

How Climate Change and Deforestation Interact in the Transformation of the Amazon Rainforest

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This file contains all reviewer reports in order by version, followed by all author rebuttals in order by version.

Version 0:

Reviewer comments:

Reviewer #1

(Remarks to the Author)

- What are the noteworthy results?

In their article, the authors disentangle the effects of regional deforestation and global climate processes on climate parameters during the past 35 years in the Amazon basin. While in respect of temperature change global processes play the dominant role, the authors identify deforestation as the dominant driver of in tendency decreasing precipitation. In contrast, the effect of deforestation on the atmospheric concentrations of the greenhouse gases CO₂ and CH₄ is negligible.

- Will the work be of significance to the field and related fields? How does it compare to the established literature? If the work is not original, please provide relevant references.

There are numerous studies investigating (1) the effects of deforestation in the Amazon on global climate, (2) the impacts of global climate change on the structure and stability of the Amazon biome and (3) regional climate effects from deforestation. Many of these studies focus on future developments (scenario analyses) and apply dynamic climate models.

To my knowledge, this article is the first attempt to differentiate between regional and global drivers and their respective impacts on regional climate. From this perspective, I regard the research as highly original and relevant for a better understanding of climate change drivers in the Amazon. In particular, since the authors put a strong emphasis on retrospective analyses, their work is an important addition to the aforementioned simulation-based analyses.

- Does the work support the conclusions and claims, or is additional evidence needed?

While to the most part, the conclusions and claims are well supported by the study results, from my point of view, it is not valid to draw conclusions related to non-linear effects such as tipping points or a potential dieback of the Amazon biome (or biome shift). In this sense, I ask the authors to add a critical reflection of the limitations of their analytical approach – either in the Preserving Amazonia's forest... or the "Conclusion" section.

- Are there any flaws in the data analysis, interpretation and conclusions? - Do these prohibit publication or require revision?

I think a careful revision is required. My three arguments:

(1) As pointed out, I am sceptical about using the introduced methodology for future projections as it does not replicate dynamic processes but in its core just extrapolates historic trends. The authors should also avoid the term simulation (page 6/22, line 199) and include a critical reflection in the manuscript (see above).

(2) My second question is why the authors only present results for the dry seasons and neglect wet seasons (except figures 4 and 6 in the supplement).

(3) Thirdly, the analysis as presented is conducted for fixed 300 km cells (areas). In order to further explore the behaviour of the presented methodology, it would be interesting to investigate how sensitive it is to scale, e.g. by systematically modifying the size and position of the cells.

- Is the methodology sound? Does the work meet the expected standards in your field?

The authors combine statistical analysis with methods from (real) analysis. To my understanding, the presented method is simple (in a positive sense), sound and robust. As I am not a mathematician by training, I would ask the editors to get another opinion from that side.

- Is there enough detail provided in the methods for the work to be reproduced?

The authors use a wide variety of datasets with different temporal coverage and spatial resolution to (if I understood correctly) generate the aggregated data for the 29 cells/areas they use for their analysis. Here a more detailed description of the data aggregation and fusion processes is required. In addition, I suggest providing the source codes of the scripts used for data analyses/aggregation.

Reviewer #2

(Remarks to the Author)

Review of: How climate change and deforestation interact in the transformation of the Amazon rainforest

Broad thoughts:

This is an important and timely piece of research which aims to disentangle the effects of land cover change and climate change in the Brazilian Legal Amazon. The research is of good quality, and I believe should be published. Currently I find the structure of the article hard to follow as a story and the figures and results are not well described nor put in context. As detailed below, the reliance on supplementary figures and references to details contained within the methods make reading this article quite challenging and present significant barriers to comprehension, in my opinion.

The main novelties are separating the climate change and land cover responses, and finding that temperature has a non-linear response, contrary to what other works have shown. I recommend perhaps considering a different order of figures to communicate this story more effectively. The messages within the current sub-headings don't seem focussed on the heading, i.e. in "Preserving Amazonia's Forest Cover: Understanding its Importance and Anticipating Future Impacts", two paragraphs pass, before there is a mention of future changes. Therein, there is insightful discussion of results in context, hence I believe, with a reorder, this could be a good and effective manuscript.

If these amendments cannot be achieved within the constraints of this journal, I would encourage to authors to think about whether this is more possible elsewhere.

Why BLA not amazon biome

How were boxes chosen? Add briefly to L51 etc (i.e. maximum number of cells within the domain, not including water?)

What forest data?

Why including other land covers?

Why say tipping point? Do you reference this/ make an assessment?

Why just dry season?

Add Data summary table for referencing on L57 and throughout

Specific thoughts:

In abstract: clarify whether you mean deforestation has impacted amazonian dry season precip and temperatures. Currently it could read like these are impacting global temperatures and precip.

L29: Perhaps in the intro somewhere you could explain why you use maximum (daytime?) dry season temperature as your indicator in the analysis. I think this is an important point, that you're choosing not to use average daily temperature.

L46: "Our study reveals that changes in temperature and precipitation in the dry season are critical for the fate of the Amazon under the combined pressure of climate change and deforestation." I think this is more for the conclusions/ abstract rather than the introduction in my opinion.

F1 caption: I find it unclear using a satellite basemap as you overlay your own green colour for forest. Where is the forest data from, would be good to cite the data here so readers can understand what they're looking at at a glance i.e. Hansen et al., 2013. Similarly, I'd like a bit more specific info about the land covers shown in the figure (and source(s)), rather than just various. If they're not crucial to the story, consider removing them from this plot. Figure 1 needs to set the scene and at the moment, a reader glancing through the figures isn't sure what to take from this.

F1: At present, I'm not sure if this is a main text figure. A suggestion could be to combine the panels into one forest cover change map, overlaid with the boxes, since the other land covers don't seem to matter in this analysis? I would also suggest removing the satellite land cover background as it distracts from the important elements you're trying to convey, i.e. that forest is being lost, particularly in the southeast.

L68: I'd prefer citations or names of datasets here, you can then point to the section, and or data table where the reader can look for more info. The data choices are very important to the results, hence should be a main feature of the text.

L70: which variables? Would be better to be a little more specific here, otherwise the reader hasn't gained anything.

L72: Really interesting and engaging way of conveying this result.

L78: I appreciate the need to be concise on words, however I do think you could briefly summarise these choices here and condense: "For a complete understanding of our approach and rationale, we refer readers to the section Data and Methods, subsection Definition of Wet and Dry Season, and 80 Data Processing, where a detailed explanation and justification are provided" to just "(See methods)". I really think this crucial info should be in the main text, rather than only in methods. As you say, the effects are different in the wet and dry season, the reader wants then to know why and how.

F2: can you say whether these linear and log fits are significant? Panel a) has a lot of data spread and it isn't immediately clear whether this would be significant. Consider printing r^2 and p values on the plot or in caption text to add robustness.

L92: Far too vague, must include some insight in the main text. If they're important enough results to mention in the main text, they should either be in a main text figure, or explicitly described in text.

L113: I wonder whether a journal with a greater number of figures would be more suitable here as in my view supplementary figures shouldn't be referenced as main figures in the text. They seem here to be used to tell parts of the main story, so should probably be main text figures. Either this or reframe the sentences so that these figures are merely adding nuance and robustness to the story.

L129: what do you mean by saying "we have accurately quantified"?

L133: Figure 4 is mentioned before Figure 3, this needs reordering, either of figures or describing figure 3 earlier. Indeed when Figure 3 is mentioned, I don't believe the results are fully described and put in context. Figure 3 has some really nice results and clearly shows the contributions to each change. I believe this should be more thoroughly described and explained. As far as I can tell, Figure 4 is repeating the information from Figure 3? It is a really nice synthesis of the information in a good looking figure, but I wonder if both figures are needed in the main text.

L139: How do these increases compare to previous work?

L143: It would be helpful to be more explicit when you say "These results highlight the synergistic interaction".

L184: To me, the following seems like a conclusion, rather than an opening for a discussion on the future impacts. Perhaps it could be moved to the conclusions, or reordered in this section. "This study shows the impact of global and land-use changes on the variables examined. Deforestation mainly drives the meteorological variables during the dry season. When considering all study areas across the Brazilian Amazonian region between 1985 and 2020, deforestation is associated with a daily maximum temperature increase of approximately 16.5%, equivalent to a temperature rise of 0.39 °C. Deforestation also has a dominant influence on the reduction in total annual rainfall. It is responsible for 74.5% of the total decrease in precipitation, resulting in a net 15.8 mm reduction in annual rainfall during the 35 years. On the other hand, deforestation had a smaller impact on GHG concentrations, which were driven predominantly by global changes."

L196: This is an important result and should be highlighted better in the paragraph, better still, within the section where you talk about the figure it relates to "within the first 10%-40% of coverage loss". I'm not sure how most of this paragraph relates to the subheading title "Preserving Amazonia's Forest Cover: Understanding its Importance and Anticipating Future Impacts".

L206: To me, this discussion of tipping points isn't central enough to the analysis for it to be referenced in the abstract. Rather I would focus on your good and important results.

L245: I think this is still a proposed tipping point, rather than a certainty?

L275: Previous analysis has found there to be strong discrepancy between precipitation datasets in particular, but also temperature datasets with respect to their changes due to deforestation. How did you choose these datasets and (also why a near surface, not a land surface temperature) and is there any way the choice of dataset might impact your result. Perhaps something worth mentioning in the text somewhere.

L290: Reading this section makes me think that some version of Supplementary Figure 5 really should be in the main text, perhaps in lieu of removing Figure 1? The results are really interesting and important. In addition to this, I'm still quite unclear as to why you are only presenting the dry-season in the main text. Is there a justification for this?

Table 1: might be useful to display some of these stats on the relevant figures, so readers can view this at the same time as seeing the results.

Figure S1: Would be nice to see this in map form as well, perhaps as a multi panel plot. You could take Figure 1 and combine with this as a new Figure S1.

Figure S5: small point, the panels are not in the same order as other plots. It would be visually helpful to be consistent, so it

is easier to flick between plots.

Editorial comments:

L83: processes for should be processes form?

L103: I'm unclear about what you mean by exchange effects. Perhaps this is obvious to others, but if not it could be worth elaborating what you mean.

L111: consider adding numbers to these data subsections, to reduce main text word count. i.e. see methods section 1.x.

L127: Possibly could condense the following into the subsequent sentence as this has already been said before: "The central question we sought to address is the extent to which the observed changes can be attributed to global climate change versus the effects of deforestation."

Reviewer #3

(Remarks to the Author)

How Climate Change and Deforestation Interact in the Transformation of the Amazon Rainforest

Reviewer summary:

Abstract:

Please provide a short explanation of the methods in the abstract.

Are 21 millimeters in the dry season and over 35 years statistically significant?

The statement on non-linear behavior and tipping points without a short explanation of methods looks confusing.

Introduction:

About the carbon and water fluxes: Please consider using some new references: <http://dx.doi.org/10.1088/2515-7620/adc06a> and <http://dx.doi.org/10.1038/s41598-025-85272-z>

Line 25: I'm not sure about the statement that the Amazon basin controls all these globally critical issues. For instance, critical freshwater is about "blue" and "green" water availability pre- and post-industrial times. However, the authors showed transgressions in these attributes even during pre-industrial events. This makes sense, even nowadays, several studies have shown some resilience in hydrological processes in the Amazon in recent events.

Line 36: You should check the Amazon basin area. It is about 6 mi km², and if you consider Tocantins, it reaches 7 mi km². But, if your study area is Legal Amazon, this number drops slightly.

Line 43: Some studies assessed the combined effect of deforestation and climate in the Amazon's watersheds. For instance, <https://doi.org/10.1029/2019WR025083>.

Line 30: I missed more studies that assessed the effects of climate change in different variables (e.g. hydrology, biodiversity, etc), even in small basins. I suggest a more detailed review of these papers.

Quantifying global and regional effects across Brazilian Amazon areas:

You could explain better how the assessment was in each area. Did you evaluate the fluxes pixel by pixel? The mean, median...?

Figure S1: You should categorize the bars by region using different colors (e.g., pristine areas, the arc of deforestation, and so on).

Evaluation of the deforestation and global climate change effects

Line 77: "Our study....". This phrase isn't in the right place. You could use it in the abstract or introduction, but not in this section.

Line 81: Is this section about results? You began to explain some methods (method), and after that, you showed results ("our analysis reveals..."). You should replace some parts of the method section.

Figure 2: I didn't understand the relationship between the temperature increase (in Figure 2) and climate change. I can see a noticeable rise in temperature with an increase in deforestation. How did you isolate climate change using $Temp = f(D, time)$?

Modeling the evolution of atmospheric variables

Line 106: I understand equations 6 and 7, but it is not clear that

Equation 1: Please explain how "B" is a parameter related to global forces/global changes.

Disentangling the Influence of Deforestation and Global Climate Change on the Amazonian Atmosphere

How did you use the equations in Table 1 to find 87 ppm and 173 ppm (CO₂ and CH₄)?

This is because your data set analysis focused only on the study area. So, the global influence is not clear.

Version 1:

Reviewer comments:

Reviewer #1

(Remarks to the Author)

Overall I think the authors comprehensively addressed the reviewers' comments and significantly improved the clarity of their manuscript.

All that is left from my side is minor remark regarding the sensitivity analysis related to the size of their study plots in Figure S1. Especially the variety between the different precipitation results shown in the lower part of the panel are not "minor". The authors did justify very well why they have chosen the 300 km resolution but I think they should also mention the scale dependency of their results. Please also add "dry season" to the upper parts of the panel.

(Remarks on code availability)

Reviewer #2

(Remarks to the Author)

I believe the authors have been thorough in addressing both my comments and the comments of other reviewers. To my knowledge this response is carefully considered and has improved the manuscript greatly. I would be happy to see this novel and interesting research published.

(Remarks on code availability)

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General Statement of Changes

In response to the reviews, we made the following major revisions:

- Restructured the figures, supplementary figures, and main text to improve narrative flow and support the progression of the results, ensuring that visual elements are better aligned with the storyline.
- Refined the discussion of non-linear dynamics and tipping points, removing speculative language and clearly stating the limitations of our empirical approach to extrapolate the results to the near future. We now emphasize that our findings are indicative of emerging trends but do not demonstrate causality or threshold behavior.
- Clarified the methodology, particularly in the Abstract and Methods sections, by explicitly describing the model structure, the data sources, the rationale behind selecting dry season data, and the spatial aggregation procedures.
- Added a detailed justification for focusing on the dry season, supported by new statistical comparisons showing the stronger and more robust climatic signals associated with deforestation during this period.
- Improved the contextual framing of the study by incorporating additional references and explanations to situate our findings within the existing literature better.

