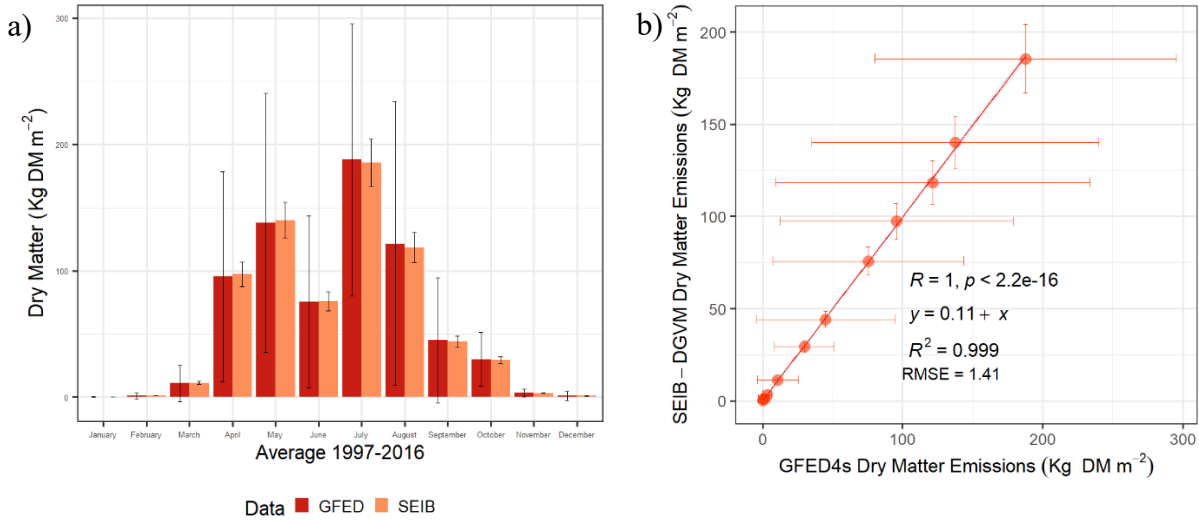Yes, the SD across multiple years (1996-2016).

Figure 8. Monthly Average Dry Matter Emission data comparison of GFED4s and SEIB-DGVM SPITFIRE (1997-2016): a) Monthly average seasonality b) Monthly average comparison. The ==standard deviation obtained from each monthly data from 1997-2016 for each data.==

Figure 12 Increase axis value fontsize

Response:

Has been adjusted as follow: