Responses to reviewers

Manuscript ID : EGUSPHERE-2025-2869: Spatializing Net Ecosystem Exchange in the Brazilian Amazon biome using the JULES model and vegetation properties.

Dear Editor, Dr Marijn Bauters

We sincerely thank you and the reviewers for the careful evaluation of our manuscript. The constructive comments and corrections were really helpful and supported a quality improvement of the manuscript.

In this letter, we have addressed all points raised by the reviewer, correcting grammar errors and also improving sentences for a more scientific and direct language. Following the reviewer's suggestion, we have included a brief discussion comparing our results with a recently published study about the spatialization of vegetation model parameters in Amazonia. This new study is in agreement with our results and support our hypothesis that the spatialization of model parameters improves the quality of carbon fluxes estimates.

General statement of changes:

- Correction of grammatical errors in the text, marked in red by the reviewer in the report.

- Introduce new sentences to clarify aspects of the leave-one-out cross-validation procedure and the selection of the independent validation site.

- Include a paragraph discussing the results from the suggested paper.

- Avoid repeated sentences in the text.

- Correction of some technical errors, such as in the sensitivity analysis equation.

We trust that this version satisfactorily addresses the concerns raised by the reviewers and hope that the Manuscript is now suitable for publication in Biogeosciences.

Sincerely

Amauri Cassio Prudente Junior, Luiz A. T. Machado, and all co-authors.

Reviewer 1 - Manuscript ID : EGUSPHERE-2025-2869: Spatializing Net Ecosystem Exchange in the Brazilian Amazon biome using the JULES model and vegetation properties.

First of all, we would like to thank the reviewer for the dedication in relation to improve the quality of our study, since the correction of minor grammar mistakes until valuable suggestions which fit with the aim of this study, as the proposal to include the new paper "Spatially varying parameters improve carbon cycle modeling in the Amazon rainforest with ORCHIDEE r8849" by Zhu et al., (2025). This paper highlights the importance of considering vegetation heterogeneity when estimating the carbon cycle in the Amazon Forest. Thank you for all the corrections you added to the manuscript, which have provided a cleaner and more precise version.. We applied all correction in the new version of the paper. We considered that this new version is able to be published in the Biogeoscience, and the reviewer's contribution helped us to achieve this objective.

Below, we provide a detailed point-by-point response. To facilitate the identification of individual responses and actions, we have employed the following color-coding strategy.

- In black are the reviewer's comments.
- In blue are the author's responses.
- *In blue italic, the new text was added to the manuscript.*

Since my initial review, I have seen that the following paper has also been published: Zhu, L., Ciais, P., Yao, Y., Goll, D., Luyssaert, S., Martínez Cano, I., Fendrich, A., Li, L., Yang, H., Saatchi, S., Dalagnol, R., and Li, W.: Spatially varying parameters improve carbon cycle modeling in the Amazon rainforest with ORCHIDEE r8849, Geosci. Model Dev., 18, 4915–4933, https://doi.org/10.5194/gmd-18-4915-2025, 2025. At a quick glance, it seems that there are many clear differences (which model is being used, what data are used to inform spatially varying parameters, which parameters are allowed to vary spatially). Given the similarity in objectives/titles, I recommend adding a short statement in the discussion (~ 1-3 sentences) about the major implications of spatially varying parameters here compared to the other piece. I apologize for the additional suggestion beyond my original review.

We would like to thank you for this relevant suggestion. This study offered many aspects that are similar to our study, even some differences such as the vegetation index that was spatialized, the strategy of spatialization, and the process-based model that was approached. This article demonstrates some similarities with our study. We have introduced new sentences in the text to explain the results of Zhu et al. and their relation to our study. The first comment is related to the similarity with the most sensitive parameters of the JULES and ORCHIDEE models in the Amazon Forest, which includes light-limited and nitrogen for photosynthesis in Tropical Evergreen trees. This sentence was included in section 2.5.1.

