

Interactive comment on “How past fire disturbances have contributed to the current carbon balance of boreal ecosystems?” by C. Yue et al.

Anonymous Referee #1

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GENERAL COMMENTS

The Yue et al study aims to quantify the legacy effects of forest fires on the carbon cycle in boreal systems. They utilize an integrated ecosystem-fire model to simulate decadal vegetation structure and fire regimes from CE 1850-2010 in the northern hemisphere boreal zone. Their model also incorporates the influence of atmospheric carbon and climate change via the fertilization effect on successional vegetation following fire. Using an iterative approach, the authors identify the proportion of the modern carbon sink that is related to the legacy effect of fires in previous decades. They identify an increasing temporal trend in the contribution of decadal fires to the modern carbon sink, with fires in the most recent 4 decades accounting for ~60% of the total legacy effect

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on the enhanced carbon storage. However, the overall legacy effect of past fires in contributing to the sink roughly balances the contribution of modern burning to carbon sources. Nonetheless, if the boreal fire regime changes in the future, it is possible that the impact of enhanced burning may exceed the fire-legacy carbon sink. Classifying the fire regimes based on fire return intervals (yrs.fire), the authors find that regions with FRIs between 10-50 years are the largest contributor to the fire-legacy carbon sink, which has important implications if fires become more frequent in the future.

Overall, this study is unique because it not only considers the effect of fires on the boreal carbon cycle, but examines this effect through time by partitioning the model into various decades. This allows for examination of how temporal changes in the fire regime along with anthropogenic changes impact the carbon sink in the boreal zone. In general, the paper is rather heavy on methods, which is understandable given the many datasets and model parameters that need to be explained. However, I think the paper needs a more substantial discussion and introduction in order to appeal to a larger audience and to clarify the implications of the study. The current discussion seems more like a list of how well the model performed and how it compares to other studies, and lacks the key component of really explaining the findings and placing those findings into a broader context. Thus, I strongly suggest that the authors restructure the discussion to give it more focus. I have some general suggestions about that, but the main point is that I want to know what the authors think their findings mean and how those findings fit into what we already know. Furthermore, the results section was rather short and not explained in a quantitative way (which may not be possible). I found it difficult to properly assess how successful the study was because there are very few statistics to help assess the model results. However, this could potentially be addressed with some modifications to the figures and some statements in the results about the impact of these errors.

Despite these issues, I do believe that the paper is suitable for Biogeosciences. It is an interesting study with some compelling implications. I would suggest accepting the

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paper pending revisions.

SPECIFIC COMMENTS

1. P 14835, L 3-5: The link between CO₂ and temperature increase on vegetation productivity should be made explicitly in this sentence. The previous sentence talks about soil carbon and the following sentence about vegetation. The logical link gets lost without being specific as to how the carbon sink is enhanced by these forcing mechanisms.

2. P 14835, Line 22: What does the phrase “in parallel with post-fire ecosystem recovery” mean? Do you mean that the equilibrium conditions of the soil following a fire occur at the same temporal scale as that of vegetation following combustion? I am not sure that is true, if that is what you mean. Please clarify.

3. Overall, I think the introduction is very straightforward. However, I think that that the discussion regarding the conceptual framework should be moved to the introduction as well. I found the entire first paragraph of section 2.2 very confusing, and ultimately had to read the Gasser and Ciais 2013 paper to understand what it meant. My general suggestion here is to introduce...very clearly...the concept of CCN in the introduction. Make it very clear to the reader that there are environmental perturbations that are new to the system since the industrial era that affect the post-fire vegetation recovery. Thus, although the boreal system has long been fire-adapted, it is the new state of CCN perturbations that enhance the legacy effect of past fires. I felt like I had to read between the lines to get that information, and it would be MUCH better if it was explained to me very clearly in the beginning. For example, HOW do these three components impact carbon storage following fires, specifically? THEN, having clearly introduced that in the intro (it would fit nicely after the paragraph about fire), KEEP the section 2.2, but make it very clear HOW you incorporate that conceptual framework into your model. For example, you talk about land use change, but that is not part of the CCN model, is it? Take the time to clearly explain each part of your model, using

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Fig 1A and B to really help with it. I think this will help the reader immensely and make the entire first half of the paper more easy to understand.

