

Reply to Referees for A New Technique to Retrieve Aerosol Vertical Profiles Using Micropulse Lidar and Ground-based Aerosol Measurements

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We thank the referee for their time and constructive comments. Below, we reproduce each comment of referee#1 and referee#2, followed by our response. Page and line numbers refer to the original submitted manuscript; the change locations of the revised manuscript and the manuscript with tracked changes are shown in parentheses, e.g., “page 25 line 527 (revised page 30 line 614; tracked page 34 line 719).”

The manuscript presents a methodology to convert lidar backscatter profiles into cloud condensation nuclei (CCN) and ice nuclei (IN) number concentration profiles by scaling the lidar-derived profiles to in situ data measured at ground level. It describes the method with emphasis on the lidar analysis, cloud screening, and hygroscopic correction, and demonstrates its application through several case studies. Additionally, it compares measurements from two locations to evaluate the approach's potential. While the manuscript is well written, it lacks essential details regarding the methodology, particularly in describing error sources, and requires revisions from the authors.

Referee #1 Major Comments:

Referee #1 comment: Although correcting for hygroscopic growth is a necessary step in converting backscatter profiles into number concentration profiles, the manuscript devotes excessive attention to this aspect while providing limited discussion on the relationship between aerosol optical and microphysical properties. It also offers technical details regarding the lidar data analysis, but omits essential aspects of the retrieval scheme.

Authors' response: Thank you for this comment. We agree with the Reviewer that correcting for hygroscopic growth is an important aspect of correctly determining aerosol concentration profiles from the lidar backscatter profiles. We also see Reviewer's point, that we have developed a very detailed method but had not described the method in enough detail in our original submission. Based on this comment, we have now expanded the text providing additional details and explanations as specified in the comments below.

Referee #1 comment: A major drawback, in my opinion, is the large uncertainty in lidar backscatter retrieval at near ranges. While the authors perform an uncertainty analysis, they do not account for uncertainties arising from the overlap function, which can significantly affect the measurements in the near range. This issue is particularly relevant for a micropulse lidar (MPL), which typically has a full overlap height of about 5–6 km (Campbell et al., 2002), and around 2

km for MiniMPL (as I could only find here: https://www-air.larc.nasa.gov/missions/discover-aq/docs/pub/AMS_Berkoff_Finalv2.pdf).

Authors’ response: We agree with the Reviewer that a major limitation of lidar data arises from uncertainties in the overlap region. In the original submission, the overlap corrections for both the micropulse lidar (MPL) and the mini micropulse lidar (MiniMPL) instruments were discussed in some detail in the main text and in the supplement. Below we provide more detail about the overlap correction function used for this study.

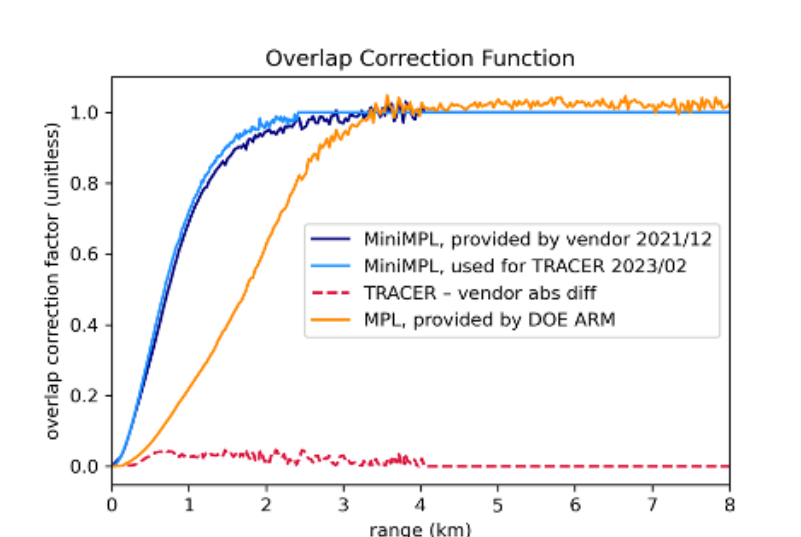


Figure 1 TAMU MiniMPL overlap function used for TRACER is shown in a solid light blue line, and the overlap function provided by the vendor is shown in a solid dark blue line. The difference between the overlap function used for TRACER and the overlap function provided by DOE ARM is shown in a dashed red line. ARM supplied the MPL overlap function shown in the orange line.

