Response Letter

Editor:

Major comments:

Did your spinup include land use areas? (How much land use even is there in the study regions?)

>> CLM includes multiple land units, including lakes, urban, glaciers, vegetation, and crops. Although we considered all land units in our simulations, the natural vegetation land unit was found to occupy the largest area, and the lake, urban, and glacier land units occupied less than 1% in both regions. Therefore, the influences of the lake, urban, and glacier units were extremely small in our simulations. We have added this in the revised manuscript.

L140: *Notably, the largest areas were the natural vegetation and crop land units, and the lake, urban, and glacier land units occupied less than 1% in both regions.*

CC1 response a bit lacking, as they raised a good point about peat fires. Even if you determine it's not an issue, you should mention this in the MS.

>> First, the impact of peat fire in our simulation was quite minimal because the peatland fractions in CLM, which were derived from three datasets (Olson et al., 2001; Tarnocai et al., 2011; Lehner and Döll, 2004), were low over both regions. (Alaska: 0%, Eastern Siberia: 2%). Recently, however, peat fires and even smouldering wildfires have been occurring frequently, becoming an issue in Alaska and Eastern Siberia (Scholten et al., 2021). We, therefore, discussed that peat fires should be considered to improve the coverage of peatland in the future, in the revised manuscript.

L335: *Moreover, inaccurate coverage of peatland can also cause a bias in burned area calculations. Peat fire and along with smouldering fire have been reported over both regions for several years (Scholten et al., 2021). However, peat fire was barely simulated in CLM-BGC5 because the fractions of peatland, which were derived from three datasets (Olson et al., 2001; Tarnocai et al., 2011; Lehner and Döll, 2004), were low over both regions. (Alaska: 0%, Eastern Siberia: 2%). On the contrary, several studies reported that there is sufficient coverage of peatland in both areas to consider the existence of peatland fires (Yu et al., 2010; Qiu et al.,* *2019). For instance, the coverage of peatland is 72–168 $10^3 km^2$, and 16–32 Pg of carbon is stocked in peatland in Alaska. Therefore, to simulate peat fires accurately, an improvement of the dataset used for peatland coverage in CLM should be considered.*

Olson, D. M., Dinerstein, E., Wikramanayake, E. D., Burgess, N. D., Powell, G. V. N., Underwood, E. C., D'Amico, J. A., Itoua, I., Strand, H. E., Morrison, J. C., Loucks, C. J., Allnutt, T. F., Ricketts, T. H., Kura, Y., Lamoreux, J. F., Wettengel, W. W., Hedao, P., and Kassem, K. R.: Terrestrial Ecoregions of the World: A New Map of Life on Earth, BioScience, 51, 933–938, 2001.

Tarnocai, C., Kettles, I. M., and Lacelle, B.: *Peatlands of Canada Map.* Geological Survey of Canada, Open File 3834. Scale 1: 6 500 000, Natural Resources Canada, Ottawa, 2000.

Lehner, B. and Döll, P.: Development and validation of a global database of lakes, reservoirs and wetlands, J. Hydrol., 296, 1–22, https://doi.org/10.1016/j.jhydrol.2004.03.028, 2004.

Qiu, C., Zhu, D., Ciais, P., Guenet, B., Peng, S., Krinner, G., Tootchi, A., Ducharne, A., and Hastie, A.: Modelling northern peatland area and carbon dynamics since the Holocene with the ORCHIDEE-PEAT land surface model (SVN r5488), Geosci. Model Dev., 12, 2961–2982, https://doi.org/10.5194/gmd-12-2961-2019, 2019.

Scholten, R. C., Jandt, R., Miller, E. A., Rogers, B. M., and Veraverbeke, S.: Overwintering fires in boreal forests, Nature, 593, 399–404, 2021.

Throughout: The paper is framed as forcing CLM with GFED4 burned areas to learn about real-world hydrological and biogeochemical cycling. However, the analyses make it more of a "model evaluation" paper—you're mostly seeing how much CLM's results are affected by its biased burned area, rather than learning much about real-world fire. You should either reconsider the framing (preferable to me —it's easier, and still an important evaluation!) or add analyses supporting your original framing.

>> As per the editor's suggestion, we have re-organized the revised manuscript to include a separate section discussing the discrepancy between the model and real-world fire.

1) Ignition process of fires and persistence

L305: *First, the limited representation of fire ignition sources and spread may create* *discrepancies between modeled and observed burned areas. Lightning, which is a major source of fire at high latitudes, especially in Alaska, has increased because of the warming climate (Kępski and Kubicki, 2022). Although the lightning frequency at high latitudes varied yearly, the climatology of the 3-hourly lightning frequency from 1995 to 2011 was used in CLM. Moreover, the calculated ratio of cloud-to-ground lightning has large uncertainties and may cause models to misestimate fire ignition and burned areas. Furthermore, it is inherent that the grid-based large-scale model is limited in capturing micro-environmental impacts on fire spread. Fires spread differs depending not only on the temperature, precipitation, wind speed, and direction but also on the composition of vegetation at the local scale.*

2) Fire duration

L313: *In addition, wildfires are strongly affected by the weather conditions after the fire ignition. For example, wind and precipitation determine the spread and duration of fire. However, in CLM5-BGC, the fire ignition and fire spread rate are simultaneously calculated based on the weather conditions of fire ignition or pre-fire. Moreover, wildfires in ecosystems persist from hours to months, depending on ecosystem characteristics and climate conditions. However, the duration of each fire is assumed to be equal to one day in CLM5-BGC (Li et al., 2012). For example, Andela et al. (2019) reported that the average fire duration in a boreal forest was longer than those in other regions, and the average size of each fire in the boreal forest was larger than those in temporal forests and under deforestation. Moreover, wind speed is an important factor determining fire spread in the model. In CLM, the spread of fire increases as the wind speed increases. However, according to Lasslop et al. (2015), there is strong variation in the burned fraction with wind speed, characterized by an increase until a certain wind speed threshold is reached and a decrease thereafter. The study suggests that global fire models should avoid a strong amplification for higher wind speeds to prevent overestimation of modelled burned areas.*

3) Fire policy management

L326: *The management system and infrastructures for fires vary by country or region. For instance, there are four types of fire policy options in Alaska, namely critical, full, modified, and limited, according to the levels of anthropogenic effort in extinguishing the fire (Phillips et al., 2022). For example, fire suppression is the highest priority at the critical protection level* *because wildfire can threaten human life and inhabited property. The lowest priority for fire-related resource assignments is applied at the limited protection level. In Alaska, areas under the full, modified, and limited management options occupy 16%, 16%, and 67% of Alaska, respectively. Critical-protection-level areas occupy less than 1% of Alaska. In CLM5-BGC, however, the suppression impact is calculated based on the GDP and population, which may underestimate burned areas in the limited regions of Alaska because of the large GDP of the United States.*

Results, throughout: Contextualize numbers. I don't have an intuitive sense of what, e.g., a difference of 5.41 mm in canopy evaporation means. What do these results mean in terms of percent difference, either between simulations/observations or between simulations? Are they biogeochemically/ecologically meaningful differences? (You don't need to give % change for every number, although in some cases that might help. What I'm saying is, you need to give the reader a better sense of what the numbers mean in relative terms.)

