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## ***Interactive comment on “SPITFIRE-2: an improved fire module for Dynamic Global Vegetation Models” by M. Pfeiffer and J. O. Kaplan***

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*Answers to comments of Reviewer 2:*

Works on developing global fire schemes are suitable for publication in this journal, and are important to quantify and understand the fire-climate-ecosystem interactions on a global scale. The manuscript “SPITFIRE-2: an improved fire module for Dynamic Global Vegetation Models” proposed by M. Pfeiffer and J. O. Kaplan describes a modified version of SPITFIRE. In SPITFIRE-2, many new equations, assumptions, and parameters are introduced into the original SPITFIRE that is a complex process-based fire model. However, the majority of the modifications have not been justified. In addition, as a global fire model, its global performance (at least the burned area)

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must be evaluated against the commonly used benchmarks (e.g. MODIS or GFED3 fire products) like another modified version of SPITFIRE (Prentice et al. 2011, GBC). The global evaluation of SPITFIRE-2 will be helpful for other global fire modelers and also make their and other user's reconstructions, mechanism analyses, or projections credible.

*Direct global evaluation of a process-based fire model against contemporary remote-sensing-based observational datasets is difficult because of the importance of anthropogenic activities that influence fire at present, both through ignitions and fire suppression. It was not our goal in developing LPJ-LMfire to produce a model for simulating present-day, industrial-era fire regimes globally. For this reason, we focused our model evaluation on a part of the world (Alaska) where fires are well documented to be subject to minimal human interference. Nevertheless, in the revised version of our manuscript we have added a new section to compare the results of our model with GFEDv3 and the Randerson et al. (2012) global burned area product. We point out that at present-day about 75% of observed mean annual global burned area occurs on land that is substantially influenced by human activities through the presence of roads, settlements, and other anthropogenic infrastructure. There are, however, a few parts of the world where human impact is expected to be minimal, and in these regions we comment on the discrepancy between modeled and observed burned area in the context of limitations to our model. We follow with suggestions for future model improvement.*

Specific comments are as follows, which I hope will help improve the ms. (1)Abstract, "With its unique properties of being able to simulate preindustrial fire. . .". Why do the authors think that other global fire models cannot simulate preindustrial fire?

*We do not think that other models cannot simulate preindustrial fire in general. How-*

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*ever, we have not found any other fire model so far that attempts to model human-fire relationships for preindustrial times. This is an innovation addressed for the first time in our fire model. We realize this formulation in the abstract was misleading, and have changed the text.*

(2) In introduction section, Para 6-10 is clearly a part of the introduction in Li et al. (2012, Biogeosciences) with a few modifications. Please cite the paper. Also, many of the modifications are incorrect, and the authors should read their references more carefully. E.g., P2352, L4-15, most simple type of fire models do not include all of the “three key processes”. E.g. modeling fire as “time-invariant loss rate” is impossible to include “fire occurrence” and “fire spread” processes.

*Due to the need to shorten and restructure the manuscript, this part of the introduction now has been completely reworked and includes a more in-detail focus on original SPITFIRE, rather than an overview of existing fire models.*

P2352, L21, please cite “Arora (2003, Agr. Forest. Meteorol) after CTEM.

P2352, L22, please change “CLM4-CND” to “CLM4-CNDV”

P2353, L15-18, if no reference can justify the statements, please remove them.

*As part of the shortening and restructuring of the introduction, the sections containing the above comments were deleted.*

P2354, L24-27, SPITFIRE is not “the only one that is potentially able to both represent

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human-vegetation-fire dynamics. . . trace gas and aerosol emissions. . .”, Li et al. (2012) can do this too.

*This sentence has been changed to reflect your comment and fit the new structure of the introduction.*

(3) In Section 2, P2355, L20, the first reason for improving SPITFIRE, “(1) burned too much in some parts of the world and not enough in others” is inaccurate. So far, no global fire model is perfect. It should be addressed more accurately (i.e., where), and it will be better if simulations in Sect. 4 can show the improvement in these regions.

*This entire section has been completely rewritten in the new version of the manuscript. In addition, as explained above, we now include a global-scale evaluation of the model performance compared to observational data in Section 4.5 of the manuscript.*

P2356, L16-17, about  $a(\text{ND})$  in SPITFIRE. In SPITFIRE,  $a(\text{ND})$  is a global constant, human ignition is a function of population density. Why the authors think that SPITFIRE is “difficult to apply to describe anthropogenic burning in the past”?

