Responses to Reviewer

We would like to thank the reviewer for the valuable comments and useful suggestions to improve our manuscript. Below are the responses and actions for each comment. To facilitate the identification of individual responses and actions, we have employed the following colour coding strategy. In black are the reviewer's comments. In blue are the author's responses, and in blue italic the new text added to the manuscript.

Main comments

First, the authors acknowledge that the availability of eddy covariance data is limited. Still, a more comprehensive assessment of how representative these sites are of the region would make it easier to see if/where extrapolations go beyond the training data. For example, because canopy height and LAI products are used to predict model parameters, it would be useful to know to what extent these four sites cover the range of variation seen across the Amazon.

The five flux towers considered in this study sit in upland forest sites, in regions subjected to subtle differences in the climate regime and stress associated with land use change. We acknowledge that the flux towers are not representative of all Amazonian ecosystems, like seasonally flooded forests. Even though upland forests represent more than 80% of the Amazon Biome, and the range of canopy height and LAI values at the 5 towers comprises most of the spatial variability of these quantities (Figure 1 in the manuscript and Figure A below). In a grid of 1-degree resolution, upland forests predominate everywhere, except in the Arc of Deforestation, where pasture-land use dominates. As such, the extrapolation from the flux tower sites to the domain of upland forests is reasonable.

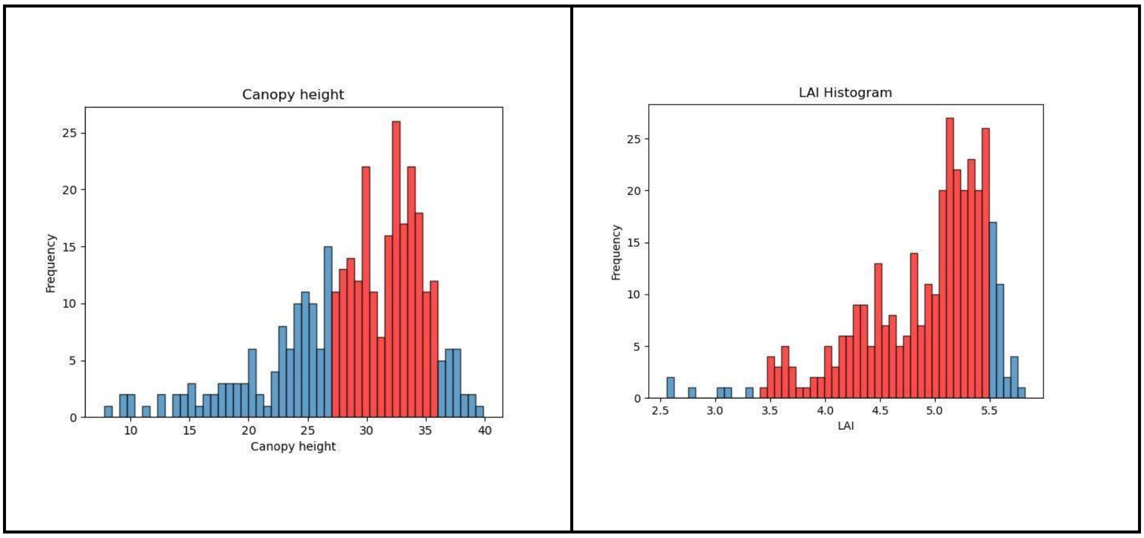

Figure A: Histogram of canopy height and LAI in the study area. The range of heights and LAI in the 5 flux towers considered in this study is highlighted in red.

To clarify this point, we have included in Table 1 the LAI values corresponding to each flux tower. We also included the following paragraph in section 2.1:

"*All the eddy covariance flux towers are located in upland (terra firme) forest sites, with canopy heights in the range 27-36 m and LAI in the range 3.26-5.46 m^2 m^{-2} (Table 1), respectively comprising 61% and 85% of the distribution of values in the study area (Figure 1). The five flux towers considered in this study represent upland forests in regions with subtle differences in the climate regime and in the level of stress associated with deforestation and climate change pressures. While the K34 and ATTO towers are located in pristine forest reserves in the Western Amazonia, the RJA tower sits in a forest reserve surrounded by agricultural areas in Southwestern Amazonia. The K67 and K83 towers sit in a forest reserve near the deforestation frontier in the Eastern Amazonia. Therefore, this set of flux towers represents the diversity of upland forests, which extend through more than 80% of the Amazon biome (Moraes et al., 2021). However, it is important to acknowledge that this set of flux towers is not representative of all Amazonian ecosystems, like seasonally flooded, swamp or white sand forests.* "

Second, given that the parameter tuning at the eddy covariance sites did not reproduce observed seasonal flux patterns (stated in line 326 and shown in Figure 4), I was surprised that seasonal patterns were so widely highlighted in subsequent Amazon-wide simulations (Figures 6, 7, discussion lines 496-507). The earlier results did not seem to support that JULES is appropriate for investigating seasonal patterns.

