Reply to referee 1:

Referee Comment 1. Page 1 Line 14-15: "We introduce a new parameterized fitting function that captures the characteristic S-shaped aerosol profiles associated with boundary layer processes."

The current sentence sounds a bit too technical and vague for an abstract because it does not clearly say why the fitting function matters. Can you include a phrase that mentions justification on the physical meaning of the fitting parameters?

Authors' Response: We thank the reviewer for the comment, and we agree that the abstract should include more motivation.

Line 14 now reads: A compact framework for describing aerosol vertical profile shape is needed to examine factors that influence aerosol vertical distributions and to represent them in model parameterizations or remote sensing retrievals. We introduce a parameterized fitting function for characteristic S-shaped aerosol profiles, with fitted parameters that represent aerosol-layer depth and stratification strength.

Referee Comment 2: Page 7 Line 153-176: "Equation 1 is well suited for representing aerosol vertical profiles,…to the transition zone."

This is scientifically reasonable, but this section reads a bit too repetitive. The main idea is strong: the fitting function gives a compact way to describe aerosol profiles when aerosols are surface-originating and no elevated transported layer is present.

A few clarifications would make this section stronger. First, the text could more clearly state the range of conditions where the function is valid, especially excluding cases with elevated transported aerosol layers or multilayer structures. Second, the physical interpretation of each parameter could be shortened and connected more directly to observable features of the profile. Third, the choice to fix $\gamma = 0.3$ is reasonable for fit stability, but it should be justified with a brief sensitivity test or goodness-of-fit comparison (e.g., some numbers instead of 'good fits'). Finally, the section would benefit from a concise statement explaining how this fitted transition-zone height will be used later in the analysis.

Authors' Response: We thank the reviewer for the helpful comment on reducing the repetitiveness of this section, clarifying when Equation 1 is applicable, justifying the fixed value of γ, and clarifying how the fitted r_m will be used.

Line 176 now reads: Equation 1 provides a parameterization for aerosol concentration that decreases from the higher concentrations fixed near the surface to the cleaner air aloft through a single S-shaped transition. It allows for flexible control over the key observable features of the profile as shown in Figure 3. To arrive at this equation, we define the transition zone as the altitude range over which aerosol concentration drops most rapidly from a well-mixed lower layer to the cleaner background aloft. The *transition zone height*, r_m, represents the midpoint of

the transition zone and is obtained by fitting Equation 1 to measured aerosol vertical distributions. Although r_m can coincide with the top of the planetary boundary layer, we use it here strictly as a metric of aerosol profile rather than boundary layer height. In Equation 1, X_0 controls the aerosol concentration at the surface, X_f represents the cleaner background concentration aloft, and k constrains how rapidly the aerosol concentration changes within the transition zone. The variables γ and f affect how aerosol concentration decreases with height below the transition zone. The parameters r_m and k are later compared with boundary layer height and potential temperature gradients to examine how boundary layer structure relates to aerosol vertical distribution.

Line 188 now reads: In this study, γ is fixed at 0.3 to improve fit stability and reduce parameter trade-offs. Because γ and f both affect the profile curvature below the transition zone, allowing both parameters to vary can produce similar fits from different parameter combinations. Fixing γ reduces this trade-off, thereby providing more stable estimates of f and other parameters. To determine a fixed value to use for γ, Equation 1 was first fitted with γ allowed to vary for all 313 aerosol profiles collected at AMF-1 during the six-month analysis period. The median fitted γ was 0.334, so we selected 0.3 as a representative fixed value near the center of the fitted distribution (Figure S.9a). Fitting Equation 1 to the same profiles with γ fixed at 0.3 retained high goodness of fit, with a median R^2 of 0.980 (Figure S.9b).

A new figure is added to the supplement:

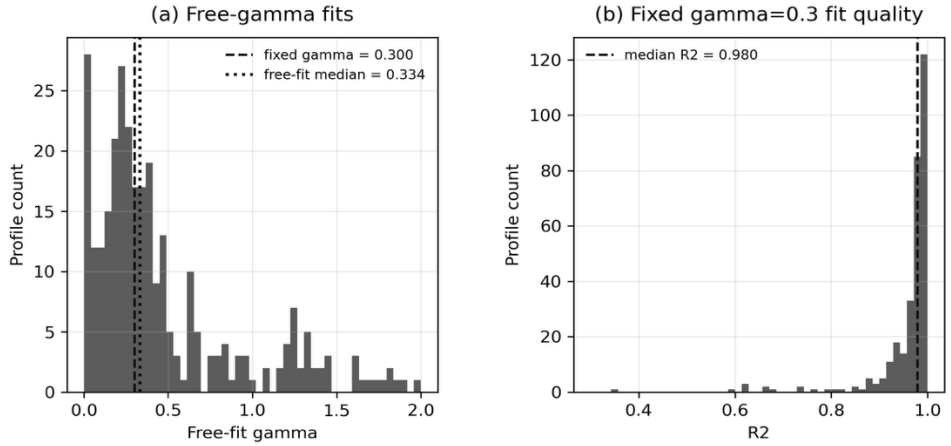


Figure S.9 Evaluation of the fixed γ value using 313 one-hour aerosol profiles centered on radiosonde sampling times between March and September 2022. (a) Distribution of fitted γ values obtained when Equation 1 was fitted with γ allowed to vary. The dashed line indicates the selected fixed value of 0.3, and the dotted line indicates the median free-fit value of 0.334. (b) Distribution of R^2 values obtained by fitting Equation 1 to the same profiles with γ fixed at 0.3. The dashed line indicates the median R^2 of 0.980.

Referee Comment 3: Equation 2: This is a reasonable extension of Equation 1. It clearly separates the background surface-driven aerosol profile from elevated layers caused by long-range transport or in-situ formation aloft. The Gaussian terms are a practical way to capture distinct layers without changing the interpretation of the original surface-anchored profile.
A few points could make the description stronger- The text could clarify how elevated layers are

identified before fitting, for example using local maxima in the lidar profile, threshold exceedance above the fitted background, or visual/manual selection. Otherwise, the Gaussian terms could appear somewhat subjective.

It is good that the method limits the number of Gaussian terms to avoid overfitting. However, the manuscript should briefly explain the criterion for choosing N = 0, 1, or 2, such as improvement in residuals, physical interpretability, or a minimum layer strength/width.

Authors' Response: We agree with the reviewer that it is important to discuss the identification of elevated aerosol layers and the fitting process of Gaussian peaks. We now state that elevated layers were identified by visual inspection of the lidar derived aerosol concentration profiles before fitting. Equation 2 was applied only when a distinct elevated aerosol layer was present above the surface-connected background profile and separated by a local minimum.