4. In regards to comment #3, I would also suggest a few changes to Figure 1. Is it possible to add some arrows that give the reader a visual understanding of the fluxes of carbon and how they differ for different portions of the landscape? I.e., thick arrows = high flux, thin = low? And/or, it would help a lot to have aspects of your equation added to the figure as well if that is possible. I.e., I think the illustration is nice, but it doesn't add a lot to helping the reader understand the conceptual design without a bit more visual information. I ended up drawing all over the figure as I read the equation before it was clear what it all meant. Remember, not everyone uses these models, so I suggest using the first figure as a way to outline the conceptual framework very clearly. Also note, the terms in your figure are not explained in the caption of the figure. There should be a legend or a more precise caption for that figure.

5. P17839, Lines 10-14: You illustrate the way in which CCN can affect emissions and legacy sinks, which is helpful. However, I think it would be suitable to list multiple ways in which this works, instead of just two examples. There needs to be a logical and clearly defined link between how CCN affects these two aspects of the carbon balance AND it needs to be explicit how these components are handled in the model. If you list the ways CCN impacts the system here, you can refer back to those examples when you explain the model. For example, you mention on P14840 that one of the terms in your equation is the carbon flux from the CCN perturbation. Why not give an example of the conditions in which this term would be high versus low? I.e., high atmospheric CO₂ versus low atmospheric CO₂? Warm summers versus cold summers? Etc. This would make it very clear to readers who do not use these type of models and really help in outlining how the model actually works. It does not have to be a lot of text. . .just some clear examples so that the reader clearly understands how the model works.

6. P 14841, L10-12: Similar to comment # 5, I am not sure I understand this. You state that the CCN perturbations are not separated in the model. I assume that means the

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atmospheric carbon and climate layers are lumped together. However, it is unclear to me, based on the previous text, what exactly the CCN perturbation actually is. . .ie, I just know it has something to do with climate, carbon, and nitrogen. Please be very clear about this and offer examples that will make that easier to understand.

7. P1782, 2nd paragraph – There are a few things that need to be clarified here:

a. What does CRUNCEP stand for?

b. What is the NCEP temporal resolution?

c. What type of climate data is the CRU data? Is it summer temperature? Annual moisture? Be explicit.

d. Was there an atmospheric CO₂ dataset used in this model? On P 14841, L 25, you state that you account for climate change (CRUNCEP dataset), atmospheric CO₂ (?), and simulated fires (lightning and human population datasets).

8. Results section: Overall, there needs to be a bit more information about how well these datasets perform. Is there any quantitative way to assess overall model performance? For example, there seem to be some large areas where the tree cover is overestimated by quite a lot (30-50%). Is this an acceptable amount in these types of models? It seems like the model ultimately matches up well with what we know, which is surprising given the large overestimates. Along these same lines, I also find figures 2-4 difficult to digest. What do the scales mean? There are no units on the figures. A possible solution - Why not create a map that shows the difference between the two datasets? This way, it is very clear to the reader which areas are problematic and gives a more quantitative overview of the model performance. I.e., deep red = areas where the vegetation cover or fire is overestimated, deep blue where the veg/fire is underestimated. I don't know if that is possible, but if it is, it could provide better visual information to the reader.

9. Discussion section – overall, I think this section could be restructured a bit to make

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it more appealing to a broader audience and to more fully explain what the findings tell us. It is a bit technical as written and focuses too much on the model performance and not enough on big-picture implications of the findings. I felt like I had to figure out what the implications of this study were on my own. . .and I did not really have enough information to do that. The discussion should clearly explain how the findings of this study add another piece of information to what we know about the fire-vegetation-carbon cycle. To do this, you need to give the readers a nice overview of what is already known and then place your findings into that context. I have a few suggestions below that may help.

a. Discussion – Section 4.1 – It is a bit underwhelming to start your discussion off with model performance, but I suppose it has to be done somewhere. It would be more interesting to start off with your major findings and then narrow down to things like model issues, but that is ultimately personal preference.

b. I feel like you are missing a key discussion section or paragraph – you need to introduce the concept of the fire-vegetation feedback, with some nice examples of how the fire regime helps structure boreal vegetation and how post-fire succession is affected by fire frequency. I feel like this link is not made in an explicit way and it should be because it is half of your major point. I.e, post-fire succession is part 1, and the impact of CCN on this process is part 2. Additionally, if you made section 4.1 the Fire-Vegetation feedback section, then you could talk about the aspects of your model that a) capture this effect and b) do not capture it well because of model issues. Since this is a key component of your study, I think it is worth really explaining in it a broader context.