>> As per the editor's suggestion, we have added the percent differences and their implications in the revised manuscript.

L274: *We observed that more rainfall reaches the ground, which would make the ground evaporation rate higher in regions with more burned areas, especially in 2004 and 2005 in Alaska. The differences in annual canopy evaporation, canopy transpiration, and ground evaporation between the two simulations were 5.41 mm and 13.37 mm, 2.3 mm and 6.26 mm, and −1.39 mm and −7.4 mm in 2004 and 2005, respectively. Canopy transpiration decreased by 3%, canopy evaporation decreased by 12%, and ground evaporation increased by 10% in 2004 and 2005 after applying the GFED4 burned area into CLM. This is consistent with the findings of Li et al. (2017) and Seo and Kim (2019), showing that canopy evaporation and canopy transpiration decreased and ground evaporation increased when comparing the simulation with and without fire. Furthermore, the total ET in the presence of fire decreased by 6.32 mm and 12.08 mm in 2004 and 2005, respectively, indicating that canopy evaporation is more strongly influenced by fires over Alaska in CLM.*

In Eastern Siberia, the patterns of canopy evaporation and ground evaporation were the same as those of Alaska. Canopy evaporation increased and ground evaporation decreased in EXP-GFED4 because the simulated burned area decreased, which was noticeable from 2009 to 2012

(Fig. 9f and 9h). However, the canopy transpiration of EXP-GFED4 was similar to that of CLM-Default. In other words, there was no significant change in canopy transpiration due to a change in burned area. Furthermore, the ET with the burned area applied changed slightly in Eastern Siberia. Differences in the average canopy evaporation and ground evaporation were −9.19 mm (28%) and 6.97 mm (10%) from 2009 to 2012, respectively. The reasons for the smaller change in canopy transpiration is related to soil moisture and leaf size.

It's good that you discuss possible reasons for the burned area and C flux results. However, these discussions are important enough (and will be long enough, once you expand them as I suggest below) that they should be moved out of the Results and into a new Discussion section.

>> As per the editor's suggestion, we have added a discussion section in the revised manuscript. It includes several discussions related to fire duration, wind speed, peat fires, carbon fluxes, and others.

1) Fire duration

L313: *In addition, wildfires are strongly affected by the weather conditions after the fire ignition. For example, wind and precipitation determine the spread and duration of fire. However, in CLM5-BGC, the fire ignition and fire spread rate are simultaneously calculated based on the weather conditions of fire ignition or pre-fire. Moreover, wildfires in ecosystems persist from hours to months, depending on ecosystem characteristics and climate conditions. However, the duration of each fire is assumed to be equal to one day in CLM5-BGC (Li et al., 2012). For example, Andela et al. (2019) reported that the average fire duration in a boreal forest was longer than those in other regions, and the average size of each fire in the boreal forest was larger than those in temporal forests and under deforestation. Moreover, wind speed is an important factor determining fire spread in the model. In CLM, the spread of fire increases as the wind speed increases. However, according to Lasslop et al. (2015), there is strong variation in the burned fraction with wind speed, characterized by an increase until a certain wind speed threshold is reached and a decrease thereafter. The study suggests that global fire models should avoid a strong amplification for higher wind speeds to prevent overestimation of modelled burned areas.*

2) Wind speed

L320: *Moreover, wind speed is an important factor determining fire spread in the model. In CLM, the spread of fire increases as the wind speed increases. However, according to Lasslop et al. (2015), there is strong variation in the burned fraction with wind speed, characterized by an increase until a certain wind speed threshold is reached and a decrease thereafter. The study suggests that global fire models should avoid a strong amplification for higher wind speeds to prevent overestimation of modelled burned areas.*

3) Peat fires

L335: *Moreover, inaccurate coverage of peatland can also cause a bias in burned area calculations. Peat fire and along with smouldering fire have been reported over both regions for several years (Scholten et al., 2021). However, peat fire was barely simulated in CLM-BGC5 because the fractions of peatland, which were derived from three datasets (Olson et al., 2001; Tarnocai et al., 2011; Lehner and Döll, 2004), were low over both regions. (Alaska: 0%, Eastern Siberia: 2%). On the contrary, several studies reported that there is sufficient coverage of peatland in both areas to consider the existence of peatland fires (Yu et al., 2010; Qiu et al., 2019). For instance, the coverage of peatland is 72–168 103km2, and 16–32 Pg of carbon is stocked in peatland in Alaska. Therefore, to simulate peat fires accurately, an improvement of the dataset used for peatland coverage in CLM should be considered.*

4) Carbon fluxes – PFT distribution

L350: *The average change rates of NEE and carbon fluxes were 4914 gC ha^{-1} and 4881 gC ha^{-1} and 771 gC ha^{-1} and 798 gC ha^{-1} in Alaska and Eastern Siberia, respectively. The response of carbon emissions to fires was much more sensitive than those of GPP, NPP, and NEP; therefore, changes in carbon emissions are a major cause of the change in the NEE, which is consistent with previous results. Carbon release owing to wildfires was more sensitive in Alaska than Eastern Siberia under CLM5-BGC, as boreal trees are more distributed in Alaska than in Eastern Siberia. Based on the above results, we suggest that more accurate fire predictions are needed to understand ecosystem carbon fluxes, especially in Alaska.*

Therefore, one can tell that the carbon fluxes were more sensitive in Alaska than in Eastern Siberia. The reasons for carbon emissions being more pronounced in Alaska than in Eastern Siberia could be explained by the vegetation distribution. The average ratio of carbon emissions to burned areas was 49.98 Tg Mha^{-1} in Alaska and 9.76 Tg Mha^{-1} in Eastern Siberia.

There was 95 Tg of leaf carbon and 8.3 Tg of live-stem carbon in Alaska and 29 Tg of leaf carbon and 2.4 Tg of live-stem carbon in Eastern Siberia in averages of CLM-Default and EXP-GFED4. Trees have a larger LAI and stems and thus more fuel combustibility and availability. Therefore, the ratio of carbon emissions to burned areas was high in forests than in grassland. Moreover, the final carbon fluxes between the atmosphere and vegetation were closely linked not only with vegetation metabolism but also with burned area and plant type. As the same fractional area burned is imposed on each PFT in a grid, the simulated carbon emission could differ from observed carbon emissions. For example, when an observation of forest fire is applied to CLM5-BGC, the fractional area burned is imposed on both grasses and trees in the same grid, causing biases in the carbon emission values. Therefore, a reasonable method of imposing grid-level burned areas into the PFT level is required.

