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.

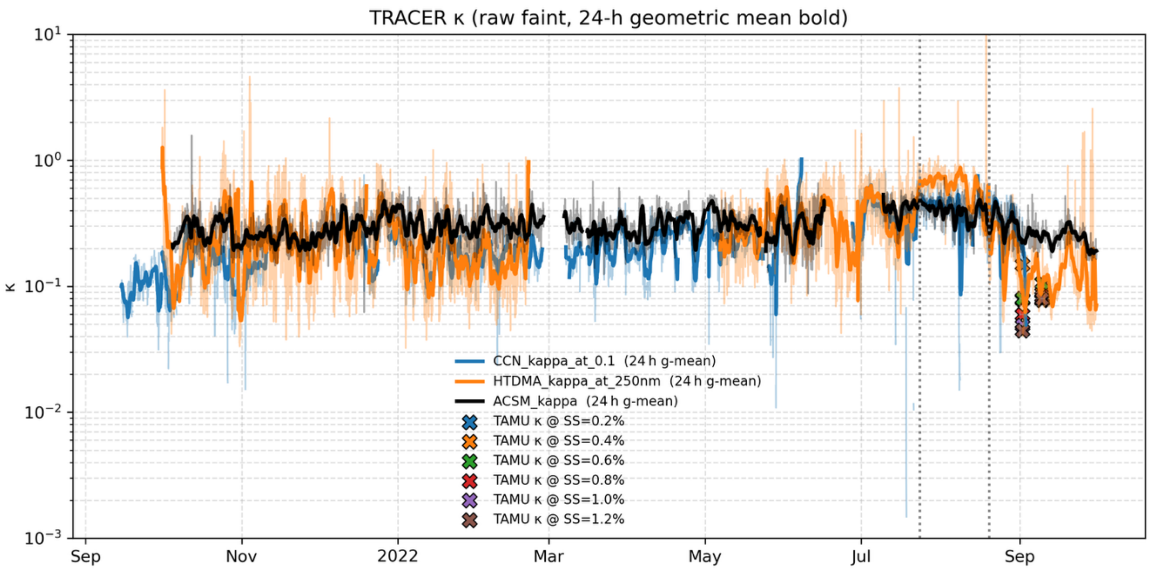

Figure S.1 Comparison of aerosol hygroscopicity parameter (κ) values derived from cloud condensation nuclei (CCN), hygroscopic tandem differential mobility analyzer (HTDMA), and aerosol chemical speciation monitor (ACSM) measurements at the first Atmospheric Radiation Measurement Mobile Facility (AMF-1) 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.