"Parameters with light-limitation of photosynthesis, such as the case of alpha were also sensitive in other Dynamic Vegetation models, such as ORCHIDEE (Organizing Carbon and Hydrology in Dynamic EcosystEms), demonstrated by Zhu et al., (2025), working with a spatialization procedure of the carbon cycle in the Amazon region. Another relevant parameter observed by Zhu et al., (2025) was related to the nitrogen use of photosynthesis, which, in the JULES model, is the fd parameter directly related to the content of nitrogen to estimate maintenance respiration (Equation 11, section 2.2). After canopy height, the fd parameter is the most sensitive parameter of JULES, followed by alpha in the Brazilian Amazon biome. Despite the difference in parametrization of these two different models, similarities of the parameters indicate relevance of nitrogen and radiation to reproduce carbon fluxes in tropical trees."

Another sentence was introduced in the final of the discussion section, reinforcing the relevance of this sort of studies taking into account the vegetation heterogeneity to estimate carbon fluxes in tropical forest as the case of the Amazon biome. Also, we pointed out important points of difference in these two studies. We utilized observed data from Eddy-covariance tower and the Zhu et al, employed LIDAR-biomass models to estimated GPP, therefore in a different spatial scale. Also, the relevance of utilizing sensitive calibrated parameters to develop statistic models of carbon fluxes based on vegetation properties to develop statistical models gives robustness of the our NEE estimative. This sentence was added in the last paragraph of the section 4.2.

"Studies regarding the spatialization carbon fluxes in the Amazon Forest utilizing process-based model are rare, however, Zhu et al., (2025) demonstrated some similarities with our work in the sensitive parameters in ORCHIDEE, regarding to light and nitrogen limitation for photosynthesis and to demonstrate the heterogeneity of carbon fluxes when

utilize a spatialization method taking into account the vegetation differences in a tropical forest, Although, these two studies reached the same conclusion, the methodologies employed were very different. Our study uses eddy covariance towers and a statistical model to spatialize carbon fluxes based on sensitive, calibrated parameters and vegetation properties. By contrast, Zhu et al.'s (2025) study uses satellite observations of tree aboveground biomass and gross primary production (GPP) at a very different spatial scale."

Line 56: quite an old ref to make this claim!

We agree with this suggestion, and we have changed for another study that represents JULES as state of art in land surface model by Harper et al (2018). This new reference was cited in the line 56.

"JULES is a community land surface model used both as a standalone system and as the land surface component of the Met Office Unified Model. It is considered the state-of-the-art for large-scale simulations (Moreira et al., 2013, Harper et al., 2018)."

Line 58: Still potentially unclear—in theory the model could be run with any number of PFTs, and 5, 9, or 13 are common choices

We would like to thank you for this suggestion, and we rephrased this sentence highlighting the number of PFT in each JULES version. The new sentence is based on lines 57-59.

"The model was progressively updated , enhancing the number of plant functional types (PFT): five PFTs (HadGEM3, Clark et al., 2012), nine PFTs (Harper et al 2016), more recently 13 PFTs (UKESM1, Harper et al., 2018), and additionally four non-vegetation land cover types."

Line 82: please specify—at the tower sites or across the whole Amazon basin?

The comparison with VPRM model was developed at the Eddy-covariance towers utilized to parametrize JULES and in the validation tower K83. We introduced a sentence in line 82 to reinforce this aspect.

"Section 2.6 describes the VPRM model that was used to compare with the JULES model at the tower sites."

Line 95: do you mean seasonally dry, or are some areas wet and others dry?

In the Southern Amazon region, despite the fact that is a wet forest, some areas have a stronger seasonal cycle with a dry season. In view of to clarify this aspect, we introduced a new sentence in lines 94-95.

"In the southern Amazon region, the RJA tower is located in a forest reserve in the state of Rondônia, characterized as Aw: Tropical savanna climate with dry season in the Köppen-Geiger climate classification (Peel et al., 2007)."

Line 102: Why was this tower chosen for validation?

The selection of the tower K83 as our reference to validate JULES spatialized method was based on the availability and quality of observed data for one year, in view of our analysis of JULES seasonality in reproduce carbon fluxes in the Brazilian Amazon biome. We introduced a new sentence to reinforce this aspect in lines 102-104.

