

## Point-by-point reply to referee comments

Dear editor, thank you very much for reviewing our manuscript. Here is a point-by-point reply to all three referees' comments.

### Response to referee #1

Line 109: Typo

Response: Corrected! Thank you.

Line 152: Better just “Forest formations”

Response: Corrected! Thank you.

Line 165: What is the difference here between fire influence and fire disturbance?

Response: This was a mistake. This sentence was meant to be written as “This model framework enables the simulation of global vegetation dynamics, including the influence of fire disturbance”. It was corrected.

Lines 262-263: I gather that these refer to moist and seasonal tropical forests in the LPJmL models, but I missed a more explicit definition of what they are and where they are in Brazil, since they are the basis for your comparisons throughout the parametrization procedure.

Response: Thank you very much for your comment. A more explicit definition of TrBE and TrBR with their corresponding vegetation in Brazil was included (lines 227-238). "In LPJmL, these forests are represented by the Tropical Broadleaved Evergreen Tree PFT (TrBE), reflecting the Amazon and the Atlantic rainforests, and by the Tropical Broadleaved Raingreen Tree PFT (TrBR), representing seasonal closed forests. In contrast, Cerrado vegetation is shaped by allometric relationships, and traits such as wood density, specific leaf area (SLA), rooting depth, and bark thickness, which together create a distinctive vegetation structure and functioning highly adapted to seasonal drought and fire occurrence. To incorporate these characteristics into the LPJmL-VR-SPITFIRE model, we used a combination of literature data and field observations to derive and calibrate the relevant parameters for the new Tropical Broadleaved Savanna tree (TrBS) parametrization. A summary of all parameters and data sources used is provided in Table 1 and 2, with detailed explanations below."

Table 1: Acronym should be defined here or in the table heading.

Response: The definition for the SLA acronym was added. Thank you.

Line 283: Remove 'already'.

Response: Corrected. Thank you!

Figure 2: Improve illustration of dotted line in the legend.

Response: Legend was improved. Thank you!

Lines 323-324: Go ahead and update this number to the fourth collection since it will be released in the next few days. Spoiler: aprox. 10.5 million hectares burned in 2024.

Response: The burned area for the Cerrado biome was updated for the 2024 MapBiomas collection. Thank you!

Line 434: 2024?

Response: The referred date was corrected to 2024. Thank you!

Line 437: Why not 2019?

Response: This was a typo! All the analysis and comparisons considered a 30-year time series from 1990 to 2019. It was corrected in the text. Thank you!

Lines 441-445: I don't understand the adoption of this approach, instead of simply filtering the burned areas of MapBiomas in each year for selecting of fire on native vegetation only.

Response: Thank you for your comment. We tested both approaches for MapBiomas burned area and the outcomes were identical. However, since we excluded human land use in our LPJmL simulations and MapBiomas Fogo inevitably has anthropic lands, we needed to weigh the LPJmL output for human land use by using the human land-use fraction map. We then decided to use the same approach for MapBiomas to keep the consistency of the comparison.

Line 442: 2024?

Response: Corrected. Thank you!

Line 447: 2024?

Response: Corrected. Thank you!

Line 487: I feel that comparing total carbon between the QCN and the modeled simulations would also be interesting. This also leads to another question I have: you didn't mention the role of the TrBS PFT modeling to improve fuel biomass estimates in the Cerrado. Don't you think this is also important to assess?

Response: Thank you for your comment. Regarding the total carbon comparison, we chose to show what we considered the most interesting results in our main text, but we now added a figure comparing total carbon in the supplementary file (Fig. S8). Part of this total carbon is used as living fuel biomass (leaves, and a proportion of sapwood and heartwood from twigs, branches and trunks that dry out and become flammable – see Thonicke et al. 2010). However, QCN products don't distinguish carbon stored in twigs, branches and trunks, just as total above- and belowground biomass, thus comparing fuel biomass between model and validation was not possible. We added this explanation in the discussion (lines 655-661).

Line 521: Remove "the".

Response: Corrected. Thank you!

Line 623: It is Figure S8.

Response: Corrected. Thank you!