In addition to these structural and conceptual revisions, we introduced new supplementary materials and analyses, including:

- A sensitivity analysis on spatial scale, assessing the robustness of results across different grid sizes.
- Additional supplementary figures illustrating seasonal comparisons, variable trends, and model performance across the 29 study regions.

These revisions collectively strengthen the manuscript's scientific contribution and ensure clearer communication of our findings and their implications.

Reviewer #1

We thank Reviewer #1 for the thoughtful and constructive review of our manuscript. We appreciate the recognition of the novelty and significance of our approach in disentangling the effects of deforestation and global climate change on Amazonian climate dynamics. The reviewer's insightful comments helped us refine the scope of our interpretations, clarify the methodological framework, and improve the overall transparency of the analysis. We address each point below in detail.

- What are the noteworthy results?

In their article, the authors disentangle the effects of regional deforestation and global climate processes on climate parameters during the past 35 years in the Amazon basin. While in respect of temperature change global processes play the dominant role, the authors identify deforestation as the dominant driver of in tendency decreasing precipitation. In contrast, the effect of deforestation on the atmospheric concentrations of the greenhouse gases CO₂ and CH₄ is negligible.

- Will the work be of significance to the field and related fields? How does it compare to the established literature? If the work is not original, please provide relevant references.

There are numerous studies investigating (1) the effects of deforestation in the Amazon on global climate, (2) the impacts of global climate change on the structure and stability of the Amazon biome and (3) regional climate effects from deforestation. Many of these studies focus on future developments (scenario analyses) and apply dynamic climate models.

To my knowledge, this article is the first attempt to differentiate between regional and global drivers and their respective impacts on regional climate. From this perspective, I regard the research as highly original and relevant for a better understanding of climate change drivers in the Amazon. In particular, since the authors put a strong emphasis on retrospective analyses, their work is an important addition to the aforementioned simulation-based analyses.

- Does the work support the conclusions and claims, or is additional evidence needed?

While to the most part, the conclusions and claims are well supported by the study results, from my point of view, it is not valid to draw conclusions related to non-linear effects such as tipping points or a potential dieback of the Amazon biome (or biome shift). In this sense, I ask the authors to add a critical reflection of the limitations of their analytical approach – either in the Preserving Amazonia's forest..." or the "Conclusion" section.

- Are there any flaws in the data analysis, interpretation and conclusions? - Do these prohibit publication or require revision?

I think a careful revision is required. My three arguments:

(1) As pointed out, I am sceptical about using the introduced methodology for future projections as it does not replicate dynamic processes but in its core just extrapolates historic trends. The authors should also avoid the term simulation (page 6/22, line 199) and include a critical reflection in the manuscript (see above).

We thank the reviewer for this important and thoughtful observation. We fully agree that our approach, based on retrospective statistical modeling, does not replicate the dynamic processes, feedbacks, or potential threshold mechanisms that would be required to robustly assess non-linear transitions such as biome shifts or ecosystem tipping points. Our methodology was designed to disentangle and quantify the relative historical contributions of global climate change and regional deforestation to observed trends in temperature, rainfall, and greenhouse gas concentrations. We aimed to explore the equations to gain insight into potential future changes. However, as the reviewer rightly notes, this approach is fundamentally empirical and trend-based, and thus inadequate for simulating future system dynamics or capturing critical feedback mechanisms.

To address these points, we have revised the manuscript as follows:

- We removed the term "simulation" from line 199 and replaced it with "extrapolation" to better reflect the nature of our calculations.
- We added a paragraph to the *Preserving Amazonia's Forest Cover* section (and referenced it earlier in the Discussion) to explicitly acknowledge the limitations of our analytical approach. In this paragraph, we clarify that while our findings highlight trends consistent with potential tipping behavior, they do not demonstrate causality or confirm thresholds; instead, they should be interpreted as indicative, not predictive, of biome-level change. The new paragraph reads as follows:

While our findings suggest trends consistent with early signs of biome destabilization, we acknowledge that our analytical approach based on statistical extrapolation has limitations in its ability to capture dynamic feedbacks, threshold responses, or ecological resilience mechanisms. However, by disentangling historical contributions of deforestation and global climate change, our method offers a valuable first-order assessment of likely trajectories if current trends persist. While limited, this approach provides a preliminary indication of the risks associated with ongoing deforestation and climate stressors in the Amazon.

- In addition, we have revised the manuscript (see, for instance, the *Abstract* and the *Significance Statement*) to avoid using the term "tipping point" in relation to our findings, to better reflect the scope and limitations of our approach.

All the suggestions discussed here were incorporated into the conclusion section, which was restructured to accommodate them. Notably, the last two paragraphs were improved, which now reads as follows:

Overall, these findings highlight the intricate relationship between deforestation and global climate change in influencing rainfall patterns across the Amazon. This interaction contributes to nonlinear trends in precipitation, amplifying the impacts of ongoing climate change. The observed reduction in total precipitation during the dry season, combined with a significant increase in maximum surface temperature linked to deforestation, underscores the crucial role of forest cover in maintaining a stable regional water cycle and mitigating climate stress. If deforestation continues unabated, the extrapolation of our results suggests a further decline in total precipitation during the dry season and an increase in maximum surface temperature, factors that could push the Amazon ecosystem toward increasingly unstable states. Emerging evidence suggests that deforestation in the Amazon is already altering South American monsoon patterns, resulting in drier conditions that may compromise the long-term resilience of the rainforest^{47,54}.

In addition, the results of this study suggest that Amazon is moving through a critical transition, potentially exacerbated by extreme events such as the unprecedented 2023 drought^{55,56}. However, we remain cautious about defining a precise deforestation threshold that could trigger biome-scale dieback, particularly because our extrapolation does not fully account for the substantial uncertainties inherent in climate–vegetation interactions, which themselves remain subject to significant uncertainty⁵⁷. Together, deforestation and climate change are driving substantial transformations across the region during the dry season, resulting in reduced rainfall, elevated temperatures, and increased atmospheric GHG levels. These findings underscore the importance of maintaining and restoring forest cover in the Amazon as a crucial strategy for mitigating climate change and ensuring the stability of ecosystems.

(2) My second question is why the authors only present results for the dry seasons and neglect wet seasons (except figures 4 and 6 in the supplement).

Thank you for this important observation. We agree that the manuscript should have more clearly explained the rationale behind focusing our analysis on the dry season, and we appreciate the opportunity to clarify this. We conducted a series of sensitivity analyses to evaluate the seasonal variability in the response of climate variables to deforestation and global climate change. These analyses revealed that the effects of deforestation are much more pronounced and statistically robust during the dry season, whereas during the wet season, the signal of land-use change is significantly weaker or even negligible. This pattern aligns with findings from recent studies (e.g., Liu et al., 2025, DOI: <https://doi.org/10.1029/2025AV001670>), which emphasise the increased sensitivity of rainfall and temperature to deforestation in the Amazon under dry conditions.

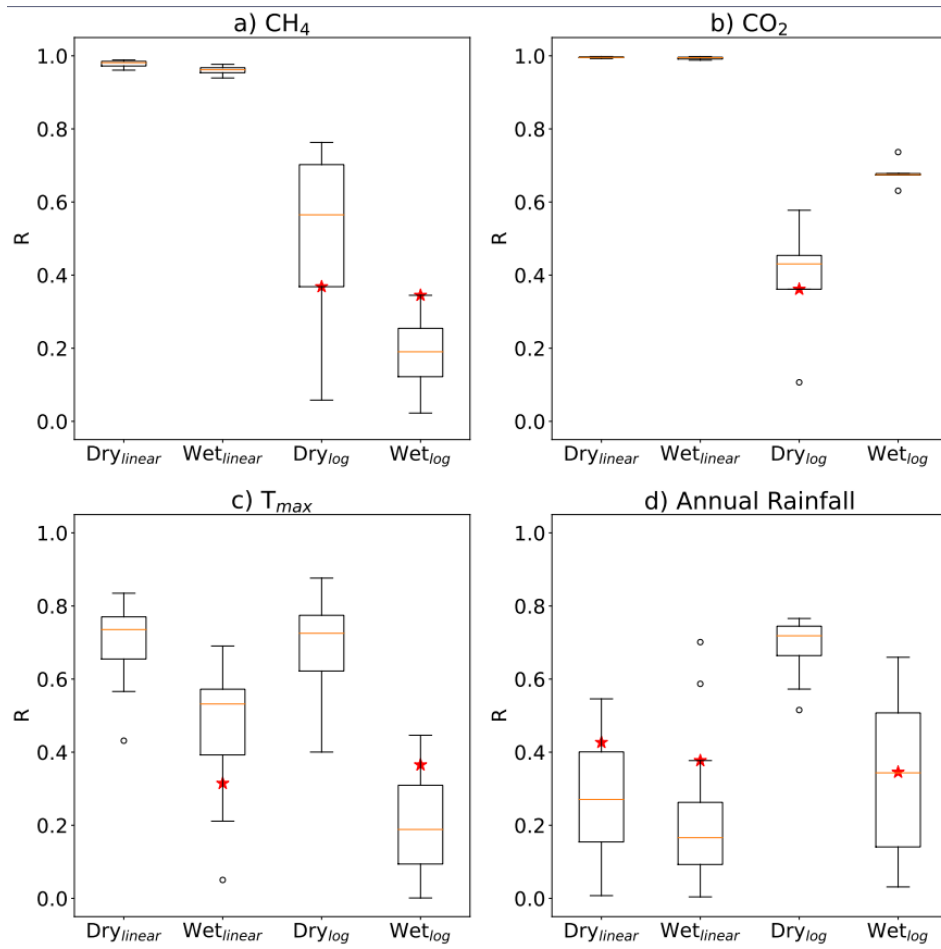


Figure 1: Boxplots obtained with the correlation coefficients (R) considering only the linear and the logarithmic components of the fits in our model for (a) CH₄, (b) CO₂, (c) T_{max}, and (d) annual rainfall during the wet and dry seasons. Red stars represent the limit at which p-value < 0.05. The absence of stars means that all fits were statistically significant.

To support this, we have highlighted more of the Supplementary Figure S7 (Figure 1 in this response letter) in the manuscript, which compares the performance of both linear and logarithmic model fits across wet and dry seasons. In both seasons, as shown in Figure 1, the linear component, associated with long-term global trends, yields high correlation coefficients for CH₄ and CO₂ ($R > 0.90$; p-value < 0.05), indicating a dominant influence from global emissions. However, the logarithmic component, which captures the regional effect of deforestation, shows much stronger correlations during the dry season: $R \sim 0.75$ for T_{max} and $R \sim 0.70$ for rainfall, compared to only $R \sim 0.50$ and $R \sim 0.30$, respectively, during the wet season, with many of these wet-season fits lacking statistical significance. In addition, a similar trend for the logarithmic component is also observed for CO₂ and CH₄, with $R \sim 0.45$ and $R \sim 0.60$ (both with average p-value < 0.05), respectively, for the dry season, whereas $R \sim 0.60$ and $R \sim 0.30$ without statistical significance, respectively, for the wet season.

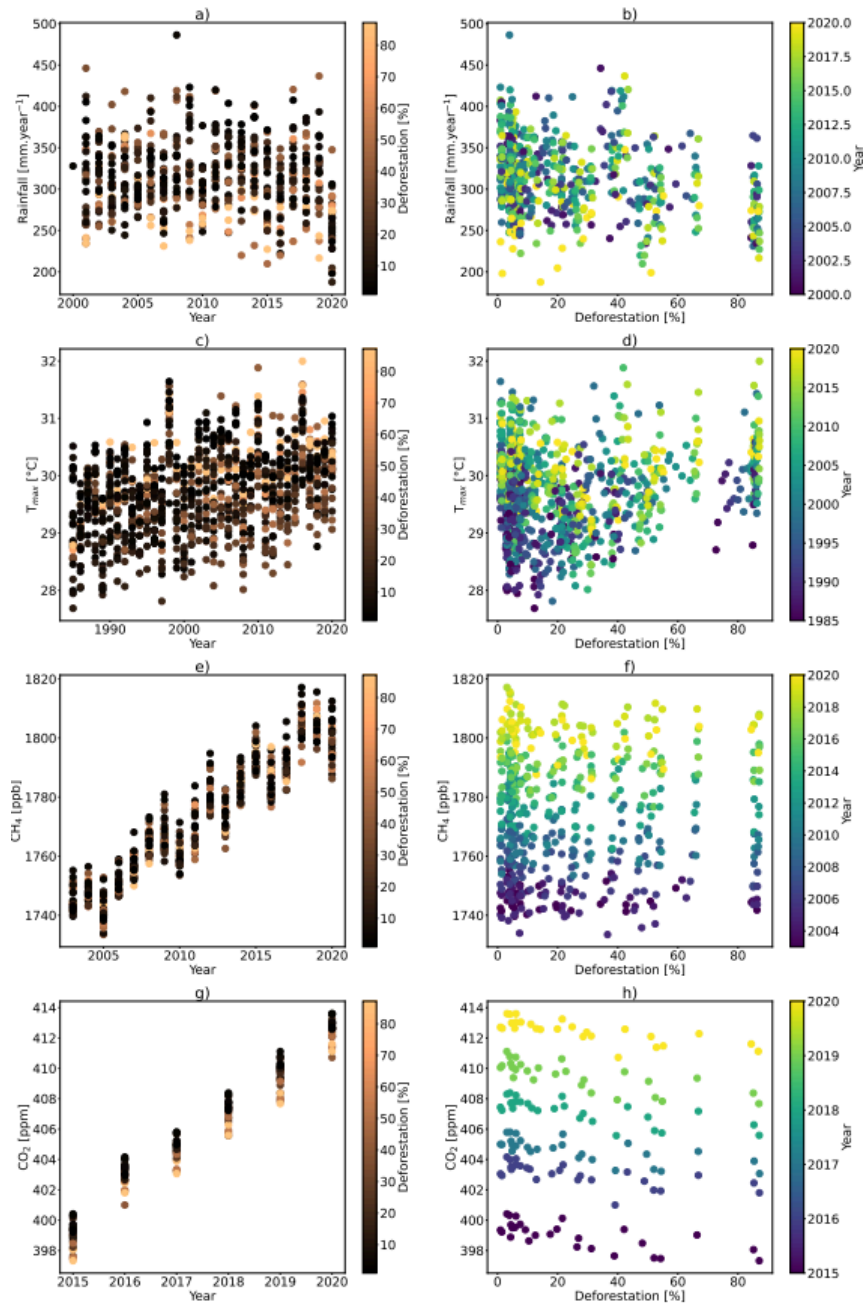


Figure 2: Relationship between wet season precipitation (a, b), maximum surface temperature (c,d), CO₂ concentrations (e, f), and CH₄ concentrations (g, h) for each year (dots are colored by deforestation percentage), and deforestation percentage (dots are colored by year), respectively, for all 29 areas.