c. Discussion section 4.2 – If you devote the first section to the vegetation-fire feedback as suggested, this section could be focused more on the impact of fires in the carbon balance under CCN perturbations. Instead of focusing on how your model differs from others, you could restructure this section and really focus on the role of fire in the carbon balance, how other studies have examined that role, and how your study takes this a step further by examining the legacy fire effect under CCN. Again, the information

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is all there, just as in the previous section, but it is a bit underwhelming as written.

d. I feel like the most important point in the discussion section is the paragraph starting with P14850, Lines 22-25. Personally, I would start the discussion with this and then explain the vegetation feedback, move into the impact of CCN, then reiterate your findings. But again, that is differences in style. I.e., if section 4.1 is restructured to focus on the fire-vegetation feedback and section 4.2 focuses on the impact of CCN on this relationship, then this point becomes very powerful and the reader will have a clear understanding of how your results show this. I.e., you will have given them the information they need to clearly understand why your findings are so interesting.

e. I found it rather compelling that 1) more recent fires contribute most to the legacy carbon sink (ie, P14846, L 20-25) and 2) fire groups with short FRIs (10-50 years) are the biggest contributor to the carbon sink (P 14847, L4-6). This seems like a very interesting finding, but it is not really brought up again in the discussion. A discussion of this could improve your implications sections. It suggests to me that areas of early successional vegetation are really strong sinks of carbon. Why? Do areas with short FRIs and recent burning have more deciduous vegetation? Higher biomass? What is the implication for the boreal biome if fires become more frequent in the future? Will the impact of CCN on these areas result in a stronger boreal sink in the long run, simply due to this vegetation feedback? Is there a threshold of burning that enhances the legacy effect, but once burning become very frequent (ie, 2-5 yr FRIS), will the legacy effect diminish and those areas act as a carbon source? I feel like you have enough information to speculate a bit about what your findings mean in a broader context. Without some sort of discussion about it, I am unsure why you added the FRI analysis at all. What does it mean?

TECHNICAL CORRECTIONS

1. P 14835, L 6: More vulnerable to what? Be explicit.
2. P 14835, L 7: What is vegetation activity? Do you mean productivity?

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3. P 14835, L 19: Replace “Besides” with “Additionally”, or another word.
4. P 14835, L 21: after “charcoal, I would add a comma and say “which restores soil carbon. . .”
5. P 14836, L 12 – What does the “contemporary period” mean? Last 150 years? Anthropocene? Be specific and clarify.
6. P14837, L19: What are “lightening-ignited fires by human”? Do you mean “suppressed by humans”?
7. P14838, L3: Replace “On top of” with something like “in addition to”
8. P14838, L8: What does DGVM stand for?
9. P14838, L25: “Evidences” is the wrong word here. Perhaps “Previous studies”?
10. P14838, L26-27: “Environmental perturbations” can mean anything, including fire. Do you specifically mean “anthropogenic impacts”? If so, state that explicitly. I know you offer a list in the next sentence, but those terms are also vague. Atmospheric CO₂ is not a perturbation. Rapidly increasing atmospheric CO₂ in response to anthropogenic activities is a perturbation. I suggest restructuring these two sentences to make to make it very clear which variables you are referring to.
11. P11839, L 4: “natural land ecosystem” is a very odd phrase. What is meant by “natural”? Be specific. . .do you mean prior to human modification?
12. P14839, L7 – “regrowth” is misspelled.
13. P14841, L4: “Different with explicit cohort simulation” – Do you mean “In contrast with the explicit. . .” Consider rewording.
14. P 14842, L25-26: I think there is a typo in this sentence. “Both lightning data sets” – do you mean “Both the lightening and population datasets”? Or were there two lightening datasets?

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15. P14843, L21 – please add a comma before “deciduous needlleef” to show it is a separate group.

16. Figure 6 – put citations in the figure legend to make it clear that these points are from other sources and that you are comparing your findings to them. I had no idea what these points were until I found them in the main text. If not in the legend, they need to be in the figure caption.

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