Indeed, our results have shown that the model calibration did not improve the representation of the NEE seasonal variability, although it did improve the mean bias. Even so, to better understand the model response to different meteorological forcings, we believe it is important to assess the NEE spatial variability in periods with contrasting atmospheric conditions. To comply with the reviewer's comment, in the discussion of Figure 6, we have acknowledged the poor representation of the NEE seasonal variability, including the following sentence in the section 3.3:

"*Despite the fact that the JULES model was not able to precisely reproduce the carbon flux seasonal cycles (Fig. 3), it is important to assess the estimated spatial variability of NEE in months with contrasting meteorological conditions, investigating the model responses.*"

We also provided a new title in the section 3.3. to "Spatial variability of carbon fluxes in Amazonia" and we selected two months in two distinct seasons in view of to understand how the meteorological effects change the spatialization in the Brazilian Amazon biome. We introduced this sentence in the section 3.3.

"Evaluating JULES over two months enables us to understand the dynamics of spatialisation in two distinct seasons. Despite JULES' limitations in reproducing seasonality, this approach is useful for determining spatial variability in dry and wet conditions."

Last, it was not clear to me whether the K83 validation exercise was conducted with in-situ meteorological data or the ERA5 meteorological data. It would be helpful to whether using ERA5 data decreases data-model agreement for all eddy covariance sites.

Thank you for raising this point. In situ meteorological data was used for both the calibration and validation of the model at the K83 tower. ERA5 meteorological data was only used for the specialization of carbon fluxes. When calibrating a process-based model, we considered that the meteorological data needs to demonstrate a high level of confidence; in this case, in-situ data is recommended (Wallach, 2019). To clarify this in the manuscript, we have reworded the sentences in section 2.3 as follows:

'The JULES model requires the meteorological variables listed in Table 2 as input. In-situ meteorological forcing data from each flux tower (Restrepo-Coupe et al., 2021; Andreae et al., 2015) were used for model calibration (Section 2.4.2) and cross-validation using K83 tower data. For the specialization of carbon fluxes, meteorological data from reanalysis was applied, as will be described in Section 2.4.'

Specific comments

- Lines 55-57: For a general audience, I think it would be helpful to describe JULES more broadly. For example, I see that JULES can be run either as a "big-leaf" or a "multi-layer" approach. From the supplement I see that the multi-layer implementation was used here, and I think a couple sentences about this should also be included in the main text.

Thank you for the suggestion. We have added a description of JULES containing equations that highlight where the most sensitive parameters are, as well as describing how JULES simulates GPP and Reco. We also introduced information on our use of the multi-layer approach to run JULES. The new organisation of the material and methods involves the JULES description in section 2.2; section 2.3 covers ancillary environmental data; section 2.4 focuses on gridded data; and section 2.5 describes the JULES model procedures and the spatialisation method. The final section provides a brief description of the VPRM model.

- Lines 139-142: I am somewhat surprised that GEDI-based products were not used for this task, as GEDI's sampling is now denser in this area (https://doi.org/10.3334/ORNLDAAC/2339). It would also be helpful to see what the Global Forest Canopy predictions are for the eddy covariate sites, perhaps in the supplement. It is somewhat hard to tell from Figure 1.

We appreciate the suggestion regarding the database used for canopy height. In view of this, we compared GEDI's sampling with the Global Forest Canopy dataset (Figure B).

Despite the high positive correlation (0.7) between these two datasets, differences can be observed mainly in the reproduction of canopy heights between 5 and 10 meters.

However, the aim of our study is not to provide the most up-to-date NEE for the Brazilian Amazon biome, but to present a methodology for JULES using spatialized main sensitivity parameters.