Line 656: You mean, readily burned?

Response: Thanks for your comment. We have changed the sentence to be clearer. "Our parameterization of the savanna tree PFT produced a vegetation type with high flammability, yet is well protected against lethal fire damage"

Line 666: This whole paragraph is slightly repetitive with what was said already in a previous paragraph (lines 601-612).

Response: Thank you for your comment. We merged the information from this paragraph with the information of the previous paragraph (Lines 601-612) and created a more concise text discussing the limitations of human ignition sources in SPITFIRE. "In Savannas, there is often extensive use of fire for land management purposes. Specifically, in the Cerrado, fire in natural areas is associated with the use of fire for deforestation and pasture management, with fire escaping to natural areas, while in areas of mechanized agriculture and planted forests, owners rather protect the areas against fire. In SPITFIRE, however, ignitions are represented solely as a function of population density, and the model does not

explicitly capture the diverse fire management regimes common in these regions. This simplification contributes to the underestimation of burned area along the Caatinga border, where expanding deforestation and intensive land management interact with natural fire regimes, as well as in southeastern Amazonia, where large-scale pasture management fires may escape and affect adjacent rainforest (MapBiomas Fogo, 2024; Cano-Crespo et al., 2015). To mitigate this, we weighed both validation data and model outputs by the human land-use fraction from MapBiomas, thereby excluding grid cells with extensive anthropogenic land use from the analysis. Recent attempts to better incorporate anthropogenic fire management into models (Perkins et al., 2024) could enhance Cerrado fire simulations, which is particularly relevant given the increasing pressures on the biome and the ongoing shifts in fire regimes (da Silva Arruda et al., 2024). Nevertheless, even with improved fire–vegetation dynamics, simulations of future trajectories of these dynamics will remain constrained if key vegetation traits, such as deep root water uptake, are not adequately represented (D’Onofrio et al., 2020; Baudena et al., 2015)."

Line 672: in the.

Response: Corrected. Thank you!

Line 731: Now is the time.

Response: The link to our code was added. <[10.5281/zenodo.16965740](https://zenodo.16965740)>

## **Response to Referee #2**

Line 109: trailing e

Response: Corrected. Thank you!

Line 165: It is unclear what fire disturbance is here

Response: This was a mistake. This sentence was meant to be written as “This model framework enables the simulation of global vegetation dynamics, including the influence of fire disturbance”. It was corrected.

Line 429: why is era interim used for evaporation and not the more recent era5? This is only a small comment and if the authors have good reason there is no need to do additional work to change this as it does not impact the results in a meaningful sense (only figure S9 I suppose)

Response: Thank you very much for your comment! We updated our ET validation to ERA5 (Hersbach, H., Bell, B., Berrisford, P., Hirahara, S., Horányi, A., Muñoz-Sabater, J., Nicolas, J., Peubey, C., Radu, R., Schepers, D., Simmons, A., Soci, C., Abdalla, S., Abellán, X., Balsamo, G., Bechtold, P., Biavati, G., Bidlot, J., Bonavita, M., ... Thépaut, J. N: The ERA5 global reanalysis. *Q J R Meteorol Soc.*, 146, 1999 2049. <https://doi.org/10.1002/qj.3803>, 2020). There were no changes in the comparison between simulations and validation.

Lines 444-445: not clear to me what is meant here, is it same thing as what is explained in line 446-448?

Response: Thank you for your comment. In our simulation, we didn't model human-managed land, only natural vegetation. However, our validation product for fire (MapBiomas Fogo) also considers fires occurring in human-used lands. To account for this, we weighed our model output and the validation from MapBiomas Fogo by a human use fraction created from MapBiomas land use cover product. As you pointed out, it's a process similar to what we did with our monthly burned area comparison for Cerrado. The difference is that, in the monthly burned area, we weighed the fire product by the human use fraction of the corresponding year, and the mean burned area maps were weighed using the mean human use fraction for the 30-year time series we analyzed.

Lines 462-466: the fraction of raingreen trees also seems reduced in the savanna simulation, it might not be very important as it only covers very small fractions in the default run as well but is there any reason for this?