*First a point of clarification:  $a(\text{ND})$  is not a global constant as it was applied in Thonicke et al. (2010). In the model results published in this paper, the authors used an unpublished global map of  $a(\text{ND})$  that divided the world into several supra-national regions each with a fixed  $a(\text{ND})$  value.*

*In general, we believe that the  $a(\text{ND})$  approach is problematic for several reasons. The first problem is estimating reasonable values of  $a(\text{ND})$ , particularly for the past. In Thonicke et al. (2010), regional values for  $a(\text{ND})$  “were obtained by an inverse method, using*

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*data on numbers of human-caused fires and population densities for various regions". As such, estimating  $aN(d)$  relied heavily on the observed relationship between humans and fire at present. Given that very few countries separate observed fires into human versus lightning-caused fires in statistical databases (e.g, USA, Canada), Thonicke et al. (2010) used EO data on number of burnt patches or fire scars to calculate regional-scale  $aN(d)$  values, and acknowledged that the proportion of fires that can be ascribed to humans can be very uncertain, particularly in regions where ancillary data or studies specifically focusing on fire-cause attribution are absent.*

*Second, as it has been determined on the basis of present-day observational data, the way  $aN(d)$  is calculated means that it is strictly only valid for contemporary applications of SPITFIRE. However, it is highly unlikely that the relationship between population density and anthropogenic ignitions observed at present day has been constant though time, especially when acknowledging the massive way in which the human relationship with fire has changed since the Industrial Revolution. Fire suppression technology, the mechanization of agriculture, laws and regulations governing the use of fire and prosecution of arson, urbanization, and the emergence of outdoor recreation have changed greatly over the past 150 years, concurrent with exponential increases in human population. A number of recent publications (e.g., Pyne (1994, 1997, 2000), Bowman et al. (2009, 2011)) commented on the importance of fire for humans in prehistoric and preindustrial time and the way in which industrialization and urbanization fundamentally changed this relationship in recent centuries. As cultural contexts change over time, so does the relationship that people have with fire. At present, especially in societies with a Western cultural background fire is mostly perceived as a threat to personal property, safety, air quality and environment and therefore banished and suppressed in most places, although awareness that too much fire suppression can also be counterproductive to the long term health of ecosystems has increased in recent decades. One fixed parameter such as  $aN(d)$  may capture spatial variation of people-fire-relationships at present, but we do not believe that estimating how this parameter may have changed with time is an appropriate way of simulating changes in fire over millennia.*

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*The third problem is the relationship between the number of fires caused by people and population density. Again, such a relationship may be correct for present-day observations, but must not necessarily also apply to preindustrial conditions. It is likely that high population densities such as in present-day Europe lead to a decline in anthropogenic fire because of direct and indirect suppression with the emphasis on avoiding damage to life and property. However, this will not hold true for preindustrial societies that used fire for, e.g., land clearing and agricultural means. It is also not necessarily true that very low population numbers will cause very little fire, as this will totally depend on the reasons why people cause fires. If all human ignitions were accidental, then such an assumption might be valid, as less people mean less risk for potential ignitions. However, if people purposely use fire to modify landscapes, e.g., as hunter-gatherer societies such as is seen in parts of Africa at present (e.g., Eva et al. (1998)), or reported in Australia and the Americas for the past (e.g., Bowman (1998); Williams (2002)) it may take only a very few dedicated individuals to cause large amounts of fire.*

(4)Section 3, Please provide references, experiment data, or field and satellite observations to justify Eqs (2), (3), (5), (12), (13), (20), (21), (22), (28), (30), and related parameters and assumptions. Units and meanings of terms in Eqs (6)-(10) are inconsistent, please revise them.

*For all of the equations listed, we now provide a detailed rationale for the formulation we developed in the relevant sections of the manuscript. With respect to the parameters in equation 2 that relate to PFT-specific ignition efficiency, it is well known that different types of living vegetation have different inherent flammability because of canopy architecture, leaf type, phenol content, etc. (e.g., Hall (2007)). In estimating these parameters, we were limited to a qualitative, top-down approach to determine appropriate values. We estimated these by looking at fire behavior at certain regions and through comparison with observed burned area from GFED3 and tree cover from*

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*GLCF tree cover dataset. In essence, we adjusted the parameters to produce results that agreed best with observations. We realize that this approach is unsatisfying and have identified it as a potentially important subject for future research in section 3.1.2 of the revised manuscript text.*

Sect. 3.1.3, please provide how to separate human populations into three groups based on their subsistence lifestyle: hunter-gatherers, pastoralists, and farmers?