Of course, the results are sensitive to the assimilated dataset. We used the Global Forest Canopy dataset because it is continuous, with no missing data, unlike the GEDI dataset, which has missing data. Another factor is that, when we began the spatialization process, the GEDI database was unavailable for simulation, so we decided to use the Global Forest Canopy database instead. However, if we use the GEDI database in future studies, we expect to increase the carbon sink in the Amazon forest. This is based on our sensitivity analysis and the JULES results in some zones that simulate a high carbon source (>0.75 kg C m^{-2} $year^{-1}$) with canopy height >35 m, as in the case of Amapá and Acre.

Regarding the question related to the canopy height for the Eddy covariance sites, important to mention that we used this dataset to provide the canopy height in the Table 1.

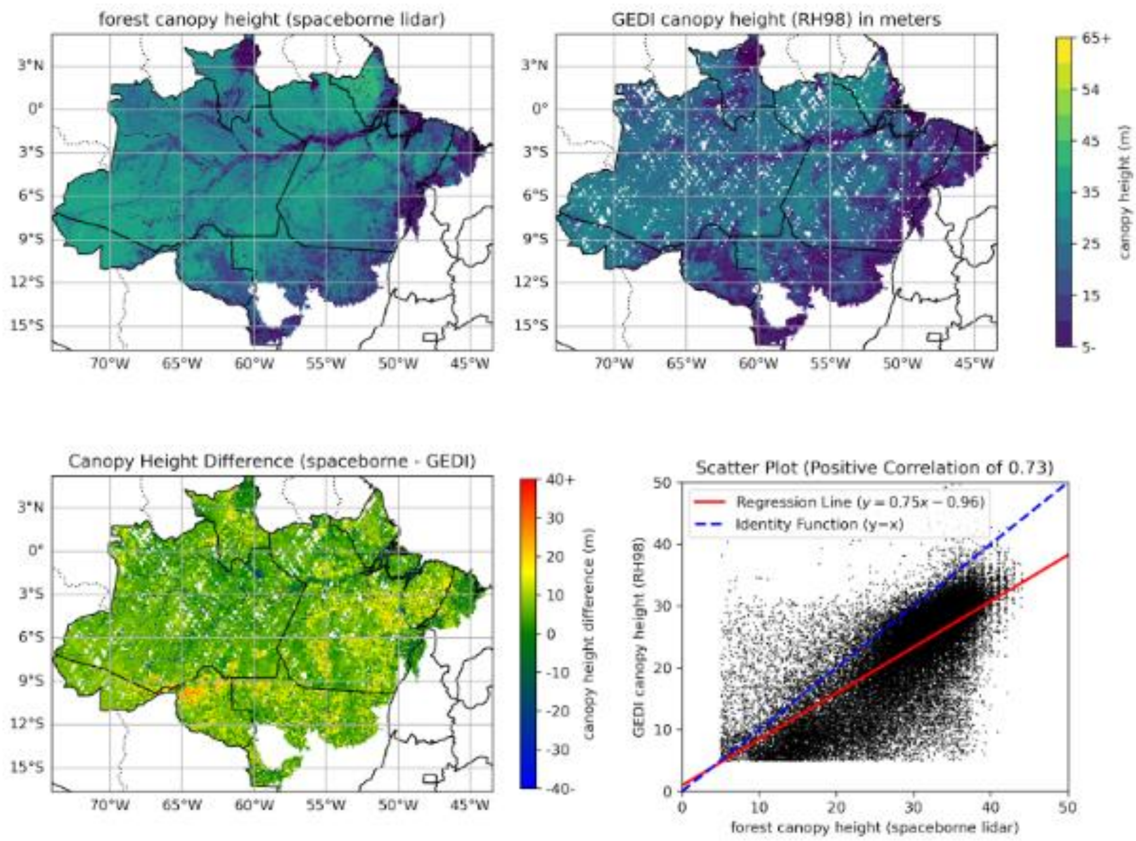

Figure B: Comparison of GEDI and Global Canopy Forest datasets of Canopy Height and a scatter plot demonstrating the correlation between these two sources in the Brazilian Amazon biome.

In the end of the discussion (section 4.2), we introduced the following sentence

"*Another area for improvement in future studies would be to use other canopy height databases, such as those based on airborne LIDAR observations, to improve the spatialization of plant physiological parameters. '*

- Line 150: Please provide a summary of the basis of European Carbon Tracker estimates, as is done for FluxCom-X.