Response: Thank you for your comment. The PFT establishment in the LPJmL model is based on competition. Each PFT has specific settings that make it more or less competitive in a range of environmental conditions. In our run without the Savanna PFT, the raingreen trees were able to establish themselves in a few areas in central Brazil. However, when the Savanna PFT was introduced, it outcompeted the raingreen trees in those areas due to its competitiveness in drier environments.

Lines 523-524: this phrase was quite unclear to me when I first read it, after reading the discussion it became clear to me but please avoid vague statements such as referring to 'real motivations' here.

Response: Thank you for your comment. The phrase was rewritten as “With the inclusion of the new TrBS PFT, the burned area estimates in the Cerrado increased, surpassing the values recorded in the MapBiomas Fogo in central Cerrado, but still underestimating burned area in the northern region of Cerrado and in the Amazon (Fig. 6)”.

Lines 556-557: unclear what spatial burned area patterns implies here, could you clarify? I would assume the model has more spatially concentrated and intense fires than observations, is that what is implied here, please be more specific.

Response: Thank you for your comment. The phrase was rewritten to be clearer. “In the Cerrado, fire-related emissions were overestimated in the Savanna scenario, particularly in the central part of the biome, reflecting the spatial patterns of burned area.”

### **Response to referee #3**

Sec. 2.2: water stress mortality. I lack explanation why it appears as a separate topic in Methods if no results are reported later related to that, no comparison of results with this type of mortality included and without it.

Response: Thank you for your comment. This was a new function implemented into the LPJmL-VR. We included results and discussion regarding the implementation of the water stress mortality function into the supplementary file (section 2.5 of the supplementary material) and referred to it on the main text (lines 464-467).

Sec. 4.2: While discussion on Amazon part is clear, I think one cannot expect an improvement here from the inclusion of Cerrado type. For the reader, it would be easier to follow the discussion if it was kept closer to the results, consequences of implementation of this PFT. For example, it would be interesting to discuss why the regional distribution of burned areas within Cerrado domain has improved in some areas but worsened in others. Also L647-648, this is not related to discussion of these results, while important for the model in general and can be moved to conclusion

Response: Thank you for your comment. We reformulated this part of the discussion to focus more on the Cerrado biome while still mentioning the Amazon. "In Savannas, there is often extensive use of fire for land management purposes. Specifically, in the Cerrado, fire in natural areas is associated with the use of fire for deforestation and pasture management, with fire escaping to natural areas, while in areas of mechanized agriculture and planted

forests, owners rather protect the areas against fire. In SPITFIRE, however, ignitions are represented solely as a function of population density, and the model does not explicitly capture the diverse fire management regimes common in these regions. This simplification contributes to the underestimation of burned area along the Caatinga border, where expanding deforestation and intensive land management interact with natural fire regimes, as well as in southeastern Amazonia, where large-scale pasture management fires may escape and affect adjacent rainforest (MapBiomas Fogo, 2024; Cano-Crespo et al., 2015). To mitigate this, we weighed both validation data and model outputs by the human land-use fraction from MapBiomas, thereby excluding grid cells with extensive anthropogenic land use from the analysis. Recent attempts to better incorporate anthropogenic fire management into models (Perkins et al., 2024) could enhance Cerrado fire simulations, which is particularly relevant given the increasing pressures on the biome and the ongoing shifts in fire regimes (da Silva Arruda et al., 2024). Nevertheless, even with improved fire-vegetation dynamics, simulations of future trajectories of these dynamics will remain constrained if key vegetation traits, such as deep root water uptake, are not adequately represented (D'Onofrio et al., 2020; Baudena et al., 2015)." We also excluded the sentence from lines 647-648.

L498-499: ET and GPP, the authors report no improvement, but could some numbers please still be put there in the sentence, not sending the reader to supplementary? It would be also nice to have some other numbers in the discussion (more quantitative comparison with previous studies).

Response: Thank you for your comment. We included a more quantitative and detailed description of the ET and GPP improvements in our main text.

