Dear Editor and Reviewers,

We sincerely thank the Editor and the reviewers for their careful evaluation of our manuscript and for the constructive comments. We have addressed every point and revised the manuscript and Supporting Information accordingly. For clarity, each reviewer comment is reproduced below, followed by our point-by-point response and a description of the corresponding revisions. All changes have been incorporated into the revised manuscript and Supporting Information.

## Summary of Major Changes

Replaced the terms “monsoon” and “pre-monsoon” with “autumn observation period” and “spring observation period” and limited interpretation to the two campaign periods.

Removed the Class I/Class II distinction and reclassified all 58 observation days as 43 NPF, 6 Undefined, and 9 Non-Event days; all affected statistics and figures were recalculated.

Added a day-by-day classification table (Table S1) and separate daily PNSD figures for NPF, Undefined, and Non-Event days (Figs. S1-S3).

Expanded the high-altitude NPF literature review and clarified the distinction between remote mountain sites and urban Lhasa.

Added a relative $H_2SO_4$-related photochemical proxy and its limitations (Sect. S1 and Fig. S5).

Softened mechanistic conclusions concerning sulfur-containing precursors and VOC-related oxidation.

Expanded the assessment of local urban emissions using particle-size evolution, wind sectors, gaseous pollutants, $PM_{2.5}$ and $PM_{10}$ supporting analyses.

Added a sensitivity analysis for estimated CCN concentrations (Fig. S7) and compared estimated CCN with $N_{100–700}$.

Defined all symbols in Eqs. (6) and (7), clarified that CCN concentrations were estimated rather than measured, and expanded figure captions.

Redrew Fig. 1, corrected figure axes and labels, improved panel spacing and legends, and defined TU as Tibet University at first use.

## Reviewer 1

**Comment 1:**

Introduction:

The introduction is overall well structured; However, it might be that the literature review is somehow narrow. I do understand that the focus of the paper is the Tibetan Plateau however there are several other studies with a focus on high altitude measurements and location very close to the one done in this study. This introduction focuses strongly on recent Tibetan Plateau background studies while giving limited attention to the broader high-altitude and free-tropospheric NPF literature. I can imagine that a comparison done with measurements presented in Himalaya such as Bianchi et al. (2021, Nature Geoscience) but also many other studies could be good for this work. Also, this comparison can been done when discussing the possible precursors. In this way the authors can also benefit by distinguish their urban Lhasa case from other mountain NPF types.

**Response 1:**

Thank you for this helpful suggestion. We agree that the original Introduction focused primarily on recent studies conducted at background sites on the Tibetan Plateau and provided insufficient discussion of the broader high-altitude and free-tropospheric NPF literature.

We have therefore expanded the Introduction to include the Himalayan studies of Venzac et al. (2008) and Bianchi et al. (2021), as well as the free-tropospheric NPF and CCN-related observations conducted at the high-altitude Chacaltaya station by Rose et al. (2017). The added discussion highlights the roles of mountain-valley circulation, vertical transport, and organic precursor chemistry in NPF at remote high-altitude sites.

We have also further clarified the distinction between these remote mountain environments and the urban Lhasa site. Previous observations at remote Himalayan sites showed that up-valley transport can supply gaseous precursors, including biogenic organic compounds, thereby promoting particle formation and subsequent transport into the free troposphere. In contrast, the TU site is located in a high-altitude urban environment and is additionally influenced by traffic, combustion, construction activities, and anthropogenic gaseous precursors. This comparison more clearly demonstrates the novelty of the present study and provides a broader context for the subsequent discussion of potential NPF precursors.

**Comment 2:**

Classification event:

It is well known that the actual classification method is subjective and probably quite qualitative. However, I have the feeling that in this case can be improved. Also, because many central results depend on the classification, like NPF frequency, J/GR statistics, and CCN formation. For example, in figure 2, I would even think that type II and even undefined can be considered as a class I event. Mostly, it seems that, the separation between Class II and Undefined events is not really clear. Something useful could be a day-by-day classification table, including event start/end times, growth-rate time windows, and

so on. An additional approach could be to use a ranking method that classified that days in function of particles that have been produced.

**Response 2:**

We thank the referee for this important and constructive suggestion. We agree that the distinction between the original Class I and Class II events was not sufficiently robust and that the subjectivity of this separation could affect the reported NPF frequency, formation and growth rates, and estimated CCN concentrations.

Following the referee's suggestion, we re-examined the PNSD evolution for every observation day and removed the distinction between Class I and Class II. The two original categories were combined into a single "NPF day" category. The revised classification now consists of NPF, Undefined, and Non-Event days. Correspondingly, all major figures and statistical analyses involving event classification, including the NPF frequency, J/GR statistics, sink analysis, and estimated CCN concentrations, were recalculated using the revised three-category classification.

