Response Reviewer 3: egusphere-2026-684

We thank the two referees, as well as Dr. Bruce Hicks and Dr. Peter A. Taylor, for their valuable comments and constructive suggestions. We greatly appreciate their feedback and have carefully addressed their comments in both our responses and the revised manuscript. Before addressing the individual comments, we would like to clarify the general aim and scope of our study.

The main aim of this study is to investigate whether the prototypical nocturnal boundary layer (NBL) above tropical rainforests, as commonly represented in weather and climate models, adequately captures the observed dynamics of this layer. By a prototypical or canonical NBL, we refer to the boundary layer developing above a bulk (zero-order) representation of the canopy and governed primarily by the interplay between turbulence generated by wind shear and stable thermal stratification associated with longwave radiative cooling.

Our aim is therefore to bridge the complexity of the observed nocturnal canopy–atmosphere system, influenced by thermal stratification, turbulence, and interactions across the canopy–atmosphere interface, with the necessarily simplified and relatively coarse representations commonly used in weather and climate models. We do not attempt to characterize all processes occurring within the canopy or all sources of variability in the observed NBL. Rather, we use the observations to assess to what extent the canonical representation captures the main characteristics and governing processes of the NBL above the rainforest, and to identify where this simplified representation may become insufficient.

To address this question, we make use of a comprehensive observational dataset to characterize the main features and governing processes of this canonical NBL above the rainforest. Specifically, we analyse: (i) the evolution of the NBL height using different criteria that reflect the different mechanisms controlling its development (Fig. 2); (ii) the characteristic vertical profiles of turbulence and state variables (Figs. 3 and 5); (iii) the stability within and above the canopy (Fig. 4), which provides an important lower boundary condition and may introduce variability at the canopy–atmosphere interface; and (iv) the individual terms in the budgets of turbulent kinetic energy, heat, and carbon dioxide above the canopy (Figs. 6, 7, and 8). These budgets enable us to quantify, among other processes, the role of stable thermal stratification associated with longwave radiative cooling near the canopy top and the mechanical production of turbulence by wind shear.

Together, these four elements provide an observational characterization of the prototypical NBL above the rainforest and establish a framework that can be used in future work to systematically evaluate model representations of turbulent kinetic energy, potential temperature, and carbon dioxide under nocturnal boundary-layer conditions.

In the revised version of the manuscript, we have further strengthened and clarified this central objective throughout the paper. Below we have responded to the comments raised one by one. If adjustments of the manuscript are indicated below the response, the newly added text is indicated in blue.

Response

1. The manuscript is considerably long, which makes it difficult to follow in several sections. I recommend carefully revising the text to remove repetitive or less relevant material and focus on the key findings. A more concise manuscript will improve readability and maintain the reader's interest.

2. *The introduction includes a summary of the study results, which would be more appropriate for the Results or Discussion section. Instead, the introduction should focus on the scientific background, motivation, relevant previous studies, and the research gap. The objectives and novelty of the study should be clearly stated at the end of the introduction, highlighting how this work differs from previous research and addresses existing knowledge gaps.*

Response (1 + 2): Thank you for pointing this out, following all the discussion on the manuscript we adjusted the introduction and other manuscript text and made the final revised manuscript more concise and adjusted the introduction to focus on the scientific background, motivation and research gap (see revised to manuscript).

3. *Please clarify whether any outlier detection, quality control, or data-cleaning procedures were performed before the final analysis. If so, describe the methods used.*

Response: In the final manuscript we have added a more elaborate data description. Here we have included the data-cleaning procedures. To respond to the raised comment, for the calculation of the half hourly fluxes, the raw eddy covariance data was processed using the standard data processing procedure of Eddy Pro (LI-COR Biosciences. 2021; Fratini & Mauder 2014). The data has been corrected for outliers, detrended, double rotated, compensated for time-lags, and corrected for spectral loss, crosswind and WPL (Webb-Pearman-Leuning) density fluctuations.

4. *Line 25: The phrase "in its immediate surrounding" is unclear. Are the authors referring to the eddy covariance footprint? If a footprint analysis was performed, please describe the methodology and discuss its implications for the results*.

Response: The phrase "in its immediate surrounding" in the text indicates that all measurements used for the study are done in the surrounding of the ATTO tall tower. We have removed this phrase and indicated the exact locations of the measurements more clearly in the revised manuscript.

(L 69-70 in Manuscript) For this study specifically, observations were collected from both the 325 m high ATTO tall tower (-2.1448° N, -59.0008° E) and the shorter 81 m high Instant tower (-2.1468° N, -59.0068° E), which are 670 m apart.

5. Please *clearly define the variables U, U* (friction velocity), and U, when they are first introduced in the manuscript.*

Response: In the manuscript, the variable U has been indicated in L 59 in the introduction. In section 2.2 u* should have been clearly indicated, this is however not the case, thank you for pointing this out. Given planned adjustments to the introduction, all the variables are introduced in at the location where they are first stated. For U this is in section 2.2 (revised manuscript) and u* in section 2.4.1 (revised manuscript).

6. *Figure 2: The figure would benefit from including units for all variables. Please ensure that the units are shown either on the axes or clearly stated in the figure caption.*

> **Response**: Thank you for the suggestion, in the revised manuscript we have indicated the units in the sub-figure titles.