Detailed comments:

Throughout: Why is the default run called "open-loop"? Wouldn't it be more straightforward to just call it "default"? Title: "Global Fire Emissions Database burned-area dataset into Community Land Model version 5.0" doesn't work. Maybe something like, "Forcing the Community Land Model version 5.0 with burned area from the Global Fire Emissions Database"? You can delete " – Biogeochemistry" to make the title simpler.

>> As per the editor's suggestion, we have changed "open-loop" to "CLM-Default" and changed the title.

L1: *Forcing Global Fire Emissions Database burned-area dataset into Community Land Model version 5.0: Impacts on carbon and water fluxes at high latitudes*

Sections 2 and 3 should be combined into a single "Methods" section. It especially doesn't make sense to have Sect. 2.2 in a different section from the rest of the experimental design. Also, Sect. 3 has the same name as Sect. 3.2.

Here's my suggested reordering under a single "Sect. 2, Methods", new ← original: 2.1 ← 2.1: Model description /2.2 ← 3.1: Site description /2.3 ← 3.2: Experimental design 2.4 ← 2.2: Fire and C fluxes datasets

>> As per the editor's suggestion, we have changed the section number.

L10: Capitalize “Global Fire Emissions Database” and “Community Land Model”

>> We have changed these in the revised manuscript.

L9: *In this study, we employed the daily burned areas from satellite-based Global Fire Emission Database (version 4) (GFED4) into Community Land Model (version 5.0), with a biogeochemistry module (CLM5-BGC) to identify the effects of accurate fire simulation on carbon and water fluxes over Alaska and Eastern Siberia.*

L14: "trends" should be "signs" or "directions"

>> As per the editor's suggestion, we have changed them in the revised manuscript, as shown below.

L14: *The results showed that the simulated carbon emissions with burned areas from GFED4 (i.e., experimental run) were significantly improved in comparison to the open-loop run (that is default run), which resulted in opposite signs of the net ecosystem exchange for 2004, 2005, and 2009 over Alaska between the default and experimental runs.*

L26: Delete "remarkably"—too opinionated

>> We have deleted this in the revised manuscript.

L31: Replace ", at" with "in"

>>We have changed it in the revised manuscript.

L38: "regions" is weird here, since it usually refers to geographical areas. Try replacing "carbon in belowground regions" with "belowground carbon".

>> We have changed it in the revised manuscript, as shown below.

L38: *This could result in the release of belowground carbon, which can increase the levels of carbon dioxide in the atmosphere.*

L71: Capitalize “Community Earth System Model”

>> We have capitalized it in the revised manuscript.

L75: Hyphen needed in "sub grid"

>> We have revised it.

L84: Capitalize "Lightning Imaging Sensor" and "Optical Transient Detector"

>> We have capitalized them in the revised manuscript.

L94, 104: What do "24.26" and "24.27" refer to? Equation numbers? I don't see those anywhere in Lawrence et al. (2019).

>> As captured below, the equation is found in the Technical Description of version 5.0 of Community Land Model (CLM).

24.1.3 Fire impact

In post-fire regions, we calculate PFT-level fire carbon emissions from biomass burning of the jth PFT, ϕ_j (g C s^{-1}), as

$$\phi_j = A_{b,j}\mathbf{C}_j \bullet \mathbf{CC}_j \tag{24.26}$$

where $A_{b,j}$ (km^2 s^{-1}) is burned area for the jth PFT; $\mathbf{C}_j$ =(C_{leaf}, C_{stem}, C_{root}, C_{ts}) is a vector with carbon density (g C km $^{-2}$) for leaf, stem (live and dead stem), root (fine, live coarse and dead coarse root), and transfer and storage carbon pools as elements; $\mathbf{CC}_j$ = ($\mathbf{CC}_{leaf}$, $\mathbf{CC}_{stem}$, $\mathbf{CC}_{root}$, $\mathbf{CC}_{ts}$) is the corresponding combustion completeness factor vector (Table 24.1). Moreover, we assume that 50% and 28% of column-level litter and coarse woody debris are burned and the corresponding carbon is transferred to atmosphere.

Tissue mortality due to fire leads to carbon transfers in two ways. First, carbon from uncombusted leaf, live stem, dead stem, root, and transfer and storage pools $\mathbf{C}'_{j1}$ = $(C_{leaf}(1-CC_{leaf}), C_{livestem}(1-CC_{stem}), C_{deadstem}(1-CC_{stem}), C_{root}(1-CC_{root}), C_{ts}(1-CC_{ts}))_j$ (g C km^{-2}) is transferred to litter as

$$\Psi_{j1} = \frac{A_{b,j}}{f_j A_g}\mathbf{C}'_{j1} \bullet M_{j1} \tag{24.27}$$

L96 (Eq. 1), L106 (Eq. 2): All vectors should be in boldface italics: https://www.geos cientific-model-development.net/submission.html#math

>> We have corrected them in the revised manuscript.

L114: Delete "Especially, the " "represent" should be "represents"

>> We have corrected them in the revised manuscript.

L127: “leaf size” should be “leaf area”

>> We have corrected them in the revised manuscript.

L141–145 Is Veraverbeke et al. (2015) the citation for AKFED? If so, cite that in the first sentence here. If not, add the correct citation—and then why is Veraverbeke et al. (2015) discussed at all?

>> Yes, Veraverbeke et al. (2015) is the citation for AKFED. We have corrected it in the revised manuscript.

L170*: We also used data on Alaskan carbon emissions from the AKFED (Veraverbeke et al., 2015) to evaluate the model performance for carbon emissions in Alaska (Table 1).*

L144: “presumed” is almost certainly not the right word. “Calculated”? “Determined”?

>> We have changed it into “estimated”.

L174: *They estimated that the highest carbon emission was 69 Tg C in 2004 and the annual carbon emission was 15 Tg C*.

L146: Not just EXP-GFED4, right? Also OL?

>> Yes, that is correct; we have corrected it in the revised manuscript.

L169: Replace “but” with “and”

>> We revised this in the revised manuscript.

L195: Replace “big fires” with “”large burned areas or “anomalous years”; “big fires” implies individual contiguous burn patches, which may not be the case.

>> We revised this in the manuscript.

L196: *Studies suggested that these large burned areas were associated with a high lightning frequency and drought*

L199: What is this sentence trying to say? Why “especially”? What’s special about it?

