Response to reviewer comments on the manuscript "*Quiet New Particle Formation is a significant aerosol source in the Amazon boundary layer*", submitted for publication at ACP.

Dear Editor, we would like to thank you and the reviewers for their valuable comments and practical suggestions to improve our manuscript. Below are the responses and changes in the manuscript related to each reviewer's comment. To make it easier to identify the individual answers and actions, we used the following color code strategy:

In black and italic are the reviewer's comments.

In blue are the author's responses.

In orange are the text modifications we made in the manuscript.

Responses to Reviewer #1:

Reviewer comment:

In this manuscript, the authors use 10-year particle number size distribution measurements from the ATTO during the wet season to demonstrate "quiet NPF, which does not show a typical banana signature. While the quiet NPF is relatively weak in intensity, it occurs more frequently than the downward transport of aerosol particles during rainfall events. The authors show that the frequent quiet NPF accounts for nearly half of 10–25 nm particle production during the wet season, and it potentially represents an important source of nanoparticles that helps sustain aerosol number concentration in the Amazon. The research topic is very important and fits the scope of Atmospheric Chemistry and Physics well. Overall, the manuscript is well written. I recommend publication of the manuscript after the authors address the following comments.

Author response:

Dear Reviewer #1, thank you for the careful reading of the manuscript and for the constructive and insightful comments. We particularly appreciate the reviewer's recognition of the relevance of the topic and the clarity of the manuscript. Below, we respond to each comment in detail and describe the additional analyses and clarifications implemented in the revised manuscript.

Major comment 1: Influence of anthropogenic emissions

Reviewer comment:

Aerosols observed at the ATTO and ZF2 sites can occasionally be influenced by anthropogenic emissions. Such influence, while infrequent, could have a non-negligible impact on the analysis of the quiet NPF, because the intensity of the quiet NPF is weak. Have the SMPS data been screened for potential influences from anthropogenic emissions before the analysis?

Author response:

We thank the reviewer for raising this critical point. Given the weak intensity of Quiet NPF, it is indeed essential to assess whether occasional anthropogenic influences could bias the results. Importantly, in the central Amazon, the anthropogenic ultrafine particles transported over long distances typically would have diameters larger than 10–25 nm. As a result, such contributions are not expected to produce the size-resolved growth signatures characteristic of Quiet NPF. Nevertheless, differences in the physical properties of the aerosol population could potentially affect the characteristics of the process.

To explicitly test the robustness of our conclusions, we performed an additional screening of the non-event-day dataset using black carbon (BC) as a tracer for anthropogenic influence. Following Valiati et al. (2025), we used a BC concentration of 0.064 µg m^{-3} as an upper threshold representative of pristine aerosol conditions at ATTO during the wet season. This value corresponds to the average BC concentration observed under conditions in which regional biogenic processes dominate aerosol properties. Using this threshold is therefore a conservative choice, while still retaining sufficient data coverage for statistically meaningful analysis.

We compared two datasets (both only during the wet season):

1. **All non-event days**, as used in the original analysis.

2. **Non-event days under periods with low anthropogenic influence,** defined by 5-minute intervals with BC < 0.064 µg m^{-3},

For both datasets, we analysed the normalized PNSD, (ii) the growth rate derived using the appearance time method, the J_{10}, and the DPR_{10}.

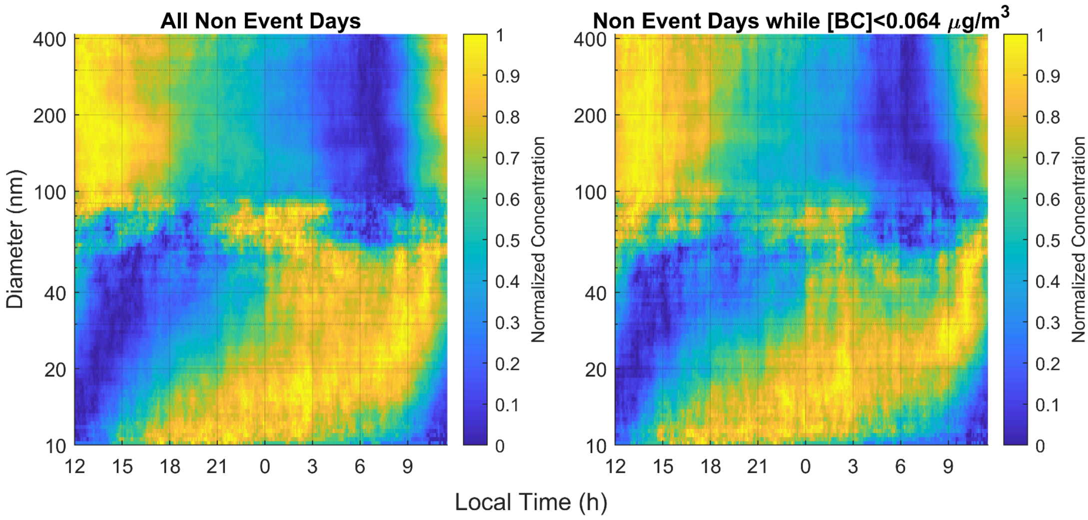


Figure R1. Median diurnal cycle of the normalized PNSD during non-event days in the wet season at ATTO. (a) All non-event days. (b) Non-event days under periods of low anthropogenic influence, defined by [BC] < 0.064 μg m^{-3}.

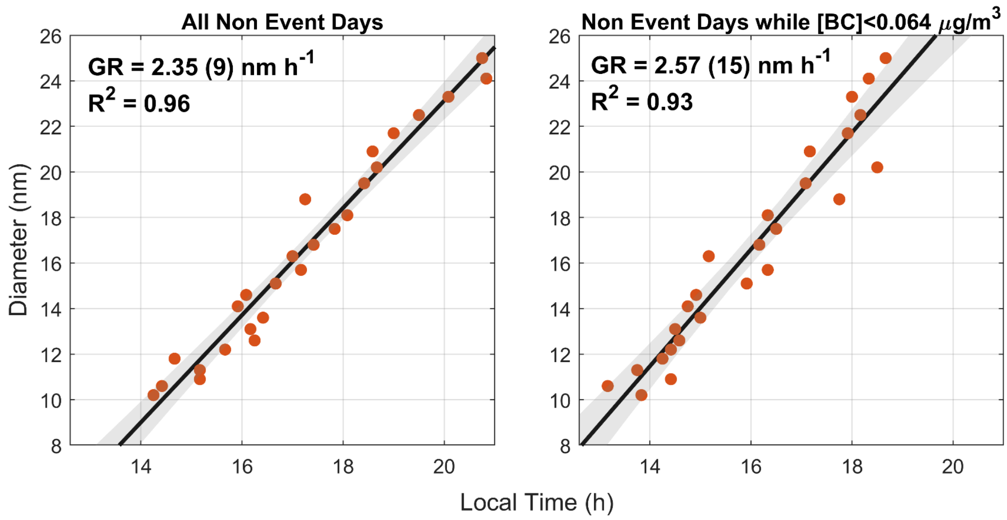


Figure R2. GR of particles between 10 and 25 nm derived using the appearance time method for non-event days during the wet season at ATTO. (a) All non-event days. (b) Non-event under periods of low anthropogenic influence ([BC] < 0.064 μg m^{-3}).

As shown in **Figure R1**, the normalized PNSD shows the same growth pattern across both datasets, indicating that the Quiet NPF signature is not driven by anthropogenic contamination. **Figure R2** shows that the GR derived for all non-event days is 2.35 ± 0.09 nm h^{-1} (as reported in the main text), while for non-event days with low BC concentrations it is 2.57 ± 0.15 nm h^{-1}. The two estimates are statistically consistent at the 95% confidence level.

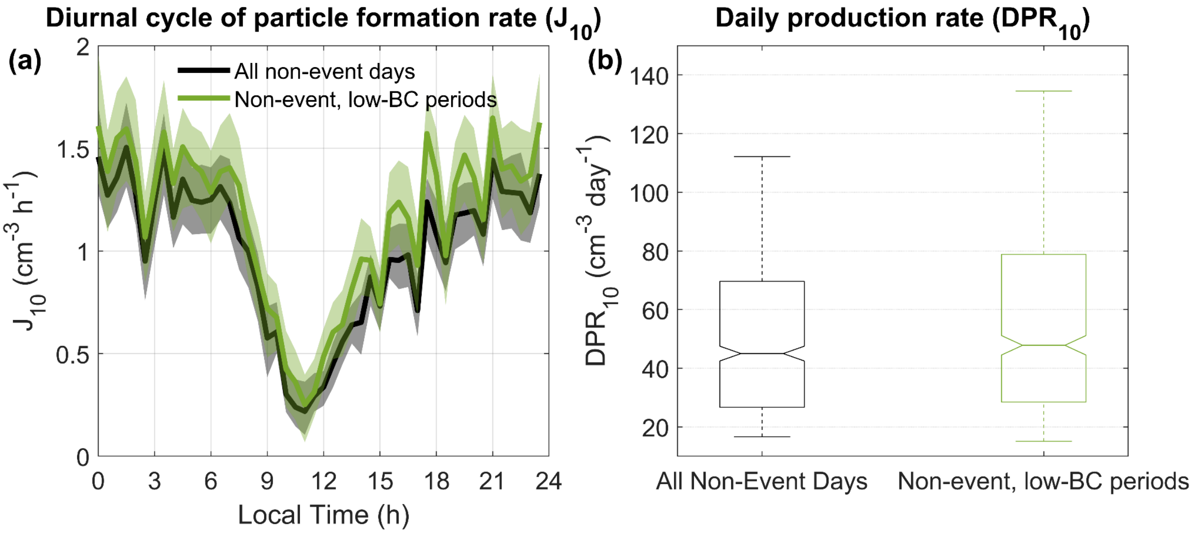


Figure R3 - **(a)** Median diurnal cycle of J_{10} and **(b)** boxplot of DPR_{10} comparing all Non-event days (black) with Non-event under periods of low anthropogenic influence (green).

Figure R3a compares the median diurnal cycle of J_{10} for all non-event days (black) and for non-event days under low-BC conditions (green). Shaded areas indicate the 95% confidence interval of the median, estimated via bootstrap. Although J_{10} values are slightly higher under low-BC conditions, the medians overlap for each 30-minute interval, indicating statistical consistency of the diurnal J_{10} cycle between the two datasets.

Figure R3b shows a boxplot of the DPR_{10}, with medians (95% CI) of 45 (42–48) cm^{-3} day^{-1} for all non-event days and 48 (45–51) cm^{-3} day^{-1} for low-BC non-event days. A Wilcoxon rank-sum test indicates no statistically significant difference between the two DPR_{10} distributions ($p > 0.01$), consistent with the overlapping uncertainty ranges of the median.

Taken together, GR, J_{10}, and DPR_{10} do not show clear systematic differences between the two datasets. Any potential tendency toward higher values under low-BC conditions, if present, would be small and consistent with a reduced condensation sink associated with lower background particle concentrations, and does not alter the physical interpretation of the results. We therefore conclude that anthropogenic factors do not significantly affect the characteristics of the Quiet NPF observed in this study. Accordingly, we retain the full non-event-day dataset to preserve statistical representativeness and include this sensitivity analysis as a new section in **Appendix D**, thereby strengthening the robustness of our conclusions.

Manuscript changes:

We added the conclusions of this sensitivity analysis (**Appendix D**), together with the percentile-based analysis (**Appendix F**), to the main text (see the response to the **Major Comment** from Reviewer #2). Specifically, the sentence starting at line 83 has been revised from:

"A similar pattern was also observed in an independent analysis of the PNSD during the wet seasons of 2008–2014 at the nearby ZF2 site in the Central Amazon. Despite the coarser resolution, they reveal an identical nocturnal growth pattern with sub-50 nm particle concentrations peaking at night (**Fig. S1**). This consistency across sites in the Amazon underscores the regional significance of Quiet NPF, a process characterized by subtle growth signatures that become apparent only through detailed statistical normalization."

to

"A similar pattern was also observed in an independent analysis of the PNSD during the wet seasons of 2008–2014 at the nearby ZF2 site in the Central Amazon. Despite the coarser resolution, the data reveal an identical nocturnal growth pattern, with sub-50 nm particle concentrations peaking at night (**Fig. S1**). Together with additional sensitivity tests, this consistency strengthens the robustness of our interpretation. Specifically, screening for anthropogenic influence shows no systematic effect on the Quiet NPF signature (**Appendix D**), whereas analyses using different statistical aggregations indicate that the same sequential increase in particle diameter (10-25 nm) persists across a wide range of concentration percentiles (**Appendix F**). Taken together, these independent lines of evidence indicate that Quiet NPF represents a general statistical property of non-event days in the Central Amazon, is not significantly affected by anthropogenic influence, and reflects particle formation processes that occur very frequently and become detectable only through detailed statistical normalization."