NPF days were identified primarily by the appearance of a distinct new particle mode at small diameters followed by identifiable growth toward larger sizes. Continuous growth throughout the entire day was not required, because temporary interruptions may result from changes in air masses, boundary-layer development, variations in precursor availability, or missing measurements. For days with weak, discontinuous, or ambiguous modal evolution, visual inspection of the PNSD was further supported by the mean particle number concentrations in the 3–25 and 25–100 nm size ranges and candidate particle growth rates. These parameters were used as supporting evidence rather than as fixed classification thresholds, because particle number concentrations can also be affected by background aerosol levels and local primary emissions.

Based on this re-evaluation, some days originally classified as Undefined, including 12 and 18 April 2025, were reassigned to the unified NPF-day category because their PNSDs and supporting particle-growth characteristics provided sufficient evidence of particle formation and subsequent growth. The remaining Undefined days exhibited enhanced small-particle concentrations or partial modal evolution, but the formation and growth patterns remained too weak, discontinuous, or ambiguous to be classified confidently as NPF. Undefined days were therefore retained as a separate category and included in the non-NPF group only when comparisons between NPF and non-NPF conditions were required.

To improve the transparency and reproducibility of the classification, we have added a day-by-day summary in Table S1. The table provides the revised classification, original growth subgroup, NPF start and end times, mean $N_{3-25}$ and $N_{25-100}$ concentrations, candidate GR time windows, and corresponding GR values for each observation day. Daily PNSD plots for NPF, Undefined, and Non-Event days are presented separately in Figs. S1–S3. Following this revision, the 58 observation days were classified as 43 NPF days, 6 Undefined days, and 9 Non-Event days.

**Comment 3:**

Monsoon NPF mechanism and NPF mechanism in general:

The study says that monsoon NPF is mainly associated with $SO_2$ availability and therefore $H_2SO_4$ formation. This is can also be reasonable, but since the authors couldn't measure all the parameters such as sulfuric acid, or bases such as ammonia or amines, or organic molecules and their oxidation products. SO2 is clearly quite high and therefore can be a reason for the NPF. One possibility could be to calculate Sulphuric Acid proxy from SO2 and see how it compare to the formation rate. Because of all of that I would say that the interpretation that monsoon NPF is sulfur-precursor-driven should be softened unless additional analysis such as at least Sulphuric Acid proxy Vs Formation rate. Also, the paper discusses possible VOC-related oxidation in the pre-monsoon season but cannot constrain it. We understand that these measurements are very complicated, especially in such location, however, considering recent literature on HOMs/OOMs in mountain and TP environments, the author should be more critical in highlighting these limitations. They have a beautiful data set also without going too much in details on the NPF mechanism.

**Response 3:**

We thank the referee for this important and constructive comment. We agree that the original manuscript placed excessive emphasis on a sulfur-precursor-driven mechanism, considering that gaseous $H_2SO_4$, ammonia, amines, VOCs, and their oxidation products were not directly measured.

First, because the October–November and March–April campaigns were relatively short and cannot fully represent the broader monsoon and pre-monsoon seasons, we have replaced "monsoon" and "pre-monsoon" with "autumn observation period" and "spring observation period," respectively, throughout the manuscript. We have also avoided generalizing the differences observed during these two campaigns as representative seasonal patterns or mechanisms.

Following the referee's suggestion, we calculated a relative $H_2SO_4$-related photochemical proxy for periods with concurrent $SO_2$, $J(O(^1D))$, and CS measurements during the autumn observation period. The proxy was expressed as $[SO_2]\ J(O(^1D))/CS$, representing the potential photochemical production of $H_2SO_4$ relative to its condensational loss. The calculation method, data-processing procedure, assumptions, and limitations have been added to Sect. S1 of the Supplement. The corresponding results are presented in Fig. S5.

The relative $H_2SO_4$-related proxy was generally higher on NPF days than on non-NPF days during the particle-formation period, providing additional evidence for an association between sulfur-containing precursor availability and autumn NPF. However, because the spectral measurements required to derive $J(O(^1D))$ were available only during part of the autumn campaign, the proxy analysis did not provide continuous coverage of all observation days. In addition, no site-specific relationship between $J(O(^1D))$, OH, and measured gaseous $H_2SO_4$ was available. We therefore use the proxy only as a relative indicator and do not interpret it as an absolute $H_2SO_4$ concentration or as definitive evidence of a uniquely sulfur-driven mechanism.

Accordingly, we have softened the mechanistic interpretation throughout the Abstract, Results and Discussion, and Conclusions. The revised manuscript now states that the higher $SO_2$ concentrations and enhanced relative $H_2SO_4$-related

proxy on NPF days suggest that sulfur-containing precursors likely contributed to particle formation and early growth during the autumn observation period, rather than demonstrating that sulfur precursors exclusively controlled NPF.