>> We meant that the simulated burned area in Eastern Siberia increased with time (2001–2012), which is not shown in GFED. To clarify this, we have re-written the sentence in the revised manuscript.

L200: *Although the GFED burned area in Eastern Siberia did not vary significantly over time, the simulated burned area increased from 2001 to 2012 at a rate of 0.33 Mha/year.*

Paragraph at L201–5 needs a total rework.

>> As per the editor's suggestion, we have re-written the paragraph in the revised manuscript.

L203: *Figure 4 shows the spatial distribution of the burned areas of GFED4 and CLM-Default in 2004 over Alaska. The number of grid cells (0.5 × 0.5 degree) in CLM-Default where the burned areas exceeded 0.1 ha in 2004 was more than 50. In contrast to the GFED4 burned areas, there were two grid cells with more than 0.1 ha of burned areas simulated using CLM5-BGC in Alaska (Table 2). Table 2 shows that CLM5-BGC has a limitation in simulating large burned areas in Alaska. Small fires were simulated in more grid cells, and the simulated burned areas were more widely distributed than those in the GFED4 products.*

“inadequately” is a value judgment; whether the model performs adequately depends on what question it’s being used to answer. Replace this with something that describes the CLM bias objectively.

>> We have removed it, as we have re-written the paragraph according to the previous suggestion.

L201: Re-state grid cell resolution here.

>> We have added the grid-cell resolution in the revised manuscript.

L204: *The number of grid cells (0.5 × 0.5 degree) in CLM-Default where the burned areas exceeded 0.1 ha in 2004 was more than 50.*

L202: Observed by GFED? Or AKFED?

>> The sentence has been deleted in the revised manuscript.

L202–3:”a few”? How many?

>> We have clarified it in the revised manuscript.

L 204: *In contrast to the GFED4 burned areas, there were two grid cells with more than 0.1 ha of burned areas simulated using CLM5-BGC in Alaska (Table 2).*

L204: "simulating largely burned areas"? What does this mean?

>> We have clarified it in the revised manuscript.

L205: *Table 2 shows that CLM5-BGC has a limitation in simulating large burned areas in Alaska.*

L204: "more grid cells"? Relative to what?

>> We have clarified it in the revised manuscript.

L206: *Small fires were simulated in more grid cells, and the simulated burned areas were more widely distributed than those in the GFED4 products.*

Paragraphs at L207–26 need rework.

Please combine these paragraphs. You do some discussion in the second paragraph, which is confusing because the paragraph break makes it seem like you're moving on to something else.

>> As per the editor's suggestion, we have re-written these paragraphs and moved them to the discussion section in the revised manuscript.

L304: *Difference in burned area between the model and observation may be attributed to incorrect input data such as lightning frequency and fire management as well as a misrepresentation of fire processes. First, the limited representation of fire ignition sources and spread may create discrepancies between modeled and observed burned areas. Lightning, which is a major source of fire at high latitudes, especially in Alaska, has increased because of the warming climate (Kępski and Kubicki, 2022). Although the lightning frequency at high latitudes varied yearly, the climatology of the 3-hourly lightning frequency from 1995 to 2011 was used in CLM. Moreover, the calculated ratio of cloud-to-ground lightning has large* *uncertainties and may cause models to misestimate fire ignition and burned areas. Furthermore, it is inherent that the grid-based large-scale model is limited in capturing micro-environmental impacts on fire spread. Fires spread differs depending not only on the temperature, precipitation, wind speed, and direction but also on the composition of vegetation at the local scale.*

In addition, wildfires are strongly affected by the weather conditions after the fire ignition. For example, wind and precipitation determine the spread and duration of fire. However, in CLM5-BGC, the fire ignition and fire spread rate are simultaneously calculated based on the weather conditions of fire ignition or pre-fire. Moreover, wildfires in ecosystems persist from hours to months, depending on ecosystem characteristics and climate conditions. However, the duration of each fire is assumed to be equal to one day in CLM5-BGC (Li et al., 2012). For example, Andela et al. (2019) reported that the average fire duration in a boreal forest was longer than those in other regions, and the average size of each fire in the boreal forest was larger than those in temporal forests and under deforestation. Moreover, wind speed is an important factor determining fire spread in the model. In CLM, the spread of fire increases as the wind speed increases. However, according to Lasslop et al. (2015), there is strong variation in the burned fraction with wind speed, characterized by an increase until a certain wind speed threshold is reached and a decrease thereafter. The study suggests that global fire models should avoid a strong amplification for higher wind speeds to prevent overestimation of modelled burned areas.

The management system and infrastructures for fires vary by country or region. For instance, there are four types of fire policy options in Alaska, namely critical, full, modified, and limited, according to the levels of anthropogenic effort in extinguishing the fire (Phillips et al., 2022). For example, fire suppression is the highest priority at the critical protection level because wildfire can threaten human life and inhabited property. The lowest priority for fire-related resource assignments is applied at the limited protection level. In Alaska, areas under the full, modified, and limited management options occupy 16%, 16%, and 67% of Alaska, respectively. Critical-protection-level areas occupy less than 1% of Alaska. In CLM5-BGC, however, the suppression impact is calculated based on the GDP and population, which may underestimate burned areas in the limited regions of Alaska because of the large GDP of the United States.

You should also discuss the issues with wind speed in global fire models: Lasslop et al. (2015), https://www.publish.csiro.au/wf/WF15052

>> We have added this issue in the discussion section in the revised manuscript.

L314: *In CLM, the spread of fire increases as the wind speed increases. However, according to Lasslop et al. (2015), there is strong variation in the burned fraction with wind speed, characterized by an increase until a certain wind speed threshold is reached and a decrease thereafter. The study suggests that global fire models should avoid a strong amplification for higher wind speeds to prevent overestimation of modelled burned areas.*

"position"?

>> The related sentence has been re-written, and the word has been omitted from the revised manuscript.

"misunderstanding" is not the right word. Do you mean "misrepresentation"?

>> We changed the word to "the limited representation"

What do you mean by "the limitation of using point data in the grid-based model"?

>> It has been clarified in the revised manuscript.

L310: *Furthermore, it is inherent that the grid-based large-scale model is limited in capturing micro-environmental impacts on fire spread. Fires spread differs depending not only on the temperature, precipitation, wind speed, and direction but also on the composition of vegetation at the local scale.*

L219: "Persistence" ("duration" would be clearer) has what units?

>>We have added the unit in the manuscript.

L310: *However, the duration of each fire is assumed to be equal to one day in CLM5-BGC (Li et al., 2012).*

L220: "fires can last longer" in CLM or real life?

>> The sentence has been omitted from the revised manuscript.