Line 202 now reads: Elevated layers were identified by visual inspection of the lidar-derived aerosol concentration profiles and were counted only when a distinct local maximum above the surface-connected profile was separated from the lower aerosol layer by a relative local minimum. Specifically for this study, we allow at most two Gaussian terms when elevated layers are apparent. The fitting function with N elevated aerosol layers is given by:

$$X_{\mathrm{aug}}(r) = \frac{X_0 - X_f}{1+f} \cdot \frac{1 + f e^{-\frac{r}{\gamma}}}{1 + \left(\frac{r}{r_m}\right)^{r_m k}} + \sum_{j=1}^{N} A_j \exp\left(-\frac{1}{2}\left(\frac{r - r_{c,j}}{\sigma_j}\right)^2\right) + X_f \qquad (2)$$

Line 208 now reads: The value of N was selected as the minimum number of Gaussian terms needed to represent visually distinct elevated layers, with N = 0, 1, or 2 corresponding to no elevated layer, one elevated layer, or two elevated layers, respectively.

Referee Comment 4: Page 9: Line 219-221: "The pronounced relative humidity dependence of the depolarization ratio in these layers, together with the HYSPLIT results, suggest a major contribution from hygroscopic sea salt aerosol."

The sea-salt interpretation should be stated more cautiously. The RH dependence, low-level Gulf trajectories, and depolarization behavior are consistent with hygroscopic aerosol such as sea salt, but they do not uniquely identify sea salt. Other hygroscopic aerosol types from marine or coastal sources may also contribute.

Authors' Response: Good point. We have revised the manuscript as follows:

Line 246 now reads: The pronounced relative humidity dependence of the depolarization ratio in these layers, together with the HYSPLIT results, is consistent with contributions from hygroscopic aerosol, such as sea salt aerosol or water soluble organic aerosol.

Referee Comment 5. Page 10: Line 238-240: "The thermal structure could also limit vertical mixing and help shape the observed aerosol layering. Aerosol radiative effects may, in turn, reduce solar radiation at the surface and therefore surface heating, strengthening the inversion and helping to maintain the layering."

Does this imply to aerosol direct radiative impacts? The sentence suggesting aerosol radiative effects may strengthen the inversion feels speculative. Unless this is supported by radiation measurements or model sensitivity tests, it may be better to say this is possible feedback rather than an inferred mechanism.

Authors' Response: It would be an overinterpretation of the results to draw conclusions about direct radiative impacts. Based on the Reviewer's comment, we acknowledge that this assumption was overly speculative. We have therefore removed that sentence and revised the text to focus on the observed potential-temperature structure and associated stability.

Line 266 now reads: The alignment of the sharp decrease in aerosol concentration with the potential-temperature inversion is consistent with the stable layer limiting vertical mixing and maintaining the observed aerosol stratification.

Referee Comment 6. Line 246-250: "BLH-LL, is 140 m in the early morning (10:59–11:59 UTC) and 320 m around midnight … that develops near the surface during nighttime."

The discussion of BLH-RiB versus BLH-LL is useful, but it should more clearly explain why they differ: BLH-LL captures the shallow nocturnal stable layer, while BLH-RiB and the fitted transition height may correspond more closely to the top of the residual aerosol layer or inversion-capped mixed layer.

Authors' Response: We agree that the difference between BLH-RiB and BLH-LL could be explained more clearly. We revised the text to clarify that the two methods are based on different diagnostics and can therefore identify different layer heights under nocturnal stable conditions.

Line 211 now reads:
2.4 Boundary layer height determination

Boundary-layer height may contribute to aerosol profile shape and therefore may covary with the fitted parameters in Equation 1. To compare the aerosol profiles with BLH, we use two BLH products from the Houston observational dataset from Lamer et al. (2024).

The first estimate, referred to as BLH-RiB, is derived from the bulk Richardson number, which combines virtual potential-temperature stratification and horizontal wind to characterize their influences on turbulent mixing (Stull, 2012). BLH-RiB is assigned to the lowest altitude at which (RiB) reaches 0.5 (Lamer et al., 2024).

The second estimate, referred to as BLH-LL, follows the potential-temperature approach adapted by Lamer et al. (2024) from Liu and Liang (2010). Each profile is first categorized as convective, stable, or neutral residual according to its near-surface potential-temperature structure. The boundary-layer top is then diagnosed using features appropriate to the identified regime. For convective and neutral-residual profiles, the method uses the increase in potential temperature from near the surface with its vertical gradient. For stable profiles, BLH-LL represents the top of

the shallow stable layer, identified from the minimum potential-temperature gradient (Lamer et al., 2024; Liu and Liang, 2010).

Line 274 now reads: As described in Section 2.4, BLH-RiB and BLH-LL are based on different measurements and criteria. BLH-RiB is defined using a bulk Richardson-number threshold calculated from virtual potential-temperature and wind profiles, whereas BLH-LL is determined from regime-specific features of the potential-temperature profile alone. While BLH-RiB remains near the ~1 km inversion described above, BLH-LL is much lower, 140 m in the early morning (10:59–11:59 UTC) and 320 m around midnight (05:00–06:00 UTC), consistent with a shallow nocturnal stable boundary layer near the surface. The two BLH estimates agree more closely in the early afternoon (17:00–18:00 UTC) and early evening (23:00–00:00 UTC). This separation between the shallow nocturnal BLH and the higher inversion is consistent with the formation of a residual layer. Aerosols that accumulate within the deeper daytime boundary layer often remain suspended above the much shallower nocturnal layer, forming a residual layer at night.

Referee Comment 7: Page 11. Line 271-272: "Figure 6b, which shows larger depolarization ratios in the 0-2 km and 2-4 km ranges, separated by a layer of smaller depolarization ratio in between."

Looks like there is some separation between the two layers instead of 0-2 and 2-4, I see more like 0-2 and 2.5-4. (between the low-level aerosol layer and the elevated layer). Please clarify.

Authors' Response: The referee is right to point out that there is separation between the two layers. We have revised the manuscript to distinguish the lower aerosol layer from the elevated aerosol layer and changed the elevated-layer range from 2–4 km to 2.5–4 km.

Line 301 now reads: An elevated aerosol layer between approximately 2.5 and 4 km is visible in Figure 6b, which shows larger depolarization ratios in the 0–2 km and 2.5–4 km ranges, separated by a layer of smaller depolarization ratio in between. The elevated aerosol layer becomes more distinct in the evening hours and persists into the night. A similar elevated layer between around 2.5 and 4 km is also faintly visible in the backscatter signal of Figure 6a.

