Reviewer #1 (Nicholas O'Mara)

Review of Earth System Dynamics manuscript: egusphere-2025-1424

This new compilation is impressive, and the analysis is thorough and detailed. I really appreciate the authors efforts to parse the records by climate/ecology to undergo a nuanced dissection of the competing influences of many factors on vegetation structure and fire regime and how these differ across geographies. The manuscript is very well written. They frame and motivate the problem well, the arguments are logical, the figures are clear and impactful, and it is overall quite pleasant to read. This study warrants speedy publication in Earth System Dynamics following minor revisions. I break down my review into major overarching comments followed by in-line comments and recommendations.

Response #1. We sincerely appreciate the positive assessment of our manuscript.

Overarching comments:

Throughout the manuscript, the term "biomass" appears to be used interchangeably with "tree cover". As a means of estimating vegetation structural change, the authors use the fraction of arboreal pollen in sediment cores. This method estimates the fraction of vegetation in a region which is composed of trees, however this is not a measure of biomass *per se*. All else equal, more trees on a landscape would equate to more biomass, but a ratio alone does not tell you this. Grasses can make up significant portions of the total biomass of ecosystems, particularly in tropical savannas (*e.g.*, Cerrado). The authors should take a careful look at the instances where they make claims about changes in biomass when they are actually measuring tree pollen fraction to infer changes in tree cover. Grass biomass is an important fuel source especially in tropical savannas like the Cerrado, so I urge caution to the authors on broadly equating increased tree cover with biomass in the context of fuel availability. I flag such instances in the in-line comments.

Response #2. Thank you very much for your observation. We will modify such instances accordingly, following your in-line comments by clearly stating woody or arboreal biomass when directly related to our compiled arboreal pollen data.

The description of the charcoal records is insufficient. The authors spend a decent portion of their methods section describing the dominant pollen types in the records that they compiled for each region but only list the number of records for charcoal without further description. Charcoal comes in many forms which record different aspects of fire regimes across multiple spatial scales. For instance, are all of the charcoal in the synthesis microcharcoal? Or are macrocharcoal particle records also included? One must read between the lines and look at the column title in the supplement table to infer this. A more complete description of the charcoal records including at a minimum the size fraction of the records used in this synthesis is needed.

Response #3. We agree that descriptions regarding charcoal data could be clarified and improved. Accordingly, we will have revised the methods to ensure greater accuracy on this topic. More specifically, after standardization, we analyzed both macroscopic (>100µm) and microscopic (<100µm) charcoal data jointly, as performed in Power et al. (2008, 2010), Mooney et al. (2011), Gosling et al. (2021). The following sentence was included:

"*For charcoal composites, both micro- (< 100 µm) and macro- (> 100 µm) particles were included. Charcoal raw counts were converted into concentrations and then to influx using site-specific sedimentation rates, to account for differences in sedimentation rates across sites (Marlon et al., 2016).*"

References:

Gosling, et al.: Scarce fire activity in north and north-western Amazonian forests during the last 10,000 years, Plant Ecol. Divers., 14, 143–156, https://doi.org/10.1080/17550874.2021.2008040, 2021.

Marlon, et al.: Reconstructions of biomass burning from sediment-charcoal records to improve data-model comparisons, Biogeosciences, 13, 3225–3244, https://doi.org/10.5194/bg-13-3225-2016, 2016.

Mooney, S. D., et al.: Late Quaternary fire regimes of Australasia, Quat. Sci. Rev., 30, 28–46, https://doi.org/10.1016/j.quascirev.2010.10.010, 2011.

Power, M. J., et al.: Changes in fire regimes since the last glacial maximum: An assessment based on a global synthesis and analysis of charcoal data, Clim. Dyn., 30, 887–907, https://doi.org/10.1007/s00382-007-0334-x, 2008.

Power, M. J., et al: Fire history and the global charcoal database: A new tool for hypothesis testing and data exploration, Palaeogeogr. Palaeoclimatol. Palaeoecol., 291, 52–59, https://doi.org/10.1016/j.palaeo.2009.09.014, 2010.