Expand discussion of fire duration into its own paragraph and add citations. Much literature exists about both (a) real-world fire durations (especially in Alaska, where large fires contribute a huge proportion of burned area), (b) the effect of the constant-duration (or max 1 day) assumption in fire models, and (c) the effect of including dynamic, > 1 day fire duration in models.

>> As per the editor's suggestion, we have added an explanation in the revised manuscript

L310: *In addition, wildfires are strongly affected by the weather conditions after the fire ignition. For example, wind and precipitation determine the spread and duration of fire. However, in CLM5-BGC, the fire ignition and fire spread rate are simultaneously calculated based on the weather conditions of fire ignition or pre-fire. Moreover, wildfires in ecosystems persist from hours to months, depending on ecosystem characteristics and climate conditions. However, the duration of each fire is assumed to be equal to one day in CLM5-BGC (Li et al., 2012). For example, Andela et al. (2019) reported that the average fire duration in a boreal forest was longer than those in other regions, and the average size of each fire in the boreal forest was larger than those in temporal forests and under deforestation. Moreover, wind speed is an important factor determining fire spread in the model. In CLM, the spread of fire increases as the wind speed increases. However, according to Lasslop et al. (2015), there is strong variation in the burned fraction with wind speed, characterized by an increase until a certain wind speed threshold is reached and a decrease thereafter. The study suggests that global fire models should avoid a strong amplification for higher wind speeds to prevent overestimation of modelled burned areas.*

Paragraph about Alaskan fire policy needs expansion. What do those different levels mean? How much area is in each level, especially in your study area?

>> In Alaska, areas are divided by priority for firefighting. For example, firefighting in critical areas takes precedence over those in other areas. In Alaska, areas under the full, modified, and limited management options occupy 16%, 16%, and 67% of Alaska, respectively. We have added these in the revised manuscript.

L324: *The management system and infrastructures for fires vary by country or region. For instance, there are four types of fire policy options in Alaska, namely critical, full, modified, and limited, according to the levels of anthropogenic effort in extinguishing the fire (Phillips* *et al., 2022). For example, fire suppression is the highest priority at the critical protection level because wildfire can threaten human life and inhabited property. The lowest priority for fire-related resource assignments is applied at the limited protection level. In Alaska, areas under the full, modified, and limited management options occupy 16%, 16%, and 67% of Alaska, respectively. Critical-protection-level areas occupy less than 1% of Alaska. In CLM5-BGC, however, the suppression impact is calculated based on the GDP and population, which may underestimate burned areas in the limited regions of Alaska because of the large GDP of the United States.*

L224: "anthropophonic" is not a word. "anthropogenic"?

>> We have corrected it.

It's unclear what the difference is between Sections 4.2 and 4.3. You should strongly consider combining them to tell a more cohesive story about your results.

>> In section 4.2, we explained the difference in carbon fluxes between the two simulations. Therefore, we have combined the two sections and moved a few paragraphs to the discussion section.

L241–9

Did C emissions change much between what Veraverbeke et al. looked at (GFED3s) and GFED4?

>> We have deleted a few sentences about GFED3 because we consider them unnecessary.

Be clearer throughout about when you're discussing CLM vs. GFED (vs. real life?) combustion completeness factors.

>> We have deleted a few sentences about GFED3 because we consider them unnecessary. In addition, we have clarified our meaning regarding the combustion completeness factors in the revised manuscript, as shown below.

L430: *The combustion completeness factor for leaves is 0.8 and that for stems ranges from 0.27–0.8, depending on the PFTs in CLM5-BGC. According to van der Werf et al. (2010), the* *combustion completeness factor of aboveground live biomass, which ranges from 0.3–0.4 in the boreal region, is lower than that in other regions. Therefore, the combustion completeness factors for boreal trees may be lower than the current default value in CLM5-BGC.*

The carbon emission simulation was highly improved after replacing the fire simulation with GFED4 in Eastern Siberia (Figure 5b); the correlation was improved from 0.41 in CLM-Default to 0.88 in EXP-GFED4, and the RMSE was reduced from 19.74 g m^{-2} year^{-1} in CLM-Default to 4.2 g m^{-2} year^{-1} in EXP-GFED4, compared with the GFED4 products. In Eastern Siberia, grasses are dominant, suggesting that the value of the combustion completeness factors for grass in CLM5-BGC is more similar to those of GFED4 products than to those of boreal trees.

You cite the combustion completeness factors for GFED3 (van der Werf et al., 2010) instead of the dataset you actually used (GFED4; Giglio et al., 2013). There were actually important changes to how combustion completeness works in GFED4!

>> GFED (v3 and v4) emissions are derived from the Carnegie-Ames-Stanford Approach (CASA) biosphere model. In the model, the metrics for combustion completeness (CC) are used to calculate emissions (Seiler and Crutzen, 1980). Therefore, we have cited van der Werf et al. (2010) in the manuscript. van der Werf et al., (2010) reported on the value of combustion completeness factors, but there is little mention of the value of combustion completeness factors in Giglio et al. (2013).

L248: Tilde should be an en dash

>> We have corrected it in the revised manuscript.

L251: "form" should be "from"

>> We have corrected it in the revised manuscript.

L253:

"more reliable" in what? GFED/CASA or CLM?

>> The value of the combustion completeness factors for grass in CLM5-BGC is more similar

to those of GFED4 products. We have clarified this in the revised manuscript.

L437: *In Eastern Siberia, grasses are dominant, suggesting that the value of the combustion completeness factors for grass in CLM5-BGC is more similar to those of GFED4 products than to those of boreal trees.*

"dominant" in what? Observations and/or GFED/CASA and/or CLM?

>> We have deleted this word because we found it unnecessary.

L256–61: This paragraph feels weird in a section about carbon fluxes without you first having discussed GPP/NEP/NPP. LAI is an explanatory factor of those things and thus should go after the GPP/NEE/NEP discussion.

>> As per the editor's suggestion, we have moved the explanation on LAI after that on GPP/NPP/NEP.

L238: *Unlike carbon emissions, the regionally-averaged GPP, NPP, and NEP (Fig. 6c–6h) did not significantly change in EXP-GFED4. The differences in GPP, NPP, and NEP are less than 3%, indicating that fires rarely impacted carbon fluxes related to vegetation and decomposition. This is because the ratio of the fire area to the total area was relatively small. For example, the highest annual burned area of all simulations was 6 Mha, which accounted for 6.87% of our study domain. The simulated LAIs in Alaska and Eastern Siberia are presented in Fig. 6a and 6b, respectively. In Alaska (Fig. 6a), the difference in LAI between CLM-Default and EXP-GFED4 was the largest in 2005 (0.03 m2/m2). Although the difference in burned area between CLM-Default and GFED4 (Fig. 3a) was the largest in 2004, the largest difference in LAI was in 2005 since vegetation damage caused by fire in 2004 had not fully recovered, and the difference in burned area in 2005 was also quite large. In Eastern Siberia (Fig. 6b), the difference in the simulated LAI between CLM-Default and EXP-GFED4 has been large since 2009, when the difference in the size of burned areas was amplified (Fig. 3b). Although the LAI, which affects primary GPP and other carbon fluxes, was reduced by fires, the LAI after fires was not substantially different owing to the small fire area compared to the total area.*

L264: "rate" is not correct here, as it implies something with time in the denominator. Replace "rates of changes" with "differences".