We would like to thank you for this suggestion. We provided the basis of European Carbon Tracker estimates in the section 2.4

"European Carbon Tracker provided hourly NEE at a resolution of 0.1º in latitude by 0.2° in longitude, spatial and hourly temporal resolution, calculated by the Simple Biosphere model Version 4 (SiB4), which is driven by meteorology variables from the European Centre for Medium-Range Weather Forecasts (ECMWF) Reanalysis 5th Generation (ERA5) dataset"

- Line 202: Please describe the scale factor for dark respiration.

We would like to thank you for this suggestion. We added a description of the scale factor for dark respiration in section 2.5.1.

"*Scale factor for dark respiration (fd), which is a coefficient between 0 and 1 associated with leaf dark respiration*"

We also reminded the readers that the equations and a detailed description can be found in the Section 2.1, specifically in the Equation 6 and in the Section 1 of the supplementary materials.

- Lines 293-295: Why was only the area around the ATTO tower used—were data from other areas used for predictions for other areas?

We would like to thank you for this comment. We only mentioned the ATTO site tower; however, the simulations with VPRM were performed for all towers used to calibrate JULES (K67, ATTO, RJA, K34, and the independent tower K83). We added a sentence mentioning the procedure was applied to all towers in section 2.6.

"These indices are derived from the MODIS Surface Reflectance 8-Day-L3 Global 500 m (MOD09A1) product, which is collected within a ±0.1° area around each tower evaluated in this study (ATTO, K34, K67, K83, RJA; see Table 1 for descriptions)"

- Line 363-364: The relationship with canopy height and alpha is poor. How important is this?

In fact, the relationship between alpha and canopy height is poor (R^2 = 0.01). At first glance, this appears to be a limitation, but since alpha varies very little, we are comfortable with this low correlation. Alpha is the third most sensitive parameter in the JULES model, and the value was chosen by varying alpha over a wider range than it actually varies in the Amazon region. To adjust alpha and canopy height, we used the minimum and maximum alpha values presented in the Amazon region, as shown in Figure S3.3.1 of the supplementary material. This is consistent with the range of 0.05 to 0.06 mol mol^{-1} for C3 species presented by Skilmann (2008). Using alpha with LAI extrapolates this range (see Figure S3.3.1), which includes an increase in value in regions with C4 grasses. However, this is inconsistent with the reduction of this value in plants with this metabolism. Therefore, as alpha is nearly constant, parameterising alpha has a small impact. This could be more important for other vegetation types, which is why we kept it in the adjusted list. We have added the following sentence to Section 3.2 to clarify this aspect:

"The correlation of alpha with canopy height is small; however, as alpha in the Amazon has a small range of variation (between 0.05 and 0.06 mol mol^{-1} for C_3 species, in line with Skilman, 2008), this low correlation has a small impact on the final result."

Technical corrections:

- Line 34: I think this reference should be (Brienen et al., 2015), but I don’t see the full citation in the reference section.

Thank you for this correction and we added the correct reference in the line 34 and also in the reference section.

"The Amazon forest is one of the largest carbon reservoirs in the world, being relevant to the global environment, biodiversity and climate regulation (Brienen et al., 2015)."

- Line 69: I suggest rewording "having as reference to Eddy-covariance towers in different regions of the Brazilian Amazon biome" to something like "using as references to Eddy-covariance towers in different regions of the Brazilian Amazon biome"

Thank you for this suggestion. We replaced "having" to "using" in the line 70.

"Here, we present an improvement of the JULES parameterization specifically for the Brazilian Amazon, performing a sensitivity analysis of the model parameters using as reference to Eddy-covariance towers in different regions of the Brazilian Amazon biome"

- Figure 1: I don't see the black symbol for the validation tower?

In fact, the validation tower was not presented in the Figure 1. We replaced Figure 1 with another version with validation tower K83 in black symbol.

- Line 326: Reword to "The seasonality of the carbon fluxes was not captured by any of the model simulations"

Thank you for the suggestion. We reword the sentence to "*The seasonality of the carbon fluxes was better represented by JULES optimized utilizing the Nelder-Mead method (Figure 3).*

- Line 334: Reword to “direct relation”

Thank you for the suggestion. We replaced the sentence “directly relation” to direct relation”. The sentence adapted in the section 3.1:

“NEE was used as the control variable because it is directly measured in the flux towers “

References

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