*Minor comments:*

L126-130: report numbers that are good to have in mind thinking of the impact of the work done: this is a large biome, and it is not represented in the models. I suggest moving this information to the Introduction.

Response: Thank you for your comment. We moved this information to the Introduction (lines 46-57).

L 134: 'classification system, characterized by a rainy season' – please rewrite

Response: Thank you for your comment. The phrase was rewritten as “According to the Köppen–Geiger classification, the region’s climate is predominantly tropical savanna (Aw) with a rainy season from October to April and a dry season from May to September.”

L147-150: I suggest moving these two sentences to the end of this section. There you already mention impact of fire on the vegetation formations, which you define later, in the next sentence.

Response: Thank you for your comment. We moved these phrases to the end of the paragraph.

L192 *phen* should always be written with small letters even if it starts the sentence.

Response: Corrected. Thank you!

L283: ‘earlier in their lifecycle’: I see from the figure at smaller heights. Fig. 2 does not show how quickly the trees grow, so I am not sure if ‘earlier’ is the correct word

Response: Thank you for your comment. In LPJmL,  $k_{root}$  is one of the parameters that defines how trees allocate carbon during their development. In this case, making them invest carbon in root development at a higher rate compared to other trees in the model.

Root depth and tree height are also linked in the model as they “compete for carbon” in tree development. To reflect that, we changed the sentence for “We reflect this by modifying the shape parameter of the logistic root growth function ( $k_{root}$ , Table 1), enabling TrBS to develop deeper rooting depths already at relatively small tree sizes (Fig. 2), enhancing their belowground competitiveness.”

L328-329: a bit awkward definition of VPD, it is just the difference between actual and saturation water vapour pressure. Also VPD was mentioned earlier but is explained only now.

Response: Thank you for your comment. We changed this sentence to make the definition clearer “VPD is the difference between the saturation water vapor pressure and the actual water vapor pressure in the air and is influenced by both temperature and relative humidity”. Also, we moved the definition to lines 214-215 where we first mentioned this parameter.

L337: this is easy to read as alpha multiplied by VPD. I'd suggest make 'VPD' a subscript to avoid it.

Response: Corrected. Thank you!

L444: 'we weighed the burned area': can you provide the formula or describe better how?

Response: Thank you for your comment. We reformulated the paragraph to be clearer about the weighting. "For the spatial distribution of annual burned area, we created a map of the human land-use fraction based on MapBiomas 9.0 land-use data (MapBiomas, 2024), using the mean value from 1990 to 2019 (Fig. S5). Because our simulations consider only potential natural vegetation (PNV), we multiplied both the validation and modeled area maps by this human land-use fraction. This weighting accounts for fire occurrences in human-managed areas and allows a more consistent comparison between simulated and observed burned area."

L488-492: these two sentences largely repeat each other.

Response: Thank you for your comment. We rewrote the sentences to avoid redundancy. "The inclusion of TrBS PFT significantly improved the simulated above- and belowground biomass patterns across Brazil compared to simulations without it, leading to an improved representation of the 'upside-down forest' in central Brazil (Fig. 5)."

L 492: Fig. 5 should be referenced in the next sentence, which discusses the ratio.

Response: Corrected. Thank you!

L575: not sure 'enhances' is the right word here, 'impacts' could fit better.

Response: Corrected. Thank you!

L576-578 about improved simulations: I am not sure I agree with the whole statement.

Total burned area yes, improved, also its temporal dynamics but spatial distribution of burned area has become somewhere better somewhere worse.

Response: Thank you for your comment. We rewrote the sentence "TrBS improved simulations of carbon allocation, particularly below- to aboveground biomass ratio, and better represented fire behavior, especially the temporal dynamics of burned area."

L609 'future trajectories' of what?

Response: Thank you for your comment. This paragraph was excluded and merged with the paragraph from lines 666-679. The sentence was rewritten in a clearer way. “Nevertheless, even with improved fire–vegetation dynamics, simulations of future trajectories of these dynamics will remain constrained if key vegetation traits, such as deep root water uptake, are not adequately represented”

L620 remove ‘Nevertheless’ it does not fit these sentences

Response: Corrected. Thank you!