For any lidar instrument, the so-called “overlap” is the terminology used to describe the geometric mismatch between the outgoing laser beam and the detector’s field of view, which occurs at near range. In this range, the receiver cannot capture the full backscattered signal. The manufacturer, Droplet Measurement Technologies, provides both an overlap function (generated in December 2021) and a method for recalibrating the overlap function. For comparison, Figure R1 here shows the overlap function which came with the unit (shown in solid dark blue line), generated in December 2021, and a post-campaign function generated in our laboratory on

February 21, 2023 (shown in solid light blue line). Following Welton and Campbell (2002), we recalibrated the MiniMPL overlap function by positioning the lidar horizontally, so the laser beam was parallel to the ground and free of obstructions while collecting calibration data. The MiniMPL overlap function supplied by the vendor and the post-campaign overlap function are similar overall. However, small differences at close range indicate a slight drift in the overlap function over time. The maximum percentage difference between the pre-campaign vendor and post-campaign MiniMPL overlap functions is 10.9% at 0.53 km. Deviations decrease to below 5% by 1 km and approach zero above roughly 3 km. We selected the post campaign overlap function, as it is closer in time to the TRACER campaign. For the MPL unit at the Department of Energy Atmospheric Radiation Measurement (ARM) site, ARM supplied the overlap correction function for the MPL for the TRACER campaign.

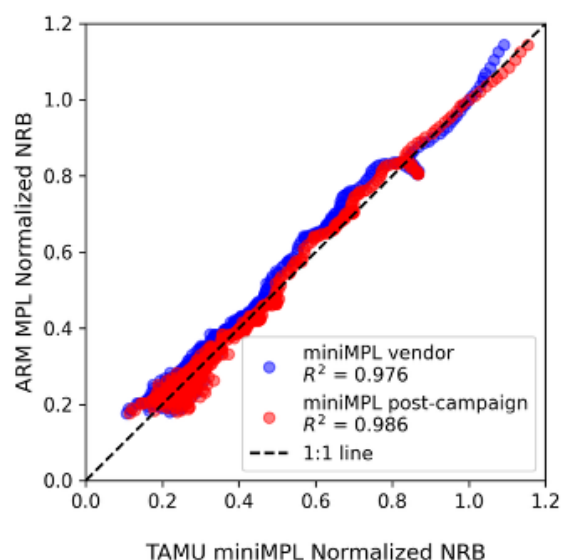


Figure 2 Comparison of MiniMPL normalized relative backscatter (NRB) profiles calculated using the original vendor-supplied overlap function shown in blue scatter points and the newly derived overlap function shown in red scatter points.

To further justify the choice of the MiniMPL overlap function, we cross-checked NRB profiles from the ARM MPL and MiniMPL, which the MiniMPL NRB during a time when the ROAM-V was parked at the ARM site and the lidars were collocated, as discussed in the original text on pages 25-26. Figure 2 compares the normalized NRB from the TAMU miniMPL to the collocated ARM MPL, showing that the post-TRACER overlap function yields stronger

agreement ($R^2 = 0.986$) than the vendor-provided function ($R^2 = 0.976$), further supporting it as the more accurate choice.

Based on the referee's comment, we now include the raw MiniMPL and MPL signals before performing overlap correction in Figure 11 to demonstrate the effectiveness of the overlap correction, as well as additional discussion in the text.