>> We have corrected them.

L290–6: This paragraph fits more in the Conclusions section.

>> We have moved one sentence of this paragraph to the conclusions section and deleted others because of overlap.

L321–31:

At some point this paragraph transitions from talking about both regions to just Alaska. Make Alaska its own paragraph, as you did for Siberia.

>> We have divided the paragraph into two paragraphs: one explaining both regions and the other explaining Alaska, with additional sentences.

L321: *To investigate the fire impacts on water fluxes, we compared the results of ET and ET components, such as canopy evaporation, canopy transpiration, and ground evaporation, in six grid cells where the differences in burned area between CLM-Default and EXP-GFED4 are the largest in Alaska and Eastern Siberia (Figure 8). Because the LAI decreases owing to wildfires, canopy evaporation and canopy transpiration decrease in the burned areas.*

We observed that more rainfall reaches the ground, which would make the ground evaporation rate higher in regions with more burned areas, especially in 2004 and 2005 in Alaska. The differences in annual canopy evaporation, canopy transpiration, and ground evaporation between the two simulations were 5.41 mm and 13.37 mm, 2.3 mm and 6.26 mm, and −1.39 mm and −7.4 mm in 2004 and 2005, respectively. Canopy transpiration decreased by 3%, canopy evaporation decreased by 12%, and ground evaporation increased by 10% in 2004 and 2005 after applying the GFED4 burned area into CLM. This is consistent with the findings of Li et al. (2017) and Seo and Kim (2019), showing that canopy evaporation and canopy transpiration decreased, and ground evaporation increased when comparing the simulation with and without fire. Furthermore, the total ET in the presence of fire decreased by 6.32 mm and 12.08 mm in 2004 and 2005, respectively, indicating that canopy evaporation is more strongly influenced by fires over Alaska in CLM.

L322: Replace "grids" with "grid cells"

>> We have corrected this in the revised manuscript.

L323: "affected" in what direction?

>> We have clarified it in the revised manuscript.

L323: *Because the LAI decreases owing to wildfires, canopy evaporation and canopy transpiration decrease in the burned areas.*

L324: "may"?

>> We have deleted the word in the revised manuscript.

L329: Replace "the CLM-dynamic global vegetation model" with just "CLM"

>> We have corrected it in the revised manuscript.

L370: Please cite the specific version (git tag or commit SHA) of CLM on which you made your changes.

>> We have added the git tag in the revised manuscript.

L465–6: Please replace citation with Rabin et al. (2018): https://gmd.copernicus.org/articles/11/815/201 8/

>> We have replaced the citation in the revised manuscript.

Figs. 2, 3, 5, 6, 9, 10: Please use more colorblind-friendly colors in Fig. 5, especially avoiding red and green. For all these figures, using different line styles (solid vs. dashed vs. dotted) and/or a variety of markers (instead of just squares) would also help. Some useful resources can be found here: https://www.geoscientific-model-development.net/submission.html#figurestables

>> We have changed the figure colors and styles in the revised manuscript, as shown below.

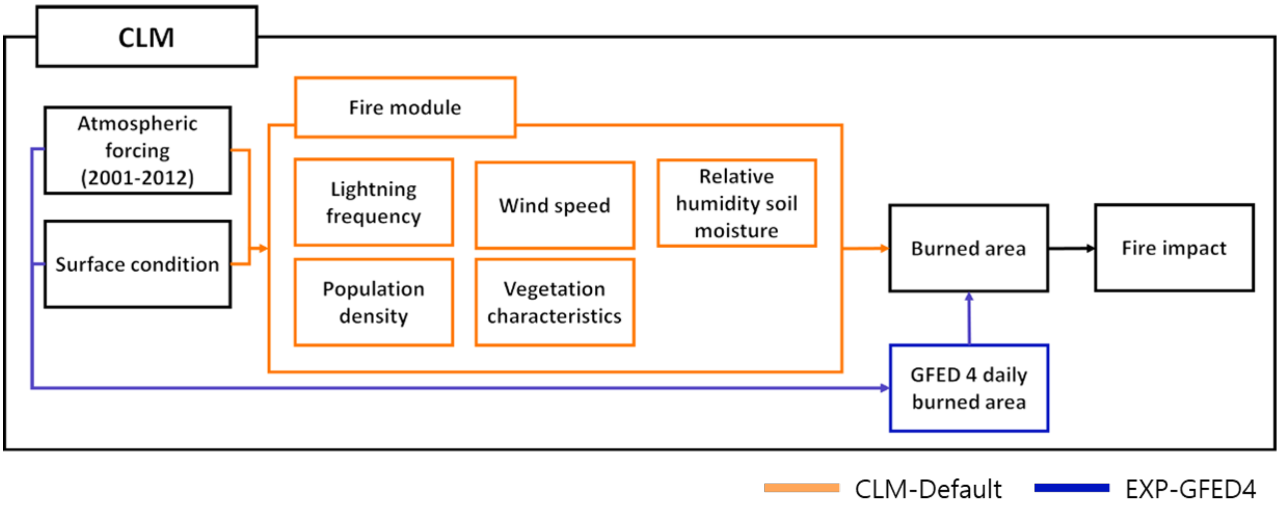

Figure 1. Flow diagram for CLM-Default (orange line) and EXP-GFED4 (blue line).

CLM-Default, default CLM5-BGC simulation; EXP-GFED4, experimental simulation with global fire emission database

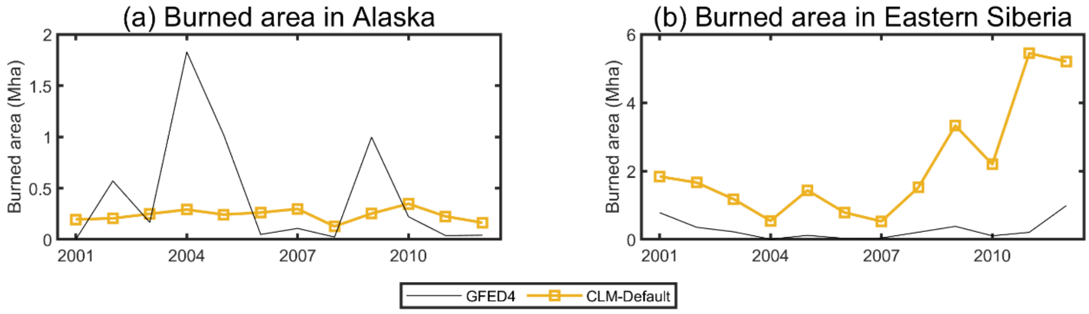

Figure 2. Burned area based on GFED4 and simulated burned area of CLM-Default over (a) Alaska (b) and Eastern Siberia from 2001 to 2012.