In addition, **Appendix D** has been added to the Appendix section.

"Appendix D: Sensitivity analysis of Quiet NPF to anthropogenic influence

Although the ATTO site is located in a remote region of the central Amazon, anthropogenic influence may occasionally reach the site via long-range or regional advection (Pöhlker et al., 2018; Holanda et al., 2023). Importantly, in the central Amazon, anthropogenic ultrafine particles transported over long distances typically have diameters larger than 10–25 nm. As a result, such contributions are not expected to produce the size-resolved growth signatures characteristic of Quiet NPF. Nevertheless, differences in the physical properties of the aerosol population could, in principle, affect the process characteristics. Given the weak intensity of Quiet NPF, even infrequent anthropogenic contributions could potentially bias the analysis if not explicitly evaluated.

To assess the robustness of our results with respect to anthropogenic influence, we conducted a sensitivity analysis using BC as a tracer. Following the aerosol population classification proposed by Valiati et al. (2025), we adopted a BC concentration of 0.064 µg m^{-3} as an upper threshold representative of pristine aerosol conditions during the wet season at ATTO, when regional biogenic processes dominate aerosol properties. This threshold corresponds to the average BC concentration under pristine conditions and provides a conservative criterion while preserving sufficient data coverage for statistically meaningful analysis.

Using this criterion, we defined two datasets for comparison:
(i) all non-event days during the wet season, and
(ii) non-event days considering only 5-minute intervals with BC < 0.064 µg m^{-3}.

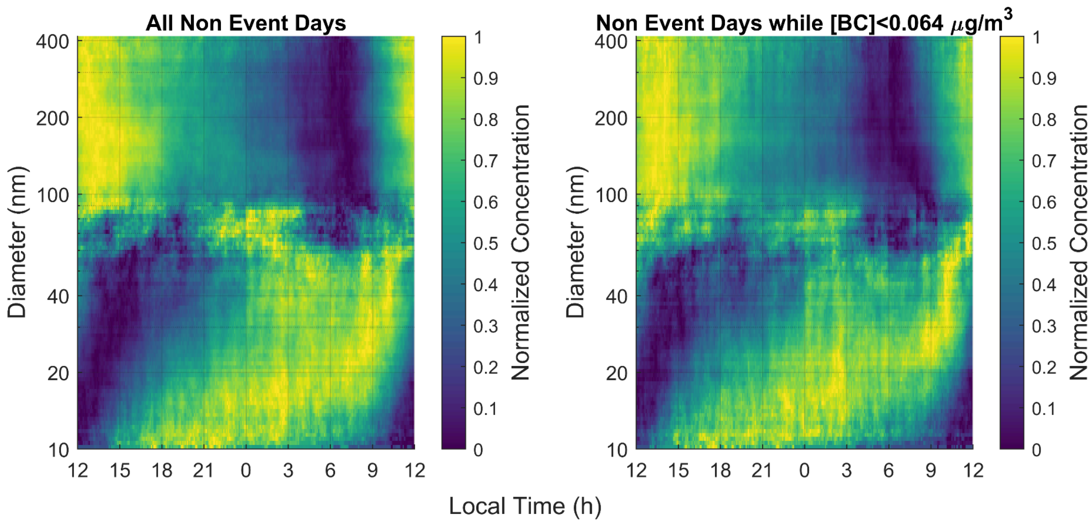


Figure D1. Median diurnal cycle of the normalized PNSD during non-event days in the wet season at ATTO. (a) All non-event days. (b) Non-event days under low anthropogenic influence, defined by BC < 0.064 µg m^{-3}.

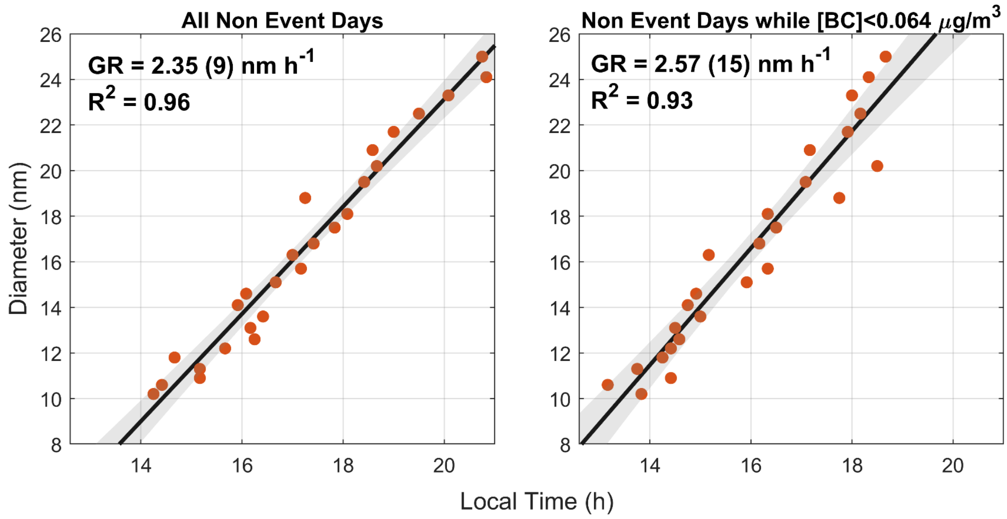


Figure D2. Growth rate (GR) of particles between 10 and 25 nm derived using the appearance time method for non-event days during the wet season at ATTO. (a) All non-event days. (b) Non-event days under low anthropogenic influence ([BC] < 0.064 µg m^{-3}).

Figure D1 shows the median diurnal cycle of the normalized PNSD for both datasets. The characteristic size-dependent temporal shift interpreted as particle formation followed by growth is consistently observed in both cases, indicating that the Quiet NPF signature is not driven by anthropogenic contamination.

Figure D2 presents the growth rates derived for the two datasets. The GR obtained for all non-event days is 2.35 ± 0.09 nm h^{-1}, while the GR under low-BC conditions is 2.57 ± 0.15 nm h^{-1}. The two estimates are statistically consistent at the 95% confidence level.

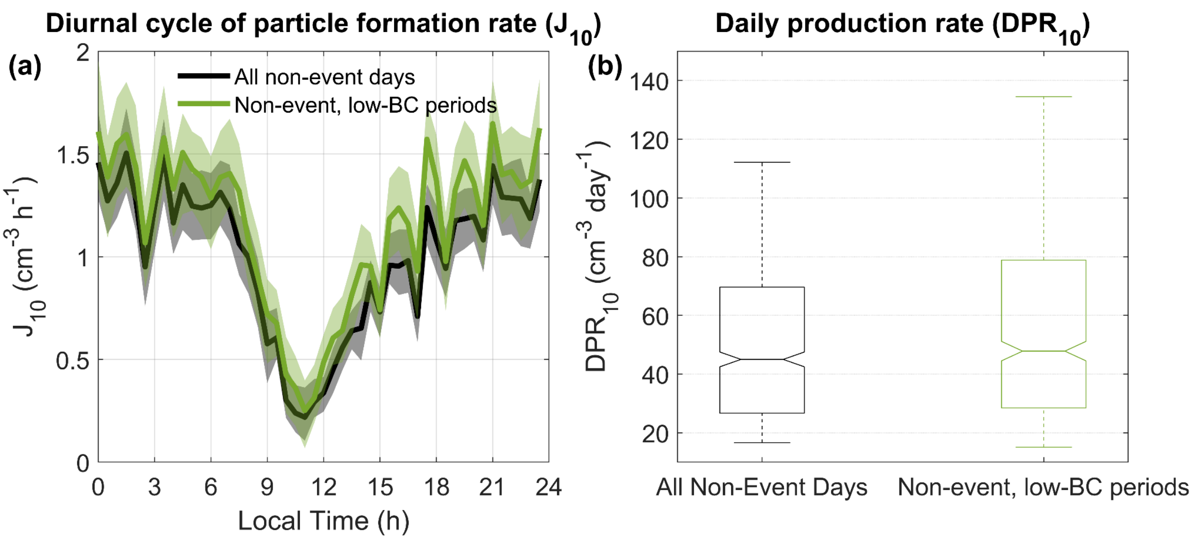


Figure D3 - **(a)** Median diurnal cycle of J_{10} and **(b)** boxplot of DPR_{10} comparing all Non-event days (black) with Non-event under periods of low anthropogenic influence (green). Shaded areas on the diurnal cycle plot indicate the 95% confidence interval of the median, estimated via bootstrap.

Figure D3a compares the median diurnal cycle of J_{10} and the distribution of DPR_{10} for the two datasets. Shaded areas indicate the 95% confidence interval of the median, estimated via bootstrap. The diurnal cycles of J_{10} show overlapping confidence intervals for all time steps, indicating statistical consistency between the datasets.

Figure D3b shows a boxplot of the DPR_{10}, with medians (95% CI) of 45 (42–48) cm^{-3} day^{-1} for all non-event days and 48 (45–51) cm^{-3} day^{-1} for low-BC non-event days. A Wilcoxon rank-sum test indicates no statistically significant difference between the two DPR_{10} distributions ($p > 0.01$), consistent with the overlapping uncertainty ranges of the median.

Taken together, GR, J_{10}, and DPR_{10} do not show clear systematic differences between the two datasets. Any potential tendency toward higher values under low-BC conditions, if present, would be small and consistent with a reduced condensation sink associated with lower background particle concentrations, and does not alter the physical interpretation of the results.

These results demonstrate that the Quiet NPF identified in this study is robust and not driven by anthropogenic contamination. Retaining the full non-event-day dataset, therefore, provides a representative characterization of Quiet NPF while maximizing statistical representativeness and strengthening the robustness of the conclusions presented in the main text."

A new paragraph was added to **Appendix A (Instrumentation and Data Processing)** at **line 213**:

"Black carbon (BC) concentrations were derived from long-term aerosol absorption measurements at ATTO. BC was primarily obtained from Multi-Angle Absorption Photometer (MAAP) measurements at 637 nm, following the site-specific calibration and correction procedures described by Saturno et al. (2018). Aethalometer (AE33) data were used to fill occasional data gaps, with inter-instrument consistency validated as described by Franco et al. (2024)."

Major comment 2: Role of other processes (mixing, emissions, deposition)

Reviewer comment:

Besides nucleation, growth, and coagulation, the dynamics of aerosol size distribution can be influenced by other processes, such as primary emission and deposition. In addition, diurnal variation of boundary layer height and resulting vertical mixing may also play a role. Could the observed temporal variations of aerosol size distribution be partially due to other processes besides nucleation, condensational growth, and coagulation? Please see the comment below for a possible test.

Author response:

We thank the reviewer for this comment. We agree that processes such as boundary-layer mixing, primary emissions, and deposition can influence aerosol size distributions and must be carefully considered when interpreting temporal variability.

Boundary-layer height variations and vertical mixing are expected to affect particle concentrations in a largely size-independent, or only weakly size-dependent, manner within a given mode, particularly for accumulation- and Aitken-mode particles. Such processes typically lead to coherent increases or decreases in particle number across broad diameter ranges and are therefore readily apparent in the absolute PNSD.

In contrast, the Quiet NPF signature identified in this study is characterized by a progressive, size-resolved temporal shift of concentration maxima within the sub-25 nm size range. This behaviour, revealed through normalization of the PNSD, reflects a sequential increase in particle diameter over time and cannot be reproduced by dilution, vertical mixing, or deposition alone, which do not generate systematic time-dependent shifts in the diameter of concentration maxima within a narrow size range.

Primary emissions can be strongly size-dependent across aerosol modes. However, within a given mode, they are not expected to account for the observed temporal progression of diameter-resolved maxima. Previous studies at ATTO have reported episodic primary biogenic particles predominantly in the coarse mode and, more rarely, within the ultrafine range (<100 nm) (Pöhlker et al., 2012; Rizzo et al., 2018; Glicker et al., 2019). To date, there is no evidence of a persistent or systematic primary emission source producing particles specifically in the 10–25 nm size range. Therefore, primary emissions are unlikely to explain the characteristic size-dependent growth pattern associated with Quiet NPF.

Taken together, these considerations support our interpretation that the observed sub-25 nm dynamics on non-event days are dominated by particle formation and growth processes, rather than by boundary-layer mixing, deposition, or primary emissions.