We have also revised the discussion of the spring observation period. The possible contribution of VOC-related oxidation is now presented only as a hypothesis that cannot be constrained by the available measurements. We further emphasize that the absence of direct measurements of $H_2SO_4$, ammonia, amines, VOCs, HOMs/OOMs, and their oxidation products prevents quantitative attribution of the molecular mechanisms during either observation period. Relevant recent studies of organic compounds and HOMs/OOMs in high-altitude Himalayan and TP environments have been incorporated to provide broader context. These limitations are now explicitly acknowledged in both the mechanism discussion and the Conclusions.

**Comment 4:**

Urban primary emissions vs NPF:

I think it would be good if the authors could try to better separate regional NPF from local primary ultrafine particle emissions. This could include analysis of wind direction, $BC/NO_2/SO_2$ spikes, rush-hour timing, and whether events occur simultaneously across broader size ranges. Considering the unique location this would add strength and very interesting new information to the study.

**Response 4:**

We thank the referee for this important suggestion. We agree that distinguishing atmospheric NPF from local primary ultrafine-particle emissions is particularly important at the urban Tibet University (TU) site. We have therefore strengthened this aspect of the analysis using the available PNSD, size-segregated particle number concentrations, gaseous pollutants, wind conditions, and $PM_{2.5}$ and $PM_{10}$ measurements.

First, the revised NPF classification does not rely solely on an increase in small-particle number concentration. An NPF day requires the appearance of a distinct new particle mode at small diameters followed by identifiable modal growth toward larger sizes. Short-lived particle-number spikes without subsequent systematic growth were not classified as NPF. This criterion helps distinguish atmospheric NPF from primary-emission plumes, which generally produce transient enhancements over relatively fixed size ranges rather than a coherent banana-shaped growth pattern.

Second, the size-segregated diurnal profiles provide additional evidence for this interpretation. On NPF days, the morning increase in $N_{3-25}$ was followed by an enhancement in $N_{25-100}$, consistent with particle formation and subsequent growth. In contrast, evening enhancements in $N_{25-100}$, particularly when they occurred without a preceding increase in nucleation-mode particles, may have been influenced by local urban emissions and are now interpreted cautiously in the revised manuscript. Variations in $N_{100-700}$ were comparatively weaker during the principal particle-formation period, indicating that the NPF classification was not based on a simultaneous concentration increase across the entire measured size range.

Third, we compared $SO_2$, $NO_2$, and $O_3$ under different wind directions on NPF and non-NPF days (Figs. 8 and 9). The results showed differences in gaseous pollutants and transport conditions between day types, but no single wind sector or

short-lived pollutant enhancement consistently explained all identified NPF events. The aerosol inlet was located approximately 20 m above ground level, which reduced, but did not eliminate, the direct influence of nearby traffic exhaust and resuspended road dust.

Because BC measurements were unavailable, we additionally examined the diurnal variations in $PM_{2.5}$ and $PM_{10}$ for the revised day categories during both observation periods (Fig. R1). The increases in nucleation-mode particle number concentration on NPF days were not accompanied by corresponding daytime spikes in $PM_{2.5}$ or $PM_{10}$ during the principal particle-formation period. Daytime $PM_{2.5}$ concentrations were not higher on NPF days than on Non-Event days, whereas $PM_{10}$ concentrations were broadly comparable between the two categories. These results suggest that the identified events were not simply manifestations of broader fine-particle pollution or dust episodes.

Nevertheless, $PM_{2.5}$ and $PM_{10}$ are mass-based measurements dominated by larger particles and cannot substitute for BC as tracers of traffic-related ultrafine-particle emissions. Moreover, measurements were available at only one site. We therefore cannot fully separate regional-scale NPF from all local primary ultrafine-particle influences or determine the spatial extent of individual events. We have explicitly acknowledged this limitation and have avoided describing the identified events as definitively regional. Instead, the revised manuscript interprets them as atmospheric NPF events observed at an urban site, while recognizing that local urban emissions may affect precursor availability, particle sinks, and parts of the measured ultrafine-particle population.