To further illustrate this point, we now include the new Supplementary Figure S5 in the revised manuscript, which is also shown in this response letter as Figure 2. This figure illustrates the temporal and spatial relationships between deforestation and each variable during the wet season, similar to those shown in the manuscript for the dry season (Supplementary Figure S4). It confirms the limited influence of local land cover changes during this period. In addition, it is worth mentioning that when our model (represented by Equation 4 in the manuscript) is applied to the different variables during the wet season, the model correlation with the actual data is very

low ($T_{\max}$ and rainfall with $R \sim 0.35$ and ~ 0.20 , respectively. CO_2 and CH_4 have $R > 0.90$ due to the reasons highlighted previously) when compared with the correlations for the dry season (Table 1 in the manuscript), although both when considering the combination of linear and logarithmic effects have $p\text{-value} < 0.05$.

These results underscore the importance of focusing on the dry season in our analysis. This is when deforestation-driven changes to the surface climate are most detectable, statistically significant, and physically interpretable.

We have revised the manuscript to include a detailed justification for performing the calculations using only the dry season data. In the updated manuscript, under the section *Evaluation of the Deforestation and Global Climate Change Effects*, we have added the following paragraph:

Deforestation and global climate change influence rainfall, temperature, and GHG mixing ratios in distinct ways across the wet and dry seasons^{14, 46, 47}. However, several studies have shown that the regional climatic impacts of deforestation are more pronounced and meaningful during the dry season, when the forest is more vulnerable to moisture deficits and surface-atmosphere interactions are intensified. In our analysis, the dry season consistently exhibited stronger correlations between deforestation and key climate variables, including maximum temperature and precipitation (See Supplementary Figure S4), while the wet season showed weaker and often statistically insignificant relationships (See Supplementary Figure S5). Therefore, our study focuses exclusively on the dry season to isolate and quantify the climatic effects of deforestation with greater precision. A detailed explanation and supporting statistical evidence are provided in the Data and Methods, subsection Definition of Wet and Dry Season, and Data Processing.

We also improved Section *Data and Methods*, Subsection *Definition of Wet and Dry Season, and Data Processing*, and referenced the relevant figures accordingly. The new text reads as follows:

Our analysis evaluated the dry and wet seasons separately to assess the seasonal impact of deforestation on each variable. Given the spatial heterogeneity of seasonal cycles across the Amazonian region, we categorized the dry and wet season months based on the 25th and 75th percentiles of rainfall (see Supplementary Figure S9). The wet and dry seasons were determined by analyzing the precipitation patterns specific to each area within the Amazon region. A comprehensive analysis of the entire time series for each area was conducted to derive an average precipitation annual cycle from 2000 to 2020. The 75th quartile, representing months with the highest annual rainfall, was identified as the wet season. In contrast, the 25th quartile, representing months with the lowest total rainfall, was designated as the dry season. It is worth noting that the composition of each quartile may vary across Amazon. Based on quartiles, this methodology ensures an objective approach to defining the seasons. Thus, the dry and wet season data were computed for each time series and obtained based on the 25th and 75th quartiles, respectively, and their annual averages for each area. This was necessary to ensure accurate comparisons regarding the change in forest cover.

Using the wet and dry classifications of each of the 29 studied areas, we evaluate the sensitivity of deforestation to rainfall, temperature, and greenhouse gases. The

trends and significance are only significant for the dry season. During the dry season, the relationship between deforestation and climatic variables is statistically robust, with median correlation coefficients of $R \sim 0.75$ for maximum temperature and $R \sim 0.70$ for rainfall. However, in the wet season, these correlations decrease substantially to $R \sim 0.50$ and $R \sim 0.30$, respectively, with most of the trends lacking statistical significance. Supplementary Figures S4 and S5 (the temperature evolution for the dry season is presented in Figure 2) present the scattering plots for dry and wet seasons, clarifying this aspect.

We evaluate the sensitivity of deforestation to rainfall, temperature, and trace gas mixing ratios by applying wet and dry season classifications across the 29 study regions. Statistically significant trends emerge predominantly during the dry season. 10/26 In this period, the relationship between deforestation and climatic variables is particularly strong, with median correlation coefficients of $R \sim 0.75$ for maximum temperature and $R \sim 0.70$ for rainfall. In contrast, during the wet season, these correlations decline substantially to $R \sim 0.50$ and $R \sim 0.30$, respectively, and most trends are not statistically significant. Supplementary Figures S4 and S5, along with Figure 2 (which illustrates the evolution of dry-season temperature), present scatter plots for both seasons, highlighting the seasonal contrasts.

Deforestation disrupts the natural modulation of the water and energy cycles, leading to reduced rainfall and elevated surface temperatures, particularly during the dry season, in line with previous findings⁴⁷. The linear component of our model, representing the influence of large-scale climatic drivers, shows consistently high correlation coefficients for CO_2 and CH_4 ($R > 0.90$) in both seasons, suggesting that variations in GHG mixing ratios are primarily governed by global-scale processes and are relatively insensitive to local deforestation. In contrast, the logarithmic component, capturing the regional-scale effects of deforestation, exhibits marked seasonal variability.

These findings confirm that the climatic impacts of deforestation are most pronounced during the dry season, offering a more distinct and statistically robust signal of its regional influence. Conversely, the wet season appears less responsive to local land cover changes, likely due to the overriding influence of large-scale atmospheric dynamics. Accordingly, our analysis emphasizes the dry season, where the signal of deforestation can be more accurately isolated and quantified.

(3) Thirdly, the analysis as presented is conducted for fixed 300 km cells (areas). In order to further explore the behaviour of the presented methodology, it would be interesting to investigate how sensitive it is to scale, e.g. by systematically modifying the size and position of the cells.

We thank the reviewer for this insightful suggestion regarding scale sensitivity. As noted, our analysis was conducted using fixed $\sim 300 \times 300 \text{ km}^2$ grid cells, and this choice was carefully justified in the manuscript. Specifically, this scale was selected based on two main criteria: (1) it encompasses the typical spatial extent of deforestation paths in the Amazon, ensuring that aggregated land use change signals are representative of regional trends (Smith, C., Baker, J. & Spracklen, D., 2023; DOI: <https://doi.org/10.1038/s41586-022-05690-1>); and (2) it aligns with the spatial scale of mesoscale atmospheric processes, such as deep convection and

squall lines, whose average horizontal dimensions are in the range of 75–150 km in radius (Machado et al., 2018; DOI: <https://doi.org/10.5194/acp-18-6461-2018>). This ensures that climate and land cover interactions are meaningfully captured within each cell.

Furthermore, this approach has been independently validated and applied in a recent peer-reviewed study (Teixeira et al., 2025; DOI: <https://doi.org/10.1016/j.foreco.2025.122662>), which adopts the same spatial resolution ($\sim 300 \times 300 \text{ km}^2$) to characterize the spatial evolution and morphology of deforestation patches in the Amazon. We also added this new citation to the manuscript and the *Data and Methods* section to enforce our choice of the area size.

To further address the reviewer’s suggestion, we conducted a targeted sensitivity analysis to evaluate the robustness of our results with respect to the spatial scale used in the study. Specifically, we examined how different cell sizes— $50 \times 50 \text{ km}^2$, $100 \times 100 \text{ km}^2$, $200 \times 200 \text{ km}^2$, and $300 \times 300 \text{ km}^2$ —affect the time series trends of maximum temperature and precipitation during the dry season. These tests were centered on two representative regions: one with the highest observed forest loss (almost 35%) and one with the lowest ($\sim 1\%$) over the analysed 35 years, based on our 29-area domain (sectors 3 and 9 from Figure S2 and Figure 1 of the revised manuscript).

The results, presented now in the new Supplementary Figure S1 (Figure 3 of this letter), show that while minor variations in absolute values are observed across different spatial resolutions, the trends in temperature increase and precipitation decrease remain consistent among the different sizes of the regions. This reinforces the stability and robustness of the parametric approach employed in our study across different spatial scales.

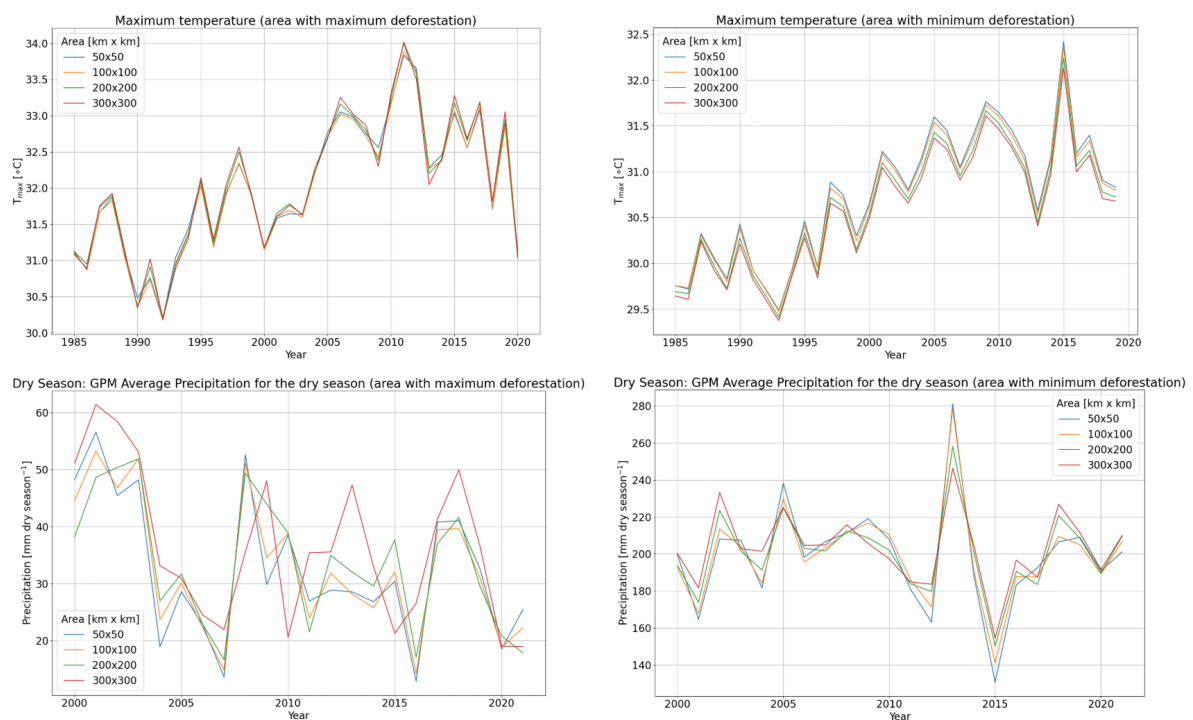


Figure 3: Sensitivity analysis of grid size on climate variable trends in areas with maximum (left panels) and minimum (right panels) forest loss over the analysed 35 years. Top panels: Time series of

dry-season maximum surface temperature (T_{max}) for different grid sizes ($50 \times 50 \text{ km}^2$, $100 \times 100 \text{ km}^2$, $200 \times 200 \text{ km}^2$, and $300 \times 300 \text{ km}^2$). Bottom panels: Corresponding time series of dry-season GPM precipitation for the same grid sizes. Each curve represents the spatial average over a grid centered in the target area. Despite minor differences in absolute values, the overall trends are consistent across scales, supporting the robustness of the methodology regardless of grid size.

Therefore, we maintained the use of $300 \times 300 \text{ km}^2$ grid cells as our standard for three main reasons: (i) this resolution aligns with the average extent of deforestation pathways and disturbance fronts in the Amazon, thus allowing for a regionally meaningful signal (Smith et al., 2023); (ii) it matches the scale of atmospheric systems that dominate convective and moisture recycling processes in the region (Machado et al., 2018); and (iii) it has been successfully applied in recent Amazon-wide studies, such as Teixeira et al. (2025), which used this resolution to characterize the dynamics of deforestation morphology and spatial evolution. Together, the theoretical rationale and empirical sensitivity tests indicate that our conclusions are robust across spatial scales within the mesoscale range.

We have revised the manuscript to incorporate the suggested sensitivity analysis. The updated paragraph that justifies the choice of the $300 \times 300 \text{ km}^2$ analysis areas now reads as follows:

To disentangle the regional effects of deforestation from the global effects of climate change in the Brazilian Amazon, data on 29 areas of $\sim 300 \times 300 \text{ km}^2$ between 1985 and 2020 were considered. Deforestation is defined here based on the MapBiomas land cover classification as any loss of native forest vegetation, regardless of the resulting land use class. The particular area size was selected for two reasons. First, they encompass a sufficiently large area to represent the observed path length of deforestation, as indicated by previous studies³⁸, and have recently been adopted in similar spatial analyses of Amazonian land cover dynamics⁴⁴. This ensures that the effects of deforestation within a given region are adequately captured and analyzed. Second, the dimension of $\sim 90,000 \text{ km}^2$ is within the mesoscale range, encompassing atmospheric phenomena like thunderstorms, squall lines, and deep convection, which are characterized by radii between 75 and 150 km. The 29 areas were chosen to maximize spatial coverage of the BLA while excluding areas dominated by water bodies or permanent wetlands, ensuring reliable surface climate and land cover analysis. To assess the robustness of our findings across different spatial scales, we conducted a sensitivity analysis using smaller grid sizes (50×50 , 100×100 , and $200 \times 200 \text{ km}^2$). The results, shown in Supplementary Figure S1, indicate that the long-term trends in temperature and precipitation remain consistent across scales, reinforcing the suitability of the $300 \times 300 \text{ km}^2$ resolution adopted in this study.

- Is the methodology sound? Does the work meet the expected standards in your field?

The authors combine statistical analysis with methods from (real) analysis. To my understanding, the presented method is simple (in a positive sense), sound and robust. As I am not a mathematician by training, I would ask the editors to get another opinion from that side.

- Is there enough detail provided in the methods for the work to be reproduced?

The authors use a wide variety of datasets with different temporal coverage and spatial resolution to (if I understood correctly) generate the aggregated data for the 29 cells/areas they use for their analysis. Here a more detailed description of the data aggregation and fusion processes is required. In addition, I suggest providing the source codes of the scripts used for data analyses/aggregation.

We thank the reviewer for this helpful and constructive suggestion. In the revised manuscript, we have improved the Methods section to provide a clearer and more detailed description of the spatial and temporal aggregation procedures used to harmonize the datasets across the 29 fixed grid cells in the Amazonian region. Specifically, we now clarify the spatial resolution of each dataset, the temporal coverage, the aggregation steps applied (e.g., monthly or annual averages), and the selection of these 29 areas.