GFED4, global fire emission database (version 4); OL, CLM-Default, default CLM5-BGC simulation

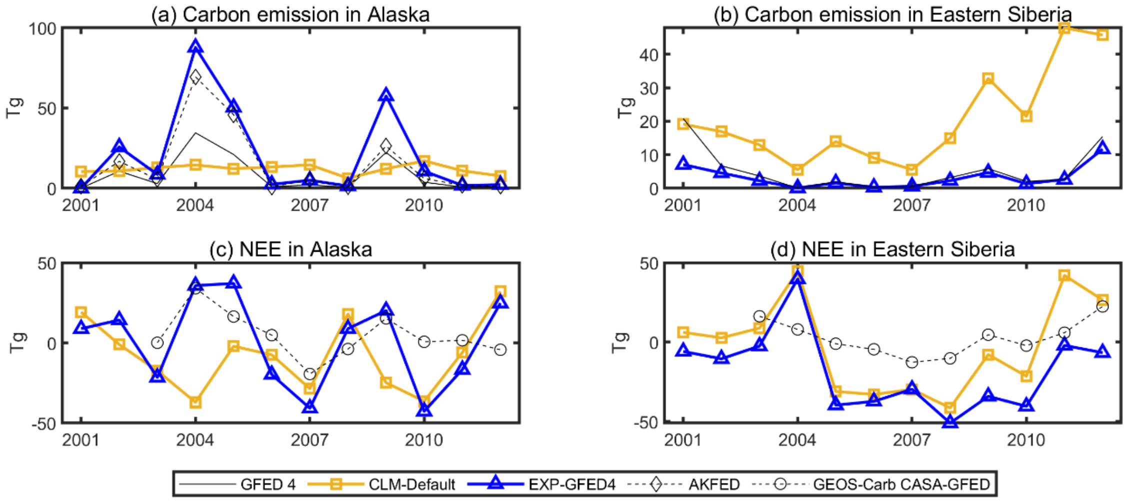

Figure 3. Simulated carbon fluxes of CLM-Default and EXP-GFED4 such as carbon emission (a,b), and (c,d) in Alaska (a,c) and Eastern Siberia (b,d) from 2001 to 2012. GFED carbon emission (a,b) and AKFED carbon emission (a) are added to evaluate the performance of carbon emission in CLM-Default and EXP-GFED4 runs. Also, NEE of GEOS-Carb CASA-GFED was added to evaluate the performance of NEE in CLM-Default and EXP-GFED4 runs (c, d).-

CLM-Default, default CLM5-BGC simulation; EXP- GFED4, experimental simulation with global fire emission database (version 4); AKFED; Alaskan Fire Emissions Database; NEE, net ecosystem exchange

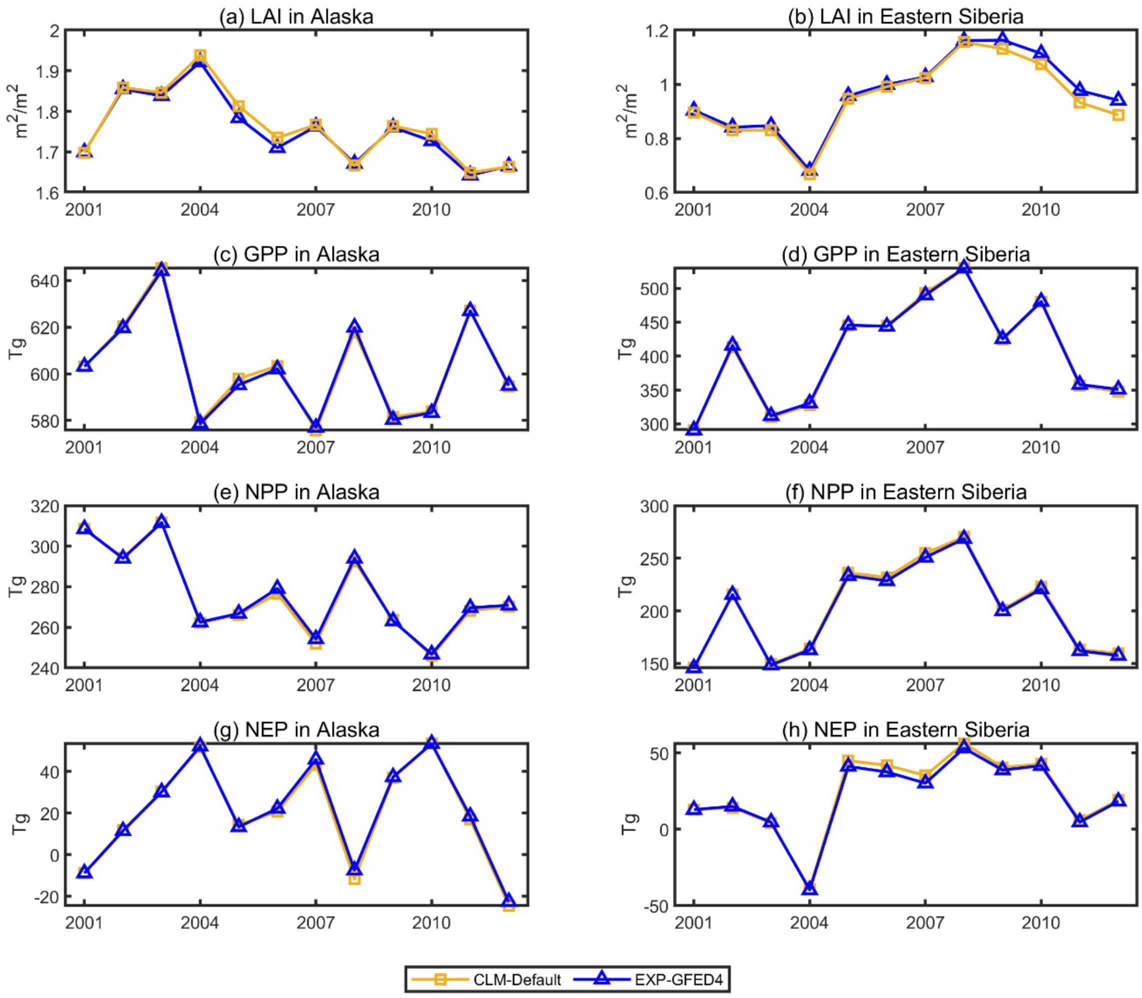

Figure 4. Simulated LAI (a, b), and carbon fluxes of CLM-Default and EXP-GFED4 such as GPP (c, d), NPP (e, f), and NEP (g, h) in Alaska (a, c, e, g) and Eastern Siberia (b, d, f, h) from 2001 to 2012.