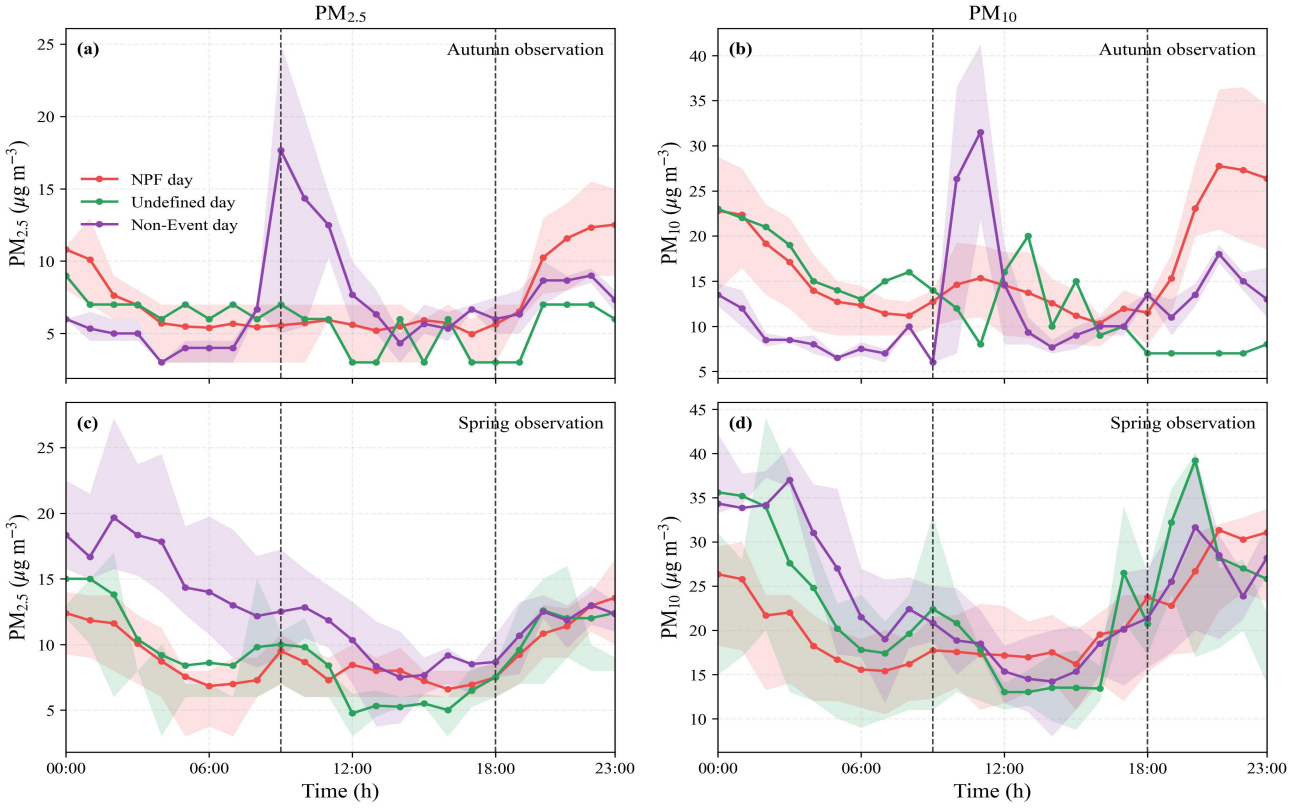


**Figure R1. Diurnal variations in $PM_{2.5}$ and $PM_{10}$ concentrations for NPF, Undefined, and Non-Event days during the autumn and spring observation periods. Solid lines represent hourly mean concentrations, and the shaded areas indicate the interquartile ranges. The vertical dashed lines indicate 09:00 and 18:00 local time. $PM_{2.5}$ and $PM_{10}$ are**

**used as supporting indicators of broader particulate-matter pollution and dust influences rather than as direct tracers of traffic-related ultrafine-particle emissions.**

**Comment 5:**

Line 25 – Define TU. I guess you mean TP.

**Response 5:**

Thank you for pointing this out. TU refers to Tibet University rather than the Tibetan Plateau. We have now defined the abbreviation at its first occurrence as "Tibet University (TU)." The abbreviation TP is used separately for the Tibetan Plateau.

**Comment 6:**

Figure 1 – "Tibetan Plateau" is not visible. Also, define TU in the caption.

**Response 6:**

Thank you for this helpful comment. We have redrawn Fig. 1 using the provincial-level administrative boundaries of China to provide a clearer and unambiguous geographical context for the observation site. The revised figure clearly shows the location of the Tibet Autonomous Region and the Tibet University (TU) observation site. Because the provincial administrative boundaries do not correspond to the physical geographical extent of the Tibetan Plateau, we have not attempted to delineate or highlight the plateau in the revised map. TU is now explicitly defined as Tibet University in the figure caption.

**Comment 7:**

Figure 2 – Fix the Panel a Y-axes description. Caption is missing explanation.

**Response 7:**

Thank you for pointing this out. We have corrected the y-axis label in Fig. 2a to particle diameter, Dp (nm), and clarified the color-bar label as $\mathrm{d}N/\mathrm{d}\log D_p$ ($cm^{-3}$). We have also expanded the caption to explain the content of each panel, the PNSD color scale, the modal fitting curves, and the modal contributions.

**Comment 8:**

Figure 3 – fixe axes labels here as well. Too many overlaps.

**Response 8:**

Thank you for this suggestion. We have revised the layout of Fig. 3 by adjusting the axis-label positions, font sizes, panel spacing, and legend placement. Overlapping labels and tick marks have been removed, and the axis labels have been corrected and repositioned for improved readability.

**Ccomment 9:**

Caption in general could contain more information related to the figures.

**Response 9:**

Thank you for this helpful suggestion. We have reviewed and expanded the captions throughout the manuscript. The revised captions now describe the content of individual panels, define the principal symbols and abbreviations, specify the relevant units and statistical quantities, and explain the meanings of lines, colors, markers, and shaded areas where applicable. This allows the figures to be interpreted more independently from the main text.