Given the diversity in spatial and temporal resolutions across datasets (e.g., Landsat-based LULC at 30 m, ERA5 at $0.25^\circ \times 0.25^\circ$, AIRS at $1^\circ \times 1^\circ$, and OCO-2 at $0.5^\circ \times 0.625^\circ$), we employed a consistent spatial averaging procedure to compute mean values of each variable within each of the 29 areas. All variables were initially aggregated to monthly values per grid cell to ensure temporal comparability. To address differences in temporal coverage (e.g., GPM from 2000, CH₄ from 2002, CO₂ from 2015), we applied a parametric modeling approach (described in Equations 8 and 9 of the manuscript) to reconstruct continuous time series for each variable. This enabled us to extrapolate trends backward, ensuring that all variables could be analyzed over a common time period from 1985 to 2020. This information is now clearly described in the revised manuscript, on the subsection “Land Use and Land Cover Data” and “Greenhouse Gases and Weather Data.” Particularly, the new paragraph describing the calculations and aggregations reads as:

All datasets were first re-aggregated into monthly means for each of the 29 study regions. Based on the long-term climatological patterns, each region's time series was then classified into wet and dry seasons, following a percentile-based threshold applied to the monthly precipitation data. This classification allowed us to capture the distinct seasonal responses of atmospheric variables to forest loss. For each season, we subsequently computed annual means, enabling a robust comparison of dry- and wet-season dynamics and a consistent assessment of long-term trends across datasets with different temporal coverage. Given the varying temporal coverage of the datasets (Tmax: 1985–2020; rainfall: 2000 - 2020; CH₄: 2002–2020; CO₂: 2015–2020), we applied our obtained parametric modeling approach (see Equations 7 and 8) to reconstruct and extend the time series across the full analysis period (1985–2020). This approach allowed us to capture long-term trends and ensure temporal consistency across variables. By harmonizing datasets with different native resolutions and time spans, this framework enabled robust and consistent comparisons across variables and study regions, facilitating an integrated analysis of the impacts of deforestation and climate change.

Additionally, the source code used for data aggregation, modeling, and figure generation has been provided in a public GitHub repository (<https://github.com/marcomac27/ClimateChangeDeforestationPaper>), in line with Nature Communications' reproducibility requirements.

Reviewer #2:

We thank Reviewer #2 for the thoughtful and constructive review of our manuscript. We appreciate the recognition of the novelty and significance of our approach in disentangling the effects of deforestation and global climate change on Amazonian climate dynamics. The reviewer's insightful comments helped us refine the scope of our interpretations, clarify the methodological framework, and improve the overall transparency of the analysis. We address each point below in detail.

Review of: How climate change and deforestation interact in the transformation of the Amazon rainforest

Broad thoughts:

This is an important and timely piece of research which aims to disentangle the effects of land cover change and climate change in the Brazilian Legal Amazon. The research is of good quality, and I believe should be published. Currently I find the structure of the article hard to follow as a story and the figures and results are not well described nor put in context. As detailed below, the reliance on supplementary figures and references to details contained within the methods make reading this article quite challenging and present significant barriers to comprehension, in my opinion.

The main novelties are separating the climate change and land cover responses, and finding that temperature has a non-linear response, contrary to what other works have shown. I recommend perhaps considering a different order of figures to communicate this story more effectively. The messages within the current sub-headings don't seem focussed on the heading, i.e. in "Preserving Amazonia's Forest Cover: Understanding its Importance and Anticipating Future Impacts", two paragraphs pass, before there is a mention of future changes. Therein, there is insightful discussion of results in context, hence I believe, with a reorder, this could be a good and effective manuscript.

If these amendments cannot be achieved within the constraints of this journal, I would encourage to authors to think about whether this is more possible elsewhere.

We sincerely thank Reviewer #2 for their thoughtful and encouraging feedback on the originality and relevance of our study. We are particularly grateful for the constructive suggestions aimed at improving the manuscript's structure, clarity, and flow. We fully agree that a clear and coherent narrative is essential for effectively communicating our findings, especially given the complexity of the topic. In response, we undertook a careful revision of the manuscript with a strong focus on improving the overall readability and logical progression of the text. We improved the presentation of figures and reorganized the results sections to better align visual elements with the narrative. We also refined how key findings are introduced and discussed in the main text to ensure that the most relevant results are highlighted in the appropriate sections of the manuscript. Finally, we revised the language throughout to enhance clarity, eliminate redundancies, and address ambiguities in wording and phrasing. These improvements collectively aim to deliver a clearer and

more compelling account of our methodology and results, thereby supporting the study's main messages more effectively.

Below are the one-by-one responses to the reviewer's questions.

Why BLA not amazon biome

We thank the reviewer for this pertinent question. We chose to focus our analysis on the Brazilian Legal Amazon (BLA) rather than the whole Amazon biome mainly because the key land cover datasets used in this study (e.g., MapBiomas Collection 6.0) are produced and explicitly validated within the BLA, with higher spatial detail and classification accuracy in Brazilian territory. This ensures greater consistency and reliability in deforestation estimates and land use trajectories. The BLA region represents more than 60% of the entire Amazon and encompasses the majority of the heavily deforested areas. In addition, the BLA is the main administrative region used in national and international climate and deforestation policy frameworks (e.g., Brazil's Forest Code, Amazon Fund, and monitoring by INPE/PRODES). As such, our results are directly relevant to ongoing efforts in governance, restoration, and mitigation.

The following modifications were implemented to improve the clarity of the manuscript regarding the aspect of using BLA instead of the whole Amazon biome:

- Last paragraph of the *Introduction* section:

In this study, we use observational remote sensing data to quantify the effects of 35 years of deforestation and global climate change on the regional climate in Brazil's Legal Amazon (BLA). The datasets used, along with their spatial and temporal coverage, are summarized in Table 1. The BLA was chosen because it corresponds to the official jurisdiction used in Brazil's environmental policy and monitoring frameworks (e.g., MapBiomas⁴³), and because high-resolution, long-term land use data are reliably available for this territory. Moreover, the BLA encompasses the majority of the Amazon biome within Brazil, where deforestation has been most intense and extensively monitored. A comprehensive assessment of the long-term trends of key climatic variables allowed us to quantify changes and determine the relative contributions from the driving forces.

- Subsection *Land Use and Land Cover Data*:

The land use and land cover (LULC) data were obtained from the MapBiomas Project⁴³, an initiative dedicated to monitoring and mapping changes in LULC throughout Brazil. The MapBiomas platform effectively collects and processes extensive geospatial data from various sources, including satellite imagery captured by different sensors. By implementing advanced classification and analysis algorithms, it identifies and maps alterations in land cover over time. MapBiomas has generated Brazil's most detailed, up-to-date, and longest time series of LULC mapping. We used Collection 6.0 from MapBiomas for this study. This collection comprises maps with an annual temporal resolution covering the period from 1985 to 2020. The spatial resolution of the data is 30 meters based on Landsat satellite images. The global accuracy of the

MapBiomas Collection 6 land-use and land-cover maps stands at 87.4%. These datasets are available on Google Earth Engine as a data asset and can be freely accessed through the platform's website at <https://brasil.mapbiomas.org> (accessed June 19, 2022).

In our analysis, deforestation is defined as the conversion of areas classified as "forest" in MapBiomas to any other land cover class, including agriculture, pasture, urban areas, water bodies, or natural non-forest formations. This inclusive definition encompasses all transitions that lead to forest loss, regardless of the subsequent land use. Our estimates of deforestation do not consider specific transitions (e.g., forest-to-agriculture or forest-to-mining). Deforestation fractions were calculated as annual averages within each of the 29 study areas, based on the percentage of forest cover loss relative to the initial forest area in 1985. We emphasize that the analysis focuses on the Brazilian Legal Amazon (BLA), rather than the full Amazon biome, due to the availability and consistency of spatially explicit deforestation and land cover data provided by MapBiomas, which is optimized and validated within Brazilian territory. While the Amazon biome extends beyond Brazil's borders, the BLA encompasses the vast majority of its forest area under national jurisdiction and includes the regions experiencing the highest rates of deforestation. As such, it provides a policy-relevant and analytically consistent domain for our regional climate assessment.

We acknowledge the distinction between the BLA and the Amazon biome and now clarify this choice more explicitly in the *Methods* section of the manuscript. We have also revised wording throughout the text to ensure that this distinction is transparent to readers.

How were boxes chosen? Add briefly to L51 etc (i.e. maximum number of cells within the domain, not including water?)

We thank the reviewer for this important question. The 29 fixed grid boxes used in our analysis were selected using a spatial tiling approach over the BLA, with each grid cell measuring approximately $300 \times 300 \text{ km}^2$ (~90,000 km²). This spatial scale was chosen based on two main scientific criteria:

1. It is large enough to encompass the typical spatial extent of deforestation fronts in the Amazon, allowing us to capture coherent land cover transformation patterns and their regional climate signals. This criterion is supported by recent findings by Smith et al. (2023; DOI: <https://doi.org/10.1038/s41586-022-05690-1>).
2. It corresponds to the mesoscale dimension of key atmospheric processes in the Amazon, such as squall lines, deep convection, and mesoscale convective systems, which typically have horizontal dimensions of 75–150 km in radius (Machado et al., 2018; DOI: <https://doi.org/10.5194/acp-18-6461-2018>). This ensures that land-atmosphere interactions are properly captured within each cell.

This spatial resolution has been independently applied and validated in a recent study by Teixeira et al. (2025; DOI: <https://doi.org/10.1016/j.foreco.2025.122662>), which analyzed the spatial evolution and morphology of deforestation patches using a comparable grid-based approach. The final set of 29 cells was selected to maximize land coverage within the BLA while excluding cells dominated by surface water bodies or permanent inundation zones, which could bias land cover analysis or affect surface climate signals. In addition, we conducted a sensitivity analysis to assess the robustness of our methodology with respect to spatial scale. For this, we re-evaluated the trends in maximum temperature and precipitation during the dry season using alternative grid sizes of 50×50 km², 100×100 km², and 200×200 km², centered on the same locations as the original 300×300 km² grid cells. We focused on areas with the highest and lowest deforestation fractions across the study period (1985–2020) to capture the full range of land cover gradients.

The results, summarized in the new Supplementary Figure 1 (also shown as Figure 2 in this letter), indicate that while there are minor variations in magnitude due to scale, the temporal trends and general patterns in temperature increase and precipitation reduction remain consistent across all grid sizes. This confirms that our findings are not strongly dependent on the chosen spatial resolution and that the 300×300 km² resolution offers a reliable and representative balance between capturing regional climate dynamics and deforestation processes. Given the consistency across scales and the precedent in the literature, we maintained the 300 km² resolution for the main analysis.

We improved the manuscript by adding text to clarify the question discussed here. For instance, the main modifications were made in section *Quantifying global and regional effects across Brazilian Amazon areas*. It's the first paragraph now reads as:

To disentangle the regional effects of deforestation from the global effects of climate change in the Brazilian Amazon, data on 29 areas of ~ 300 × 300 km² between 1985 and 2020 were considered. Deforestation is defined here based on the MapBiomas land cover classification as any loss of native forest vegetation, regardless of the resulting land use class. The particular area size was selected for two reasons. First, they encompass a sufficiently large area to represent the observed path length of deforestation, as indicated by previous studies³⁸, and have recently been adopted in similar spatial analyses of Amazonian land cover dynamics⁴⁴. This ensures that the effects of deforestation within a given region are adequately captured and analyzed. Second, the dimension of ~90,000 km² is within the mesoscale range, encompassing atmospheric phenomena like thunderstorms, squall lines, and deep convection, which are characterized by radii between 75 and 150 km. It is worth mentioning that the 29 areas were chosen to maximize spatial coverage of the BLA while excluding areas dominated by water bodies or permanent wetlands, ensuring reliable surface climate and land cover analysis. To assess the robustness of our findings across different spatial scales, we conducted a sensitivity analysis using smaller grid sizes (50×50, 100×100, and 200×200 km²). The results, shown in Supplementary Figure S1, indicate that the long-term trends in temperature and precipitation remain consistent across scales, reinforcing the suitability of the 300×300 km² resolution adopted in this study.

What forest data? Why including other land covers?

We thank the reviewer for raising this point. In our study, land use cover data were obtained from MapBiomas Collection 6.0, which provides annual land use and land cover maps for Brazil from 1985 to 2020, at 30-meter spatial resolution. This dataset is widely used and validated across Brazilian biomes, providing the most consistent long-term forest classification for the BLA. To define deforestation, we considered any transition from land cover classes labeled as "forest" by MapBiomas to any other class, including agriculture, pasture, urban areas, non-forest natural formations, or water. This inclusive approach enables us to capture all significant forest loss events, regardless of the final land use, thereby providing a more comprehensive assessment of landscape transformation and its impact on regional climate variables.

We chose this broader definition to:

1. Avoid underestimating forest degradation that does not fall neatly into "agriculture" or "pasture" categories.
2. Account for complex and mixed post-deforestation land uses that may not be resolved in annual classifications.
3. Remain consistent with national-level assessments of total forest loss used in Brazil's environmental monitoring programs.

We have now clarified this definition and rationale in the *Land Use and Land Cover Data* subsection (Data and Methods). We revised the section *Quantifying global and regional effects across Brazilian Amazon areas* to briefly state how forest data were defined and why all non-forest transitions were included in the deforestation metric.

Why say tipping point? Do you reference this/ make an assessment?

We thank the reviewer for raising this important point. We agree that our analytical framework, which is based on empirical trend analysis and statistical extrapolation, does not provide a process-based assessment of ecosystem tipping points or critical thresholds. Our methodology is designed to disentangle and quantify the historical contributions of deforestation and global climate change to observed changes in surface climate and atmospheric composition in the BLA. However, it does not simulate the internal feedbacks, nonlinear transitions, or resilience mechanisms that would be required to formally identify or predict tipping point behavior. In response to this comment, and consistent with feedback from another reviewer, we have revised the manuscript to avoid using the term "tipping point" in relation to our findings. Instead, we refer to the emergence of destabilizing trends or to the risk of critical transitions in a more cautious and qualified manner. We have also added a paragraph in the *Preserving Amazonia's Forest Cover* section to explicitly acknowledge the limitations of our approach in assessing biome-scale regime shifts. The revised *Conclusion* section reflects this updated framing. It emphasizes that, while our results reveal trends that may be consistent with increasing system

vulnerability, they should be interpreted as indicative early warnings, not as definitive evidence of an approaching tipping point.

Why just dry season?