*Separating human populations into groups by subsistence lifestyle could be done in any number of ways, depending on the region and time period of interest. For example, a model run for the Last Glacial Maximum (21ka) would need to distinguish only one group of human population because it is well known that agriculture had not yet developed at that time. For the purposes of the current model description paper, we feel it is sufficient to state that this information on human lifestyle is necessary model input, but as we do not show any paleo-results, we do not specify how it should be done. An application of our new fire model for the Late Glacial and Holocene period, where the distinction of human lifestyles will be done, is the subject of another paper. For more insight on our group's research on past anthropogenic land cover change, see also the publications by Kaplan et al. (2011, 2012 ).*

P2369, L16, SPITFIRE allowed fires to burn no more than 241min rather than one day, please revise it.

*We revised this sentence to reflect this fact.*

P2370, L7-16, How does the increase of maximum crown area and maximum sapling establishment rate influence other regions?

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*The increase of maximum crown area is most relevant for the wet tropics, such as those found in the Amazon basin, where trees experience little disturbance and optimal growth conditions. In most other regions outside the tropics, the new full maximum crown area of 30 m<sup>2</sup> instead of 15 m<sup>2</sup> is usually not reached. We clarify this point in section 3.2.2 of our revised text. Changing the maximum establishment rate affects most regions, but effects on biomass are strongest where simulated biomass is high. We now provide a supplementary figure S3 that shows the before-and-after comparison of global biomass for a scenario completely without fire and a scenario with natural burning and agricultural land use, as well as a figure S4 that shows global maximum crown area for these two scenarios and reveals at what places maximum crown area plays a role for aboveground biomass reduction (all areas where simulated crown area exceeds 15 m<sup>2</sup>).*

P2378, L13-14, please quantify “too many trees being killed”.

*This paragraph has become obsolete as we managed in the meantime to re-implement the cambial kill scheme using the corresponding equations from original SPITFIRE.*

(5)Section 4, Lack simulation results to show the advantage of human ignition described in 3.1.3. Global performance (at least burned area) of the fire scheme need be evaluated against GFED3 or MODIS fire product. Comparing with the global performance of original SPITFIRE is also helpful. It's better to shorten the evaluation of fire simulations in Alaska.

*As described above, we now include a section discussing the global model performance with respect to observed global burned area. On the other hand, our*

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*formulation for preindustrial human ignitions is not applicable to the present-day and cannot be directly compared with modern observations. A separate manuscript comparing the model results with paleo-archives of past fire frequency in the context of human influences is currently in preparation. In this paper we feel it is important to provide a complete description of the model, in a journal that has the purpose of publishing model descriptions, to facilitate future publications and make our model more accessible to the wider community. Even if not all parts of the model have been evaluated, and indeed as the other reviewers comment, it may be impossible to perform a comprehensive model evaluation of some of our formulations, it is important for this model description paper that we include all components of the complete model as it currently stands.*

(6) In section 6, P2399, L24-25: Without the evaluation through global fire simulations, how can the authors conclude “The updated fire model SPITFIRE-2 is a major improvement on past global fire models and will be particularly useful for studying changes in global fire on millennial timescales”?

*While we now provide a global-scale comparison with observed burned area, which was not included in Thonicke et al. (2010), we also realize this language was a too strong and have toned it down in our revised manuscript. Nevertheless, we do believe that our updated fire model represents an improvement over the original LPJ-SPITFIRE, particularly in as far as we are able to simulate fire more realistically in the boreal and subarctic regions.*

Figures:

S3: This figure illustrates the effect on global biomass caused by the changes to

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maximum crown area and maximum establishment rate in LPJ. Panels a) to c): Scenario completely excluding fire, to illustrate how the underlying basis biomass for fires changes. Panel a): Old LPJ parameterization, with a maximum crown area constraint of  $15 \text{ m}^2$  and a maximum establishment rate of  $0.12 \text{ individuals m}^{-2}$ . Panel b): New parameterization with a maximum crown area constraint of  $30 \text{ m}^2$  and a maximum establishment rate of  $0.15$ . Panel c) Difference in biomass between b) and a): a reduction in living biomass can be observed globally, but total values of reduction are highest in the equatorial tropics where total biomass is highest. Panels d) to f) show global biomass for a simulation run including anthropogenic land use based on HYDE land use and lightning-caused burning on non-agricultural land, for the old parameterization of maximum crown area and maximum establishment rate in panel d) and the new parameterization in panel e), and the difference between e) and d) shown in panel f).