Manuscript changes:

The paragraph at line 78 has been revised from:

“In contrast, the normalized PNSD shown in Fig. 1b presents daily maxima and minima for each diameter bin, scaled independently from 0 to 1. Larger particles (diameter > 100 nm) exhibit relatively homogeneous diurnal behaviour, reflecting their common response to variations in boundary layer height. Smaller particles (diameter < 50 nm) demonstrate significant size-dependent dynamics, with ~10 nm peaks at 18:00 followed by progressively larger peaks, culminating at ~60 nm by noon the next day.”

to:

“In contrast, the normalized PNSD shown in Fig. 1b presents daily maxima and minima for each diameter bin, scaled independently from 0 to 1. Accumulation mode particles exhibit relatively homogeneous diurnal behaviour, reflecting their common response to variations in boundary-layer height, which are expected to affect particle concentrations in a largely size-independent or only weakly size-dependent manner within a given mode. In comparison, the normalized PNSD for the smaller particles (diameter < 50 nm) exhibits a progressive, size-resolved temporal shift that cannot be explained by dilution or vertical mixing alone, with ~10 nm particles peaking at 18:00 followed by progressively larger peaks, culminating at ~60 nm by noon the next day.”

Major comment 3: Median PNSD versus normalized PNSD

Reviewer comment:

The authors derived GR from the median PNSD on non-event days using the appearance-time method within the diameter range of 10-25 nm. Does the median PNSD show a similar pattern as the normalized distribution in Fig. 1b, at least for the size range of 10-25 nm? I understand the concentration is likely very low, but the pattern could be revealed by using a logarithmic color scale.

Author response:

We appreciate this suggestion. We explicitly tested whether the growth pattern observed in the normalized PNSD could also be visually identified in the median absolute PNSD when a logarithmic color scale was applied. As shown in **Figure R4**, the median absolute PNSD does not clearly reveal particle growth in the 10–25 nm range, even on a logarithmic scale. This is due to extremely low particle concentrations in this size range and the dominance of larger modes, which mask the subtle diurnal variability associated with Quiet NPF.

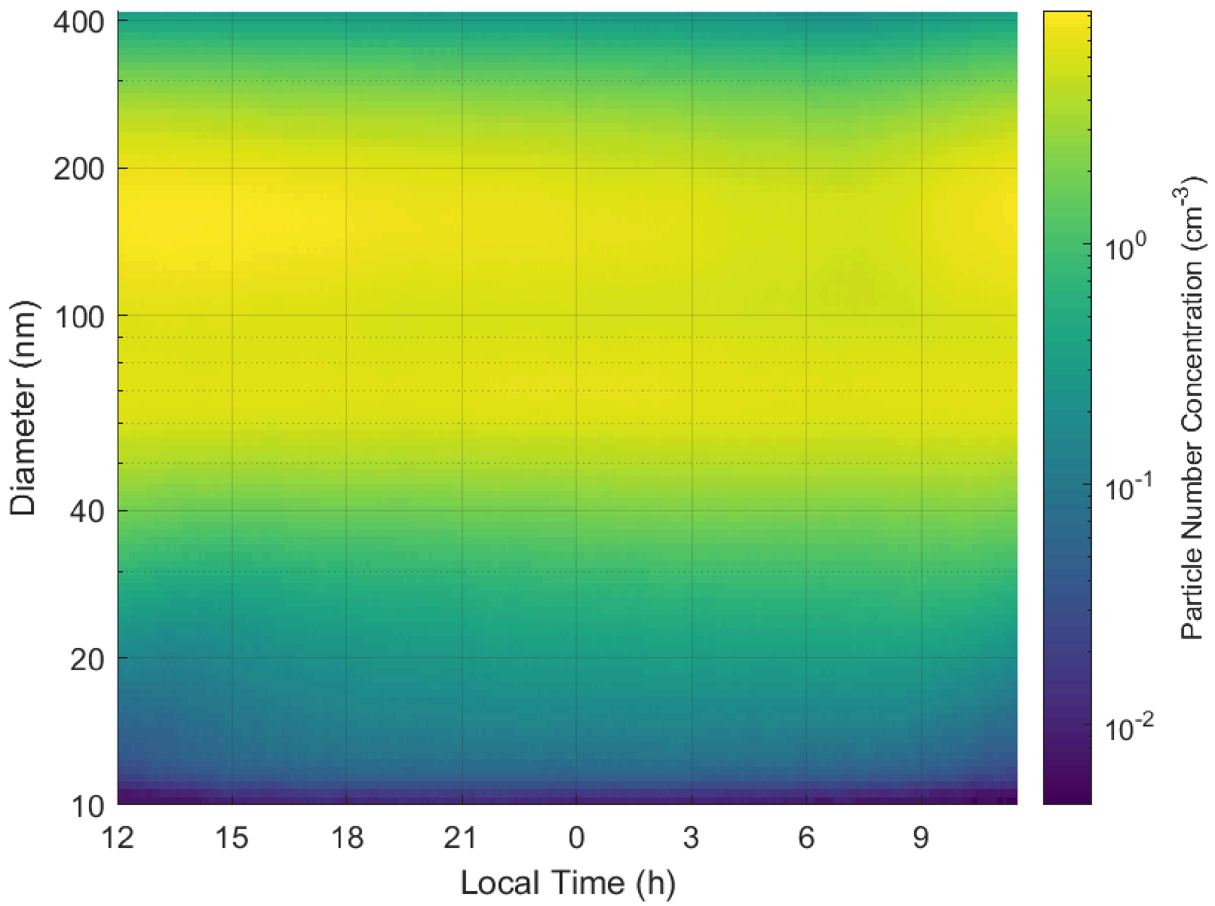


Figure R4. Median diurnal cycle of the absolute particle number size distribution during non-event days at ATTO in the wet season, displayed using a logarithmic color scale.

This behaviour is consistent with previous observations at other locations, as discussed by Kulmala et al. (2022a), where Quiet NPF signatures are not discernible in absolute size distributions but emerge only after normalization and statistical aggregation. These constraints motivate the use of the normalization approach introduced by Kulmala et al. (2022a), which enhances size-dependent temporal features independently of absolute concentration. Importantly, this method does not introduce artificial growth signatures but rather reveals systematic behaviour that is otherwise masked in the absolute PNSD due to the low particle concentrations in the 10-25 nm size range.

Major comment 4: Approximation in Eq. (1) and comparison of J_{10} estimates

Reviewer comment:

In Eq. (1), the last (i.e., third) term on the right-hand side is essentially J25 (formation rate of 25 nm particles). J25 is the product of the GR and the size distribution (i.e., dN/dDp) at 25 nm. In Eq (1), the concentration at 25 nm (i.e., dN/dDp at 25 nm) is approximated using the average particle concentration between 10 and 25 nm. Such approximation could lead to substantial biases, especially when there are large variations in aerosol size distribution between 10 and 25 nm. I would suggest that the authors calculate the last term on the right-hand side using dN/dDp at 25 nm. In addition, J10 is also given by the product of GR and dN/dDp at 10 nm. If the variation of aerosol size distribution is dominated by growth and coagulation, J10 calculated using the two approaches are expected to agree. Therefore, a comparison of J10 derived using the two methods can help corroborate that other processes, such as mixing due to change of boundary layer height, emissions, etc., play a negligible role in the observed temporal variations of aerosol size distribution.

Author response:

We thank the reviewer for this valuable methodological suggestion. We agree that, if the temporal evolution of particle concentrations between 10 and 25 nm is primarily governed by condensational growth and coagulation, different formulations of the growth-related term in the aerosol population balance equation should yield consistent estimates of J_{10}.

In principle, three equivalent formulations can be used to express the growth contribution (third term of equation 1 from the main text) to J_{10}:

(i) $GR \times \left(\frac{N_{10-25}}{\Delta D_p}\right)$, based on the average particle concentration between 10 and 25 nm (hereafter J_{10}*; used in the original manuscript);

(ii) $GR \times \left(\frac{dN}{dD_p}\right)_{10\,nm}$; and

(iii) $GR \times \left(\frac{dN}{dD_p}\right)_{25\,nm}$ (hereafter J_{10}**).

In the original submission, we closely followed the methodology of Kulmala et al. (2022a), primarily to ensure comparability with previous studies, to reduce noise by integrating over multiple size bins, and to avoid excessive dependence on the smallest size bins near the instrumental lower cutoff. At ATTO, particles near 10 nm experience substantial diffusive losses in the 60 m inlet line, and concentrations in individual bins can occasionally drop to zero, preventing reliable correction for transport efficiency.

Nevertheless, we recognize the value of the reviewer's proposed test, particularly the comparison between J_{10}* and J_{10}**. We therefore recalculated J_{10} using dN/dD□ at 25 nm (J_{10}**) and compared it with the formulation used in the original manuscript (J_{10}**).

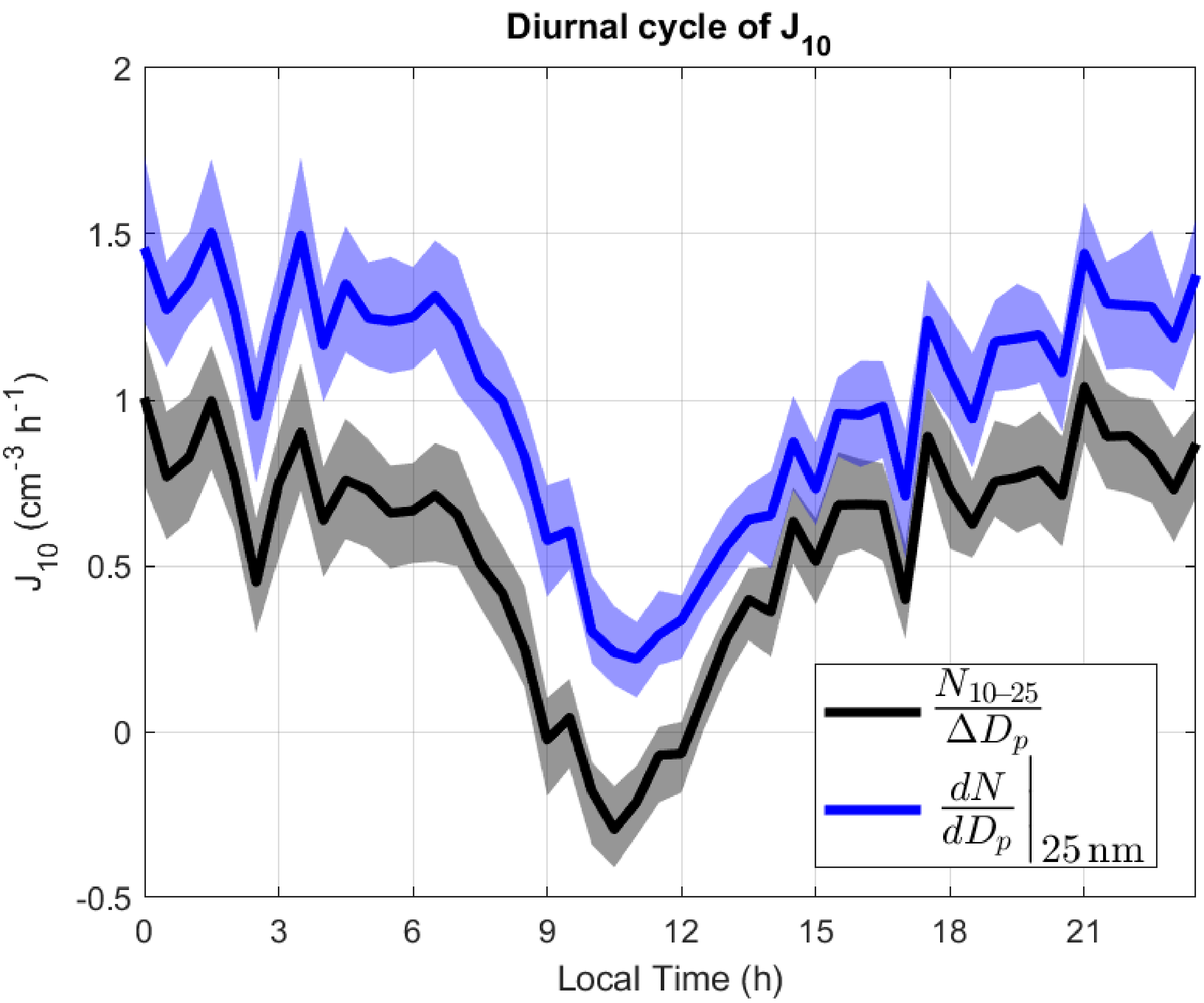


Figure R5 - Median diurnal cycle of the particle formation rate at 10 nm (J_{10}) during non-event days, calculated using two formulations of the growth-related term in the aerosol population balance equation. The black curve shows J_{10} derived from the average particle concentration between 10 and 25 nm (J_{10}*), while the blue curve shows J_{10} calculated using dN/dD□ evaluated at 25 nm (J_{10}**). Shaded areas on the diurnal cycle plot indicate the 95% confidence interval of the median, estimated via bootstrap.