Line 342 now reads: In addition to the low-level aerosol structure discussed above, elevated aerosol layers between 2.5 and 4 km can be seen in early evening (Figure 7c) and at midnight (Figure 7d).

Referee Comment 8. Figure 7: Could you please explain why BLH-RiB and BLH-LL do not agree in the first and 4th panels?

Authors' Response: As we described above, BLH-RiB is diagnosed using a bulk Richardson number, and BLH-LL is diagnosed using the potential-temperature profile. We add a sentence at the end of the paragraph to discuss the difference.

Line 339 now reads: In addition, the disagreement between BLH-RiB and BLH-LL in Figures 7a and 7d reflects the different sensitivities of the two BLH diagnostics under stable nighttime conditions.

Referee Comment 9: For both the cases: For all cases, it would be helpful to discuss the surface aerosol concentrations together with the vertical mixing and boundary-layer dynamics in more detail. The elevated layer above ~2.5 km appears to be associated with long-range transported aerosols. How much of this aerosol is mixed downward into the boundary layer, and how deep does the homogeneous mixing extend?

Comparing Figures 7 and 10, the aerosol vertical profiles are clearly different, which is useful for the case-study comparison. The case in Figure 10 appears to show cleaner aerosol conditions at higher altitudes. Can these profiles capture differences in synoptic aerosol regimes? For example, if there is synoptically driven dust loading, which is common in summertime, would these vertical profiles be able to identify and represent that elevated dust layer? For. e.g., Figure 7 could be compared with the vertical dust distributions from the columnar dust MERRA-2 analysis products.

Authors' Response: We acknowledge the referee's suggestion to discuss the relationship between surface aerosol concentrations, vertical mixing, and elevated aerosol layers in more detail. We revised the case-study discussion to clarify that the lidar-derived profiles can show whether an elevated layer remains separated from or begins to merge with the lower aerosol layer. For the 21–22 July case, the elevated layers between approximately 2.5 and 4 km remain separated from the lower layer by a region of lower aerosol concentration, indicating limited merging during the observed period. However, these profiles alone cannot quantify the amount of aerosol mixed downward.

Following the referee's suggestion, we examined MERRA-2 dust mass mixing-ratio profiles for the three case-study periods, as shown in the figure below. For the 21–22 July case, MERRA-2 shows dust extending from approximately 2 to 4 km, consistent with transported dust being a possible contributor to the elevated aerosol layers. However, the spatial and vertical resolution of MERRA-2 is too coarse to resolve the layer structure observed by the lidar or quantify downward mixing. We therefore present this comparison as a qualitative review in the response but do not include it in the revised manuscript or Supplement. A systematic comparison of lidar observations with different MERRA-2 aerosol fields could be an interesting direction for future research and could provide additional insight into the sources and transport of elevated aerosol layers. The focus of this study is still the surface connected aerosol profile and its relationship to boundary-layer dynamics. We fit the elevated layers so that r_m and k describe the lower aerosol transition.

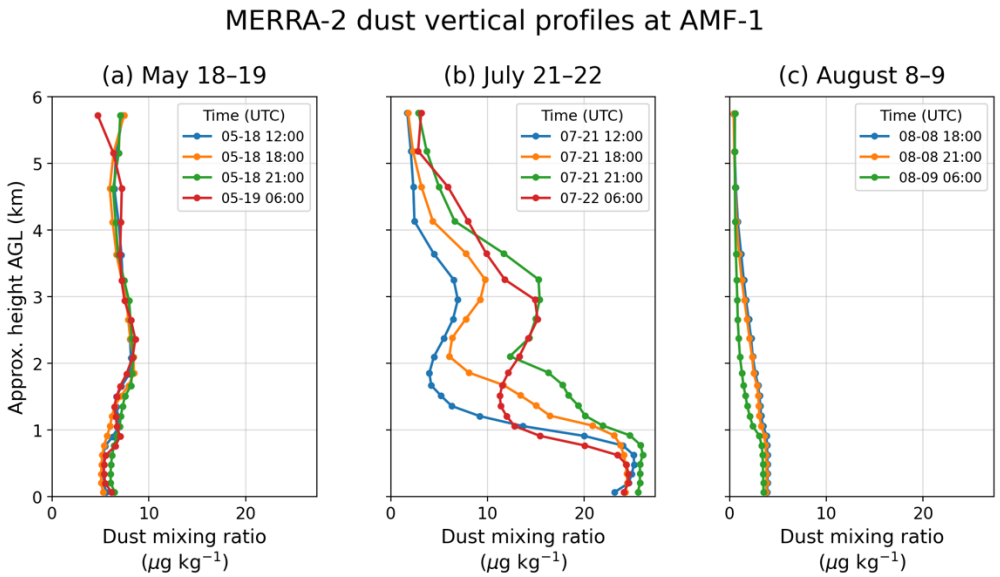


Figure R1. Modern-Era Retrospective Analysis for Research and Applications, Version 2 (MERRA-2) dust mass mixing-ratio profiles at the model grid cell nearest the AMF-1 site during the three case-study periods: (a) 18–19 May, (b) 21–22 July, and (c) 8–9 August 2022. Curves represent profiles at the UTC times listed in each panel. Altitude represents approximate height above ground level derived from the MERRA-2 model layers (GMAO, 2015).

Line 342 now reads: In addition to the low-level aerosol structure discussed above, elevated aerosol layers between 2.5 and 4 km can be seen in early evening (Figure 7c) and at midnight (Figure 7d). These layers remain separated from the lower aerosol layer by a region of lower aerosol concentration, indicating limited merging between the elevated and lower layers during this period. These layers also coincide with a high-RH layer aloft and are bounded by upper-level inversions, consistent with stratification helping maintain vertical separation. While these profiles suggest distinct layers, they cannot entirely rule out some degree of downward mixing; furthermore, the co-location with RH and inversions does not establish causality or rule out a shared driver.

Referee Comment 10: Page 14, Line 331-332: “The gradual change in 1-2 km backscatter around 16:00-02:00 UTC (18–19 May) may indicate some degree of vertical mixing.”

This is hard to see in the plot. It looks more like a clean and vertically well mixed in the types of the aerosols as indicated by the depolarization ratio, so it would help if the aerosol concentrations in the ground are also stable and have less variation in the diurnal cycle. Can you discuss more on the diurnal cycle of the aerosol concentration measured in the ground?

Authors’ Response: We agree with the referee that the original statement was not sufficiently specific and was difficult to verify directly from Figure 9. We revised the text to describe the feature more cautiously as a smoother transition between the low-level aerosol layer and air aloft, supported by the lack of a distinct depolarization separation. The surface and low-level aerosol concentrations are discussed in the following paragraph associated with Figure 10, where we describe their increase during boundary-layer development and subsequent decrease after the sea-breeze-driven air-mass transition.