The use of charcoal/pollen ratio records in this context surprises me. The authors say they multiply such records by the sedimentation rates of the cores to get an influx like unit, but this cannot be done. For such data to be ecologically meaningful, either (1) the pollen accumulation rate would have to be linearly correlated with the sedimentation rate and not a product of vegetation coverage within the watershed of the lake or (nearby river in the case of marine cores), or (2) the pollen accumulation rate would have to have such low variance that the change in charcoal accumulation rate drives the observed signal. Without convincing evidence in support of either of those scenarios, one cannot expect the charcoal numbers in these ratios to reflect changes in burning on the landscape. I suggest the authors remove such records from the compilation.

Response #4. We appreciate the thoughtful comment regarding the use of pollen/charcoal ratios in our analysis. We agree with the argument, and we will exclude the ratio-based records from the z-score composite curves to maintain methodological consistency. Only four records were based on the pollen/charcoal ratio, two of them were not included in any subregion, one was included in NEB, and one in NNeo. However, for NEB where no composite curve was generated due to the scarcity of available charcoal data, we will keep the pollen/charcoal ratio for qualitative comparison (red curve in Fig. R1.1e – see below). This will be kept as simple charcoal/pollen ratios z-scores to provide at least some regional perspective. Additionally, two other curves were included in the new Fig. 8 (Fig. R1.1a,e), one from a record containing both charcoal and pollen data (Ledru et al., 2006) and another of δD-based reconstructed precipitation from a marine core off NEB.

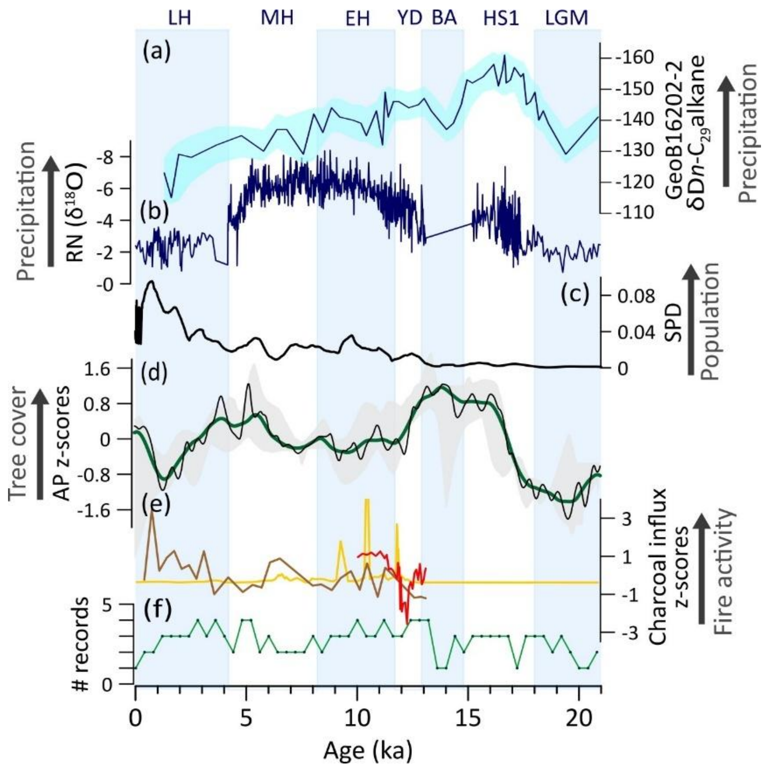

Fig. R1.1. Updated Fig. 8 – Northeastern Brazil (NEB) vegetation, fire, climate regimes, and human occupation: (a) δD n-C_{29} alkane from GeoB16202-2 (Mulitza et al., 2017). (b) Speleothem $\delta^{18}O$ from Rio Grande do Norte cave (RN) (Cruz et al., 2009). (c) Summed density probability of ^{14}C ages from archeological sites in NEB (N = 542) (Araujo et al., 2025). (d) Arboreal pollen (AP) z-scores composites using 1000-yr (green) and 400 yr (black) smoothing half-window. Gray areas represent 2.5th and 97.5th confidence intervals. (e) Charcoal influx z-scores from single sites (yellow: Ledru et al. (2006); brown: De Oliveira et al., 1999; red: Bouimetarhan et al., 2018). (f) Number (#) of records with available pollen data in a 400-yr time bin.

Reference:

Ledru, M. P., et al.: Millenial-scale climatic and vegetation changes in a northern Cerrado (Northeast, Brazil) since the Last Glacial Maximum, Quat. Sci. Rev., 25, 1110–1126, https://doi.org/10.1016/j.quascirev.2005.10.005, 2006.