7. *Section 3.2 (Temporal Evaluation of Stability Within and Above the Canopy): The first paragraph of this section is difficult to follow and contains several unclear statements. I recommend rewriting this paragraph to improve clarity and better communicate the main findings.*

> **Response:** We appreciate that you point this out, given all the comments we have decided to condense our text in the revised manuscript. For the updated version of section 3.2 we refer to the revised manuscript.

8. *The study is based on approximately two weeks of observations. Please discuss whether this observation period is sufficient to draw broader conclusions regarding nocturnal canopy-atmosphere interactions in the Amazon rainforest. It would be helpful to acknowledge this limitation and discuss its implications.*

> **Response:** We believe the observations are representative of the NBL during the Amazonia dry season. However, there are limitations: 1) during the wet season changing cloud cover and precipitation change the atmospheric structure and NBL development (Biscaro et al., 2021). 2) our observations are limited to one year there cannot be accounted for multi-year climate variability, caused by for example the ENSO modes. Studies by Carneiro and Fisch (2020) and Souza et al. (2026), found that these climate modes have an influence on the evolution of the NBL. 3) the observations do only apply to regions on top of a plateau and not to lower elevated regions close to a river. Close to the rivers and in the valleys, the vegetation is less dense and possible influences by the river breeze are possible (de Oliveira and Fitzjarrald, 1993). We have highlighted these limitations more clearly in the discussion in the revised manuscript

9. *The Results and Discussion sections would be strengthened by a more comprehensive comparison with previous studies. Please discuss how your findings agree with or differ from the existing literature and explain the possible reasons for any differences.*

> **Response**: We agree with the reviewer, in the revised manuscript we have extended our comparison of our results to excising literature. Below we give one example of how is carried out. When necessary, and throughout the manuscript, we have included these references to improve the perspective of our study. The example is:
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> Recently two new studies estimating the h_NBL at the ATTO site have been published. In the first by Mendonca et al., (2026) they estimate h_NBL using the maximum of the nocturnal low-level jet (NLLJ). In the study they estimate h_NBL to be between 81 and 247 m, this in accordance with our estimated range with the windspeed criteria (156 $\pm$ 46.5 m). Additionally, they find the height of the NLLJ to be dependent on the wind direction. We observe a NLLJ for two nights (12-13 and 17-18 August), these nights are dominated by winds from a North / Northeastern direction. In line with the paper, the NLLJ height is between 80-100 m.
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> In the second by Souza et al. (2026) they show the variability of h_NBL during the wet and dry season (including the CloudRoots observation period). In the dry season of 2022, they find an average h_NBL of 120 +- 28 m, which is lower than our average value with ranges between 142 and 164 m through the night. The difference can be attributed to the different methods used

to estimate h_NBL. In the paper by Souza et al. (2026) they use turbulent fluxes to estimate h_NBL. We use five different methods, which all yield slightly different results. It would be fairer to compare their results with our turbulent based estimate (Ri). With the estimation using the Ri, we find a h_NBL of 134 +- 29.5 m, which is closer to the values found by Souza et al. (2026).

10. *The Results section is overly detailed, and several paragraphs are difficult to follow. Consider condensing the presentation by focusing on the most important findings and improving the clarity of several sentences. A more concise presentation will make the results easier to interpret and more engaging for readers.*

Response: Thank you for pointing this out, in the revised manuscript we have condensed our results section.

References

Biscaro, T. S., Machado, L. a. T., Giangrande, S. E., & Jensen, M. P. (2021). What drives daily precipitation over the central Amazon? Differences observed between wet and dry seasons. *Atmospheric Chemistry and Physics*, *21*(9), 6735–6754. https://doi.org/10.5194/acp-21-6735-2021

Carneiro, R. G., & Fisch, G. (2020). Observational analysis of the daily cycle of the planetary boundary layer in the central Amazon during a non-El Niño year and El Niño year (GoAmazon project 2014/5). *Atmospheric Chemistry and Physics*, *20*(9), 5547–5558. https://doi.org/10.5194/acp-20-5547-2020

De Oliveira, A. P., & Fitzjarrald, D. R. (1993). The Amazon river breeze and the local boundary layer: I. Observations. *Boundary-Layer Meteorology*, *63*(1–2), 141–162. https://doi.org/10.1007/bf00705380

LI-COR Biosciences. (2021). Eddy Covariance Processing Software (Version 7.0.8) [Software]. Available at www.licor.com/EddyPro.

Fratini, G. & Mauder, M. (2014). Towards a consistent eddy-covariance processing: an intercomparison of EddyPro and TK3. *Atmospheric Measurement Techniques*, 7, pp. 2273-2281. DOI: https://doi.org/10.5194/amt-7-2273-2014.

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Souza, C., Mendonça, A. C. S., Van Asperen, H., D'Oliveira, F. A., Botía, S., Martins, L. G. N., Hall, D. H., Santana, R. A., Fisch, G., Oliveira, L. R., Mata, J. R., Figueiredo, R., Portela, B. T. T., Quesada, C. A., and Dias-Júnior, C. Q.: Estimation of Nocturnal Boundary Layer Height in the Central Amazon, Supported by Gas Concentration Profiles, EGUsphere [preprint], https://doi.org/10.5194/egusphere-2025-6531, 2026.