## Reviewer 2

**Comment 1:**

I would recommend removing the distinction between NPF event Class I and Class II, and suggest these to be called NPF events. As seen from the supplement figures S1 and S2, there seem to be some days (Oct 26, March 25 and March 26) classified as Class I days, which by definition of Class I should show uninterrupted growth of particles but there are clear gaps in the measured PNSD data. On the other hand, some days (at least Oct 10 and Oct 19) seem to have quite continuous growth of particles, but these days have been classified as Class II days.

**Response 1:**

We thank the referee for this important suggestion. We agree that the distinction between the original Class I and Class II events was not sufficiently robust. As the referee noted, some days originally classified as Class I contained temporary gaps in the measured PNSD, whereas some Class II days exhibited relatively continuous particle growth. In addition, the similar magnitudes and diurnal variations of $J_3$ and $J_7$ between the original Class I and Class II events further indicated that maintaining two separate NPF event classes was not well justified.

We have therefore removed the Class I–Class II distinction from all main analyses and combined the two original categories into a single "NPF day" category. The revised classification now consists of NPF, Undefined, and Non-Event days. NPF days were identified primarily from the appearance of a distinct new particle mode followed by identifiable growth toward larger sizes in the daily PNSD. Continuous and uninterrupted growth throughout the entire day was not required because temporary gaps may result from changes in air masses, boundary-layer development, variations in precursor availability, or missing measurements.

For days with weak, discontinuous, or ambiguous modal evolution, the visual interpretation of the PNSD was further supported by the mean particle number concentrations in the 3–25 and 25–100 nm size ranges and candidate particle growth rates. These supporting parameters were used to improve the transparency and consistency of the day-by-day classification rather than as fixed classification thresholds.

Following this revision, 43 NPF days, 6 Undefined days, and 9 Non-Event days were identified during the 58 measurement days. The dates specifically mentioned by the referee, including 26 October 2024, 25 and 26 March 2025, and 10 and 19 October 2024, are now all included in the unified NPF-day category. Figures 2, 3, 5 – 7, and 10 and the corresponding statistical analyses have been revised using the new classification. Figures S1 – S3 now show the daily PNSDs for NPF, Undefined, and Non-Event days, respectively. In addition, Table S1 provides the revised day-by-day classification, NPF start and end times, particle number characteristics, and candidate growth rates. The original growth subgroup is retained in Table S1 only for comparison and traceability and is not used in the revised main analyses.

**Comment 2:**

Particle formation rates J3 and J7 seem to have almost identical magnitude and diurnal variation (Fig 6) for Class I and Class II events. This would also support having only one NPF event class (combination of the Class I and Class II days).

**Response 2:**

Thank you for this observation. We agree that the similar magnitudes and diurnal variations of $J_3$ and $J_7$ for the former Class I and Class II events provide additional support for combining these two categories. Accordingly, we have removed the distinction between Class I and Class II and reclassified both categories as NPF days. Figure 6 and the corresponding text have also been revised based on the new three-category classification. Please see our Response 1 for further details regarding the revised classification.

**Comment 3:**

Have the authors compared the calculated CCN concentrations (calculated assuming const. hygroscopicity and supersaturation) to the measured accumulation mode number concentrations $N_{100–700}$, which is in many studies used as proxy for CCN? Based on Figures 5d and 10a, the diurnal variation of both these seems similar but the calculated CCN concentrations seem to be higher.

**Response 3:**

Thank you for this helpful suggestion. We have now directly compared the estimated CCN concentrations with $N_{100-700}$, which was obtained by integrating the measured PNSD over the 100–700 nm size range at the corresponding timestamps. The comparison is provided below as Fig. R2.

The estimated CCN concentrations were strongly correlated with $N_{100-700}$, with Spearman correlation coefficients of 0.91 during the autumn observation period (N=9665) and 0.82 during the spring observation period (N=8452). This result confirms that the two quantities exhibited broadly consistent temporal variability. However, as the reviewer correctly noted, the estimated CCN concentrations were systematically higher than $N_{100-700}$. The median CCN/$N_{100-700}$ ratios were 3.54 (interquartile range: 2.98–4.28) during the autumn observation period and 2.36 (1.88–2.90) during the spring observation period. The hourly median ratios also remained above unity throughout the day (Fig. R2).

This difference is expected because, under the assumed $\kappa$ of 0.12 and supersaturation of 1.2%, the calculated critical activation diameter was approximately 43.45 nm. Therefore, the estimated CCN concentrations include potentially activatable particles between approximately 43 and 100 nm in addition to particles in the accumulation-mode size range. In contrast, $N_{100-700}$ excludes these potentially activatable Aitken-mode particles and consequently represents a more conservative proxy for CCN under the assumed conditions. We have clarified this distinction in Sect. 3.4 and emphasized that the reported CCN concentrations are estimates based on the assumed hygroscopicity and supersaturation rather than direct CCN measurements.