Median diurnal cycle of particle formation rates at 10 nm (J_{10}) during non-event days, calculated using two formulations of the growth-related term in the aerosol population balance equation. The black curve shows the formulation used in the original manuscript (J_{10}*), based on the average particle concentration between 10 and 25 nm. In contrast, the blue curve shows the formulation suggested by Reviewer #1 (J_{10}**), based on dN/dD□ at 25 nm. Shaded areas represent the interquartile range.

Figure R5 shows the median diurnal cycles of J_{10} derived using both approaches. The two formulations exhibit nearly identical diurnal evolution, and their time series yields high temporal agreement ($R^2 > 0.99$, $p < 0.01$). This close correspondence strongly supports the interpretation that the observed sub-25 nm particle dynamics are governed by the same physical processes (condensational growth and coagulation) rather than by boundary-layer mixing or primary emissions. If additional and independent processes were substantially contributing within the 10–25 nm size range, the two formulations would not be expected to produce such closely correlated temporal behaviour.

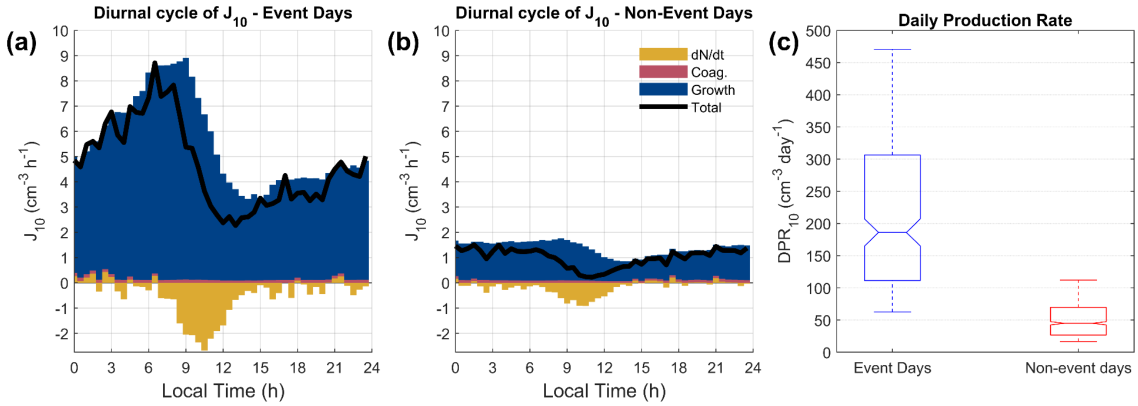
The systematically higher J_{10} values obtained with J_{10}** are attributed to measurement limitations rather than to physical differences. Particles at 25 nm are subject to substantially lower inlet losses and near-unity CPC counting efficiency, whereas the integrated 10–25 nm formulation remains more affected by residual, sometimes uncorrectable, diffusional losses. In particular, zero-count occurrences in the smallest bins prevent full recovery of the true concentration, even after loss correction. This effect was already indicated in the original manuscript by slightly negative median J_{10} values during part of the non-event-day cycle (line 131), which are not physically meaningful and imply incomplete loss compensation.

Contrary to our initial expectations, using a single bin at 25 nm did not introduce appreciable additional noise into the J_{10} estimates. For non-event days, the use of J_{10}** increases the median J_{10} by 45% and the median DPR_{10} by 35%. Importantly, this methodological change increases both J_{10} and DPR_{10} proportionally for event and non-event days, and therefore does not alter the physical interpretation of the results. Consequently, the relative contribution of Quiet NPF to total 10–25 nm particle production remains essentially unchanged (≈45%). We therefore adopt the reviewer's suggested formulation (J_{10}**) in the revised manuscript, as it provides a more accurate estimate of particle formation rates.

For transparency and comparability with previous formulations (e.g., Kulmala et al., 2022a), the comparison between J_{10}* and J_{10}** is now documented in **Appendix E**.

Manuscript changes:

Figure 3 of the main text was revised accordingly.



The sentence starting at line 131 has been removed:

"The median total J_{10} during the middle of non-event days is slightly negative, which may result from unaccounted particle losses, such as deposition onto particles larger than the upper detection limit of the SMPS (420 nm) or vertical dispersion."

The sentence starting at line 143 has been revised from:

"Median daily production rates (interquartile range) were 117 (61–204) cm^{-3} day^{-1} for event days and 28 (15–45) cm^{-3} day^{-1} for non-event days."

to

"Median daily production rates (interquartile range) were 186 (111–309) cm^{-3} day^{-1} for event days and 45 (27–70) cm^{-3} day^{-1} for non-event days.";

The sentence starting at line 162 has been revised from:

"Nevertheless, due to its higher frequency, Quiet NPF makes a considerable contribution to the population of 10–25 nm particles, with an estimated daily production rate of approximately 28 cm^{-3} day^{-1}. While this rate is lower than the 117 cm^{-3} day^{-1} observed during Amazonian banana event days, Quiet NPF accounts for roughly 45% of sub-25 nm particles during the wet season, highlighting its essential role in sustaining the Amazonian aerosol population."

to

"Nevertheless, due to its higher frequency, Quiet NPF makes a considerable contribution to the population of 10–25 nm particles, with an estimated daily production rate of approximately 45 cm^{-3} day^{-1}. While this rate is lower than the 186 cm^{-3} day^{-1} observed during Amazonian banana event days, Quiet NPF accounts for roughly 45% of sub-25 nm particles during the wet season, highlighting its essential role in sustaining the Amazonian aerosol population."

Also, **Equation 1** from **Appendix B** has been revised from:

$$J_{10} = \frac{dN_{10-25}}{dt} + CoagS \times N_{10-25} + \frac{GR}{\Delta d_p} \times N_{10-25}$$

to:

$$J_{10} = \frac{dN_{10-25}}{dt} + CoagS \times N_{10-25} + GR \times \left(\frac{dN}{dDp}\right)_{25}$$

In addition, **Appendix E** has been added to the Appendix section.

"Appendix E: Sensitivity of J_{10} estimates to the formulation of the growth term

The formation rate of 10 nm particles (J_{10}) is derived from the aerosol population balance equation following the framework of Kulmala et al. (2012, 2022a). In this formulation, the growth-related term can be expressed in different, but in principle equivalent, ways if particle evolution in the 10–25 nm size range is governed primarily by condensational growth and coagulation.

In the main analysis, J_{10} is calculated using the product of the particle growth rate (GR) and the particle number evaluated at 25 nm $(dN/dDp)_{25}$. This choice minimizes the influence of residual inlet and counting-efficiency limitations affecting the smallest detected particles, which are particularly relevant at ATTO due to the 60 m inlet line.

For comparison and continuity with previous studies, we also evaluated J_{10} using an alternative formulation in which the growth-related term is approximated by the average particle concentration between 10 and 25 nm, divided by the corresponding size interval, as used in long-term analyses (Kulmala et al., 2022a). Under ideal observational conditions, both formulations are expected to yield comparable results.

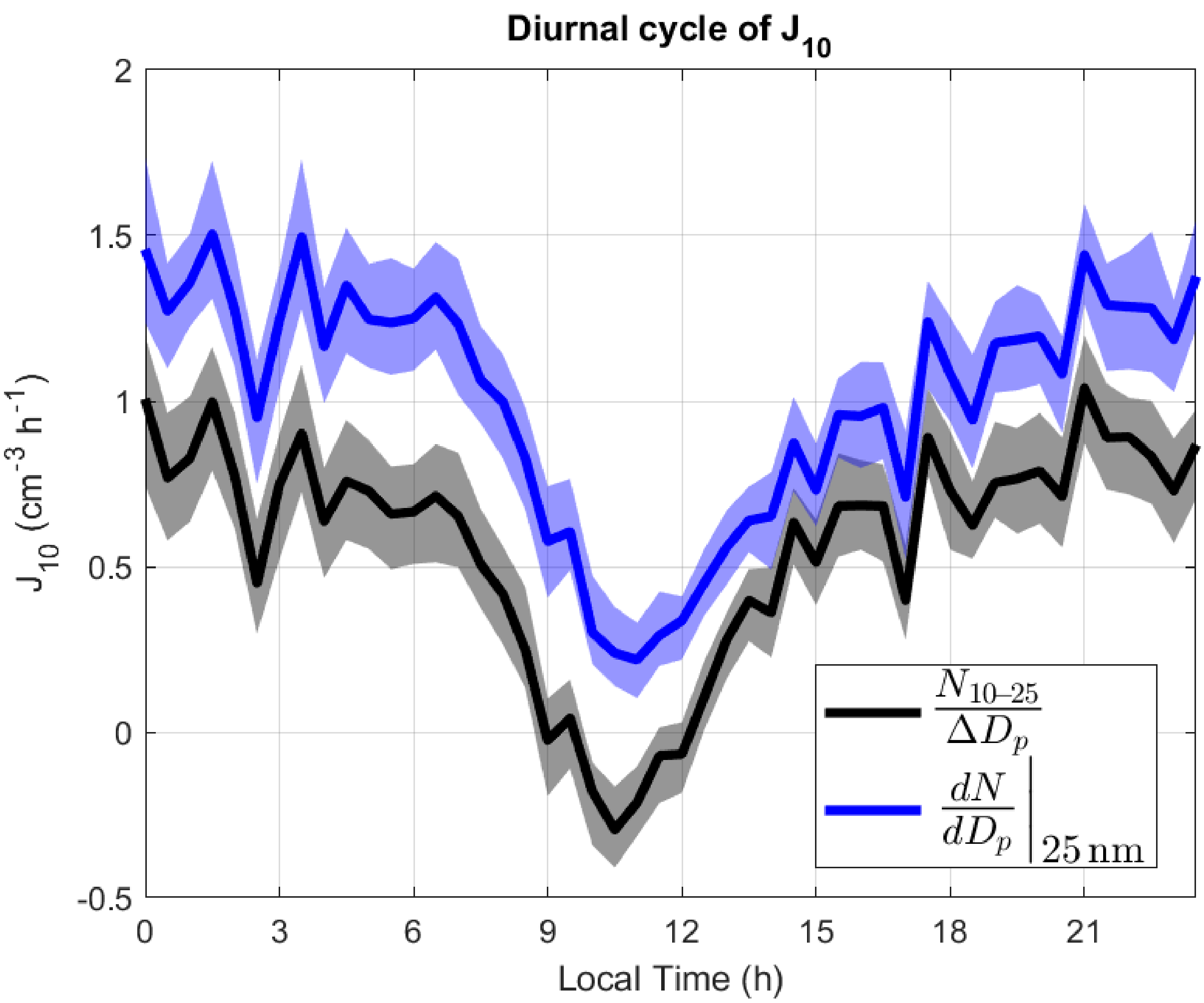


Figure E1 - Median diurnal cycle of the particle formation rate at 10 nm (J_{10}) during non-event days, calculated using two formulations of the growth-related term in the aerosol population balance equation. The black curve shows J_{10} derived from the average particle concentration between 10 and 25 nm, while the blue curve shows J_{10} calculated using dN/dD_p evaluated at 25 nm. Shaded areas on the diurnal cycle plot indicate the 95% confidence interval of the median, estimated via bootstrap.

Figure E1 shows the median diurnal cycle of J_{10} during non-event days calculated using both formulations. The two approaches exhibit nearly identical temporal evolution throughout the day, with a high correlation ($R^2 > 0.99$, $p < 0.01$), indicating that both capture the same underlying physical process controlling sub-25 nm particle dynamics. However, the formulation based on $(dN/dD_p)_{25}$ yields systematically higher J_{10} values.

This difference is attributed to size-dependent observational limitations. Particles near 25 nm experience substantially lower diffusional losses and higher counting efficiencies than particles close to the lower detection limit, whereas formulations that rely on concentrations in the 10–25 nm range are more strongly affected by residual, sometimes uncorrectable, losses when individual bins approach zero counts. These effects result in low bias in J_{10} estimates derived from the integrated 10–25 nm formulation under ATTO measurement conditions.