Figure 1 would benefit from a panel plotting either the fire radiative power or burned area data used in the modern analysis. The amount of burning across these biomes is highly variable. A map of where fires occur today would help the reader in interpreting the paleorecord compilations presented here.

Response #5. Thank you for the suggestion. We will include fire activity along with vegetation distribution. A preliminary updated version of Fig. 1a that includes fire activity can be checked below (Fig. R1.2).

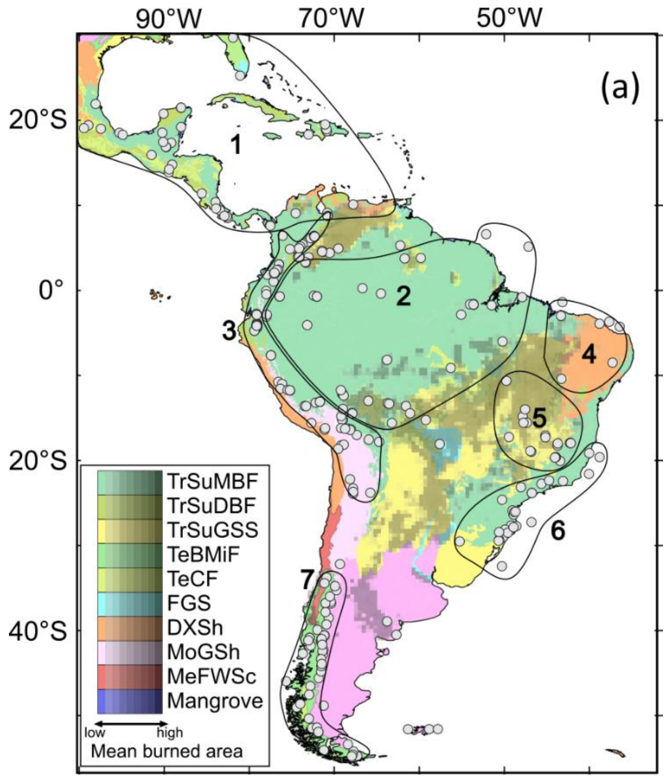

Fig. R1.2. Updated Fig. 1 – Vegetation and climate settings of the Neotropics. Studied sites (white circles) and target subregions (numbered polygons) are depicted. **(a)** Ecoregions from Oslon et al. (2001): TrSuMBF – Tropical subtropical moist broadleaf forests; TrSuDBF – Tropical subtropical dry broadleaf forests; TrSuGSS – Tropical subtropical grasslands, savannas, and shrublands; TeBMiF – Temperate broadleaf mixed forests; TeCF – Temperate coniferous forests; FGS – Flooded grasslands and savannas; DXSh – Desert and xeric shrublands; MoGSh – Montane grasslands and shrublands; MeFWSc – Mediterranean forests, woodlands, and scrubs . Mean burned area of the last 12 years from Laurent et al. (2018).

I would encourage the authors to emphasize that the majority of the sites in this study, except those in region 5 (Central Eastern Brazil) in the Cerrado, are currently situated in more forested regions that do not burn as much as tropical savannas. This would tie in within the results of the modern analysis (Figure 3) to show that one might expect more fire in the past if grasses where a more dominant fraction of the local vegetation.

Response #6. This helpful comment prompted us to strengthen the connection between Section 5.1, “Modern climate–fire–vegetation relationships”, and the subsequent discussion of regional patterns. We would like to emphasize, however, that some areas currently covered by mostly forested vegetation were dominated by more open vegetation types in the past. This is particularly evident in Southeastern South America (SESA) (Fig. R1.3) and Southern Andes (SAn). In SESA, for example, we observe a shifting relationship between tree cover and fire activity over time, with both arboreal pollen (AP) and charcoal increasing during Termination 1, followed by a continued rise in AP and stabilization of fire activity. Therefore, while only the Cerrado and high-altitude Andes are predominantly covered by open vegetation under modern conditions, regions such as SESA and SAn were also covered by open vegetation in the past and likely exhibited different fire–vegetation dynamics (e.g., Fig R1.3).