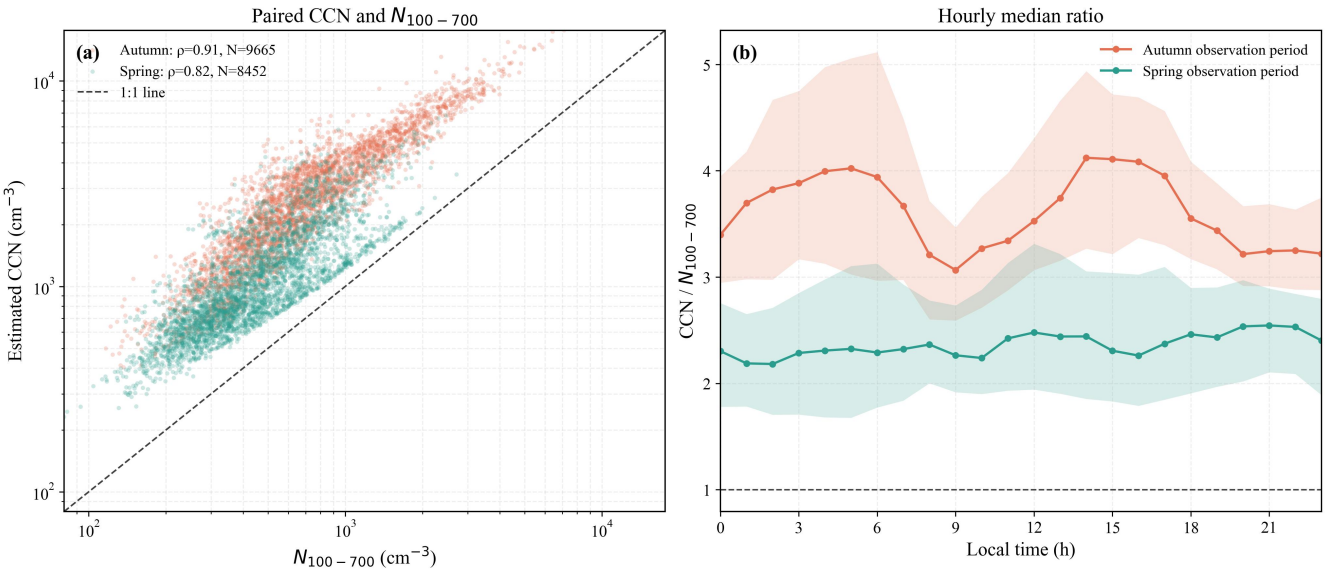


**Figure R2. Comparison between estimated CCN concentrations and particle number concentrations in the 100–700 nm size range $N_{100–700}$ during the autumn and spring observation periods. (a) Paired estimated CCN and $N_{100–700}$ concentrations at corresponding timestamps. The dashed line denotes the 1:1 relationship, and ρ and N represent the Spearman correlation coefficient and number of valid paired observations, respectively. (b) Hourly median CCN/$N_{100-700}$ ratios; the shaded areas represent the interquartile ranges. CCN was estimated using (κ = 0.12) and a supersaturation of 1.2%.**

**Comment 4:**

Please define all symbols used in Equations 6 and 7.

**Response 4:**

Thank you for pointing this out. We have revised the description following Eqs. (6) and (7) and now define all symbols used in these equations. The revised text reads:

CCN concentration is quantitatively calculated based on κ-Köhler theory (Petters and Kreidenweis, 2007). This method aims to determine the number of particles that can be activated at a specific supersaturation (S).

$$A = \frac{4\sigma_{s/a} M_w}{RT\rho_w} \tag{6}$$

$$\kappa = \frac{4A^3}{27 D_c^3 \ln^2 S_c} \tag{7}$$

In Eqs. (6) and (7), $D_c$ is the critical dry particle diameter for CCN activation, $S_c$ is the critical saturation ratio, and A is the Kelvin term. The parameter κ represents the influence of particle chemical composition on hygroscopicity and solution water activity. $\sigma_{s/a}$ is the surface tension of water against air. $M_w$ and $\rho_w$ are the molar mass and density of water, respectively. R is the universal gas constant, and T is the absolute temperature (K). In this study, κ and S were set to 0.12 and 1.2 %, respectively.

## Reviewer 3

We sincerely thank the referee for the positive assessment of the scientific relevance and strengths of our study and for the constructive suggestions. We have carefully considered all the comments and have revised the terminology used for the observation periods, clarified the representativeness and uncertainty of the measurements, strengthened the event-classification procedure, added a sensitivity analysis for the estimated CCN concentrations, softened the interpretation of possible NPF mechanisms, and expanded the discussion of local urban emissions. Our point-by-point responses are provided below.