We thank the reviewer for this important question. We recognize that the rationale for focusing on the dry season must be clearly stated, and we have revised the manuscript accordingly to provide a full justification, supported by both literature and statistical evidence. As detailed now in both the Introduction and the Data and Methods section, our decision to focus on the dry season is based on the fact that the regional climatic impacts of deforestation are significantly more pronounced and statistically detectable during this period. This aligns with recent studies (e.g., Liu et al., 2025) showing that land-atmosphere feedbacks in the Amazon are particularly sensitive to surface changes during the dry season, when the forest is more vulnerable to water stress and convective dynamics are more locally driven. In our own analysis, we performed a comparative seasonal evaluation using the parametric model described in the manuscript. The logarithmic component, which isolates the local effects of deforestation, showed consistently stronger correlations during the dry season (e.g., $R \sim 0.75$ for $T_{\max}$ and $R \sim 0.70$ for rainfall), while these relationships declined sharply during the wet season ($R \sim 0.50$ and $R \sim 0.30$, respectively), with many fits losing statistical significance. The full results, including a new Supplementary Figure (see Supplement Figures S4 and S5 on the revised manuscript), now clarify this difference and are referenced in the main text. We have also added a detailed explanation of how dry and wet seasons were objectively defined for each region based on long-term precipitation quantiles (25th and 75th percentiles), ensuring a robust and regionally adaptive seasonal classification. These results indicate that the dry season provides a more reliable window for isolating the regional climatic signal of deforestation. Therefore, our analysis focuses on this period to maximize interpretability and statistical rigor. We have revised the manuscript to highlight this rationale and to guide readers to the relevant sections.

Add Data summary table for referencing on L57 and throughout

We thank the reviewer for this helpful suggestion. We have created a summary table (now Table 1) that lists all datasets used in the study, including variable names, spatial resolution, temporal coverage, and data source or platform. This table provides a quick reference to support the reader's understanding of our methodological framework. We also refer to this table at the first mention of datasets in the *Evaluation of the Deforestation and Global Climate Change Effects* section and the Methods section.

Table 1: Summary of datasets used in the analysis, including spatial and temporal coverage and data sources.

Variable	Dataset/Sour ce	Spatial Resolution	Temporal Coverage	Access Platform
<i>Land cover / deforestation</i>	<i>MapBiomas Collection 6.0⁴⁵</i>	<i>30 m</i>	<i>1985–2020</i>	<i>Google Earth Engine</i>

Rainfall	GPM	~11 km	2000–2020	GEE
T _{max} (2m)	ERA5 Reanalysis ⁵⁹	0.25° × 0.25°	1985–2020	GEE
CH ₄ (400 hPa)	AIRS (Aqua satellite) ⁶⁰	1°	2002–2020	NASA Giovanni
CO ₂	OCO-2 Gridded ⁶¹	0.5° × 0.625°	2015–2020	NASA Giovanni

Specific thoughts:

In abstract: clarify whether you mean deforestation has impacted amazonian dry season precip and temperatures. Currently, it could read like these are impacting global temperatures and precip.

We thank the reviewer for this helpful observation. We agree that the original wording in the abstract could be misinterpreted to suggest that deforestation has influenced global precipitation and temperature patterns. To address this, we revised the sentence to clearly specify that the observed changes are regional and refer specifically to the Amazonian dry season. The revised sentence now reads:

This study quantifies the relative contributions of deforestation and global climate change to observed shifts in key Amazonian climate parameters. We analyzed long-term atmospheric and land cover change data across 29 areas in the Brazilian Legal Amazon from 1985 to 2020, using parametric statistical models to disentangle the effects of forest loss and global forcing on temperature, precipitation, and greenhouse gas mixing ratios. While the rise in atmospheric methane (CH₄) and carbon dioxide (CO₂) mixing ratios is primarily driven by global emissions (>99%), deforestation has significantly increased surface air temperatures and reduced precipitation during the Amazonian dry season.

L29: Perhaps in the intro somewhere you could explain why you use maximum (daytime?) dry season temperature as your indicator in the analysis. I think this is an important point, that you're choosing not to use average daily temperature.

We thank the reviewer for this thoughtful comment. We agree that it is important to clarify our choice of maximum daily surface air temperature (T_{max}) as a key climate indicator in the analysis. Our preliminary assessments evaluated the model's performance using maximum, average, and minimum daily temperatures, as shown in Figure 4 below, considering only the dry season data. The results revealed that T_{max} exhibits the strongest and most statistically robust relationship with forest cover loss, with R = 0.63. While the average temperature (T_{mean} in Figure 4, below) also showed a detectable signal (R = 0.43), it was notably weaker. In contrast, the minimum temperature (T_{min} in Figure 4) showed a negligible correlation (R = 0.16) with deforestation, and the model fits did not work properly. Based on this evaluation, we selected T_{max} as the most suitable temperature variable to represent the effects of climate change induced by deforestation. We have now added this clarification to the Introduction section of the revised manuscript.

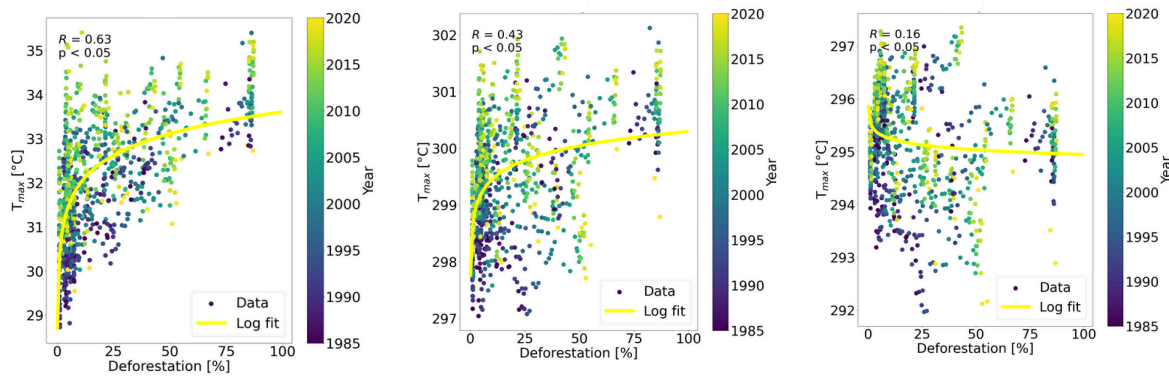


Figure 4: Relationship between maximum (left), average (middle), and minimum (right) daily temperatures with respect to deforestation for the dry season.

For clarification, we improved the manuscript and added the following sentence to the first paragraph of Section *Evaluation of the deforestation and global climate change effects*:

The maximum surface air temperature was used because it provides the clearest and most statistically significant indication of the impact of deforestation compared with the minimum and mean air temperatures.

L46: “Our study reveals that changes in temperature and precipitation in the dry season are critical for the fate of the Amazon under the combined pressure of climate change and deforestation.” I think this is more for the conclusions/ abstract rather than the introduction in my opinion.

We agree with the reviewer that the sentence at line 46 conveys the result of our study rather than setting up its motivation, and it is more appropriate for the *Conclusion* or *Abstract*. In response, we have removed it from the *Introduction* and ensured that the message is clearly articulated in the concluding paragraphs of the manuscript, where the implications of our findings are discussed.

F1 caption: I find it unclear using a satellite basemap as you overlay your own green colour for forest. Where is the forest data from, would be good to cite the data here so readers can understand what they’re looking at at a glance i.e. Hansen et al., 2013. Similarly, I’d like a bit more specific info about the land covers shown in the figure (and source(s)), rather than just various. If they’re not crucial to the story, consider removing them from this plot. Figure 1 needs to set the scene and at the moment, a reader glancing through the figures isn’t sure what to take from this.

F1: At present, I’m not sure if this is a main text figure. A suggestion could be to combine the panels into one forest cover change map, overlaid with the boxes, since the other land covers don’t seem to matter in this analysis? I would also suggest removing the satellite land cover background as it distracts from the important elements you’re trying to convey, i.e. that forest is being lost, particularly in the southeast.

We thank the reviewer for this thoughtful and constructive feedback. We agree that Figure 1 plays a key role in setting the spatial context of our analysis and appreciate the opportunity to clarify its composition and purpose more explicitly. The figure is

not based on a generic satellite image or color basemap. Instead, both the background and the forest cover overlay are derived directly from the MapBiomass Collection 6.0 land use and land cover (LULC) classification, which is based on Landsat imagery and provides annual maps at 30-meter spatial resolution from 1985 to 2020 (Souza Jr, C. M. et al., 2020, DOI: <https://doi.org/10.3390/rs12172735>). The forest areas shown in green correspond to MapBiomass classes labeled as “Forest,” while non-forest land covers (including agriculture, pasture, natural non-forest formations, and urban areas) appear in light yellow or beige tones. Water bodies are shown in blue.

In response to the reviewer’s concern, we have revised the caption of Figure 1 to:

- Clearly state that the map is based on MapBiomass data, not a satellite image,
- Identify the meaning of the colors used (forest vs. non-forest),
- Explain the grid boxes and their role in the analysis,
- Highlight the central message of the figure: the extent and regional concentration of forest loss between 1985 and 2020.

We recognize the suggestion to simplify the figure by removing other land cover types or replacing the background entirely. However, we decided to retain the current version because it serves an important communication function: it shows the landscape transformation over time, not only forest loss, but also how other land uses have expanded across space. This helps the reader understand the heterogeneity in land use patterns among the 29 study areas. We agree that the original caption was insufficiently descriptive. We believe the revised version now clarifies what is shown and how it supports the objectives of the paper. Additionally, we now cite MapBiomass explicitly in the figure caption to increase transparency regarding data sources.

The new Figure 1 caption now reads as:

Spatial distribution of forest and non-forest land cover in the Brazilian Legal Amazon (BLA) in 1985 (left) and 2020 (right), based on classifications from MapBiomass Collection 6.0⁴⁵. The green areas represent forest cover as defined by MapBiomass, corresponding to regions with intact native vegetation. Non-forest land covers are shown in yellow and beige tones and include pasture, agriculture, urban areas, and natural non-forest formations. Water bodies are displayed in blue. The black line delineates the boundary of the BLA, and the black squares represent the 29 fixed grid cells (each ~ 300 × 300 km²) selected for our analysis. These regions were selected to assess the relative impact of deforestation and global climate change on dry season temperatures, precipitation, and greenhouse gas concentrations. The figure illustrates widespread forest loss over the past 35 years, particularly in the southeastern portion of the Amazon.

L68: I'd prefer citations or names of datasets here, you can then point to the section, and or data table where the reader can look for more info. The data choices are very important to the results, hence should be a main feature of the text.

We thank the reviewer for emphasizing the importance of dataset transparency. In response, we revised the sentence at line 68 to include the names of the main datasets used in the analysis (e.g., MapBiomass, ERA5, GPM, AIRS, OCO-2), as these are central to the credibility and interpretation of our findings. We also added a reference to Table 1, which summarizes the spatial resolution, temporal coverage, and sources of all datasets. These changes have improved the readability and comprehension of the data used in the study. Thank you again for your suggestion.

The new sentence now reads as:

This analysis is based on long-term remote sensing and reanalysis datasets, including MapBiomass (land cover), ERA5 (temperature), GPM (precipitation), AIRS (CH₄), and OCO-2 (CO₂). A detailed description is provided in the section Data and Methods, and Table 1 presents a summary of dataset specifications.

L70: which variables? Would be better to be a little more specific here, otherwise the reader hasn't gained anything.

We thank the reviewer for the comment. We agree that the sentence was overly broad, and we have since rewritten it to explicitly state the particular variables that are impacted by global drivers (e.g., CO₂ and CH₄) and those that are more sensitive to regional deforestation (e.g., maximum temperature and precipitation). This change improves clarity and better frames the rationale behind the modeling approach presented in the following sections.

L72: Really interesting and engaging way of conveying this result.

We thank the reviewer for this encouraging comment and are glad to hear that our approach to communicating this result was clear and engaging. This section was designed to effectively illustrate the differentiated influence of deforestation and global climate change on regional climate variables, and we appreciate the positive feedback.

L78: I appreciate the need to be concise on words, however I do think you could briefly summarise these choices here and condense: "For a complete understanding of our approach and rationale, we refer readers to the section Data and Methods, subsection Definition of Wet and Dry Season, and 80 Data Processing, where a detailed explanation and justification are provided" to just "(See methods)". I really think this crucial info should be in the main text, rather than only in methods. As you say, the effects are different in the wet and dry season, the reader wants then to know why and how.

We thank the reviewer for this helpful suggestion. We fully agree that the rationale for focusing on the dry season and its definition should be clear to the reader early in the manuscript. In the revised version, we have already added a new paragraph that explicitly addresses this point. It summarizes the seasonal differences observed in

our analysis, provides scientific justification for focusing on the dry season, and refers to the full methodological details presented later in the *Data and Methods* section. We hope this addition resolves the concern and improves the clarity and transparency of our approach.

The new paragraph now reads as:

Deforestation and global climate change influence rainfall, temperature, and GHG mixing ratios in distinct ways across the wet and dry seasons^{14, 46, 47}. However, several studies have shown that the regional climatic impacts of deforestation are more pronounced and meaningful during the dry season, when the forest is more vulnerable to moisture deficits and surface-atmosphere interactions are intensified. In our analysis, the dry season consistently exhibited stronger correlations between deforestation and key climate variables, including maximum temperature and precipitation (See Supplementary Figure S4), while the wet season showed weaker and often statistically insignificant relationships (See Supplementary Figure S5). Therefore, our study focuses exclusively on the dry season to isolate and quantify the climatic effects of deforestation with greater precision. A detailed explanation and supporting statistical evidence are provided in the Data and Methods, subsection Definition of Wet and Dry Season, and Data Processing.

F2: can you say whether these linear and log fits are significant? Panel a) has a lot of data spread and it isn't immediately clear whether this would be significant. Consider printing r^2 and p values on the plot or in caption text to add robustness.

We thank the reviewer for this valuable suggestion. In response, we have updated the manuscript's Figure 2 to include the Pearson correlation coefficient (R) and p -value for both the linear (panel a) and logarithmic (panel b) fits, as shown below (Figure 5 of this response letter and Figure 2 of the revised manuscript). As now shown in the figure, both fits are statistically significant ($p < 0.05$; in fact, both p -values are virtually zero), with $R = 0.47$ for the linear fit and $R = 0.63$ for the logarithmic fit. We also revised the figure caption to explicitly report the statistical significance and provide a clearer guide for the reader to interpret the results.