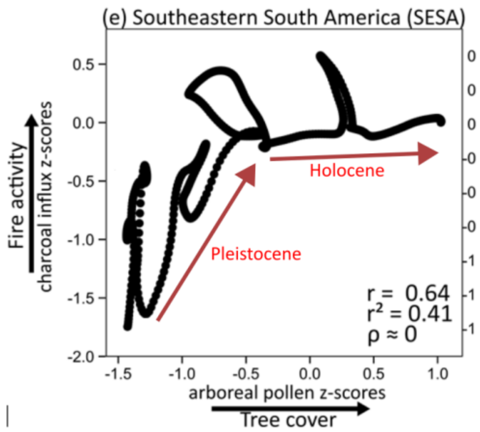

Fig. R1.3 – Correlation between arboreal pollen z-scores and charcoal influx z-scores in Southeastern South America (SESA).

"These fire-prone conditions are typical of tropical savannas and grasslands (Fig. 3a,b), such as in CEB, where a regular frequency of fire events is key in maintaining biodiversity and the physiognomy of vegetation (Bernardino et al., 2022; Mistry, 1998). In modern day CEB, however, fire regime is mostly limited by fuel moisture (moisture-limited condition, negative biomass-fire correlation), except towards its transition to semiarid conditions (Fig. 3a,b) (Alvarado et al., 2020). In arid and semiarid environments, such as NEB, or high-altitude areas, such as CAn, fire activity is generally hindered due to biomass limitation (fuel-limited conditions, positive biomass-fire correlation) (Fig. 3a-e). On the other hand, under wet conditions of tropical rainforests, such as Amazonia or parts of NNeo, fire activity is limited due to constant fuel moisture (moisture-limited condition) (Fig. 3a,b)."

Figures 12 and 13. I really like the time snapshot analysis presented in these figures. However, it is a little bit difficult to have to read across the panels and compare the colors between points to see if the z-scores increased or decreased through time by comparing the color to the previous time slice. When I first looked at these maps, I expected that they were displaying the trends rather than the mean z-scores for the time slice. One minor change you could make to these figures would be to change the markers depending on whether the mean z-score increased or decreased compared to the last time slice. *E.g.*, upward triangle for increase above some threshold between 21-19 to 19-14.8, downward triangle for decrease below some threshold, and circle for no change outside of some threshold. This would really help as the reader is going through your later portion of the discussion when you are providing a broad overview of the trends through time. Additionally, the time slice labels are backward, they should be in chronological order, *e.g.*, "(c) 21 – 19 ka". You have it right in the figure caption, just reversed in the panel labels.

Response #7. We improved the description on how to interpret these maps in the methodology.

"*Each site-specific data point represents a mean z score calculated relative to its own long-term mean (base period: 21,000 to 200 yr BP). As a result, the colors of the dots within a single map reflect deviations from local baseline conditions and should not be directly compared across sites to infer geographic gradients or absolute levels of fire activity or tree cover. However, spatial clusters of similar z-score trends, such as consistently positive values in a region, may indicate coherent regional patterns, for example a general expansion in tree cover or intensification of the fire regime.*"

We will also fix the backward labels mentioned. However, we prefer not to represent changes using different symbols, as this may introduce even more complexity. In some cases, sites may not display continuous changes between time slices due to, e.g. hiatuses or sampling resolution, which would require an additional symbol to distinguish these instances from increases, decreases, or stable conditions. We decided to use this approach as it has already been successfully used in other studies (e.g., Marlon et al., 2016; Mooney et al., 2011; Power et al., 2008). As a side note, in Power et al. (2008), triangles are used, but simply to indicate positive or negative z-scores for a given timeslice.

References:

Marlon, et al. Reconstructions of biomass burning from sediment-charcoal records to improve data-model comparisons, Biogeosciences, 13, 3225–3244, https://doi.org/10.5194/bg-13-3225-2016, 2016.

Mooney, S. D. et al.: Late Quaternary fire regimes of Australasia, Quat. Sci. Rev., 30, 28–46, https://doi.org/10.1016/j.quascirev.2010.10.010, 2011.

Power, et al.: Changes in fire regimes since the last glacial maximum: An assessment based on a global synthesis and analysis of charcoal data, Clim. Dyn., 30, 887–907, https://doi.org/10.1007/s00382-007-0334-x, 2008.