Importantly, the higher J_{10} values obtained using $dN/dD_{\square}|_{25}$□□ represent a proportional shift affecting both event and non-event days, and therefore do not alter the inferred relative contribution of Quiet New Particle Formation to total 10–25 nm particle production. Instead, they provide a more robust quantitative estimate of absolute formation and production rates under conditions where losses at the smallest sizes cannot be fully corrected due to zero-count limitations.

For these reasons, the main text adopts the $dN/dD_{\square}|_{25}$□□ formulation for J_{10}, whereas this appendix presents a sensitivity analysis to ensure transparency and comparability with earlier methodological approaches."

Major comment 5: Use of J_{10} versus J_{25} (or J_{50}) for downdraft events

Reviewer comment:

The particles transported by downdrafts are typically greater than ~ 20 nm. Therefore, J10during the events may not accurately reflect the contribution of downward transport. For example, if all particles transported into boundary layer by downdrafts are larger than 25nm, J10 calculated using Eq. (1) is essentially zero. From the perspective of comparing the contributions to CCN, it may be better to compare J25 or even J50.

Author response:

We thank the reviewer for this suggestion. We agree that particles transported by convective downdrafts in the Amazon typically peak at diameters of ~20–30 nm (Franco et al., 2022). At the same time, previous studies at ATTO have shown that rainfall-driven downdrafts can also trigger new particle formation near the canopy, leading to an increase in particle concentrations below ~20 nm (Machado et al., 2024). As a result, J_{10} during event days captures the combined effect of downward transport of pre-existing particles and the appearance of newly formed particles following convective events.

We also agree that formation rates at larger sizes (e.g., J_{25} or J_{50}) are more directly related to cloud condensation nuclei (CCN) relevance. However, the primary objective of this study is to identify and characterize a previously overlooked source of newly formed particles in the Amazon boundary layer, rather than to directly quantify CCN concentrations. For this purpose, J_{10} is the most sensitive metric, as it tracks the emergence of particles at the lower end of the measurable size range, where new particle formation first occurs.

At larger particle sizes, additional processes become increasingly important, including vertical transport, deposition, and primary local or regional emissions. Under such conditions, the assumptions underlying the aerosol population balance equation (that sources and sinks other than condensational growth and coagulation are negligible) are no longer strictly valid. Extending the balance-equation analysis to J_{25} or J_{50} would therefore require additional assumptions and process representations that are beyond the scope of this letter.

We therefore retain J_{10} as the most appropriate metric for isolating the impact of the Quiet NPF process. Nevertheless, we acknowledge that the extent to which Quiet NPF contributes to CCN-relevant particle sizes remains uncertain and represents an important direction for future research.

A clarifying sentence was added to the concluding paragraph to explicitly state that, while Quiet NPF is identified as a significant source of newly formed particles, its contribution to CCN-relevant sizes remains uncertain.

Manuscript changes:

The following sentence that starts at Line 192 has been revised from:

"Our findings underscore the complexity of aerosol dynamics in this unique environment and emphasize the necessity of future research focused on elucidating the interplay between chemical precursors and meteorological factors. Despite recent advances in understanding the aerosol secondary production within the Amazonian atmosphere, our study reveals a potential New Particle Formation mechanism that might be underrepresented, warranting future model evaluation. Future studies should incorporate long-term measurements of sub-10 nm particles and detailed analyses of low-volatility precursor compositions, further clarifying the distinct processes contributing to aerosol formation in the Amazon."

to

"Our findings underscore the complexity of aerosol dynamics in this unique environment and indicate that Quiet NPF represents a significant source of newly formed particles, although its quantitative contribution to CCN-relevant sizes remains uncertain. While recent advances have improved our understanding of secondary aerosol production in the Amazon, our results suggest that this pathway may be underrepresented in current frameworks and merit further evaluation in both observations and models. Addressing this gap will require long-term measurements of sub-10 nm particles and detailed analyses of low-volatility precursor composition, enabling a more precise separation of the processes governing aerosol formation in the Amazon."

Major comment 6: Diurnal discrepancy in J_{10} timing

Reviewer comment:

Line 174-175: The particle concentration at 10 nm peaks around 18:00, suggesting the highest J10 in the late afternoon with the assumption that the diurnal variation of GR is negligible. However, J10 calculated from Eq. (1) is the highest during night (Line168-169). I am wondering whether such discrepancy suggests processes other than condensational growth and coagulation may also influence the observed temporal variations of aerosol size distribution. Please see the comment above.

Author response:

We thank the reviewer for this insightful comment.

Importantly, J_{10} is not an instantaneous measure of particle appearance at 10 nm, but a net formation rate integrated over the relatively broad size range from 10 to 25 nm. Under Quiet NPF conditions, growth rates are low, so particles require several hours to traverse this diameter interval. As a result, J_{10} reflects the cumulative balance of growth and losses across this size range, rather than the timing of the initial increase in 10 nm particle concentrations alone.

While the concentration of ~10 nm particles peaks in the late afternoon, the slow growth implies that particles formed during this period contribute to the 10–25 nm population over an extended period, including nighttime hours. Because coagulation rates between 10 and 25 nm are explicitly accounted for in the balance equation and do not exhibit strong diurnal variability, they cannot explain the observed timing of the J_{10} maximum.

In addition, daytime conditions in the Amazon boundary layer are characterized by strong vertical mixing and a deeper mixed layer, which may disperse newly formed particles originating near the canopy and dilute their contribution to the locally observed 10–25 nm population. At night, the shallower and more stable boundary layer favours particle accumulation within the sampled air mass, resulting in higher and more constant J_{10} values.

Taken together, the nighttime maximum in J_{10} is therefore a natural consequence of (i) slow particle growth rates, (ii) the wide diameter interval over which J_{10} is evaluated, and (iii) boundary-layer dynamics affecting particle residence and dilution. No additional processes beyond condensational growth, coagulation, and mixing are required to explain the observed diurnal pattern.

Manuscript changes:

The following sentence was added to Line 131:

"Because J_{10} represents a net formation rate integrated over the 10–25 nm size range under slow-growth conditions, its diurnal maximum reflects cumulative growth and residence within this interval rather than the timing of the late-afternoon peak in 10 nm particle concentrations. In addition, dilution within a deeper, well-mixed BL during daytime likely contributes to reduced daytime J_{10}."

Additionally, the following longer and more speculative section has been revised from:

An intriguing difference emerges between the Amazonian banana events driven by downdrafts and precipitation, which predominantly occur during the daytime, with maximum J10 after sunrise, and Quiet NPF, characterized by maximum particle concentrations and J10 observed at night. A plausible explanation for this nocturnal enhancement includes reduced nighttime accumulation-mode particle concentrations, which decrease the coagulation and condensation sinks for small particles and their precursors. Additionally, nighttime atmospheric conditions involve a significant reduction in the isopreneto-monoterpenes ratio (Yáñez-Serrano et al., 2015, 2020), which potentially alleviates isoprene's known suppressive effects on nucleation (Heinritzi et al., 2020). The initial growth stage of Quiet NPF likely commences during the daytime, as indicated by a concentration peak of ~10 nm particles around 18:00. Daytime oxidation of VOCs, molecular clustering, and the formation of extremely low-volatility and ultra-low-volatility organic compounds (ELVOCs and ULVOCs) are presumed to initiate particle nucleation and early growth (Mohr et al., 2019; Schervish & Donahue, 2020). However, the observed slow growth rates suggest relatively lower concentrations of ELVOCs and ULVOCs within the Amazon BL, potentially linked to isoprene-related suppression mechanisms (Heinritzi et al., 2020; Curtius et al., 2024). Instead, the subsequent growth to larger Aitken-mode sizes may rely predominantly on the condensation of more abundant higher-volatility organic compounds (Liu et al., 2022; Curtius et al., 2024). Therefore, a plausible scenario involves initial slow nucleation and growth driven by limited ELVOC/ULVOC levels, transitioning into faster growth facilitated by higher-volatility compounds.

to

A systematic difference is observed between downdraft-driven banana events, which predominantly occur during daytime, and Quiet NPF, for which J_{10} exhibits higher and more sustained values during nighttime. This behaviour is consistent with lower accumulation-mode particle concentrations at night, which reduce the condensation and coagulation sinks, while daytime dilution within a deeper, well-mixed BL likely contributes to lower J_{10} values. The late-afternoon peak in ~10 nm particle concentrations suggests that the initial stage of Quiet NPF likely begins during daytime, whereas the slow growth rates imply weak condensational fluxes.

Minor comments

Reviewer comment:

Line 41: The vertical transport of sub-50nm particles by downdraft during rainfall events was first proposed by Wang et al., (2016).

Manuscript changes:

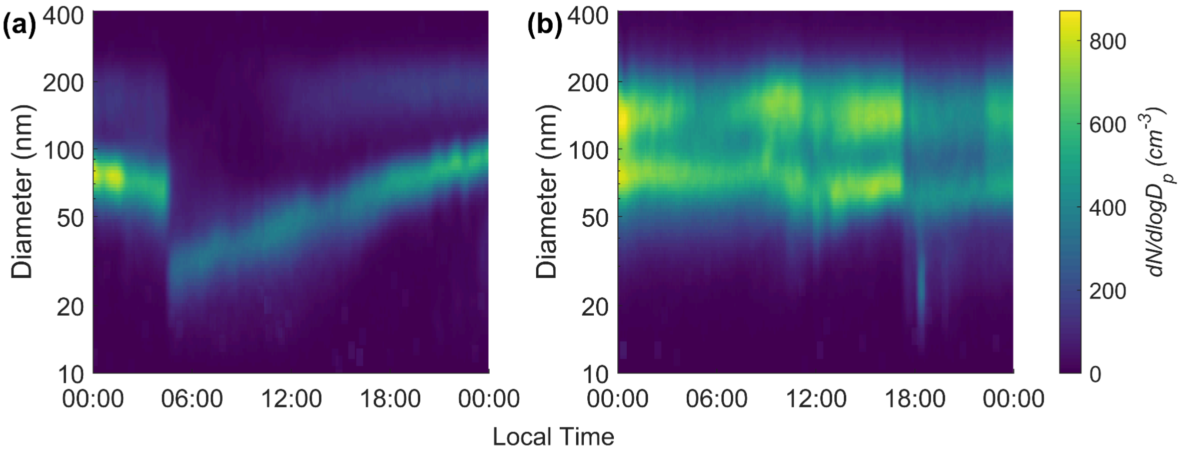
We have added "Wang et al. (2016)" as a reference that proposes the vertical transport of sub-50 nm particles by downdrafts.

Reviewer comment:

Figure B1: For the y-axis label, "p" should be subscript. In addition, variables are commonly written in italic.

Manuscript changes:

The y-axis label from Figure B1 has been corrected, with the subscript "p" added and all variables written in italic, as shown below.



Responses to Reviewer #2:

"Quiet New Particle Formation is a significant aerosol source in the Amazon boundary layer" by Meller et al. describes a phenomenon that the authors associate with "Quiet New Particle Formation (NPF)." Quiet NPF was first described by

Kulmala and colleagues and refers to NPF and growth events that are almost undetected due to their low number concentrations, but are nonetheless important as they are believed to occur on days that were previously assigned as non-NPF event days. This is an interesting study from an important field site. While I appreciate the brevity of this manuscript, I feel that the authors have left out some key details. Please see the following comments (specific questions are preceded by line number).

Author response:

We thank the reviewer for the careful reading and constructive comments. We particularly appreciate the request for clarification regarding our assumption that Quiet NPF occurs on non-event days. We agree that this is a critical point and welcome the inclusion of more substantial evidence supporting this argument in the paper. Below, we provide a detailed explanation and new supporting analyses that address this point.

Major comment from Reviewer #2: Is the Quiet NPF phenomenon occurring on every non-event day?

Reviewer comment:

One central question I had upon reading this manuscript was whether the authors are assuming that quiet NPF is occurring every day that would normally be assigned as a non-event day. Figure 1 shows average size distributions, and in several places the analysis suggest that non-event days are significant and relevant to quiet NPF, but there is never anything said directly about this.

Author response:

We thank the reviewer for the opportunity to clarify this central conceptual point. The comments are addressed collectively by the clarification below and by the new percentile-based analysis (**Appendix F**), which demonstrates that Quiet NPF is treated as a statistically robust ensemble behaviour of non-event days.