S4: Panel a): Simulated maximum crown area for a world without fire after implementation of a maximum crown area threshold of  $30 \text{ m}^2$  instead of  $15 \text{ m}^2$ . Panel b): Simulated maximum crown area for a simulation run with lightning-caused fire. All places with maximum crown area between  $15 \text{ m}^2$  and  $30 \text{ m}^2$  are areas where the increase of maximum crown area contributes to the reduction of live biomass by decreasing individual density compared to the old parameterization.

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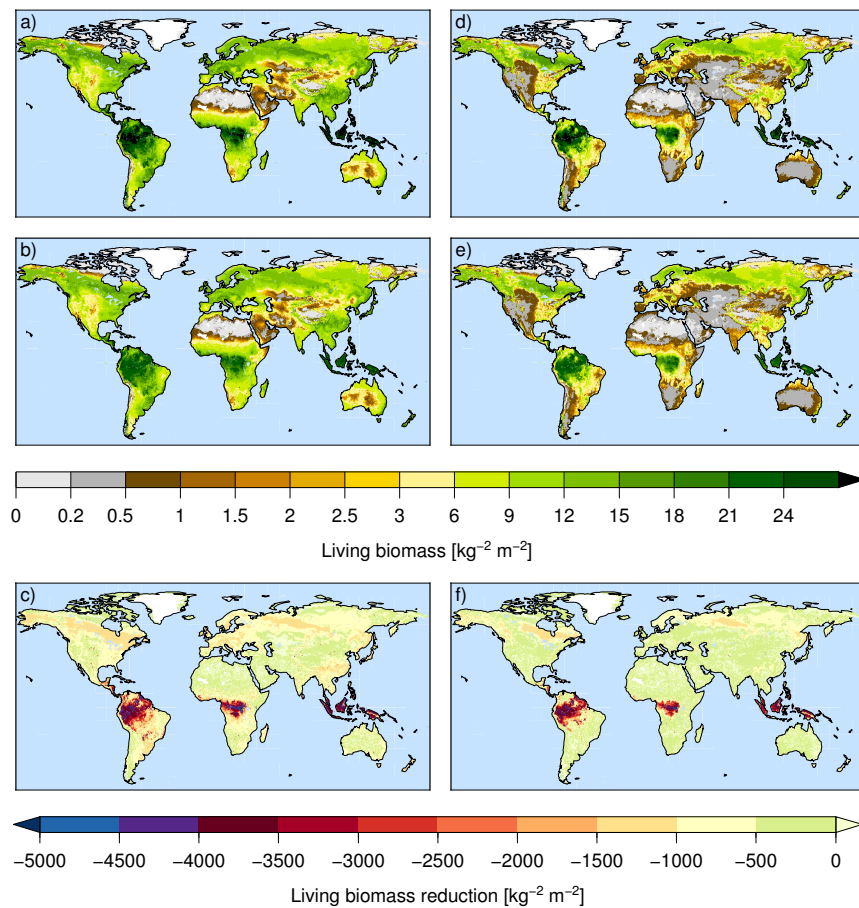
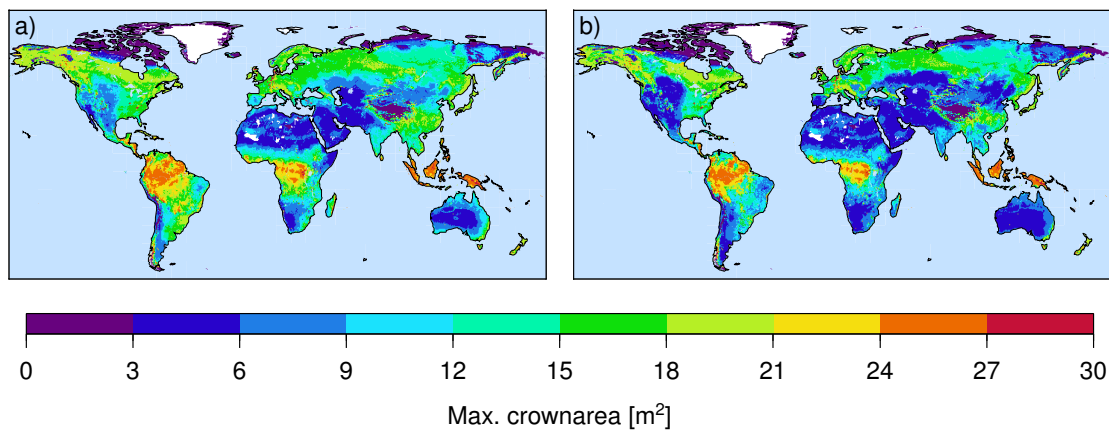


Fig. 1. Supplementary figure S3



**Fig. 2.** Supplementary figure S4

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