LAI, leaf area index; CLM-Default, default CLM5-BGC simulation; EXP-GFED4, experimental simulation with global fire emission database (version 4); GPP, gross primary production; NPP, net primary production; NEP, net ecosystem production

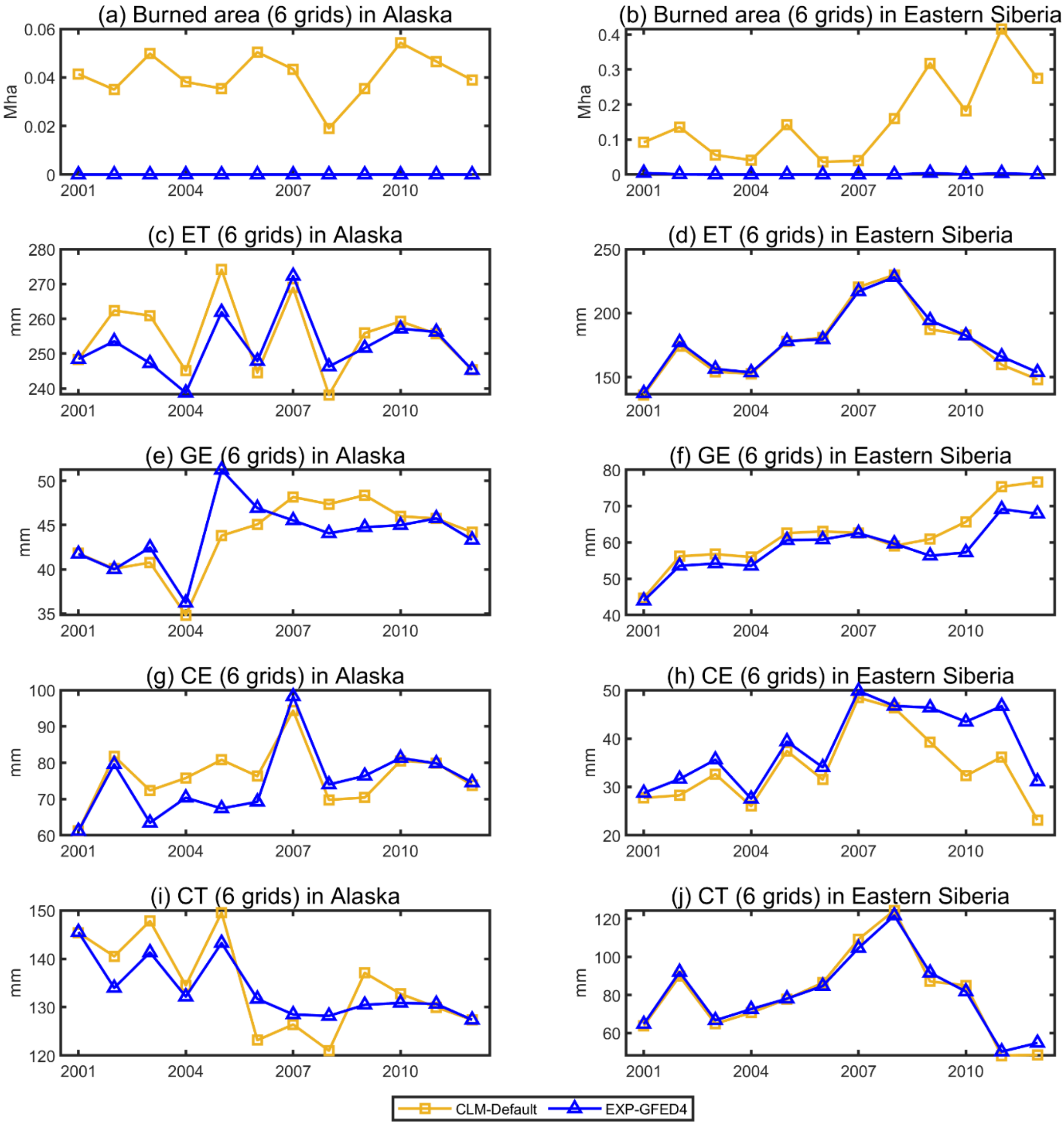

Figure 5. Simulated burned area (a, b), and water fluxes of CLM-Default and EXP-GFED4 such as ET (c, d), ground evaporation (GE; e, f), canopy evaporation (CE; g, h), and canopy transpiration (CT; i, j) in five grids where the difference in burned area between CLM-Default and EXP-GFED4 is highest in Alaska (a, c, e, g, i) and Eastern Siberia (b, d, f, h, j) from 2001 to 2012.

CLM-Default, default CLM5-BGC simulation; EXP-GFED4, experimental simulation with global fire emission database (version 4); ET, evapotranspiration

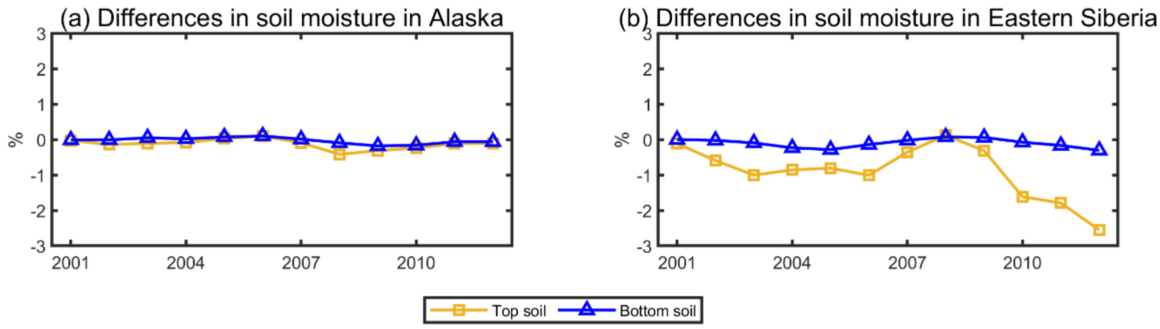

Figure 6. Differences (the value of OL- the value of EXP-GFED4) in simulated top soil (0–20 cm) moisture and bottom soil (70–150 cm) moisture in Alaska (a) and Eastern Siberia (b).

CLM-Default, default CLM5-BGC simulation; EXP-GFED4, experimental simulation with global fire emission database (version 4)