In this study, we interpret Quiet NPF as a process that occurs virtually continuously on non-event days across a wide range of intensities, rather than as a strictly intermittent, on–off phenomenon. This interpretation follows the conceptual framework proposed by Kulmala et al. (2022a, 2024) and Aliaga et al. (2023), in which atmospheric new-particle formation is described as a continuum process when considered statistically.

Importantly, the detectability of Quiet NPF at the daily scale is not continuous. Quiet NPF is characterized by very low particle concentrations and, in the Amazon, slow growth rates, which generally prevent its identification in individual daily size distributions at ATTO. This limitation has also been reported for other environments, including forested sites, in Kulmala et al. (2022a). It arises from a combination of factors, including inlet losses at 60 m height, air-mass heterogeneity, and low signal-to-noise ratios in the sub-25 nm size range. As a result, normalization and ensemble averaging over long time periods are required to reveal the underlying size-dependent temporal evolution of this process.

To provide explicit evidence that the Quiet NPF signature is not an artefact of averaging or driven by a small subset of days, we extended the analysis by examining different percentiles (10th to 90th) of the normalized particle number size distribution (**Figure R6**). The characteristic slow and sequential increase in particle diameter is consistently observed across a broad range of percentiles, particularly from the 10th to the 80th percentiles. This demonstrates that the Quiet NPF signal reflects a general statistical property of non-event days rather than being dominated by a small number of specific cases.

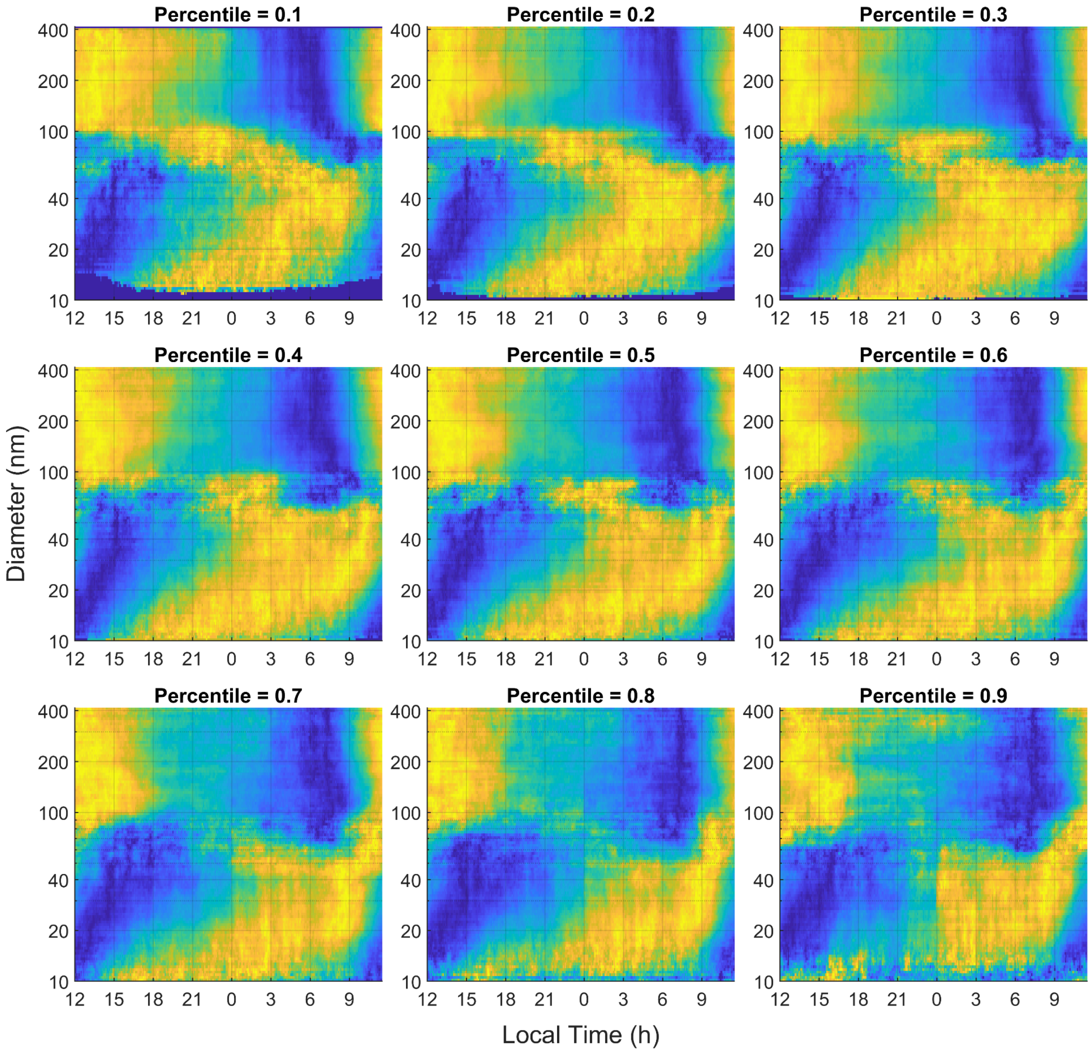


Figure R6. Diurnal evolution of the normalized PNSD during non-event days is shown for different concentration percentiles (10th to 90th, in steps of 10%). The characteristic slow and sequential increase in particle diameter is consistently observed across a wide range of percentiles, demonstrating that the Quiet NPF signature is a general statistical property of non-event days and not an artefact of averaging or of a small subset of high-concentration days.

While this result supports the interpretation that Quiet NPF is a phenomenon virtually always present on non-event days across a wide range of intensities, it does not imply that the process is spatially homogeneous, i.e., that it has a continuous intensity over large regions. The formation and growth of new particles depend on atmospheric conditions that vary in space and time, such as oxidation capacity, precursor availability, meteorology, and air-mass history. The observed ensemble behaviour is therefore consistent with a scenario in which particle formation occurs heterogeneously in space and time, potentially within localized air masses, and becomes detectable only through statistical aggregation across many realizations.

Manuscript changes:

Appendix F has been added to the Appendix section, and specific changes to the main text related to this issue are described below, along with responses to comments 1-5.

Appendix F: Percentile-based analysis of Quiet NPF occurrence on non-event days

Quiet New Particle Formation (Quiet NPF) is characterized by very low particle concentrations and, in the Amazon, slow growth rates, which generally preclude its identification at the scale of individual daily PNSDs. This limitation is particularly relevant at ATTO, where measurements at 60 m height are affected by inlet line losses, air-mass heterogeneity, and low signal-to-noise ratios in the sub-25 nm size range. As discussed by Kulmala et al. (2022a), normalization and ensemble averaging are essential for revealing the statistical signature of this process.

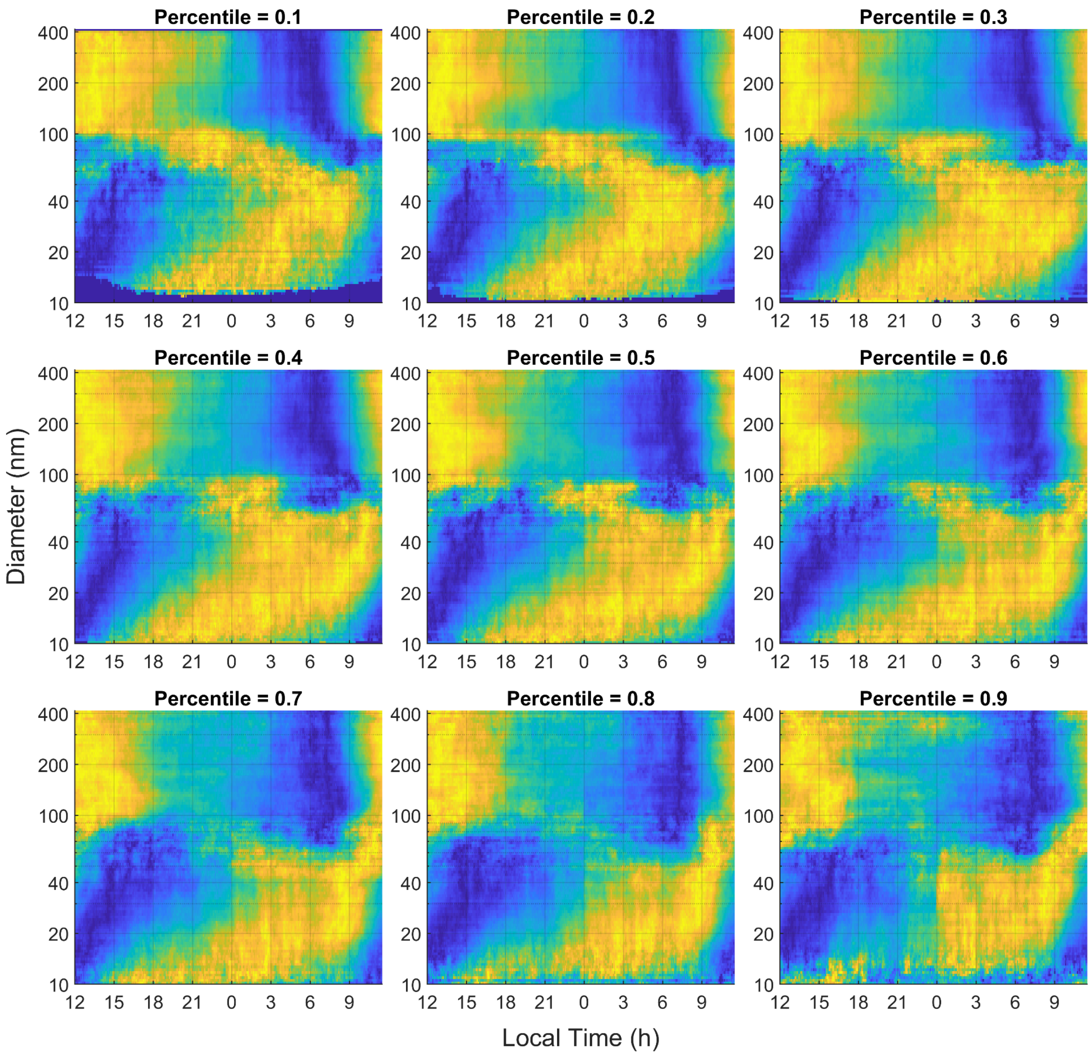


Figure F1. Diurnal evolution of the normalized particle number size distribution during non-event days is shown for different concentration percentiles (10th to 90th, in steps of 10%). The characteristic slow and sequential increase in particle diameter is consistently observed across a wide range of percentiles, demonstrating that the Quiet NPF signature is a general statistical property of non-event days and not an artefact of averaging or of a small subset of high-concentration days.

To explicitly test whether the Quiet NPF signature identified in this study (characterized in the main text using the median normalized PNSD) reflects a general property of non-event days rather than an artefact of averaging or a limited subset of days, we extended the analysis by examining different percentiles of the normalized PNSD. **Figure F1** shows the diurnal evolution of particle size distributions for percentiles ranging from the 10th to the 90th percentile, calculated independently for each size bin and local time.

Across a broad range of percentiles, particularly from the 10th to the 80th percentiles, the normalized PNSDs exhibit a gradual and sequential increase in particle diameter over time, consistent with particle formation followed by growth. The persistence of this pattern across percentiles demonstrates that the Quiet NPF signature is not dominated by high-concentration outliers or by a small number of specific days, but instead reflects a systematic statistical feature of non-event days in the Amazon boundary layer.

While this result supports the interpretation that Quiet NPF is a phenomenon virtually always present on non-event days across a wide range of intensities, it does not imply that the process is spatially homogeneous, i.e., that it has a continuous intensity over large regions. The formation and growth of new particles depend on atmospheric conditions that vary in space and time, such as oxidation capacity, precursor availability, meteorology, and air-mass history. The observed ensemble behaviour is therefore consistent with a scenario in which particle formation occurs heterogeneously in space and time, potentially within localized air masses, and becomes detectable only through statistical aggregation across many realizations.

Together with the normalized median analysis presented in the main text, the percentile-based results confirm that ensemble averaging does not artificially generate the observed growth pattern but instead reveals the underlying statistical imprint of a weak yet pervasive particle-formation process in the Amazon boundary layer.

Reviewer comments related to Major Comment (Comments 1–5)

Comment 1

Reviewer comment:

64: This seems like a critical point to bring up the assumption that quiet NPF is NOT observed by viewing individual days, and that for the remainder of the manuscript, the assumption is that this phenomenon is happening every day that a classical event is not observed. If this is not a correct assumption, then I am missing an important point of this paper, and that, too, should be addressed.