Regarding data availability, I suggest that the authors make the smoothed z-score time series of AP and charcoal influx available in the supplement or permanently stored in a public archive. These new synthesis curves are valuable information for paleoclimatologists, paleoecologists, anthropologists, climate modelers, *etc.*, who might wish to compare them with their data. As I am sure the authors are aware from the webplotdigitizing they did for this study, it is always a relief when the key data for a paper are easily accessible for future analysis and plots don't need to be unnecessarily and painstakingly recreated.

Response #8. We agree. All composite curves will be provided as Supplementary data.

In-line comments:

19-20: I suggest you remove the "in the one hand" and "on the other hand" they are just not necessary to the point of the sentence which is already clear and concise.
Agree.
24-25: Perhaps add "with additional impacts from human activity" to the end of the sentence which starts with "Temperature …"
Agree.
26: "Biomass growth" this should be "tree growth"
Agree, but we opt for "arboreal growth".
46: "process" should be "processes"
Agree.
50: Glacial/interglacial cycles were occurring (although much more muted) in the Neogene. I suggest you change this to something like "onset of pronounced glacial/interglacial cycles in the Quaternary"
Agree.
51: Change "were responsible for" to "played a significant role in"
Agree.
52: Please clarify here if you mean in setting the modern ecosystem distributions or modulating changing ecosystem distributions through time.
Agree.
56-57: "Weaker fire regime" is not very clear to a general reader. I am okay with the use of weaker and stronger fire regimes throughout the paper, but take a sentence here to explain what characteristics constitute and "weak" versus "strong" fire regime. Additionally, you could maybe also clarify also here what "fire activity" means because you use this general term in the text as well.
Agree. We will provide some explanation in the method section, to avoid a break in the introduction for explaining the concept. While our approach does not allow us to distinguish specific aspects of the fire regime such as intensity, severity, frequency, seasonality, spatial extent of the burned vegetation, we use the broader

terms "fire regime" or "fire activity" to reflect the general response of fire to environmental changes, which is directly interpreted from values of charcoal influx. "*Changes in charcoal records can be linked to past fire activity and used to infer shifts in fire regimes. While our approach does not allow us to resolve specific components of the fire regime (e.g., intensity, severity, frequency, seasonality, spatial extent of burned vegetation), we consider fire regime as the collective changes in charcoal influx trends within a given region over a long timescale. We use fire activity as a more general term to describe variability in charcoal influx.*"

Also see our Response #5 to Reviewer #3 (Paula A. Rodríguez-Zorro).

81 and throughout: You interchange "mm.yr-1" and "mm yr^{-1}" I recommend you adopt the second in all cases, the added period is unnecessary.

Agree.

86-87: "...marked by weak seasonality with mean monthly temperatures ranging between 25 and 27 °C and mean annual precipitation of..." would be better as a comma-separated list: ""...marked by weak seasonality, mean monthly temperatures ranging between 25 and 27 °C, and mean annual precipitation of..."

Agree.

93-94: It is not clear to me which positive feedback loop you are referring to. *E.g.* fire impacts on vegetation structure and knock-on effects on temperature and future fire likelihoods, fires emitting greenhouse gases leading to overall warming and thus more fires, *etc*. Please clarify.

Agree. We will change to "*Persistent moist conditions of the rainforest naturally inhibit wildfires. However, initial fire events whether triggered by severe droughts (e.g., related to El Niño), ongoing climate changes, and/or human impacts further increase forest flammability through canopy degradation and fuel accumulation. This favors subsequent fire events, thereby fostering a positive feedback loop (Brando et al., 2020; Bush et al., 2008; Cochrane et al., 1999; Nepstad et al., 1999).*"

99: "area" should be "areas"

Agree.

103-104: "moist-laden" should be "moisture-laden"

Agree.

199: I suggest you change "...open grasslands to closed shrublands and woodlands..." to "...open grasslands and savannas to closed shrublands and woodlands..."

Agree.

121: "...the occurrence South Atlantic..." should be "...the occurrence of the South Atlantic..."

Agree.

125-145: This is largely a style choice, so up to you, but in all preceding paragraphs you list temperature ranges from low to high (which is convention) but here you list high to low. I see that you might be doing this intentionally as you describe the regions from north to south, but it is a little weird to read temperature ranges from 16 to 3 °C.

Thank you for noting this. The reversed temperature sequence (16 to 3°C) was indeed intentional to match the north-to-south latitudinal progression (32°S to 55°S). We will adapt the text to "Mean annual temperature ranges from 3 to 16 °C between the latitudes 55 and 32°S".