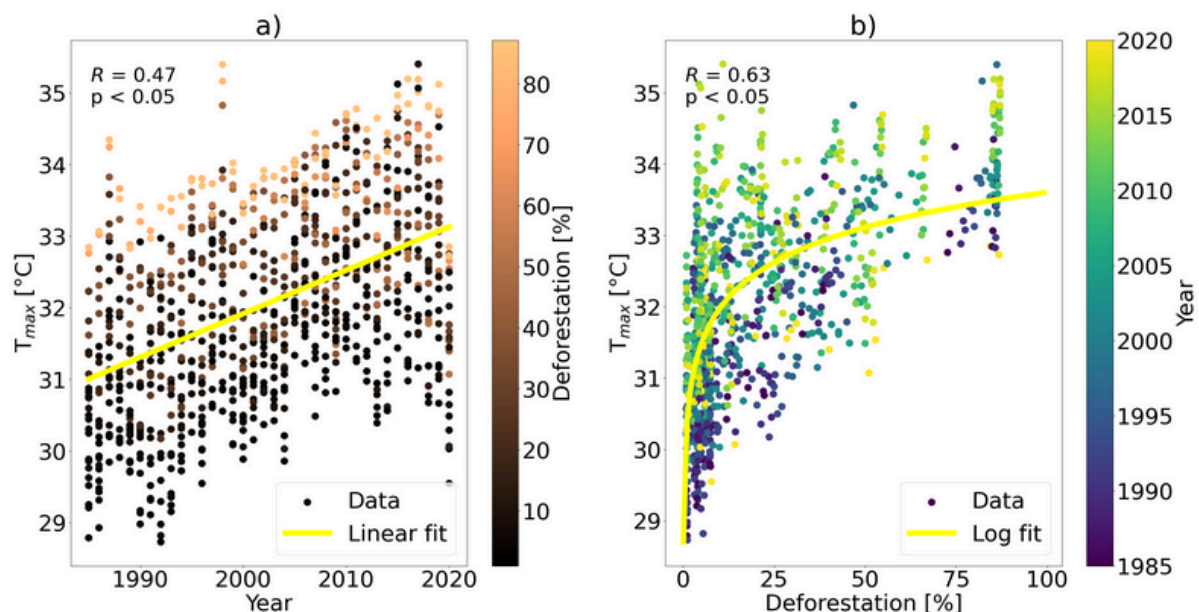


Figure 5: Relationship between dry season daily maximum surface temperature (Tmax) and (a) year, and (b) deforestation percentage, for all 29 areas. In panel (a), data points are colored by deforestation percentage, and a linear fit is applied ($R = 0.47$, $p < 0.05$). In panel (b), data points are colored by year, and a logarithmic fit is applied ($R = 0.63$, $p < 0.05$). Both relationships are statistically significant. The yellow lines represent the fitted linear (a) and logarithmic (b) models.

L92: Far too vague, must include some insight in the main text. If they're important enough results to mention in the main text, they should either be in a main text figure, or explicitly described in text.

We thank the reviewer for this valuable observation. Our intention with this paragraph was to provide a general introductory synthesis of the broader atmospheric responses, while reserving detailed statistical results for the subsequent sections, where each variable is discussed more thoroughly. However, we acknowledge that the original wording was too vague and could give the impression of a lack of clarity or specificity. To address this, we have revised the paragraph to offer a clearer conceptual summary of the patterns observed across variables, without introducing numerical detail prematurely. The new version clarifies the contrasting responses of different variables to temporal (global) and spatial (regional/deforestation) drivers, while pointing forward to the in-depth analyses presented in the main text. The revised paragraph now reads:

We assessed the impacts of regional and global contributions of these parameters during the dry season by fitting linear and logarithmic equations to the dataset. More details are presented in section Data and Methods. These results contrast with a recent study, which reported a linear response of temperature to deforestation⁴⁸. However, their analysis does not disentangle climate change's contribution from deforestation, which our findings indicate is essential for capturing the nonlinear response. By isolating the effects of deforestation, we demonstrate that temperature increases with forest loss logarithmically, emphasizing the distinct role of land-use changes in modifying regional climate. This interplay is explored in detail in the following sections, where we disentangle the respective contributions of time and forest loss to the observed patterns.

L113: I wonder whether a journal with a greater number of figures would be more suitable here as in my view supplementary figures shouldn't be referenced as main figures in the text. They seem here to be used to tell parts of the main story, so should probably be main text figures. Either this or reframe the sentences so that these figures are merely adding nuance and robustness to the story.

We thank the reviewer for this thoughtful suggestion. We agree that the old Supplementary Figure S3 (now Supplementary Figure S6 in the revised manuscript) contributes valuable insight by visualizing the fitted surfaces from our model in three-dimensional space. However, to maintain clarity and conciseness in the main text and in accordance with the journal's figure limits, we have decided to keep this figure in the Supplementary Information. In response to the reviewer's concern, we have revised the corresponding sentence in the main text to better frame this figure as providing complementary detail rather than being central to the core results. The updated sentence embedded in the following paragraph now reads:

Supplementary Figure S6 presents the fitted three-dimensional surfaces that depict how each climate variable responds to both time (year) and the fraction of deforestation, as modeled by Equation 4. These visualizations offer complementary insight into the nonlinear interactions captured by our approach. The parametric formulations used to construct these surfaces are provided in Table 2 and serve as the foundation for disentangling the respective contributions of global climate change and regional deforestation. To assess the model's performance, we evaluated the quality of the fit for each variable, which is also shown in Table 2. In addition, Supplementary Figure S7 presents the correlation coefficients individually for the linear and logarithmic contributions, showing that the dry season fits were statistically significant, with confidence levels above 95%, unlike those observed for the wet season. All fits were statistically robust ($p < 0.05$) and showed strong correlation coefficients ($R \geq 0.69$), confirming the reliability of our approach.

L129: what do you mean by saying “we have accurately quantified”?

We thank the reviewer for highlighting this point. To avoid overstating the precision of our analysis, we have revised the sentence to remove the word “accurately” and instead emphasize the statistical robustness of the modeling approach. The updated sentence now reads:

Using the parameterized equation, we successfully isolated the individual effects of global emissions and deforestation on changes in GHG mixing ratios and weather parameters.

L133: Figure 4 is mentioned before Figure 3, this needs reordering, either of figures or describing figure 3 earlier. Indeed when Figure 3 is mentioned, I don't believe the results are fully described and put in context. Figure 3 has some really nice results and clearly shows the contributions to each change. I believe this should be more thoroughly described and explained. As far as I can tell, Figure 4 is repeating the information from Figure 3? It is a really nice synthesis of the information in a good looking figure, but I wonder if both figures are needed in the main text.

We thank the reviewer for this insightful comment. We agree that the previous order of figures and the limited contextualization of the manuscript's Figure 3 may have hindered the narrative flow and clarity. To address this:

1. We have reorganized the text so that the manuscript's Figure 3 is now introduced and discussed *before* Figure 4. This reordering ensures that the core quantitative results, i.e., the separate contributions of deforestation and global climate change to each variable, are properly contextualized and presented before we introduce a synthesized visualization.
2. We have expanded the discussion of the manuscript's Figure 3, especially to highlight the observed variability across the 29 regions as shown in the boxplots. This figure now serves as the main vehicle for communicating our quantitative findings in the section “*Disentangling the Influence of Deforestation and Global Climate Change on the Amazonian Atmosphere.*”

3. Figure 4 has been retained in the main text because it provides a complementary and integrated visualization of the findings in Figure 3. Figure 3 provides a more detailed statistical breakdown, whereas Figure 4 summarises this information in a concise visual format that makes it easier to interpret and compare. This figure is now referenced later in the section *“Preserving Amazonia’s Forest Cover: Understanding its Importance and Anticipating Future Impacts”*, where its synthetic character supports the broader discussion of ecological and policy implications.

We believe that this restructuring enhances the manuscript’s readability and more effectively conveys the progression from quantitative analysis to integrated interpretation.

L139: How do these increases compare to previous work?

We thank the reviewer for this important comment. Our study is, to our knowledge, the first to quantitatively separate the contributions of global climate change and regional deforestation to the observed changes in temperature and precipitation across the Amazon. While no prior work has directly partitioned these drivers, several recent studies support our findings. For example, Gatti et al. (2021) observed stronger warming and carbon fluxes in the eastern and southeastern Amazon, regions with strong deforestation, compared to more preserved western areas. These spatial gradients are consistent with our results, in which the largest temperature increases are associated with the most heavily deforested regions. We have now included this comparison in the main text to provide additional context and reinforce the robustness of our findings.

L143: It would be helpful to be more explicit when you say “These results highlight the synergistic interaction”.

We thank the reviewer for this helpful suggestion. We agree that the phrase “synergistic interaction” was too general and have revised the sentence to clarify the physical meaning. The updated version now explains that the observed increase in temperature is the result of an interaction in which global climate change amplifies the regional climatic response to deforestation, while deforestation itself contributes to local warming through reduced evapotranspiration and surface energy balance changes. This revised sentence reads:

These results highlight that the observed increase in maximum temperature during the dry season cannot be attributed solely to global climate change or deforestation. Instead, it reflects a synergistic interaction in which long-term global warming amplifies the sensitivity of local climate to land-use change, while deforestation intensifies regional heating and reduces evapotranspiration, further exacerbating the warming trend.

L184: To me, the following seems like a conclusion, rather than an opening for a discussion on the future impacts. Perhaps it could be moved to the conclusions, or reordered in this section. “This study shows the impact of global and land-use changes on the variables examined. Deforestation mainly drives the meteorological

variables during the dry season. When considering all study areas across the Brazilian Amazonian region between 1985 and 2020, deforestation is associated with a daily maximum temperature increase of approximately 16.5%, equivalent to a temperature rise of 0.39 °C. Deforestation also has a dominant influence on the reduction in total annual rainfall. It is responsible for 74.5% of the total decrease in precipitation, resulting in a net 15.8 mm reduction in annual rainfall during the 35 years. On the other hand, deforestation had a smaller impact on GHG concentrations, which were driven predominantly by global changes.”

We thank the reviewer for this helpful observation. We agree that the paragraph at line 184 was written as a summary of findings and could be misread as a conclusion rather than a prelude to the discussion of future impacts. To address this, we have revised the paragraph to clarify that it serves as a transition into the analysis of future scenarios. The revised version briefly recaps the main findings and introduces their relevance for understanding the projected trajectory of deforestation-driven changes. We believe this restructuring improves the logical flow and strengthens the narrative leading into the forward-looking discussion.

L196: This is an important result and should be highlighted better in the paragraph, better still, within the section where you talk about the figure it relates to “within the first 10%-40% of coverage loss”. I’m not sure how most of this paragraph relates to the subheading title “Preserving Amazonia’s Forest Cover: Understanding its Importance and Anticipating Future Impacts”.

We thank the reviewer for this valuable observation. We acknowledge that the original paragraph did not sufficiently emphasise the key finding that the most significant climate impacts occur during the initial stages of deforestation.. In response, we have rewritten the paragraph to emphasize this finding more clearly, both in its phrasing and placement. The revised text now highlights the 10–40% threshold more explicitly and frames it as a core scientific insight with strong implications for conservation and climate resilience. This adjustment also helps the paragraph better align with the subheading “*Preserving Amazonia’s Forest Cover: Understanding its Importance and Anticipating Future Impacts.*”

The new paragraph now reads as:

Our findings show that the most pronounced climate impacts occur early in the deforestation process, within the first 10–40% of forest cover loss. This nonlinear response suggests a steep initial degradation of local climate regulation functions. While further deforestation continues to alter the climate, the marginal impact becomes less dramatic after this threshold. It underscores the disproportionate importance of preserving existing forest areas before they cross these critical initial loss intervals. Comparisons between the least and most deforested areas further reinforce this aspect: regions that have retained more forest cover show greater climate stability, while those with extensive land cover conversion exhibit intensified warming and drying trends (see Supplementary Figure S8). These results emphasize that avoiding even early-stage deforestation is essential for safeguarding the biome’s meteorological resilience and minimizing future disruptions to rainfall and temperature patterns.

L206: To me, this discussion of tipping points isn't central enough to the analysis for it to be referenced in the abstract. Rather I would focus on your good and important results.

We appreciate the reviewer's observation and fully agree that the original framing of a potential "tipping point" was not adequately supported by the methodology or central to the analytical framework of the study. In response, we have removed references to "tipping points" from the abstract and throughout the main text, where appropriate. The manuscript has been restructured to emphasize the core results, including the quantified contributions of deforestation and global climate change to observed changes in temperature, precipitation, and greenhouse gas concentrations. This ensures that the focus remains on our most robust and well-supported findings.

L245: I think this is still a proposed tipping point, rather than a certainty?

We thank the reviewer for this important observation. We fully agree that our results should not be interpreted as confirming a tipping point in the Amazon, but rather as suggesting potential early signs of ecological destabilization under ongoing pressures from deforestation and climate change. To address this, we revised the paragraph in question to explicitly avoid deterministic language and better reflect the limitations of our analysis. Specifically, we now state that the Amazon may be approaching a critical ecological transition. However, we emphasise that we remain cautious in referring to this as a definitive tipping point. This is partly due to structural uncertainties in current climate and vegetation models, and partly due to our extrapolation based on historical data, which does not account for the effects of other factors, such as the response of vegetation to these changes. This revision clarifies that our findings are consistent with *potential* transition signals but do not constitute predictive evidence of a biome-scale threshold being crossed.

L275: Previous analysis has found there to be strong discrepancy between precipitation datasets in particular, but also temperature datasets with respect to their changes due to deforestation. How did you choose these datasets and (also why a near surface, not a land surface temperature) and is there any way the choice of dataset might impact your result. Perhaps something worth mentioning in the text somewhere.

We appreciate the reviewer's thoughtful observation regarding discrepancies across climate datasets, particularly for precipitation and temperature in regions such as the Amazon. These differences are indeed critical when evaluating the impacts of deforestation. In our study, we selected datasets based on three main criteria: (1) spatial resolution and domain coverage over the Brazilian Legal Amazon, (2) temporal coverage matching our 1985–2020 analysis window, and (3) scientific validation and widespread use in peer-reviewed literature. Yes, the choice of dataset can have some influence on the estimated trends, particularly in regions like the Amazon, where observational coverage is sparse and environmental variability is high. To minimize uncertainties, we deliberately selected datasets that are widely used and validated in the scientific literature. In addition, we restructured and expanded the subsections *Greenhouse Gases and Weather Data* and *Land Use and Land Cover Data* to clearly present our dataset choices, including their sources, spatial and temporal resolutions, and relevance to our research objectives.

L290: Reading this section makes me think that some version of Supplementary Figure 5 really should be in the main text, perhaps in lieu of removing Figure 1? The results are really interesting and important. In addition to this, I'm still quite unclear as to why you are only presenting the dry-season in the main text. Is there a justification for this?

We appreciate the reviewer's comment and agree that the results shown in the old Supplementary Figure 5 are valuable. However, we respectfully chose to keep this figure in the Supplementary Material because the variability in the impacts of deforestation across regions is already robustly illustrated in the main text via the boxplots in Figure 3, which display the distribution of deforestation and global climate change contributions for all 29 areas. These boxplots convey the spatial variability across the Amazon and the statistical range of responses in a compact and integrative way, which we consider suitable for the main text. Including Supplementary Figure 5 would be partially redundant and may divert focus from the primary narrative centered on the parametric attribution analysis.