Line 368 now reads: As seen in Figure 9, no notable elevated aerosol layers are observed on this day. The NRB field shows some variability near 1 km throughout the day, but the depolarization ratio does not show a distinct separation at this altitude. This suggests that the aerosol structure is more continuous than in the previous cases. Together with the weaker inversion shown in Figure 10, this pattern is consistent with weaker stratification and more effective vertical mixing within the lower atmosphere.

Referee Comment 11: Page 17, Line 394-396: "A profile was classified as having an elevated layer when it showed a distinct local maximum in aerosol concentration above the low-level aerosol layer and was separated from it by a relative local minimum."

This is a very impressive. Out of the 144 cases, how many days were classified as having elevated aerosol layers? This information could be useful for future model simulations, particularly for understanding how elevated aerosols contribute to the regional and seasonal aerosol distribution in the vertical dimension. Perhaps, there could be statistically relevant vertical profiles with the averages/stds in concentrations for different weather/aerosol regimes.

Authors' Response: The elevated aerosol layers were visually identified rather than automatically detected. 34 out of 157 selected profiles are classified as containing elevated aerosol layers and are fitted with Equation 2. In addition, we apologize that the number of retained profiles was not updated correctly in the original manuscript. The correct number is 157 retained profiles from 313 profiles, not 144. Among these 157 profiles, 34 were classified as containing elevated aerosol layers. Because elevated layers may be present in some profiles but not others collected on the same day, we report the number of classified profiles rather than the number of days.

Line 431 now reads: Profiles that were first fitted with Equation 1 with $R^2 < 0.98$ and were visually classified as containing an elevated aerosol layer were then refit using Equation 2 with one or two Gaussian terms. A profile was visually classified as having an elevated layer when it showed a distinct local maximum in aerosol concentration above the low-level aerosol layer and was separated from it by a relative local minimum. After model selection, only profiles with final fit quality $R^2 > 0.98$ were retained for the statistical analysis to ensure that the fitted parameters represented well-resolved profile structure. Overall, 157 of 313 profiles met this strict quality criterion. 34 out of 157 selected profiles are classified as containing elevated aerosol layers and are fitted with Equation 2.

Referee Comment 12. Section 3.5. Could elevated transported aerosol layers or humidity-driven aerosol growth bias the inferred relationship between stability and k? This is important because aerosol layering may not always be controlled by local thermodynamic structure alone, especially during long-range transport or strong hygroscopic growth conditions. How sensitive is the relationship between k and $d\theta/dz$ to the choice of ±100 m and the 100 m Gaussian smoothing? This directly tests whether the result is physically robust or partly an artifact of methodological choices.

Authors' Response: Yes. Although the manuscript only explored the relationship between stability and k, it is possible that other factors could influence the value of k. Factors could include transported aerosol layers entrained into the boundary layer mixing, boundary layer growth, collapse, and residual layer formation as discussed in the manuscript.

To address the referee's methodological question, we performed sensitivity tests by varying the Gaussian smoothing FWHM and the search-window width around r_m. The regression slope remained positive across the tested choices, although its magnitude and R^2 varied. This result indicates that the sign of the relationship is robust while its strength depends on the operational definition of local stability. The baseline 100 m choice was not selected to maximize R^2. The results have been added to the Supplement as Figure S.13, and Section 3.5 has been revised as follows.

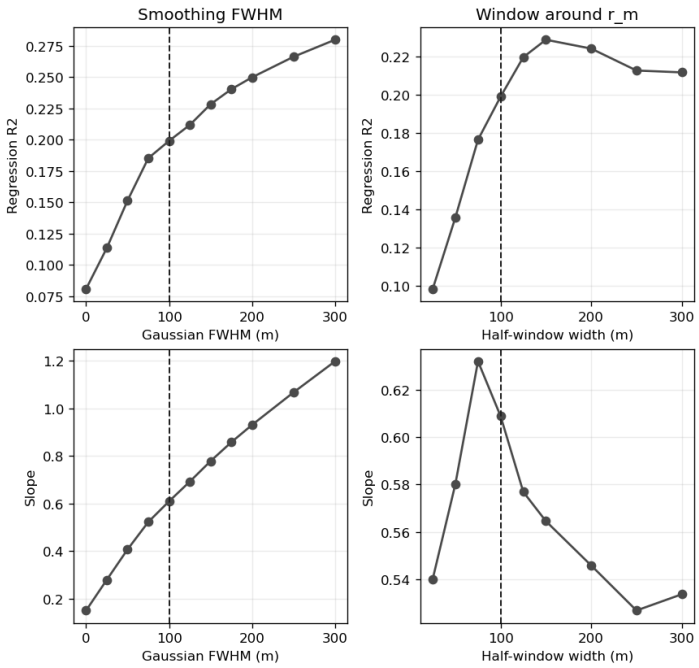


Figure S.13 Sensitivity of the relationship between aerosol transition sharpness k and local potential-temperature gradient to the definition of the stability metric. Left panels show how the regression R^2 and slope change when the Gaussian smoothing full width at half maximum (FWHM) applied to the radiosonde potential-temperature profile is varied. Right panels show how the regression R^2 and slope change when the half-window width used to search for the local maximum dθ/dz around the fitted transition-zone height r_m is varied. Dashed vertical lines indicate the baseline 100 m smoothing FWHM and ±100 m search window used in the main analysis. The positive relationship remains across the tested parameter ranges, while the regression strength and slope vary with the operational definition of local stability.

Line 505 now reads: A statistically significant ($p << 0.01$) and limited positive correlation ($R^2 = 0.20$) is found between the potential temperature gradient at r_m and the curve-fitted transition sharpness parameter k. Sensitivity tests using different Gaussian smoothing scales and search-window widths show that the positive relationship remains, although the slope and R^2 vary with

the operational definition of the local stability metric (Figure S.13). This result shows that the local atmospheric stability near r_m appears to contribute to the shape of the aerosol profile but does not fully define it. A possible physical explanation is that stronger stability can suppress vertical exchange across the aerosol transition zone, allowing a sharper aerosol concentration gradient to persist. In contrast, weaker stability may permit more gradual mixing between the lower aerosol rich layer and cleaner air aloft, resulting in a more gradual transition zone and smaller k values. Because the correlation is limited, we interpret dθ/dz near r_m as a partial constraint on aerosol stratification rather than as the only control on k. Additional variability may arise from transported aerosol mixing with the lower layer, residual uncertainty in the hygroscopic-growth correction, and the history of boundary-layer growth, collapse, and residual-layer formation.