140: "…southward-displaced…" should be "…southwardly displaced…"

We will slightly modify this part to "*Precipitation is controlled by the Southern Westerly Winds (SWW), which shift southward during austral summer,* […]"

165: For example, here is the only place in the text you mention microcharcoal. See overarching comments for method recommendations.

This comment was addressed in the overarching comments above.

201-203: "For charcoal composites, …" You need to either provide strong justification that this is a viable method or remove such records from the compilation. See overarching comment.

Agree.

295: "Despite represented by…" should be "Despite being represented by…"

Agree.

303: Is this a mistaken paragraph break at the end of this line?

This was intentional as an introduction sentence for the following paragraphs in which we describe the distinct regional patterns. We included a ":" to the end of this line to make it clearer.

315: Figure 4 should have y-axis labels. A single label common for all subplots would be fine. The two columns appear unnecessarily squished together horizontally; I think you can add a little separation between the two which should give ample room for the y-axis labels.

Indeed. Thank you for the suggestion. We will fix Fig. 4 accordingly.

341: "…high level…" and "…fire regime…" should be "…high levels…" and "…fire regimes…"

Agree.

349: "p-values" can just be "p"

Agree.

351: "condition" should be "conditions"

Agree.

354: drop the "and" before "likely"

Agree.

359: "…coeval to…" should be "…coeval with…"

Agree.

357-358: I do not really see a slope break? The decline appears to be part of the larger trend of declining AP % since the EH. So, I would avoid calling it abrupt.

We will remove the word “abrupt.” Our intention was to convey that the Late Holocene decline in tree cover appears more pronounced than the gradual decrease observed since the Early Holocene, which we interpret as a shift likely amplified by direct human activity.

378: “…featured a reduced…” should be “…featured reduced…”

Agree.

380-382: I thought Amazonia is generally moisture limited, so isn’t it surprising that low rainfall leads to low fire activity?

Yes, indeed, multiple interacting forcings contribute to a complex response. For example, the Amazon is a highly heterogeneous and predominantly fire-limited ecosystem, with marked west–east and north–south gradients. During the LGM, eastern Amazonia is interpreted to have been drier (Häggi et al., 2017; Wang et al., 2017) while western Amazonia was wetter, or as wet as modern conditions (Baker et al., 2001; Cheng et al., 2013). In addition, the southern and eastern Amazon rainforests were relatively smaller compared to their pre-Industrial extension (Mayle et al., 2000), possibly as a consequence of lower CO_2 (Maksic et al., 2022) and drier conditions (Fontes et al., 2017).

Despite these regional contrasts, charcoal records consistently indicate low fire activity during the LGM and part of Termination 1 across the eastern (Hermanowski et al., 2012), central-northern (Blaus et al., 2024; Bush et al., 2004) and southern (Cordeiro et al., 2014; Fontes et al., 2017) Amazonia. A different scenario is reported for southwestern Amazonia (Burbridge et al., 2004) with decreasing fire activity towards the Holocene. Over eastern and southern Amazonia, forest vegetation was largely replaced by savannas during the late Pleistocene. This seemingly counterintuitive pattern may be explained by colder temperatures, reduced convective activity (and consequently fewer lightning ignitions), or even increased megafauna herbivory limiting fuel accumulation. We will incorporate this point into the discussion.

References:

Baker, et al.: The history of South American tropical precipitation for the past 25,000 years, Science, 291, 640–643, https://doi.org/10.1126/science.291.5504.640, 2001.

Blaus, et al.: Climate, vegetation, and fire, during the last deglaciation in northwestern Amazonia, Quat. Sci. Rev., 332, 108662, https://doi.org/10.1016/j.quascirev.2024.108662, 2024.

Burbridge, et al.: Fifty-thousand-year vegetation and climate history of Noel Kempff Mercado National Park, Bolivian Amazon, Quat. Res., 61, 215–230, https://doi.org/10.1016/j.yqres.2003.12.004, 2004.

Bush, et al.: Amazonian paleoecological histories: one hill, three watersheds, Palaeogeogr. Palaeoclimatol. Palaeoecol., 214, 359–393, https://doi.org/10.1016/S0031-0182(04)00401-8, 2004.

Cheng, et al.: Climate change patterns in Amazonia and biodiversity, Nat. Commun., 4, 1411, https://doi.org/10.1038/ncomms2415, 2013.