"The K83 tower was used as an independent reference point to validate the spatialization model. This tower was selected as independent data based on the availability and quality of observational data over a period of one year.

Line 110: I think it would be more appropriate to say something like "includes multiple kinds of upland forest communities"

We agree with this suggestion, and we replaced the sentence in the line 111.

"Therefore, this set of flux towers includes multiple kinds of upland forests communities, which extend through more than 80% of the Amazon biome (Moraes et al., 2021)."

Line 173: Consider naming Supplemental equations S1, S2, …for clarity?

We agree with this suggestion and we corrected Supplementary equations in the text as the example in line 173.

"where N_l, N_s and N_r are nitrogen contents of leaf, stem and root, respectively and β is the soil moisture stress factor based on Cox et al., 1998 (see equation S9 and S10 on Supplementary materials)."

Line 260: I think I understand how this was done, from looking at the Moreira reference. To address Reviewer 2's comment, I think more details should be added

We considered the suggestion, and we added a sentence clarifying how Moreira et al (2013) developed the initialization procedure of JULES, in which consist in initializing the model with fields as close as possible to observation. We added a new sentence in the lines 258-260.

"To initialize the JULES simulations, we adopted the strategy employed by Moreira et al. (2013) which consists in initializing the model with fields as close as possible to observations. We ran JULES from the start to the end of the simulation period."

Line 290: I don't think this adequately addresses Reviewer 2's comment, which was that this formula is a non-standard metric. It is not RMSD (where dividing by N is under the radical)

We agree with this suggestion. In fact, we committed a typo and corrected the MAD equation. In view of this change, we added a new sentence in the lines 276-278 and also in the equation in line 290.

"The effect of these changes on NEE calculations was quantified using the mean absolute deviation (MAD, g C m^{-2} day^{-1}) (Equation 14) and Δvar (%) (Equation 15)."

Line 335: This LOO exercise was done using values predicted by the spatialization linear equations from canopy height and LAI, correct? If so, it would be easier to follow if this was described after that process was presented.

The Leave-One-Out cross validation exercise was done utilizing values predicted by the linear equations provided by the spatializing procedure taking into account the sensitive parameters as independent variables and vegetation properties (Canopy Height and LAI) as dependent variables. We removed one of the available towers and analyzed each scenario, as described in Supplementary Material Section S.4. We replaced the sentence of the cross-validation method to section 2.5.3 related to the spatialized JULES in the Amazon. Please, see the lines 377-380.

"After that, a leave-one-out cross-validation method was used to validate the calibration in different parts of the Brazilian Amazon biome (Wallach et al., 2018), utilizing the predict values obtained by the spatialization linear equations from canopy height and LAI."

Line 367: Replace with a dot that is not at the bottom of the text to be clear about multiplication?

We accepted the suggestion, and we replaced with a dot in the equation 18.

Line 411: this analysis was just using one site?

The local sensitive analysis was developed at the ATTO tower, the selection of this tower was based on the location based on the center of the Amazon biome and also the availability and quality of NEE observed data in this tower. We added a new sentence in the lines 418-419, reinforcing that the local sensitive analysis was developed at ATTO Tower.

"After the identification of the model parameters with highest sensitivity in the ATTO tower, utilized as reference for the local sensitive analysis for the Brazilian Amazon biome, the JULES model was calibrated for each flux tower, following the methods described in Section 2.5.2. "

Line 529: perhaps "increase in the estimated carbon sink", unless there is reason to believe the other two are more accurate?

We agree with this suggestion, and we replace "overestimation" to "increase in the estimated carbon sink in Amazonia". We added a new sentence in lines 536-538.

"Figure 7 clearly shows that the three different modelling approaches using JULES (optimized, default, and spatially fixed best adjusted parameters) result in an increase in the estimated carbon sink in Amazonia (i. e., more negative NEE values) during both the wet and dry seasons, when compared to Carbon Tracker and FluxCom-X."

Line 546: state default value as reference?