Referee Comment 13. Section 3.6. This question might be out of the scope of the current work; however, it could be important to help understand some of the discrepancies in predicted profiles.

These analyses are based on bulk aerosol concentrations. Do you think the results, or the prediction of the vertical profiles, would change if aerosol size distributions were considered? For example, would the relationships differ if accumulation-mode and coarse-mode particle number concentrations were analyzed separately? It would be interesting to see.

Authors' Response: We thank the reviewer for this question. At this time, we expect that the results could differ if information on vertical variations in aerosol size distribution were available. However, the present retrieval is based on micro pulse lidar backscatter constrained by ground-based aerosol measurements, and it does not resolve size-resolved aerosol vertical distributions.

Referee Comment 14. Abstract: The abstract could be strengthened by presenting the main results more directly.

While it provides a helpful overview of the motivation and scope of the study, the specific findings are somewhat understated. I recommend revising the abstract to clearly state the key results, including the observed links between aerosol vertical profiles, BLH, static stability, and the predictive capability demonstrated in the study.

Authors' Response: Good point. We have revised the abstract:

Aerosol vertical distributions are a major source of uncertainty in quantifying aerosol–cloud–climate interactions. Using observations collected during the 2022 TRACER campaign in Houston, Texas, we investigate how atmospheric boundary layer dynamics shape the vertical structure of aerosol populations in a coastal urban environment. Our lidar retrieval combines micropulse lidar backscatter with ground-based aerosol measurements to obtain aerosol concentration profiles. A compact framework for describing aerosol vertical profile shape is needed to examine factors that influence aerosol vertical distributions and to represent them in model parameterizations or remote sensing retrievals. We introduce a parameterized fitting

function for characteristic S-shaped aerosol profiles, with fitted parameters that represent aerosol-layer depth and stratification strength. This parameterization is applied to case studies demonstrating how boundary-layer dynamics, including turbulent mixing, capping inversion strength, and sea-breeze circulations, influence aerosol vertical distributions. Case studies show that aerosol concentrations decrease rapidly near strong capping inversions, the depth of the lower aerosol layer changes with boundary-layer growth and collapse, and sea-breeze passage produces strong coastal–inland differences as maritime air replaces continental aerosol. Analysis of the six-month dataset shows weak but statistically significant positive relationships between daytime boundary layer height and fitted aerosol layer depth, and between the local potential temperature gradient near the aerosol layer top and fitted stratification strength parameter. Finally, we demonstrate an approach for estimating aerosol profile shape from boundary-layer height and potential-temperature gradients using the fitted parameterization. These results show that this parameterization provides simple, interpretable diagnostics for linking aerosol profile shape to boundary-layer dynamics.

Minor comments:

Referee Minor Comment 1: Page 6. Figure 3. Replot the figure with proper y-axis labeling. Please show the y limits and major and minor ticks in both the axes.

Authors' Response: The figure has been updated:

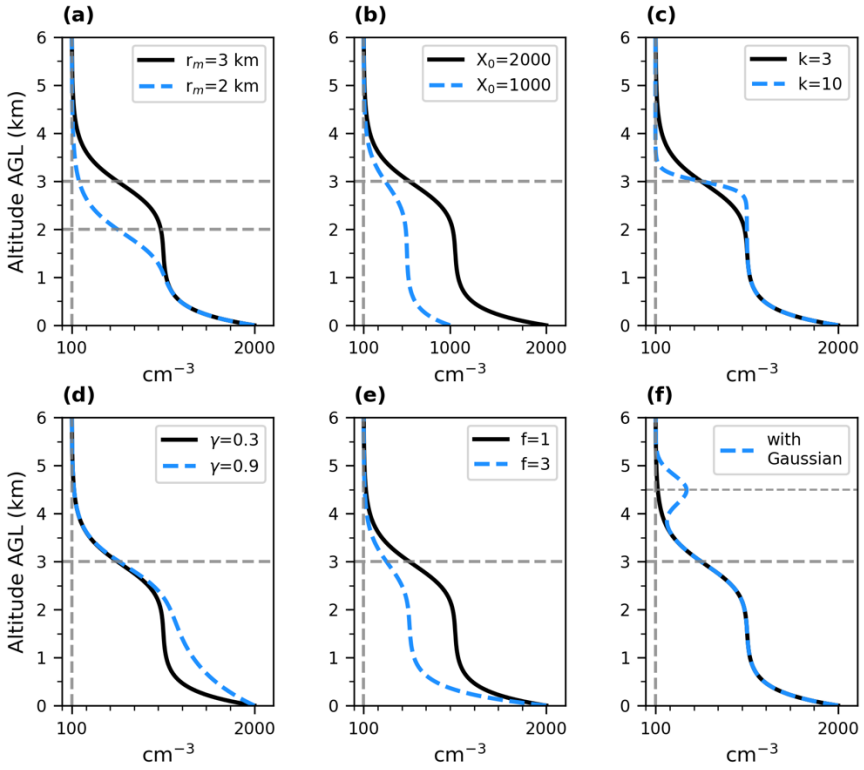


Figure 3 Effects of individual fitting function parameters on the aerosol vertical profile shape. Each panel varies one parameter while others are held constant. Solid black lines show the reference profile, and dashed blue lines show the parameter modified profiles. Horizontal gray dashed lines mark transition zone height r_m. Vertical gray dashed lines denote a constant

concentration of 100 cm^{-3} (a) r_m shifts the height of the transition zone; (b) X_0 sets the surface concentration; (c) changing parameter k changes the sharpness of the transition; (d) changing parameter γ changes the shape of near surface decline in concentration; (e) changing parameter f influences the magnitude of the exponential decay; and (f) adds a Gaussian peak to represent an elevated aerosol layer.