Cordeiro, et al.: Palaeofires in Amazon: Interplay between land use change and palaeoclimatic events, Palaeogeogr. Palaeoclimatol. Palaeoecol., 415, 137–151, https://doi.org/10.1016/j.palaeo.2014.07.020, 2014.

Fontes, et al.: Paleoenvironmental dynamics in South Amazonia, Brazil, during the last 35,000 years inferred from pollen and geochemical records of Lago do Saci, Quat. Sci. Rev., 173, 161–180, https://doi.org/10.1016/j.quascirev.2017.08.021, 2017.

Häggi, et al.: Response of the Amazon rainforest to late Pleistocene climate variability, Earth Planet. Sci. Lett., 479, 50–59, https://doi.org/10.1016/j.epsl.2017.09.013, 2017.

Hermanowski, et al.: Palaeoenvironmental dynamics and underlying climatic changes in southeast Amazonia (Serra Sul dos Carajás, Brazil) during the late Pleistocene and Holocene, Palaeogeogr. Palaeoclimatol. Palaeoecol., 365–366, 227–246, https://doi.org/10.1016/j.palaeo.2012.09.030, 2012.

Maksic, et al.: Brazilian biomes distribution: Past and future, Palaeogeogr. Palaeoclimatol. Palaeoecol., 585, 110717, https://doi.org/10.1016/j.palaeo.2021.110717, 2022.

Mayle, et al.: Millennial-Scale Dynamics of Southern Amazonian Rain Forests, Science (80-.)., 290, 2291–2294, https://doi.org/10.1126/science.290.5500.2291, 2000.

Wang, et al. Hydroclimate changes across the Amazon lowlands over the past 45,000 years, Nature, 541, 204–207, https://doi.org/10.1038/nature20787, 2017.

385-389: This intra-region spatial variability is really interesting. Are there enough records to split Amazonia up further and potentially make curves of E vs W or N vs S? If so, that could make for a nice supplementary figure. But if not, okay!

This would be indeed very interesting. However, to carry out such analysis we would have to limit our scope to the Holocene and focus on Amazonia. Particularly, more detailed discussions on Holocene fire and vegetation in Amazonia have been done in Gosling et al. (2021), Smith et al. (2018), and Mayle and Power (2008), for example. Still, we will include some of these nuances and references related to regional heterogeneity in the discussion.

References:

Gosling, et al.: Scarce fire activity in north and north-western Amazonian forests during the last 10,000 years, Plant Ecol. Divers., 14, 143–156, https://doi.org/10.1080/17550874.2021.2008040, 2021.

Mayle, F. E. and Power, M. J.: Impact of a drier Early–Mid-Holocene climate upon Amazonian forests, Philos. Trans. R. Soc. B Biol. Sci., 363, 1829–1838, https://doi.org/10.1098/rstb.2007.0019, 2008.

Smith, R. J. and Mayle, F. E.: Impact of mid- to late Holocene precipitation changes on vegetation across lowland tropical South America: A paleo-data synthesis, Quat. Res. (United States), 89, 134–155, https://doi.org/10.1017/qua.2017.89, 2018.

436: "...the influence different..." should be "...the influence of different..."

Agree.

438: "moist-laden" should be "moisture-laden"

Agree.

441: "...speleothem cores suggest primarily reflect..." remove either "suggest" or "primarily reflect"

Agree.

444-446: This is an interesting point. I wonder if you could comment further here about the potential impacts of llama grazing on grassy fuel loads?

It is challenging to disentangle the specific impacts of llama grazing from broader human influences at this stage. However, if considering grazing pressure alone, increased llama activity could have reduced grassy fuel loads, consistent with findings from other regions where megafauna or livestock grazing limits fine flammable biomass (Blackhall et al., 2017; Fuhlendorf and Engle, 2004; Furquim et al., 2024; Gill et al., 2009), even though the grazing-fire relationship is not always straightforward (e.g., Blackhall et al., 2017). Additionally, the continued anthropogenic use of fire may have sustained relatively high fire activity, potentially offsetting the fuel-reducing effects of llama grazing alone. Warming conditions and an increase in fuel availability could also have contributed to more intense fires.