Author Response:

We thank the reviewer for highlighting this important conceptual point. As clarified in our response to Major Comment above, our interpretation is that the physical processes associated with Quiet NPF occur very frequently during non-event days, with strongly varying intensity, rather than as a strictly intermittent or on–off phenomenon. Importantly, Quiet NPF is generally not detectable at the scale of individual daily size distributions due to its weak signal, particularly in the Amazon.

To make this assumption explicit and to strengthen the manuscript, we now add a brief clarification in the main text, supported by new sensitivity analyses presented in Appendices D and F. In Appendix F, we demonstrate that the characteristic slow and sequential increase in particle diameter is consistently observed across a wide range of concentration percentiles, confirming that the Quiet NPF signature represents a general statistical property of non-event days rather than an artefact of averaging or a small subset of days.

Manuscript changes:

The sentence starting at line 83 has been revised from:

"A similar pattern was also observed in an independent analysis of the PNSD during the wet seasons of 2008–2014 at the nearby ZF2 site in the Central Amazon. Despite the coarser resolution, they reveal an identical nocturnal growth pattern with sub-50 nm particle concentrations peaking at night (**Fig. S1**). This consistency across sites in the Amazon underscores the regional significance of Quiet NPF, a process characterized by subtle growth signatures that become apparent only through detailed statistical normalization."

to

"A similar pattern was also observed in an independent analysis of the PNSD during the wet seasons of 2008–2014 at the nearby ZF2 site in the Central Amazon. Despite the coarser resolution, the data reveal an identical nocturnal growth pattern, with sub-50 nm particle concentrations peaking at night (**Fig. S1**). Together with additional sensitivity tests, this consistency strengthens the robustness of our interpretation. Specifically, screening for anthropogenic influence shows no systematic effect on the Quiet NPF signature (**Appendix D**), whereas analyses using different statistical aggregations indicate the same sequential increase in particle diameter (10-25 nm) persists across a wide range of concentration percentiles (**Appendix F**). Taken together, these independent lines of evidence indicate that Quiet NPF represents a general statistical property of non-event days in the Central Amazon, is not significantly affected by anthropogenic influence, and reflects particle formation processes that occur very frequently and become detectable only through detailed statistical normalization."

The sentence starting at line 150 has been revised from:

"Although the absence of rain-related downdrafts and classical NPF events does not guarantee that Quiet NPF is active every non-event day, we use the mean characteristics of non-event days to estimate its typical contribution. This approach is consistent with recent studies suggesting that new particle formation occurs across a spectrum of intensities, from prominent events to more subtle, persistent processes (Kulmala et al., 2022a; Aliaga et al., 2023)."

to

"Although the absence of rain-related downdrafts and classical NPF events does not imply in principle that Quiet NPF is active on every non-event day, we use the median characteristics of non-event days to estimate its typical contribution. By examining additional percentiles, we find consistent signatures across the distribution, supporting the applicability of this statistical approach to the full set of non-event days (see **Appendix F**). This approach is consistent with recent studies suggesting that new particle formation spans a continuum of intensities, from pronounced events to weaker, persistent processes (Kulmala et al., 2022a; Aliaga et al., 2023)."

Comment 2

Reviewer comment:

88: If my point for line 64 is made clear, then it will be understandable why this potential temperature analysis is being performed on all non-event days. As it is currently written, it seems to suggest that all non-event days are relevant to quiet NPF. I would argue that this point needs to be clearer here.

Author Response:

As clarified above and in the revised manuscript, our analysis explicitly treats all non-event days as relevant to Quiet NPF in a statistical sense. Once this framework is made explicit, the use of all non-event days for the potential temperature analysis follows naturally and consistently.

Comment 3

Reviewer comment:

102: It would be helpful to the reader to remind them that this growth rate analysis is being performed on the average normalized size distribution.

Author Response:

We agree and thank the reviewer for this suggestion. We now make this point more explicit at the location indicated by the reviewer to improve clarity.

Manuscript change:

The sentence has been revised from:

"To characterize Quiet NPF, we calculated its characteristic GR based on the median PNSD during non-event days through the appearance time method within the diameter range of 10–25 nm (Lehtipalo et al., 2014; Kulmala et al., 2022a)."

to:

"To characterize Quiet NPF, we derived a single characteristic GR by applying the appearance time method to the median PNSD of all non-event days within the 10–25 nm diameter range *(Lehtipalo et al., 2014; Kulmala et al., 2022a)."*

Comments 4 and 5

Reviewer comment:

121: This line is the clearest indication thus far that the average properties of quiet NPF are being uniformly applied to all non-event days. But is it true that ALL non-event days have quiet NPF? What if this were not the case? It seems, to me, that average properties can be used for analysis of such things as growth rates, but individual days can be analyzed for whether or no quiet NPF could have occurred.

148: This statement requires the assumption that quiet NPF occurs on all days that are classified as non-events. This assumption again needs to be stated clearly, and either a caveat or a justification needs to be provided.

Author Response:

We thank the reviewer for raising this important conceptual point. As clarified in our response to the Major Comment, Quiet NPF is not generally detectable at the scale of individual days, but emerges as a robust statistical feature when non-event days are considered in aggregate.

To avoid ambiguity, we now explicitly state this assumption in the main text prior to the calculation of J_{10} and DPR_{10}. Specifically, we clarify that the subsequent analysis assumes that Quiet NPF-related formation and growth processes are virtually always present during non-event days, albeit with strongly varying intensity. This assumption is supported by the percentile-based analysis presented in **Appendix F**.

Manuscript Change:

The following sentence has been added to Line 108:

The following analysis assumes that Quiet NPF-related processes are virtually always present during non-event days, with varying intensity, as supported by the percentile-based analysis presented in **Appendix F**.

Comment 6

Reviewer comment:

126: I am confused about what the dN/dt term is. The only description is that it "reflects the temporal distribution of the particle number"; however, it appears to be plotted alongside coagulation and growth. This needs to be clarified in the manuscript.

Author Response:

We thank the reviewer for pointing out that the description of the dN/dt term was unclear. Following the formulation of the aerosol population balance equation described by Kulmala et al. (2012), dN/dt represents the observed time derivative of the particle number concentration, N, within a given size range—in this case, 10–25 nm. It describes the net temporal evolution of particle number, accounting for particles entering and leaving the size interval.

In the balance equation, the time evolution of particle number concentration ($\frac{dN_{Dp}}{dt}$) in a size interval [dp, dp + Δdp] is given by the difference between particle production and losses. When rearranged to express the formation rate J_{Dp}, the equation becomes:

$$J_{Dp} = \frac{dN_{Dp}}{dt} + losses,$$

where the loss terms include coagulation and condensational growth out of the size interval. In this formulation, dN/dt represents the net accumulation or depletion of particles within the size range, whereas the coagulation and growth terms quantify the physical processes that remove particles from that interval. Plotting these terms together illustrates how the observed temporal evolution of particle number is partitioned among the contributing processes.

Manuscript Change:

The sentence starting at line 238 of the **Appendix B** has been revised from:

"where $N_{10\text{-}25}$ is the concentration of particles 10–25 nm, $dN_{10\text{-}25}/dt$ its time derivative, *CoagS* the coagulation sink calculated from the size distribution, based on coagulation coefficients for each particle size (Kerminen et al., 2001; Seinfeld & Pandis, 2016), and Δd_p the size interval (25–10 nm). This size range focuses our analysis on recently nucleated particles, minimising primary source contributions."

to:

"where $N_{10\text{-}25}$ is the concentration of particles in the 10–25 nm size range, $dN_{10\text{-}25}/dt$ is the time derivative representing the net temporal evolution of particle number concentration within this interval, $(dN/dD_p)_{25}$ is the particle number size distribution evaluated at 25 nm and represents the flux of particles growing out of the selected size range, and CoagS is the coagulation sink calculated from the size distribution using size-dependent coagulation coefficients (Kerminen et al., 2001; Seinfeld & Pandis, 2016). This formulation follows the aerosol population balance framework of Kulmala et al. (2012), in which the formation rate J_{10} is obtained by combining the observed temporal change in particle number with losses due to coagulation and condensational growth. The selected size range focuses the analysis on recently nucleated particles, minimizing contributions from primary sources."

Comment 7

Reviewer comment:

130: Is the coagulation term really just one pixel in amplitude in Figure 3? Why is it so consistent across the entire day?

Author Response:

Yes, the coagulation term is small in magnitude for the 10–25 nm size range at ATTO during the wet season, but it is not constant, as seen in **Figure R7**. Its diurnal variability reflects the combined influence of (i) the concentration of accumulation-mode particles, which act as the primary coagulation sink for newly formed nanoparticles, and (ii) the concentration of particles within the 10–25 nm size range itself.

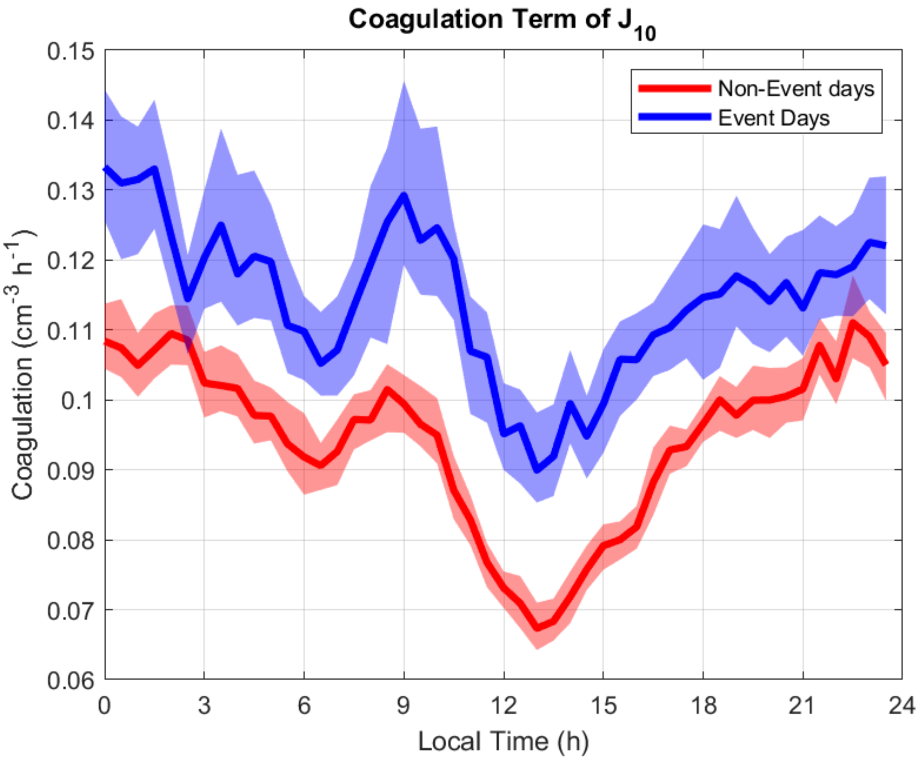


Figure R7 - Diurnal cycle of the coagulation loss term of the balance equation used to calculate J_{10} (Eq. 1 of the main text).

In brief, while the concentration of particles with D□ < 25 nm increases during nighttime due to Quiet NPF, accumulation-mode particle concentrations tend to decrease at night as a result of deposition within the shallow nocturnal boundary layer. Because the coagulation sink depends on both the concentration of small particles and the abundance of accumulation-mode particles, it reaches a maximum during the middle of the night. The overall magnitude of the coagulation term nevertheless remains small, as accumulation-mode particle concentrations during the wet season are relatively low and exhibit only moderate diurnal variability. As a result, its limited dynamic range appears visually compressed in **Fig. 3**, although the coagulation term is physically present and varies consistently with the diurnal aerosol population.

***Additional changes*:**

In addition to the revisions described above, we made a few minor editorial adjustments. The reported rounded GR value was updated from 2.3 to 2.4 nm h^{-1}, and the corresponding R^2 values in the main text were adjusted from 0.95 to 0.96 to reflect rounding consistency. Furthermore, multiple instances of the term "boundary layer" were replaced by the abbreviation "BL" to improve conciseness and reduce word count, without affecting clarity.

The following references were added to the manuscript:

Holanda, B. A., Franco, M. A., Walter, D., Artaxo, P., Carbone, S., Cheng, Y., Chowdhury, S., Ditas, F., Gysel-Beer, M., Klimach, T., Kremper, L. A., Krüger, O. O., Lavric, J. V., Lelieveld, J., Ma, C., Machado, L. A. T., Modini, R. L., Morais, F. G., Pozzer, A., Saturno, J., Su, H., Wendisch, M., Wolff, S., Pöhlker, M. L., Andreae, M. O., Pöschl, U., and Pöhlker, C.: African biomass burning affects aerosol cycling over the Amazon, Commun Earth Environ, 4, 154, https://doi.org/10.1038/s43247-023-00795-5, 2023.