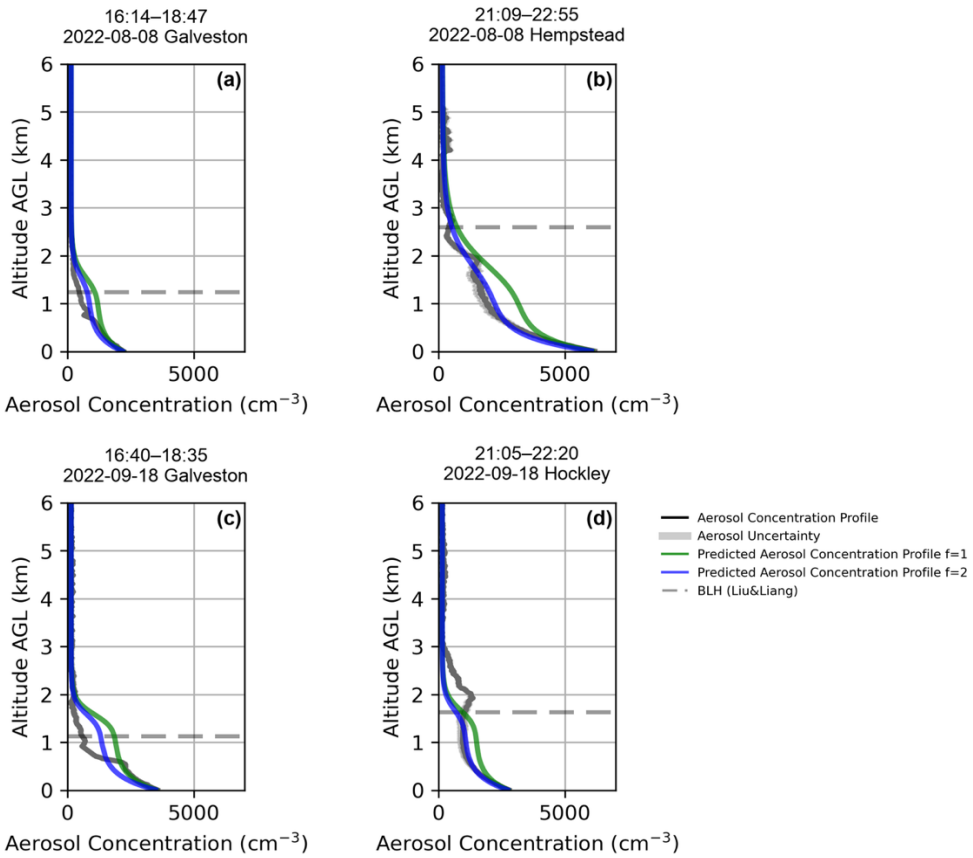
Referee Minor Comment 2: Figure 10: Can you please explain what was the motivation behind choosing a very wide variations in the averaging window and the frequency (even in Figure 13)?

Authors' Response: The averaging windows are longer for the TAMU Mini-MPL profiles because the portable Mini-MPL has a weaker laser and requires longer averaging to achieve signal-to-noise ratios comparable to MPL. The windows were still chosen to remain within periods of similar boundary-layer and aerosol conditions.

Line 385 now reads: The TAMU profiles use longer averaging windows because the lidar measurements required longer temporal averaging to obtain enough cloud-free profiles for the retrieval.

Referee Minor Comment 3: Figure 13: Is the dark gray line showing aerosol concentration? Could you please clarify that in the legend?

Authors' Response: Yes, the dark gray line shows aerosol concentration profile. The legend has now been updated as shown below:



References:

Global Modeling and Assimilation Office (GMAO): MERRA-2 inst3_3d_aer_Nv: 3D, 3-hourly, instantaneous, model-level, assimilation, aerosol mixing ratio V5.12.4 (M2I3NVAER 5.12.4), Goddard Earth Sciences Data and Information Services Center (GES DISC), Greenbelt, MD, USA [data set], https://doi.org/10.5067/LTVB4GPCOTK2, 2015.

Reply to referee 2:

We thank Anonymous Referee #2 for the helpful comments. We would first like to clarify that the parameterized fitting functions presented in Equations 1 and 2 were developed in the current manuscript. Equation 1 is introduced here to represent surface-anchored aerosol vertical profiles, and Equation 2 extends this framework to include distinct elevated aerosol layers so that profiles containing elevated layers can still be represented during the boundary-layer analysis. The previously published Chen et al. (2025, AMT) study developed the retrieval method for deriving aerosol concentration profiles from micropulse lidar and ground-based aerosol measurements but did not introduce the profile-parameterization functions used in the present study.

Main comments:

Referee Comment: The main issue with the manuscript is that the authors note that the relationship between BLH and r_m is weak (r-squared < 0.2) and show in Figure 11 that most estimates of BLH are lower than the height of the lidar-retrieved aerosol gradient (r_m). Given the scatter of the data in Figure 11 (and Figure 12), the gray zone cannot represent the 95% confidence level for the range of BLH observed during the campaign. Consequently, applying a linear relationship between the two parameters (r_m = 0.27 * BLH + 1.25) as shown in Figure 11 is not informative – and the uncertainties of using meteorological profiles to estimate vertical profiles of aerosol concentrations need to be quantified (in Section 3.6).

Authors' Response: We thank the referee for pointing out that the gray shaded region in Figures 11 and 12 could not represent the 95% uncertainty range for the observed scatter. In the original figures, the 95% prediction interval mentioned in the figure captions was mistakenly left out of the actual figure. We have added the 95% prediction intervals to Figures 11 and 12 and revised the captions to clarify that the dashed gray lines and darker gray shading indicate the 95% confidence interval for the fitted mean regression line, whereas the dotted gray lines indicate the 95% prediction interval for individual observations.

The referee was right to point out that the relationship between the BLH and r_m is weak, and we agree that the weak relationship should not be interpreted as a reliable single predictor of r_m. However, we retain the linear regression because it provides a summary of the observed correlation and quantifies the limited explanatory power of BLH. The low R^2, large scatter, and prediction intervals are used to show that BLH alone is insufficient to determine aerosol transition height. At the same time, the regression indicates a statistically significant, though weak, positive relationship between BLH and r_m. To be clearer, we added the sentence below:

At line 472, the text now reads: Therefore, the regression is used here to summarize the observed correlation between BLH and r_m and to assess the explanatory power of BLH. Based on the results, the regression should not be used as a standalone predictor of aerosol transition height.

Referee Comment: Similarly, the authors hypothesize that stronger stability suppresses vertical mixing leading to sharper transitions in aerosol concentrations at the top of the boundary layer. However, Figure 12 also shows a weak relationship between stability (d_theta/dz) and transition gradient of aerosol concentrations (k) and contradicts the authors' statements that d_theta/dz is a useful metric for representing the strength of the aerosol gradient.

While statistically significant (low p-values), the predictive power of the relationships using BLH and d_theta/d_z remains low. Section 3.6 then attempts to use the weak relationships (BLH vs r_m and d_theta/dz vs. k) to predict the vertical profiles of aerosols using meteorological profiles and measured aerosol number concentrations at the surface. The authors compare two predicted cases with lidar profiles (Figure 13) and acknowledge the limits in their proposed method of using estimated BLH values as a reliable predictor of r_m height and atmospheric stability (d_theta.dz) to represent the gradient (k) of aerosol concentrations at r_m.