**Comment 1:**

The study is based on two relatively short observational campaigns: 9 October–10 November 2024 and 25 March–22 April 2025. While these measurements provide valuable insight into NPF characteristics during the selected monsoon and pre-monsoon periods, the limited duration may not fully represent the broader seasonal variability. The authors should add a short discussion on the representativeness of these campaign periods and clarify whether the reported seasonal differences can be generalized to typical monsoon and pre-monsoon conditions over Lhasa.

**Response 1:**

We thank the referee for this important comment. We agree that the two approximately one-month campaigns cannot fully represent the broader seasonal variability of NPF in Lhasa. Moreover, the October–November and March–April measurements do not correspond strictly to the summer monsoon and pre-monsoon seasons. We have therefore replaced "monsoon" and "pre-monsoon" with "autumn observation period" and "spring observation period," respectively, throughout the manuscript.

We have also revised the Abstract, Results and Discussion, and Conclusions to avoid generalizing the observed differences as representative seasonal patterns or mechanisms. The comparison is now explicitly described as a comparison between two campaign-based observation periods. We further acknowledge that interannual variability and the relatively short duration of each campaign may have influenced the observed NPF frequencies and atmospheric conditions. Longer-term continuous measurements covering complete annual cycles will be required to determine whether these differences are representative of typical autumn and spring conditions in Lhasa.

**Comment 2:**

The NPF event classification relies mainly on visual inspection of particle size distribution evolution. The authors should briefly clarify how classification uncertainty was handled, especially for weak or discontinuous events.

**Response 2:**

We thank the referee for this helpful suggestion. We have revised the event-classification method to reduce reliance on visual inspection alone. The original Class I and Class II categories were combined into a single “NPF day” category because their separation was not sufficiently robust. The revised classification consists of NPF, Undefined, and Non-Event days.

NPF days were identified primarily by the appearance of a distinct new particle mode at small diameters followed by identifiable growth toward larger sizes. Continuous growth throughout the entire day was not required because temporary interruptions may result from changes in air masses, boundary-layer development, variations in precursor availability, or missing measurements. For weak, discontinuous, or ambiguous cases, the PNSD interpretation was further supported by mean particle number concentrations in the 3–25 and 25–100 nm size ranges and candidate particle growth rates. These supporting parameters were used to improve classification transparency rather than as fixed thresholds.

Days showing enhanced small-particle concentrations or partial modal development but lacking sufficiently clear formation and subsequent growth were retained as Undefined days. To make the classification traceable, Table S1 now provides the revised day-by-day classification, NPF start and end times, size-segregated particle number concentrations, candidate GR calculation windows, and corresponding GR values. The daily PNSDs for NPF, Undefined, and Non-Event days are presented separately in Figs. S1–S3.

**Comment 3:**

Since CCN concentrations were estimated rather than directly measured, the authors should mention the uncertainty associated with the assumed $\kappa$ value and supersaturation.

**Response 3:**

We thank the referee for pointing this out. We agree that the absolute estimated CCN concentrations depend on the assumed particle hygroscopicity and supersaturation. We have now explicitly stated throughout the manuscript that CCN concentrations were estimated from the measured PNSD using the $\kappa$-Köhler framework rather than directly measured.

We also conducted a sensitivity analysis using $\kappa$ values of 0.08, 0.12, and 0.20 and supersaturations of 0.6 %, 0.8 %, and 1.2 % (Fig. S7). As expected, the assumed parameters substantially affected the critical activation diameter and the absolute estimated CCN concentrations. However, estimated CCN concentrations remained consistently higher during the autumn observation period than during the spring observation period across the tested parameter combinations. We have therefore clarified that the estimated CCN values are more suitable for interpreting relative differences and response patterns than for over-interpreting their absolute magnitudes.

**Comment 4:**

The possible role of VOCs in pre-monsoon particle growth is discussed, but VOCs were not measured. This point should be stated more cautiously.

**Response 4:**

We agree with the referee and have softened this interpretation. The revised manuscript no longer attributes spring particle growth to VOC-related oxidation. Instead, it states that a contribution from VOC-related oxidation cannot be excluded but cannot be constrained using the available measurements. We also explicitly acknowledge that VOCs, HOMs/OOMs, and their oxidation products were not directly measured, preventing quantitative attribution of their roles in particle formation or growth. The discussion and Conclusions have been revised accordingly.

**Comment 5:**

The site is influenced by local urban sources such as traffic, combustion, construction, and dust. The authors should briefly discuss how these emissions may affect NPF interpretation.

**Response 5:**

We thank the referee for this important comment. We agree that local urban emissions may influence both the measured ultrafine-particle population and the interpretation of NPF at the TU site. We have therefore expanded the site description and the discussion of urban-source influences. Traffic and combustion emissions may provide gaseous precursors and directly emitted ultrafine particles, whereas construction activities and resuspended dust may increase the pre-existing aerosol population and particle sink, thereby affecting the survival and growth of newly formed particles.