While our primary goal is to provide a broader overview of vegetation and fire dynamics, we acknowledge the relevance of this point. In response to this and a comment from Reviewer #2, we will include a few remarks throughout the discussion considering the influence of grazing, even though it was likely of secondary importance considering the timespan of our analyses and human impacts during the Holocene.

References:

Blackhall, et al.: Effects of biological legacies and herbivory on fuels and flammability traits: A long-term experimental study of alternative stable states, J. Ecol., 105, 1309–1322, https://doi.org/10.1111/1365-2745.12796, 2017.

Fuhlendorf, S. D. and Engle, D. M.: Application of the fire-grazing interaction to restore a shifting mosaic on tallgrass prairie, J. Appl. Ecol., 41, 604–614, https://doi.org/10.1111/j.0021-8901.2004.00937.x, 2004.

Furquim, et al.: Interactive effects of fire and grazing on vegetation structure and plant species composition in subtropical grasslands, Appl. Veg. Sci., 27, 1–13, https://doi.org/10.1111/avsc.12800, 2024.

Gill, et al.: Pleistocene Megafaunal Collapse, Novel Plant Communities, and Enhanced Fire Regimes in North America, Science, 326, 1100–1103, https://doi.org/10.1126/science.1179504, 2009.

501-505: It seems to me that the high rainfall observed during HS1 and during the YD ◊ EH match peaks in the charcoal influx and BA matched a trough in the charcoal influx, suggesting fuel limited conditions which would make sense for the Cerrado savanna vegetation.

These specific millennial-scale changes may suggest fuel-limited conditions during Termination 1. However, the long-term negative correlation between tree cover and fire (Fig. 9c-d of the original version of the manuscript) points to moisture-limited conditions. Uncertainties in regional patterns and chronology pose additional challenges in interpreting these short-term variabilities. Moreover, most of the Cerrado today is considered moisture-limited, with the exception to its transition to drier vegetation types (Alvarado et al., 2020). Taken together, we see robust arguments not to change the original interpretation on this specific point.

Reference:

Alvarado, et al.: Thresholds of fire response to moisture and fuel load differ between tropical savannas and grasslands across continents, Glob. Ecol. Biogeogr., 29, 331–344, https://doi.org/10.1111/geb.13034, 2020.

Also, what do you think happened *ca*. 19-17 ka? Why are the z-scores for charcoal influx so low? It's hard to tell from the figure, but does the number of records go to zero at points in this interval? It would be good to comment on this. And perhaps obscure portions of the curve which might have very low confidence due to lack of sufficient data.

This is likely an artifact resulting from the scarcity of data during this period, which makes the composite curve highly unstable and sensitive to specific records. Thus, we are not interpreting such features. The negative value reaches –2.2.

We have now included in the method section the following note of caution:

"*Caution is warranted when interpreting trends during periods with wide confidence intervals or when the composite curve approaches the upper or lower bounds of the confidence interval, or exhibits outlier shifts. These cases usually relate to periods with few records and indicate greater uncertainty and sensitivity to individual records. Strong fluctuations during such periods are likely highly uncertain and may reflect local variability of specific sites.*"

517: "Biomass growth" should be "tree growth"

Agree.

517-518: "moist-laden" should be "moisture-laden"

Agree.

535-536: I would recommend "biomass" in both cases should be "tree cover"

Done for the second case. In the first case we changed to woody biomass.

545: "biomass" should be "tree cover"

Changed to arboreal biomass.

566: "This was likely consequence from significantly…" should be "This was likely the consequence of significantly…"

Agree.

568: "tree cover increases along warming…" should be "tree cover increases along with warming…"

Agree.

574: "biomass" should be "tree cover"

Changed to woody biomass.

589-590: The human population was already quite high by 7 ka, so why is the influence on fires delayed until 3.5 ka?

Humans were very likely to influence fire during the Mid-Holocene and even earlier. However, their regional impact became more evident (in our results) when both tree cover and humidity increased over the region and, unexpectedly, fire activity also increased. This likely suggests a superimposed impact of human activity on the background natural trend.

604: “biomass” should be “tree biomass”

Agree.

606: I think it is worth pointing out to the readers that Haas et al., (2023) is a modeling study and we do not yet fully understand the impacts of low atmospheric CO_2 on global fire regimes.

Agree.

Overall, I really enjoyed this well-written and interesting paper, and I am excited to see the manuscript published following these revisions. Nice work!

Thank you very much for the throughout revision and insightful comments.