Authors' Response: We also agree that the relationship between local stability, represented by dθ/dz, and the fitted transition sharpness parameter k is weak. Therefore, although dθ/dz may serve as a useful thermodynamic constraint for estimating k, additional factors are needed to better explain and predict the transition sharpness of aerosol profiles. We have revised the text to clarify this distinction and now describe dθ/dz only as a partial thermodynamic constraint on aerosol stratification.

We edited line 512. The text now reads: Because the correlation is limited, we interpret dθ/dz near r_m as a partial constraint on aerosol stratification rather than as the only control on k. Additional variability may arise from transported aerosol mixing with the lower layer, residual uncertainty in the hygroscopic-growth correction, and the history of boundary-layer growth, collapse, and residual-layer formation.

Referee Comment: The manuscript would benefit from an in-depth analysis of the uncertainties of using meteorological profiles as a sole basis for predicting vertical profiles of aerosol. In this context, Figure 7 shows that BLH estimates are much lower than r_m heights in three out of the four cases when BLH is defined by the stable layers closest to the surface. It would strengthen the manuscript in context of the stated objectives to explore the atmospheric conditions and estimates of BLH that define boundary layer height in terms of lidar retrievals for a viable estimate of r_m height and k.

Authors' Response: Regarding using meteorological profiles in predicting aerosol vertical profile in Section 3.6, we agree that our current prediction for r_m and k have limited predictive power. Section 3.6 shows how the fitted profile parameters could be estimated from commonly available meteorological quantities when other observations are not available and where such an approach breaks down. The weak correlations are therefore part of the result. To make this limitation clearer, we revised Section 3.6 to frame the analysis as a demonstration rather than an established prediction method. We also added a quantitative comparison for the demonstrated cases shown between the predicted and lidar-retrieved aerosol profiles using normalized RMSE.

Line 527 now reads: Using the significant but weak empirical relationships established above, we next demonstrate aerosol vertical-profile prediction using these variables in place of vertical lidar measurements. Because BLH-LL showed a slightly stronger empirical relationship with r_m than BLH-RiB in the daytime AMF-1 analysis (Figure 11), the BLH-LL is used in the following analysis.

Line 537 now reads: The TAMU coastal and inland site's aerosol vertical profiles for 8 August and 18 September were chosen for the demonstration. The TAMU site was not included in the derivation of the empirical relationships from the AMF-1 dataset, allowing the demonstration to test how the AMF-1-derived relationships perform when applied to profiles from other sites. Although the predictive relationships for r_m and k are only weak to moderate, the demonstration is useful for showing both what profile features can be approximated from these variables and where the approach breaks down, particularly in situations where direct vertical measurements are unavailable.

Line 545 now reads: To quantify the profile-level uncertainty in this demonstration, we calculated the normalized RMSE between the predicted and lidar-retrieved aerosol concentration profiles for each case (Table S.5). The 8 August cases show lower errors when f = 2 is used, with normalized RMSE values of 41.7% at Galveston and 19.5% at Hempstead, compared with 72.3% and 56.7% when f = 1 is used. In contrast, the 18 September cases retain larger errors even when f = 2 is used, with normalized RMSE values of 59.5% at Galveston and 48.0% at Hockley. This result indicates that the accuracy of the predicted profile depends strongly on reliable estimation of r_m, consistent with the weak BLH-r_m relationship shown in Figure 11. This indicates that BLH alone is not a strong predictor of r_m. Since k is estimated from the potential-temperature gradient near r_m, a better prediction of r_m would also improve the estimation of the sharpness parameter k. Additionally, the factor f has a strong influence on the shape of the aerosol profile and thus requires further investigation.

Other comments:

Referee Comment: The legend in the figures showing the retrieved vertical aerosol concentration profile (e.g., Figure 5) shows a gray shaded zone representing aerosol uncertainty, which appears vanishingly small. It seems the uncertainty is calculated based on variability in total backscatter coefficient (Chen et al., AMT, 2025). However, viable calculation of uncertainty related to aerosol number concentrations should also incorporate the variability and dependence of the aerosol size distribution, as well as hygroscopicity corrections. Values of aerosol hygroscopicity and corrections factors are not stated in the manuscript and cite unpublished work (personal communication).

Authors' Response: The backscatter retrieval uncertainty is defined in Chen et al. (2025). We now include uncertainty based on variability in the surface aerosol concentration and also further clarify how the uncertainty is calculated in the manuscript. In addition, we have added a new figure to show a timeseries of κ values derived from ACSM used for the humidity correction. We agree that considering vertical variations in aerosol size distribution would be useful, but collocated, vertically resolved aerosol size-distribution measurements were not available for the retrieval periods.

Line 137 now reads: Following Chen et al. (2025), uncertainty in the retrieved aerosol concentration profile was estimated by repeating lidar retrieval and humidity correction with different aerosol lidar ratios, calibration scattering ratios, κ values, and aerosol refractive indices. A geometric standard deviation of 1.5 was used to define the κ sensitivity range by multiplying and dividing the central κ value by 1.5. Temporal variability in the surface aerosol concentration was included using the relative standard error of the mean (SEM) calculated from the condensation particle counter measurements during each retrieval period. This relative SEM was applied to the surface aerosol concentration and propagated into the profile uncertainty. The range of resulting profiles was taken as the uncertainty. This range reflects only the retrieval parameters and surface-concentration variability considered here and should not be interpreted as a complete confidence interval or as indicating high confidence in the retrieved aerosol concentration profile.