To reduce confusion between atmospheric NPF and short-lived primary-emission plumes, the revised classification does not rely solely on an increase in small-particle number concentration. An NPF day requires the appearance of a distinct new particle mode at small diameters followed by identifiable growth toward larger sizes. Short-lived particle-number spikes without subsequent systematic growth were not classified as NPF. The size-segregated diurnal analysis further showed that the morning increase in $N_{3-25}$ on NPF days was followed by an enhancement in $N_{25-100}$, supporting the interpretation of particle formation and subsequent growth. In contrast, evening enhancements in Aitken-mode particles without a preceding nucleation-mode increase may have been influenced by local urban emissions and are now interpreted cautiously.

We also examined $SO_2$, $NO_2$, and $O_3$ under different wind directions on NPF and non-NPF days (Figs. 8 and 9). The results showed differences in gaseous pollutants and transport conditions between day types, but no single wind sector or short-lived gaseous-pollutant enhancement consistently explained all identified NPF events.

Because BC measurements were unavailable, we additionally examined the diurnal variations in $PM_{2.5}$ and $PM_{10}$ for the revised day categories during both observation periods (Fig. R1). During the principal particle-formation period, the increase

in nucleation-mode particle number concentration on NPF days was not accompanied by corresponding daytime spikes in $PM_{2.5}$ or $PM_{10}$. Daytime $PM_{2.5}$ concentrations were not higher on NPF days than on Non-Event days, whereas $PM_{10}$ concentrations were broadly comparable between the two categories. These results suggest that the identified events were not simply manifestations of broader fine-particle pollution or dust episodes.

Nevertheless, $PM_{2.5}$ and $PM_{10}$ are mass-based measurements dominated by larger particles and cannot substitute for BC as direct tracers of traffic-related ultrafine-particle emissions. Moreover, measurements were available at only one fixed site. We therefore cannot completely separate regional-scale NPF from all local primary ultrafine-particle influences or determine the spatial extent of individual events. We have explicitly acknowledged this limitation and avoid describing the identified events as definitively regional. Instead, they are interpreted as atmospheric NPF events observed at an urban site, while recognizing that local emissions may affect precursor availability, particle sinks, and parts of the measured ultrafine-particle population.

**Comment 6:**

I strongly recommend the authors should consider citing the study "Comprehensive spatiotemporal analysis of long-term mobile monitoring for traffic-related particles in a complex urban environment" in the Introduction or site-description discussion, as it provides relevant context on traffic-related particle variability in complex urban environments.

**Response 6:**

We thank the referee for recommending this relevant study. We have cited Yeganeh et al. (2026) in the site-description and urban-emission discussion. The added text highlights that traffic-related $PM_{2.5}$ and BC can exhibit pronounced spatial and temporal heterogeneity within complex urban environments and that fixed-site observations may not fully capture localized emission hotspots. This reference provides useful context for interpreting the TU measurements and supports our acknowledgment that a single fixed site cannot completely characterize the spatial variability of urban traffic-related particles.

## Consolidated List of Changes in the Revised Manuscript

As summarized in Table R1, we have revised the manuscript and Supporting Information in response to all reviewer comments.

**Table R1. Consolidated Summary of Changes Made in the Revised Manuscript**

| Location | Relevant change |
|---|---|
| Title/Abstract | Terminology revised to observation-period language; CCN explicitly described as estimated; mechanistic and seasonal claims softened. |
| Introduction | Broader high-altitude and free-tropospheric NPF literature added; novelty of the urban Lhasa setting clarified. |
| Sect. 2.1 | TU defined; local-source influences, fixed-site representativeness, and sampling-site context expanded. |
| Sect. 2.3 | All symbols in Eqs. (6) and (7) defined; CCN assumptions and calculation limitations clarified. |
| Sect. 2.4 | NPF classification rewritten; Class I and Class II merged; uncertainty handling and supporting metrics described. |
| Sect. 3 | Event frequencies, J/GR statistics, sink analysis, and estimated CCN results recalculated using the revised classification. |
| Mechanism discussion | Relative $H_2SO_4$ proxy evidence added; exclusive sulfur-control and unsupported VOC attribution removed. |
| Urban-source discussion | Wind, gas, size-resolved number, and PM analyses added; regional representativeness limitation stated. |
| CCN discussion | Sensitivity to $\kappa$ and supersaturation added; estimated CCN compared with $N_{100–700}$; absolute-value uncertainty emphasized. |
| Figures | Fig. 1 redrawn; Fig. 2 axes and caption corrected; Fig. 3 overlaps removed; captions expanded throughout. |
| Supporting Information | Sect. S1, Table S1, and Figs. S1-S8 added or revised to document classification, proxy, and CCN sensitivity analyses. |
| Conclusions | Claims restricted to the two campaigns; limitations and future need for long-term and chemically comprehensive measurements added. |

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Sincerely,

Gang Zhao