Regarding the exclusive focus on the dry season, as already discussed, we have expanded our justification in the revised manuscript and the subsection *Definition of Wet and Dry Season*, and *Data Processing in Data and Methods*. Briefly, we observed that the climatic effects of deforestation are significantly more pronounced and statistically robust during the dry season, when vegetation is most stressed and surface-atmosphere interactions are enhanced. The wet season presented weaker or statistically insignificant correlations between deforestation and key variables, as supported by our statistical tests. Therefore, we focused on the dry season to ensure clarity and accuracy in quantifying the effects under conditions when they are most relevant.

Table 1: might be useful to display some of these stats on the relevant figures, so readers can view this at the same time as seeing the results.

We thank the reviewer for this helpful suggestion. In response, we have incorporated key statistical values from Table 2 (previous Table 1) directly into the relevant figures, allowing readers to more easily interpret and evaluate the robustness of our results in context. This is now implemented in the revised Figure 2, which presents the scatter plots of the different contributions (global and regional) to the temperature. We believe this integration improves the clarity and accessibility of the results and appreciate the reviewer's recommendation.

Figure S1: Would be nice to see this in map form as well, perhaps as a multi panel plot. You could take Figure 1 and combine with this as a new Figure S1.

We appreciate the reviewer's suggestion to include a map-based or multi-panel visualization for the old Supplementary Figure S1. While we agree that geographic representations can enhance visual understanding, in this particular case, our objective with Supplementary Figure S1 (now Supplementary Figure S2 in the revised manuscript) was to provide a concise overview of the temporal evolution of deforestation and climate variables across all 29 study areas. The current format enables direct comparison of trends year by year across all sites, a task that is more

challenging to achieve in map-based plots, particularly when considering the large number of regions. Given space constraints and the analytical focus of the study, we have opted to keep Supplementary Figure S1 in its current format, which efficiently summarizes the temporal behavior of the variables. However, we have revised the figure caption to better highlight its comparative purpose and ease of interpretation. The new caption reads as:

Temporal evolution of forest cover loss for each of the 29 study areas across the Brazilian Legal Amazon, calculated as the change in forest fraction between 1985 and 2020. This panel-based format allows a direct comparison of deforestation trends across all regions, supporting the identification of spatial heterogeneity in deforestation trajectories.

Figure S5: small point, the panels are not in the same order as other plots. It would be visually helpful to be consistent, so it is easier to flick between plots.

We appreciate the reviewer's attention to visual consistency. The panels in old Supplementary Figure S5 (now Supplementary Figure S8) were arranged to follow the same geographic order as presented in Figure 1, allowing for a direct spatial comparison between forest cover and variable response across the study areas. We understand the importance of consistent figure layout for ease of interpretation and have clarified this in the figure caption. If deemed preferable, we are happy to reorder the panels to match the sequence used in other figures. The new caption reads as:

Pie charts showing the relative contributions of global (blue) and regional/deforestation-driven (green) factors to changes in CO₂, CH₄, precipitation, and maximum surface temperature during the dry season across the 29 study areas. The modeled values used to compute these contributions are derived from the parametric fits in Table 1. The panels are organized following the geographic arrangement presented in Figure 1, facilitating spatial comparison.

Editorial comments:

L83: processes for should be processes form?

We thank the reviewer for identifying this editorial issue. We have revised the sentence for clarity and grammatical correctness. The phrase "processes for" has been corrected to "processes exhibit," which more accurately conveys the intended meaning. The revised sentence now reads:

As an exemplification, the analysis of the maximum daily temperature (Figure 2) shows that during the dry season, these two distinct processes exhibit a nearly linear temporal trend across all deforestation extensions, which is attributed to global climate change, as evidenced by the gradual increase in maximum temperature over the years.

L103: I'm unclear about what you mean by exchange effects. Perhaps this is obvious to others, but if not it could be worth elaborating what you mean.

We thank the reviewer for pointing out the ambiguity in our phrasing. We agree that the term "exchange effects" was unclear and have revised the sentence to more clearly reflect the intended meaning. The updated sentence now reads:

The parameters of Equation 4 were obtained by fitting observational data to separately capture the contributions of deforestation and global influence to observed changes in climate variables.

L111: consider adding numbers to these data subsections, to reduce main text word count. i.e. see methods section 1.x.

We appreciate the reviewer's suggestion to number the sections and subsections in the *Methods* to facilitate easier cross-referencing from the main text. However, Nature Communications follows a formatting style that does not allow numbered section headings in the manuscript. As an alternative, we have revised the main text to refer more concisely and precisely to the relevant subsection titles in the *Methods* (e.g., "Greenhouse Gases and Weather Data"), allowing the reader to locate supporting information efficiently without departing from journal guidelines.

L127: Possibly could condense the following into the subsequent sentence as this has already been said before: "The central question we sought to address is the extent to which the observed changes can be attributed to global climate change versus the effects of deforestation."

We appreciate the reviewer's suggestion. Indeed, the sentence as originally written reiterates information that was already implied in previous lines. We have revised the paragraph to improve clarity and conciseness by merging the idea into it, which now reads as:

To assess the effects of deforestation and global climate change on GHG mixing ratios and weather variables, we developed a novel approach that integrates linear temporal trends with the exponential trends associated with deforestation. These effects interact non-linearly due to the interdependence of deforestation (D) and time (t). As detailed in section Data and Methods, we obtained a parametric equation (Equation 4) that incorporates the linear time dependence, the logarithmic dependence on deforestation, and their nonlinear interactions. The parameters of Equation 4 were obtained by fitting observational data to separately capture the contributions of deforestation and global influence to observed changes in climate variables.

Reviewer #3 (Remarks to the Author):

How Climate Change and Deforestation Interact in the Transformation of the Amazon Rainforest

We thank Reviewer #3 for the thoughtful and constructive review of our manuscript. Your suggestions led us to improve the clarity and contextualization of the study, particularly by revising the Abstract to include a concise summary of the methodological approach and by incorporating new references that strengthen the framing of our analysis. We are grateful for your input, which contributed to refining the manuscript and enhancing its scientific communication..

Reviewer summary:

Abstract:

Please provide a short explanation of the methods in the abstract.

We thank the reviewer for this valuable suggestion. We agree that including a brief explanation of the methodological approach helps clarify how our findings were obtained. Thus, we have revised the abstract to include a concise description of the methods. Specifically, we now state that the study is based on long-term atmospheric and land cover data across 29 areas in the Brazilian Legal Amazon from 1985 to 2020, and that we used parametric statistical models to disentangle the contributions of deforestation and global climate change to changes in temperature, precipitation, and greenhouse gas concentrations. The new abstract reads as follows:

The Amazon rainforest is one of Earth's most diverse ecosystems, playing a key role in maintaining regional and global climate stability. However, recent changes in land use, vegetation, and the climate have disrupted biosphere-atmosphere interactions, leading to significant alterations in the water, energy, and carbon cycles. These disturbances have far-reaching consequences for the entire Earth system. This study quantifies the relative contributions of deforestation and global climate change to observed shifts in key Amazonian climate parameters. We analyzed long-term atmospheric and land cover change data across 29 areas in the Brazilian Legal Amazon from 1985 to 2020, using parametric statistical models to disentangle the effects of forest loss and alterations of temperature, precipitation, and greenhouse gas mixing ratios. While the rise in atmospheric methane (CH₄) and carbon dioxide (CO₂) mixing ratios is primarily driven by global emissions (>99%), deforestation has significantly increased surface air temperatures and reduced precipitation during the Amazonian dry season. Over the past 35 years, deforestation has accounted for approximately 74% of the ~21 mm dry season⁻¹ decline and 16.5% of the 2°C rise in maximum surface air temperature. Understanding the interplay between global climate change and deforestation is essential for developing effective mitigation and adaptation strategies to preserve this vital ecosystem.

Are 21 millimeters in the dry season and over 35 years statistically significant?

We thank the reviewer for bringing this important point to our attention. First, we clarify that the value reported in the abstract was misrepresented: the correct value

is a decline of approximately 21 mm during the dry season, not over the entire 35-year period, but only during the dry season. This has been corrected in the revised abstract for clarity and accuracy. Regarding statistical significance: yes, the observed trend of ~21 mm in dry season precipitation associated with deforestation is statistically significant. This result is supported by the model fit, which is performed similarly to what is shown in Figure 2b, where the logarithmic regression between deforestation and precipitation yields a p-value < 0.01, indicating strong significance. Additionally, the confidence intervals presented in the boxplots of Figure 3, calculated with the parameters from Table 1 confirm the robustness of this trend across the 29 study regions. Particularly for precipitation (and for all the variables), the p-value is nearly zero. To further clarify this point, we have updated the abstract and reinforced the statistical evidence in the relevant Results sections.

The statement on non-linear behavior and tipping points without a short explanation of methods looks confusing.

We appreciate the reviewer's observation and agree that the abstract and the overall manuscript must avoid unintended implications. Our methodology is based on retrospective statistical modeling and does not simulate ecological feedbacks or nonlinear tipping dynamics. While we observe nonlinear trends in key climate variables, such as rapid changes in temperature and precipitation associated with initial forest cover loss, we recognize that these trends do not imply confirmation of a tipping point in a mechanistic or predictive sense. To prevent confusion, we revised the abstract and the whole manuscript to remove references to tipping points and instead focus on the observed magnitude and trends of change. We also added a concise statement of our methodology to contextualize the findings (see revised abstract). These changes are consistent with the framing used throughout the revised manuscript, especially in the sections where we discuss the results, where we acknowledge the limitations of our approach in capturing critical ecological thresholds.

Introduction:

About the carbon and water fluxes: Please consider using some new references: <http://dx.doi.org/10.1088/2515-7620/adc06a> and <http://dx.doi.org/10.1038/s41598-025-85272-z>

We thank the reviewer for suggesting the inclusion of recent literature on carbon and water fluxes. We agree that both papers provide valuable context regarding large-scale drivers of carbon assimilation and evapotranspiration dynamics across South America. In response, we have incorporated both references into the Introduction section of the revised manuscript. These studies strengthen our framing by emphasizing the role of ocean-atmosphere teleconnections and regional climate variability in shaping biosphere-atmosphere interactions in the Amazon. Specifically, we added the following sentence:

Recent studies have further highlighted how ocean-atmosphere teleconnections modulate carbon assimilation and evapotranspiration dynamics across South America's major biomes, including the Amazon, at seasonal to interannual scales^{19, 20}. These findings emphasize the need to contextualize Amazonian carbon and water

fluxes not only in terms of local land-use changes but also in large-scale climate drivers.

¹⁹ *Serrão et al. (2025): Effects of large-scale climate drivers on carbon assimilation in Brazilian biomes, Environmental Research Communications.*

²⁰ *Dionizio et al. (2025): Spatiotemporal variability in evapotranspiration and its controls across South America, Scientific Reports.*

Line 25: I'm not sure about the statement that the Amazon basin controls all these globally critical issues. For instance, critical freshwater is about "blue" and "green" water availability pre- and post-industrial times. However, the authors showed transgressions in these attributes even during pre-industrial events. This makes sense, even nowadays, several studies have shown some resilience in hydrological processes in the Amazon in recent events.

We appreciate the reviewer's thoughtful observation regarding the framing of the Amazon Basin's role in regulating planetary boundaries, particularly with respect to freshwater change. Indeed, the Planetary Boundaries framework addresses blue and green water availability in terms of long-term, global-scale alterations from pre-industrial baselines. Freshwater boundary transgressions may indeed occur independently of Amazonian dynamics. In our revised manuscript, we have clarified that while Amazon has a strong regional influence on continental-scale freshwater dynamics and contributes substantially to the global hydrological cycle (e.g., through evapotranspiration and rainfall recycling), it is one of several regions influencing global freshwater change. We have modified the sentence accordingly:

Of the nine processes identified as critical for Earth system stability²¹, five with the most critical status, namely climate change, biosphere integrity, land system change, freshwater change, and biogeochemical flows, are significantly influenced by the Amazonian Basin, particularly at regional to continental scales.

Line 36: You should check the Amazon basin area. It is about 6 mi km², and if you consider Tocantins, it reaches 7 mi km². But, if your study area is Legal Amazon, this number drops slightly.

We thank the reviewer for this important observation. Indeed, the total area of the Amazon Basin can reach approximately 6 to 7 million km² when considering hydrological boundaries, including the Tocantins-Araguaia basin. However, as clarified in our study, our analysis focuses specifically on Brazil's *Legal Amazon* (Amazônia Legal), which is a well-defined socio-political and administrative region used in national environmental policy frameworks. According to the [Brazilian Institute of Geography and Statistics \(IBGE\)](#), the area of the Legal Amazon is approximately 5,015,146 km², representing around 58.9% of the Brazilian territory, consistent with the most recent official delimitation.

Line 43: Some studies assessed the combined effect of deforestation and climate in the Amazon's watersheds. For instance, <https://doi.org/10.1029/2019WR025083>.

We thank the reviewer for this insightful comment and for pointing to the study by Cavalcante et al. (2019), which indeed provides important insights into the joint

effects of land use and climate change on hydrological processes in Amazonian watersheds. We have now acknowledged this in our revised manuscript and clarified that, while several studies have examined the combined effects at local or watershed scales, our study expands on this by providing a biome-wide, long-term quantification of the separate contributions of deforestation and global climate change across key climatic variables using observational data and a parametric modeling framework. The improved text now reads as:

Particularly, deforestation has a substantial impact on the regional climate of Amazonia^{5, 22, 32, 40, 41}. Although previous studies have investigated the combined effects of deforestation and climate change in specific subregions or watersheds²⁷, the relative roles of deforestation and global climate change and their interaction in driving the transformation of the Amazon remain poorly understood and have yet to be disentangled^{25, 42}.

Line 30: I missed more studies that assessed the effects of climate change in different variables (e.g. hydrology, biodiversity, etc), even in small basins. I suggest a more detailed review of these papers.

Thank you for this suggestion. In response, we have included a more detailed review of studies that evaluated the effects of climate change on different variables, including hydrology, in both large and small Amazonian basins. Notably, studies such as Panday et al. (2015) (DOI: <https://doi.org/10.1016/j.jhydrol.2015.02.018>) and Cavalcante et al. (2019) (DOI: <https://doi.org/10.1029/2019WR025083>) have assessed the interplay between climate variability and land-use change, particularly in the Xingu and Itacaiúnas River basins, respectively. We have now revised the manuscript to incorporate these references and contextualize our findings within this broader literature.

Quantifying global and regional effects across Brazilian Amazon areas:

You could explain better how the assessment was in each area. Did you evaluate the fluxes pixel by pixel? The mean, median...?