We added the default value in the sentence (0.875 for the f0 parameter) in view of to clarify the difference in the ATTO and K34 towers in comparison to the default value based on Harper et al (2016). We added a sentence in lines 552-554.

"Also, another relevant aspect that may have induced the GPP increases in JULES's simulations was the higher values of f0 observed in some regions calibrated in this study, such as ATTO and K34 (0.95 and 0.93, respectively), in comparison with the default value determined by Harper et al (2016) (0.875)."

Line 567: it would be helpful to say explicity whether positive or negative "difference" values indicate a stronger carbon sink in the spatialized JULES model

We agree with this suggestion, and we added in the caption of the Figure 7 a sentence reinforcing this aspect:

"Differences between spatialized JULES and the other estimates are also presented. Positive and negative differences indicate stronger carbon source or sink, respectively."

Line 584: I recommend starting the discussion with a clear statement of the most important parts of the results, instead of going through the order of the analyses strictly.

We accepted this suggestion, and we added a statement of the most relevant results that would be approached in the discussion topic as the calibration results and also the NEE estimative by the spatialization procedure. We added this statement in lines 594 to 601.

"This section will discuss some relevant results demonstrated in this study. The first aspect is related to the new parametrization of JULES model in four different sites of the Brazilian Amazon biome taking into account the adjustment of the most sensitive parameters of JULES . The Nelder-Mead method was able to optimize JULES model and the new set of parameters was applied to develop a method of spatialization utilizing linear regressions with the dependent variable as canopy height or LAI and independent variable the most sensitive parameters adjusted in the calibration procedure. The second aspect of the discussion is related to the NEE estimative utilizing the JULES spatialized. In this aspect, JULES spatialized demonstrated a carbon sink of -1.34 Pg C m^{-2} in the year of 2021 being demonstrated a strong carbon source in the states of Acre and Amapa, regions characterized by specific climatic and vegetations characteristics, respectively"

Line 596: I don't think "More variable" is what is meant to be communicated here, as the value doesn't vary much among sites (as stated next)

We agree with this suggestion. In fact, it was not "more Variable" because the values varied from 0.050 to 0.058 mol/mol, however, there was a lower linear relation comparing with others sensitive parameters. Due to this fact we changed the sentence in lines 615-620.

"The cross-validation procedure also showed that the alpha parameter did not show a linear relationship with canopy height or LAI (Figure S4.2). This may be explained by the fact that the values for each tower were nearly constant, with a difference of only 0.0018 mol PAR mol CO_2^{-1}, while the other parameters exhibited greater variability between sites. In practical terms, the spatialization of the alpha parameter was almost the same as using its mean value all over the study area."

Line 613: how is this possible, if the parameters don't change in time? this seems more appropriate as a "future direction" to me

The spatialized method improved the leaf phenology due to the fact that we diversified distinct zones of carbon fluxes taking into account the mean vegetation properties instead of adopting the same parameter for distinct zones with diversity of LAI or Canopy Height. But we agree that this methodology could not provide seasonal variation. We deleted this sentence and added a new sentence in the conclusion as perspective.

"One potential improvement to this methodology would be to consider parameters, primarily the leaf area index (LAI), which varies throughout the seasonal cycle. This is because the photosynthetic capacity of the canopy and leaf phenology are among the main seasonal drivers in this region (Restrepo-Coupe et al., 2013). Using different parameterizations throughout the year would provide a more accurate description of the effect of leaf phenology in different zones and seasons for different types of trees. This is particularly important for the emergence of leaves, which open their stomata more frequently for photosynthesis than older leaves approaching senescence (Wu et al., 2016).

Line 719: awkward wording, I'm not sure what the intent is

We rephrased the sentence in view of meaning our advances of JULES spatialized has improved carbon fluxes simulations due to the heterogeneity of the Amazon biome. A new sentence was added in the lines 749-751.

"However, the JULES spatialized simulation in 2021 gave a relevant aspect to better investigate the carbon balance in these regions. It is important to note that this study developed an optimization of JULES using a limited number of Eddy-covariance towers."