Pöhlker, M. L., Ditas, F., Saturno, J., Klimach, T., Hrabě de Angelis, I., Araújo, A. C., Brito, J., Carbone, S., Cheng, Y., Chi, X., Ditz, R., Gunthe, S. S., Holanda, B. A., Kandler, K., Kesselmeier, J., Könemann, T., Krüger, O. O., Lavrič, J. V., Martin, S. T., Mikhailov, E., Moran-Zuloaga, D., Rizzo, L. V., Rose, D., Su, H., Thalman, R., Walter, D., Wang, J., Wolff, S., Barbosa, H. M. J., Artaxo, P., Andreae, M. O., Pöschl, U., and Pöhlker, C.: Long-term observations of cloud condensation nuclei over the Amazon rain forest – Part 2: Variability and characteristics of biomass burning, long-range transport, and pristine rain forest aerosols, *Atmos. Chem. Phys.*, **18**, 10289–10331, https://doi.org/10.5194/acp-18-10289-2018, 2018.

Saturno, J., Holanda, B. A., Pöhlker, C., Ditas, F., Wang, Q., Moran-Zuloaga, D., Brito, J., Carbone, S., Cheng, Y., Chi, X., Ditas, J., Hoffmann, T., Hrabe de Angelis, I., Könemann, T., Lavrič, J. V., Ma, N., Ming, J., Paulsen, H., Pöhlker, M. L., Rizzo, L. V., Schlag, P., Su, H., Walter, D., Wolff, S., Zhang, Y., Artaxo, P., Pöschl, U., and Andreae, M. O.: Black and brown carbon over central Amazonia: long-term aerosol measurements at the ATTO site, Atmospheric Chemistry and Physics, 18, 12817–12843, https://doi.org/10.5194/acp-18-12817-2018, 2018.

Valiati, R., Meller, B. B., Franco, M. A., Rizzo, L. V., Machado, L. A., Brill, S., and Artaxo, P.: Distinct aerosol populations and their vertical gradients in central Amazonia revealed by optical properties and cluster analysis, *Atmos. Chem. Phys.*, **25**, 14923–14944, https://doi.org/10.5194/acp-25-14923-2025, 2025.

Final author considerations:

In summary, the reviewer comments prompted a series of targeted sensitivity analyses and clarifications that substantially strengthened the manuscript. In the revised version, we (i) explicitly demonstrate the robustness of the Quiet NPF signature across different statistical aggregations, (ii) assess and rule out a dominant influence of anthropogenic contamination, (iii) refine the formulation of the aerosol population balance equation to improve the quantitative accuracy of J_{10} and DPR_{10}, and (iv) clarify the physical interpretation of the diurnal behavior of formation, growth, and loss terms. Together, these revisions enhance the transparency, methodological rigor, and physical interpretation of the results, while leaving the study's main conclusions unchanged.

References

Aliaga, D., Tuovinen, S., Zhang, T., Lampilahti, J., Li, X., Ahonen, L., Kokkonen, T., Nieminen, T., Hakala, S., Paasonen, P., Bianchi, F., Worsnop, D., Kerminen, V.-M., and Kulmala, M.: Nanoparticle ranking analysis: determining new particle formation (NPF) event occurrence and intensity based on the concentration spectrum of formed (sub-50 nm) particles, *Aerosol Research*, 1, 81–92, https://doi.org/10.5194/ar-1-81-2023, 2023.

Franco, M. A., Ditas, F., Kremper, L. A., Machado, L. A. T., Andreae, M. O., Araújo, A., Barbosa, H. M. J., de Brito, J. F., Carbone, S., Holanda, B. A., Morais, F. G., Nascimento, J. P., Pöhlker, M. L., Rizzo, L. V., Sá, M., Saturno, J., Walter, D., Wolff, S., Pöschl, U., Artaxo, P., and Pöhlker, C.: Occurrence and growth of sub-50 nm aerosol particles in the Amazonian boundary layer, *Atmospheric Chemistry and Physics*, 22, 3469–3492, https://doi.org/10.5194/acp-22-3469-2022, 2022.

Franco, M. A., Valiati, R., Holanda, B. A., Meller, B. B., Kremper, L. A., Rizzo, L. V., Carbone, S., Morais, F. G., Nascimento, J. P., Andreae, M. O., Cecchini, M. A., Machado, L. A. T., Ponczek, M., Pöschl, U., Walter, D., Pöhlker, C., and Artaxo, P.: Vertically resolved aerosol variability at the Amazon Tall Tower Observatory under wet-season conditions, Atmospheric Chemistry and Physics, 24, 8751–8770, https://doi.org/10.5194/acp-24-8751-2024, 2024.

Glicker, H. S., Lawler, M. J., Ortega, J., de Sá, S. S., Martin, S. T., Artaxo, P., Vega Bustillos, O., de Souza, R., Tota, J., Carlton, A., and Smith, J. N.: Chemical composition of ultrafine aerosol particles in central Amazonia during the wet season, *Atmospheric Chemistry and Physics*, 19, 13053–13066, https://doi.org/10.5194/acp-19-13053-2019, 2019.

Holanda, B. A., Franco, M. A., Walter, D., Artaxo, P., Carbone, S., Cheng, Y., Chowdhury, S., Ditas, F., Gysel-Beer, M., Klimach, T., Kremper, L. A., Krüger, O. O., Lavric, J. V., Lelieveld, J., Ma, C., Machado, L. A. T., Modini, R. L., Morais, F. G., Pozzer, A., Saturno, J., Su, H., Wendisch, M., Wolff, S., Pöhlker, M. L., Andreae, M. O., Pöschl, U., and Pöhlker, C.: African biomass burning affects aerosol cycling over the Amazon, Commun Earth Environ, 4, 154, https://doi.org/10.1038/s43247-023-00795-5, 2023.

Kerminen, V.-M., Pirjola, L., and Kulmala, M.: How significantly does coagulational scavenging limit atmospheric particle production?, *Journal of Geophysical Research: Atmospheres*, 106, 24119–24125, https://doi.org/10.1029/2001JD000322, 2001.

Kulmala, M., Petäjä, T., Nieminen, T., Sipilä, M., Manninen, H. E., Lehtipalo, K., Dal Maso, M., Aalto, P. P., Junninen, H., Paasonen, P., Riipinen, I., Lehtinen, K. E. J., Laaksonen, A., and Kerminen, V.-M.: Measurement of the nucleation of atmospheric aerosol particles, *Nature Protocols*, 7, 1651–1667, https://doi.org/10.1038/nprot.2012.091, 2012.

Kulmala, M., Junninen, H., Dada, L., Salma, I., Weidinger, T., Thén, W., Vörösmarty, M., Komsaare, K., Stolzenburg, D., Cai, R., Yan, C., Li, X., Deng, C., Jiang, J., Petäjä, T., Nieminen, T., and Kerminen, V.-M.: Quiet New Particle Formation in the Atmosphere, *Frontiers in Environmental Science*, 10, 912385, https://doi.org/10.3389/fenvs.2022.912385, 2022a.

Lehtipalo, K., Leppä, J., Kontkanen, J., Kangasluoma, J., Franchin, A., Wimmer, D., Schobesberger, S., Junninen, H., Petäjä, T., Sipilä, M., Mikkilä, J., Vanhanen, J., Worsnop, D. R., and Kulmala, M.: Methods for determining particle size distribution and growth rates between 1 and 3 nm using the Particle Size Magnifier, *Boreal Environment Research*, 19(B), 215–236, 2014.

Machado, L. A. T., Unfer, G. R., Brill, S., Hildmann, S., Pöhlker, C., Cheng, Y., Williams, J., Hartwig, H., Andreae, M. O., Artaxo, P., Curtius, J., Franco, M. A., Cecchini, M. A., Edtbauer, A., Hoffmann, T., Holanda, B., Khadir, T., Krejci, R., Kremper, L. A., Liu, Y., Meller, B. B., Pöhlker, M. L., Quesada, C. A., Ringsdorf, A., Riipinen, I., Trumbore, S., Wolff, S., Lelieveld, J., and Pöschl, U.: Frequent rainfall-induced new particle formation within the canopy in the Amazon rainforest, *Nature Geoscience*, 17, 1225–1232, https://doi.org/10.1038/s41561-024-01585-0, 2024.

Pöhlker, C., Wiedemann, K. T., Sinha, B., Shiraiwa, M., Gunthe, S. S., Smith, M., Su, H., Artaxo, P., Chen, Q., Cheng, Y., Elbert, W., Gilles, M. K., Kilcoyne, A. L. D., Moffet, R. C., Weigand, M., Martin, S. T., Pöschl, U., and Andreae, M. O.: Biogenic Potassium Salt Particles as Seeds for Secondary Organic Aerosol in the Amazon, *Science*, 337, 1075–1078, https://doi.org/10.1126/science.1223264, 2012.

Pöhlker, M. L., Ditas, F., Saturno, J., Klimach, T., Hrabě de Angelis, I., Araújo, A. C., Brito, J., Carbone, S., Cheng, Y., Chi, X., Ditz, R., Gunthe, S. S., Holanda, B. A., Kandler, K., Kesselmeier, J., Könemann, T., Krüger, O. O., Lavrič, J. V., Martin, S. T., Mikhailov, E., Moran-Zuloaga, D., Rizzo, L. V., Rose, D., Su, H., Thalman, R., Walter, D., Wang, J., Wolff, S., Barbosa, H. M. J., Artaxo, P., Andreae, M. O., Pöschl, U., and

Pöhlker, C.: Long-term observations of cloud condensation nuclei over the Amazon rain forest – Part 2: Variability and characteristics of biomass burning, long-range transport, and pristine rain forest aerosols, *Atmos. Chem. Phys.*, **18**, 10289–10331, https://doi.org/10.5194/acp-18-10289-2018, 2018.

Rizzo, L. V., Roldin, P., Brito, J., Backman, J., Swietlicki, E., Krejci, R., Tunved, P., Petäjä, T., Kulmala, M., and Artaxo, P.: Multi-year statistical and modeling analysis of submicrometer aerosol number size distributions at a rain forest site in Amazonia, *Atmos. Chem. Phys.*, **18**, 10255–10274, https://doi.org/10.5194/acp-18-10255-2018, 2018.

Saturno, J., Holanda, B. A., Pöhlker, C., Ditas, F., Wang, Q., Moran-Zuloaga, D., Brito, J., Carbone, S., Cheng, Y., Chi, X., Ditas, J., Hoffmann, T., Hrabe de Angelis, I., Könemann, T., Lavrič, J. V., Ma, N., Ming, J., Paulsen, H., Pöhlker, M. L., Rizzo, L. V., Schlag, P., Su, H., Walter, D., Wolff, S., Zhang, Y., Artaxo, P., Pöschl, U., and Andreae, M. O.: Black and brown carbon over central Amazonia: long-term aerosol measurements at the ATTO site, Atmospheric Chemistry and Physics, 18, 12817–12843, https://doi.org/10.5194/acp-18-12817-2018, 2018.

Seinfeld, J. H., and Pandis, S. N.: *Atmospheric Chemistry and Physics: From Air Pollution to Climate Change*, John Wiley & Sons, 1249 pp., 2012.

Valiati, R., Meller, B. B., Franco, M. A., Rizzo, L. V., Machado, L. A., Brill, S., and Artaxo, P.: Distinct aerosol populations and their vertical gradients in central Amazonia revealed by optical properties and cluster analysis, *Atmos. Chem. Phys.*, **25**, 14923–14944, https://doi.org/10.5194/acp-25-14923-2025, 2025.

Wang, J., Krejci, R., Giangrande, S., Kuang, C., Barbosa, H. M. J., Brito, J., Carbone, S., Chi, X., Comstock, J., Ditas, F., Lavric, J., Manninen, H. E., Mei, F., Moran-Zuloaga, D., Pöhlker, C., Pöhlker, M. L., Saturno, J., Schmid, B., Souza, R. A. F., Springston, S. R., Tomlinson, J. M., Toto, T., Walter, D., Wimmer, D., Smith, J. N., Kulmala, M., Machado, L. A. T., Artaxo, P., Andreae, M. O., Petäjä, T., and Martin, S. T.: Amazon boundary layer aerosol concentration sustained by vertical transport during rainfall, Nature, 539, 416–419, https://doi.org/10.1038/nature19819, 2016.