We thank the reviewer for this important question. We evaluated each variable (temperature, rainfall, CH₄, and CO₂) by aggregating the data within each of the 29 fixed ~300 × 300 km² areas across the Brazilian Legal Amazon. Specifically, we calculated area-averaged (mean) values for each variable within each grid cell at monthly and annual time steps. These spatial means were used to construct consistent time series for each region, which were then analyzed using our parametric model (Equation 4 in the manuscript) to disentangle the effects of deforestation and global climate change. This averaging approach ensures that local-scale variability is accounted for within each cell while preserving regional-scale trends. The choice of mean (as opposed to median or other statistics) was motivated by its consistency across datasets and its compatibility with the linear and logarithmic regression framework applied. We have revised the manuscript accordingly to clarify this methodology, particularly in the Sections *Quantifying global and regional effects across Brazilian Amazon areas*, *Evaluation of the deforestation and global climate change effects*, and *Data and Methods*, subsection *Greenhouse Gases and Weather Data*.

Figure S1: You should categorize the bars by region using different colors (e.g., pristine areas, the arc of deforestation, and so on).

We thank the reviewer for the suggestion to categorize the bars in Figure S1 by region (e.g., pristine areas, arc of deforestation). While we recognize the value of such stratification, we have chosen to maintain the current single-color format to preserve clarity and visual emphasis on the magnitude of forest cover loss in each of the 29 study areas between 1985 and 2020. Our goal with this figure is to highlight the heterogeneity in deforestation intensity across the study domain without introducing additional visual complexity that might detract from the primary message. Moreover, detailed regional classifications, such as the arc of deforestation or pristine zones, are already provided in previous studies, including Teixeira et al. (2025) (DOI: <https://doi.org/10.1016/j.foreco.2025.122662>), which contains a comprehensive map of these spatial distinctions (see, for example, their Figure 1). We now reference this complementary source in the revised caption of Figure S1 to guide readers seeking a regional breakdown of the study areas.

Evaluation of the deforestation and global climate change effects

Line 77: "Our study....". This phrase isn't in the right place. You could use it in the abstract or introduction, but not in this section.

We appreciate the reviewer's attention to the clarity and structure of the manuscript. The sentence in question was placed at the section *Evaluation of the deforestation and global climate change effects* with the intent of introducing the specific methodological approach adopted in this part of the study. While it refers to the overall study, it also serves to guide the reader into the technical discussion that follows. To better align with the reviewer's suggestion, we have revised the whole paragraph to reflect its role as a lead-in to the analytical evaluation rather than a restatement of the study's broader aims. We hope this adjustment clarifies the purpose of the sentence in its current location.

Deforestation and global climate change influence rainfall, temperature, and GHG mixing ratios in distinct ways across the wet and dry seasons^{14, 46, 47}. However, several studies have shown that the regional climatic impacts of deforestation are more pronounced and meaningful during the dry season, when the forest is more vulnerable to moisture deficits and surface-atmosphere interactions are intensified. In our analysis, the dry season consistently exhibited stronger correlations between deforestation and key climate variables, including maximum temperature and precipitation (See Supplementary Figure S4), while the wet season showed weaker and often statistically insignificant relationships (See Supplementary Figure S5). Therefore, our study focuses exclusively on the dry season to isolate and quantify the climatic effects of deforestation with greater precision. A detailed explanation and supporting statistical evidence are provided in the Data and Methods, subsection Definition of Wet and Dry Season, and Data Processing.

Line 81: Is this section about results? You began to explain some methods (method), and after that, you showed results ("our analysis reveals..."). You should replace some parts of the method section.

We thank the reviewer for their insightful comment regarding the structure of the section *"Evaluation of the deforestation and global climate change effects."* We understand the concern about blending methodological descriptions with the presentation of results, and we would like to clarify our intention with this section. This portion of the manuscript was designed to provide a conceptual and analytical overview of the approach we use to distinguish between the effects of deforestation and global climate change. Specifically, it introduces the rationale for our choice of modeling strategy by fitting linear models to represent temporal trends (as a proxy for global climate change) and logarithmic models to represent spatial deforestation impacts. These relationships form the analytical foundation for subsequent sections of the manuscript, where the disaggregated effects are further explored in detail.

Although the section references some findings (e.g., the linear trend with time and logarithmic response to deforestation), we believe this discussion is essential to guide the reader through the logic behind our analytical framework. To that end, we clarify in the text that a more detailed description of datasets and statistical fitting procedures is provided in the Data and Methods section. The sentence beginning with *"Our analysis reveals..."* marks the transition from the description of data characteristics into the modeling insights that justify our separation of effects. We respectfully argue that this integrated structure enhances the narrative coherence of the manuscript, helping readers understand why specific models were selected and how the relationships were empirically validated. Additionally, the figure referenced here plays a central role in visually introducing the dual-model structure, bridging methods, and initial findings. Nevertheless, we carefully reviewed this section to ensure that any methodological elements presented here are confined to high-level justifications, while technical implementation details remain in the Methods section. We hope that with this clarification, the reviewer agrees that the structure serves the manuscript's clarity and purpose.

Figure 2: I didn't understand the relationship between the temperature increase (in Figure 2) and climate change. I can see a noticeable rise in temperature with an increase in deforestation. How did you isolate climate change using $\text{Temp} = f(D, \text{time})$?

We appreciate the reviewer's question regarding how we isolate the effects of global climate change from those of deforestation in Figure 2. Indeed, Figure 2 was designed as an initial diagnostic visualization to highlight the distinct relationships of maximum dry-season temperature with time and deforestation, treated separately. Panel (a) presents the temporal trend of temperature across all study regions, revealing a statistically significant linear increase over the 35-year period. This trend is interpreted as the effect of global climate change, which progresses with time and is consistent across regions regardless of their specific deforestation histories. Panel (b), on the other hand, shows a logarithmic relationship between temperature and the deforestation fraction, irrespective of year, emphasizing the localized and nonlinear influence of land-use change. These two panels help establish that both time and deforestation are important drivers of temperature change, but they do not yet account for the potential interactions between the two.

To move beyond this bivariate representation, the section *"Derivation of the Parametric Fits and Calculations of the Deforestation and Global Contributions"* introduces a more robust and integrated analytical approach. We model temperature

(and other variables) as a function of both time and deforestation fraction simultaneously. The initial model assumes additive linear (for time) and logarithmic (for deforestation) contributions (Eq. 2), but this proved insufficient because deforestation itself evolves over time, introducing potential interaction effects. To capture this interdependency, we allow the regression coefficients to vary with the other variable (Eqs. 3–4), leading to a more flexible and physically interpretable four-parameter model (Eq. 5).

This parametric surface (Eq. 5) enables us to analyze the joint and interacting influences of deforestation and time (i.e., global climate change). It is adjusted using least squares fitting to observed data, and its partial derivatives (Eqs. 6–7) allow us to isolate the *marginal effects* of time (holding deforestation constant) and of deforestation (holding time constant). We then integrate these expressions over time and over the observed range of deforestation for each region, producing the absolute contributions of global and regional drivers (Eqs. 8–9). Thus, while Figure 2 provides a visual justification for modeling temperature as a function of both time and deforestation (each showing distinct and statistically significant patterns), the full attribution of changes to global or regional processes is achieved through the analytical framework outlined in the subsequent section. We revised the sections to ensure a better connection between these two parts of the text, thereby improving clarity for the reader.

Modeling the evolution of atmospheric variables

Line 106: I understand equations 6 and 7, but it is not clear that Equation 1: Please explain how "B" is a parameter related to global forces/global changes.

We thank the reviewer for highlighting the need to clarify the attribution of the parameter B in Equation 1 as being related to global forces. In our framework, Equation 1 is given by:

$$y(t, D) = A \ln D + Bt + C,$$

where y represents an atmospheric variable (e.g., temperature), D is the deforestation fraction, and t is time. The rationale for interpreting B as the contribution of global climate change stems from both theoretical expectations and empirical evidence. As shown in Figure 2a, we observe a clear, nearly linear increase in temperature over time across all regions, including those with minimal deforestation. This trend reflects the ubiquitous and regionally homogeneous influence of global climate change (e.g., rising greenhouse gas concentrations and radiative forcing), which progresses over time and is not strongly modulated by local land-use changes. Therefore, we associate the linear-in-time component (Bt) with the global forcing. But as mentioned above, in the previous response, the relationship between global and regional contributions are non-linear, so that we define B as

$$B = b_1 \ln D + b_2.$$

This is further elaborated and justified in the section *Derivation of the Parametric Fits and Calculations of the Deforestation and Global Contributions*. In that section, we

refine this initial model by allowing both A and B to vary as functions of the other independent variable (Equations 3 and 4), acknowledging that deforestation and time are not fully independent. However, the interpretation of B as the *global component* remains valid because it governs the evolution of y with time when deforestation is held constant. This logic is explicitly formalized in Equation 6, where we compute the partial derivative of $y(t,D)$ with respect to t while keeping D constant. The resulting expression

$$\left. \frac{\partial y}{\partial t} \right|_{D = \text{const}} = \gamma \ln D + b_2$$

isolates the temporal effect, where b_2 is directly associated with the time-only (global) component of the trend. This decomposition allows us to quantify the distinct contributions from global climate change and regional deforestation, as shown in Equations 8 and 9.

Disentangling the Influence of Deforestation and Global Climate Change on the Amazonian Atmosphere

How did you use the equations in Table 1 to find 87 ppm and 173 ppm (CO₂ and CH₄)? This is because your data set analysis focused only on the study area. So, the global influence is not clear.

We appreciate the reviewer's careful attention to this point. The global contributions for CO₂ (87 ppm) and CH₄ (173 ppb) presented in our manuscript were computed based on Equation 4 plus the parameters from Table 2 (previously Table 1), as shown in the section *Derivation of the Parametric Fits and Calculations of the Deforestation and Global Contributions*. Our analysis focuses on the Brazilian Legal Amazon, and the global component we refer to in this context represents the long-term atmospheric trend that cannot be explained by local or regional land-use changes (i.e., deforestation), but specifically for the Legal Amazon. Equation 4 captures this by fitting each variable as a function of both time and deforestation fraction, allowing us to statistically distinguish the signal associated with global-scale processes (represented by the linear term in time) from the regional deforestation influence (represented by the logarithmic term in deforested fraction).

Specifically, we compute the global component by integrating the time-dependent part of Equation 4 while holding the deforestation fraction constant at its mean value across the full study period (see Eq. 7). This procedure yields the total change in the variable that can be attributed to temporal trends (i.e., global influences such as fossil fuel emissions, global methane sources, etc.) within the BLA during the analysis period. Although our spatial domain is regional, the time-dependent signal extracted from the statistical model reflects processes consistent with globally observed trends in greenhouse gas concentrations. Therefore, the values of 87 ppm (CO₂) and 173 ppb (CH₄) correspond to the integrated global contributions over the 35-year period (1985–2020) within the BLA, derived from the partial derivative of Equation 4 with respect to time, as shown in Equation 7.

Responses to Reviewers

We address the remaining comments below using the following color code strategy:

- In black are the reviewer's comments.
- In blue are the author's responses.
- *In blue and italics are the text modifications we made in the manuscript or section names when referred to.*

We trust that the revisions satisfactorily address the concerns raised and hope the manuscript is now suitable for publication in *Nature Communications*.

Sincerely,

Marco Aurélio de Menezes Franco, Luiz A. T. Machado, and all co-authors

Reviewer #1 (Remarks to the Author):

Overall I think the authors comprehensively addressed the reviewers' comments and significantly improved the clarity of their manuscript.

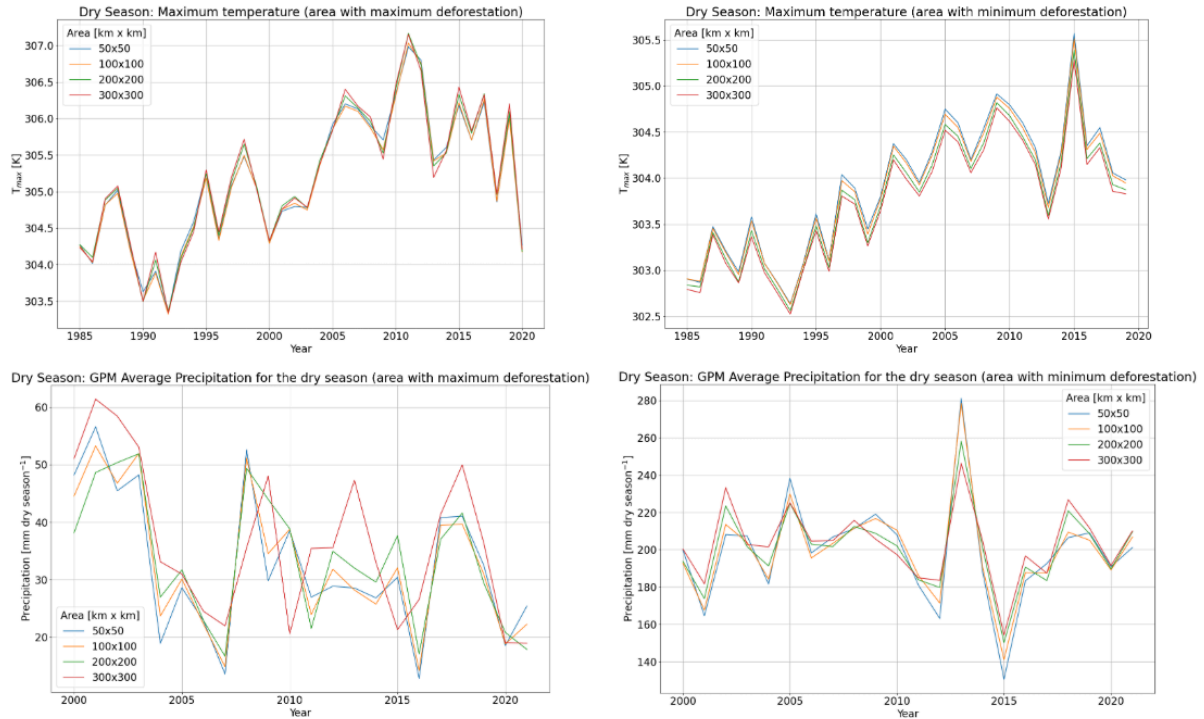
All that is left from my side is minor remark regarding the sensitivity analysis related to the size of their study plots in Figure S1. Especially the variety between the different precipitation results shown in the lower part of the panel are not "minor". The authors did justify very well why they have chosen the 300 km resolution but I think they should also mention the scale dependency of their results. Please also add "dry season" to the upper parts of the panel.

We thank the reviewer for their positive and constructive feedback. We have now mentioned the scale dependency in the manuscript, which reads as follows:

The results, shown in Supplementary Figure S1, indicate that the long-term trends in temperature and precipitation remain consistent across scales, reinforcing the suitability of the 300×300 km² resolution adopted in this study. However, greater

variability during the dry season suggests a slight scale dependency for the precipitation in the analysis.

Additionally, we have revised Figure S1 to include the label "dry season" in the upper parts of the panel, as requested (Figure S1 of the manuscript, shown below).



We appreciate the reviewer's careful attention to detail, which has helped improve the clarity of our manuscript.