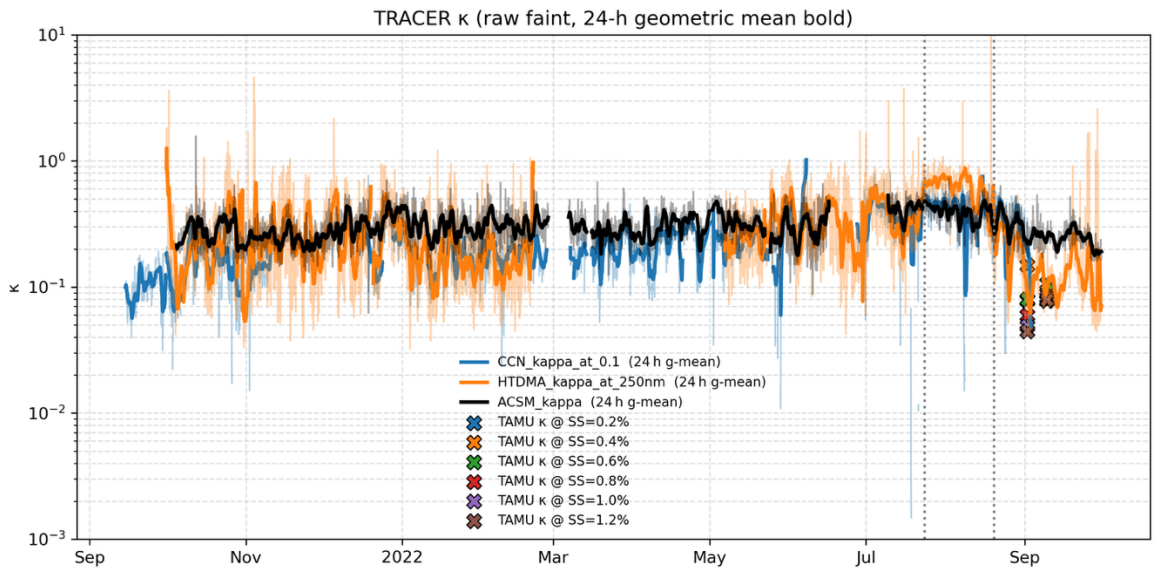


Figure S.1 Comparison of aerosol hygroscopicity parameter (κ) values derived from cloud condensation nuclei (CCN), hygroscopic tandem differential mobility analyzer (HTDMA), and aerosol chemical speciation monitor (ACSM) measurements at the first Atmospheric Radiation Measurement Mobile Facility (AMF-1) during the Tracking Aerosol Convection Interactions Experiment (TRACER). Hourly values are shown as faint lines and 24 h geometric means as bold lines. The CCN-derived κ values are shown only for comparison and were not used in the aerosol retrievals because the Atmospheric Radiation Measurement (ARM) User Facility advised against using the AMF-1 CCN data due to a reported leakage issue. ACSM-derived κ was used for the AMF-1 retrievals because it provided the best temporal coverage and was not affected by the CCN leakage issue. CCN-derived κ values from co-located Texas A&M University (TAMU) measurements are also shown.

Line 122 now reads: The aerosol hygroscopicity parameter κ used for AMF-1 retrieval was estimated from Aerosol Chemical Speciation Monitor (ACSM) aerosol composition measurements collected during the TRACER campaign, with κ values provided by M. A. Zawadowicz (personal communication, 2025), and are shown in Figure S.1. The κ values used for TAMU retrieval were estimated from CCN concentration and aerosol size distribution (Chen et al., 2025).

Referee Comment: One main assumption is that the aerosol size distribution remains the same vertically; however, previous experiments have shown large contribution of ultrafine aerosol in the Houston boundary layer, while layers aloft show the dominant presence of an accumulation mode (e.g., Brock et al., 1993; Lance et al., 2009). At the end of the manuscript, the authors recognize the need for in-situ observations of small aerosol particles that are not detected by

elastic backscatter measurements from the lidar. How much does a change in the aerosol size distribution impact estimate of aerosol number concentrations? Have the authors compared the lidar-retrieved profiles of aerosol number concentrations with in-situ airborne observations?

Authors' Response: Thanks for the informative references. We agree that vertical changes in aerosol size distribution can affect the conversion from backscatter to number concentration. Unfortunately, although airborne measurements were collected during TRACER, they were not sufficiently collocated with our retrieval periods for a direct comparison. We have clarified these limitations in the revised manuscript.

Line 132 now reads: This scaling assumes that the surface aerosol number size distribution is representative aloft. Houston aircraft measurements show that aerosol concentrations and size distributions differ among urban and industrial plumes (Brock et al., 2003; Lance et al., 2009). Such vertical variability cannot be resolved by the single wavelength lidar and remains a source of uncertainty in the retrieved aerosol concentration profiles.

Referee Comment: In addition, the lidar profiles consistently show high aerosol concentrations at the surface – even for neutrally buoyant boundary layer (for example, Figure 10g) when the boundary layer is expected to be well-mixed. How much does the uncertainty in lidar backscatter retrieval at near ranges impact the estimates of the aerosol number concentrations?

Authors' Response: We thank the reviewer for raising this point. First, the reported aerosol number concentrations are expressed per unit of ambient volume and are not normalized to standard pressure and temperature (STP). Therefore, even when aerosol particles are well mixed in terms of particle mixing ratio, their number concentration per unit ambient volume can decrease with altitude as air density decreases. The retrieved profiles do not consistently show maximum aerosol concentrations at the surface. For example, Figures 5a and 5b show aerosol concentrations within the surface-connected layer that are higher several hundred meters above the ground than at the surface. The retrieval is anchored to the surface concentration measurement but does not require concentration to decrease monotonically with altitude. We have revised the text to clarify that aerosol number concentration is reported per unit ambient air volume and is not normalized to standard temperature and pressure (STP).

Second, following the method described in Chen et al. (2025), two main sources of uncertainty affect the near range lidar data. The first is uncertainty associated with the overlap and afterpulse corrections. We apply an overlap correction to account for incomplete overlap between the laser beam and the receiver field of view and an afterpulse correction to account for detector saturation caused by internal scattering. The uncertainty associated with the overlap correction was discussed in Chen et al. (2025). The second source is extrapolation through the near-field blind zone, where lidar measurements are unavailable. We use a second-degree polynomial fit to

the dry backscatter profile above the blind zone and extrapolate the profile down to the surface. Because we vary the assumed lidar ratio and calibration scattering ratio in the backscatter retrieval, multiple backscatter profiles and corresponding blind-zone extrapolations are produced. The spread among these extrapolations represents the estimated uncertainty within the blind zone, although the extrapolation method itself was not varied. Because the lidar retrieval and its uncertainty treatment are described in detail in Chen et al. (2025), we refer readers to that paper rather than repeat the full methodology here.

Line 131 now reads: No standard temperature and pressure (STP) normalization is applied, and all aerosol number concentrations are reported per unit ambient air volume at each altitude.

Referee Comment: The justification for choosing 10 cm-3 for the free troposphere aerosol number concentration needs to be cited.

Authors' Response: We thank the reviewer for identifying the insufficient justification for X_f=10 cm^{-3}. We clarify that X_f was fitted independently for each observed aerosol profile and was fixed only in the Section 3.6 prediction demonstration. Rather than using an assumed free tropospheric value, we now set X_f to 150 cm^{-3} as a representative background concentration close to the overall median obtained from the quality-controlled AMF-1 profile fits, and have regenerated Figure 13 accordingly.

Line 534 now reads: The aerosol concentration measured on the surface is used for X_0. X_f is set to 150 cm^{-3}, as a representative background value close to the overall median obtained from the quality-controlled AMF-1 profile fits.