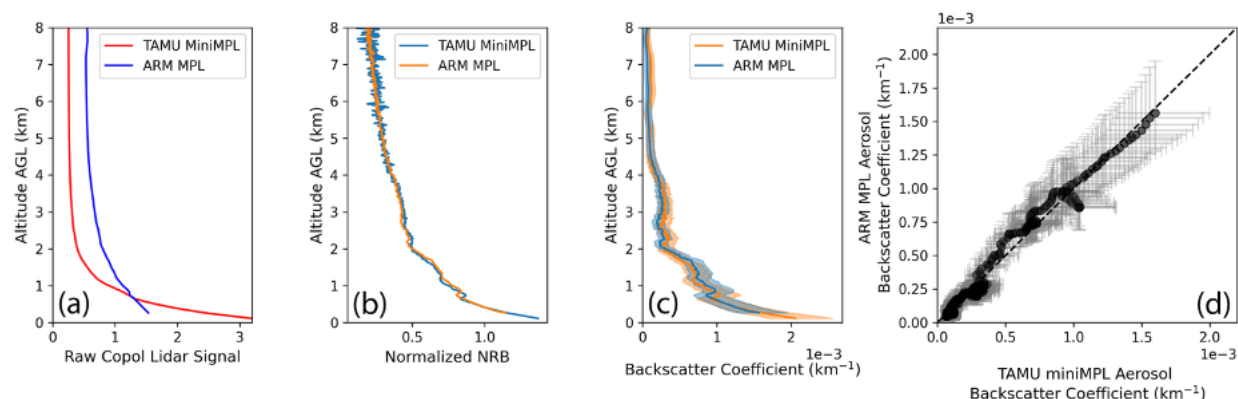


Figure 3 Revised Figure 11. Comparison of retrieved aerosol backscatter coefficient profiles derived from MiniMPL and ARM AMF-1 MPL data. (a) Raw co-polarized lidar signal of TAMU MiniMPL (red solid line) and ARM MPL (blue solid line) (b) Lidar normalized relative backscatter signal of TAMU MiniMPL (red solid line) and ARM MPL (blue solid line) after applying corrections (c) Retrieved lidar aerosol backscatter coefficient of TAMU MiniMPL (orange solid line and area) and ARM MPL (blue solid line and area) (d) Comparison of the lidar aerosol backscatter coefficients retrieved from NRB. The uncertainty interval of the retrieved aerosol backscatter coefficient is shown as error bars.

On page 25 line 527 (revised page 29 line 609; tracked page 33 line 730), the text now reads, “The TAMU ROAM-V was deployed at the AMF1 (La Porte, Texas) site on 1 September 2022, allowing miniMPL and MPL to be collocated and compared directly. The ARM MPL deployed at AMF1 collects data at a vertical resolution of 15 m and a temporal resolution of 10 s (Muradyan et al., 2021). During the collocation test, the two lidars were separated horizontally by approximately 30 meters and vertically by less than 10 meters. The data from both lidars were time-averaged between 20:00 and 22:00 UTC. Vertical profiles of the lidar raw signal, the NRB, and the aerosol backscatter coefficient, and a comparison of the lidar aerosol backscatter coefficient are shown in Figure 11a, b, c, and d, respectively. Figure 11a shows that the raw

signals from the two lidars differ significantly. However, after applying lidar-specific afterpulse, deadtime, background, and range corrections for each lidar, their NRB profiles agree closely (Figure 11b). Figure 11c and d show that the MPL and miniMPL NRB and aerosol backscatter coefficient profiles follow similar shapes and magnitudes. The miniMPL overestimates aerosol backscatter coefficients between 6 km and 8 km compared to the MPL, suggesting that the miniMPL-derived profiles may be less reliable at higher altitudes. This artifact is consistent with the spurious high-altitude enhancements discussed earlier and is likely caused by signal noise and overlap correction uncertainty in the miniMPL retrieval. The miniMPL and MPL profiles exhibit a slight vertical offset below 4 km, which may result from residual errors introduced during the afterpulse, background, or overlap corrections. The differences between the two aerosol backscatter profiles generally remain within the estimated uncertainty bounds, which primarily arise from the assumed lidar ratio and the scattering ratio at the reference height. In summary, miniMPL and MPL data are remarkably similar despite differences in their lidar designs and specifications. This agreement suggests that the more compact and less expensive miniMPL can provide comparable data quality to the more established MPL system. In addition, the use of two lidars with comparable outputs enables coordinated deployment and consistent analysis across different sites over the same period.”

Figure 1 in this reply has been added to the supplement with an explanation of the overlap functions used for TRACER.

The text in the supplement at page 2, line 31 (revised page 2, line 37) now reads: “‘Overlap’ refers to the near-range mismatch between the outgoing laser beam and the detector’s field of view, which prevents full signal capture. Droplet Measurement Technologies provided a default overlap function (Dec 2021) and a method for recalibration (Welton and Campbell, 2002). Following their method, we recalibrated the miniMPL overlap on February 21, 2023, by aligning the instrument horizontally to collect calibration data. As shown in Figure R1, the vendor and post-campaign overlap functions are similar. However, small differences of up to 10.9% were observed at close range (~0.5 km), which decrease to <5% by 1 km. We used the post-campaign overlap due to its closer timing to TRACER. The ARM MPL overlap function was supplied by the ARM program.”

Referee #1 Comment: Another missing aspect is a discussion on the scaling of the backscatter coefficient to CCN/INP values. Despite having time-resolved lidar and in situ measurements, the study scales a single profile to a single CCN/INP value. How large was the scaling factor at different supersaturations, i.e., $\text{CCN}/\beta_{\text{dry}}(R_0)$ and $\text{INP}/\beta_{\text{dry}}(R_0)$? More importantly, how did this factor evolve with time? Was there a correlation between backscatter values and CCN concentrations over time? Could you identify distinct patterns for different aerosol types? Addressing these questions could provide insight into the feasibility of retrieving CCN/INP profiles using lidar alone, as intended in previous studies referenced in the introduction.

Authors' response: We did not use a scaling factor to convert backscatter values directly into CCN concentrations, nor did we attempt to derive an empirical relationship between CCN and aerosol optical properties. Instead, we used the aerosol dry backscatter profile to linear scale aerosol, CCN, and INP concentrations measured at the surface at the same time the backscatter profile was taken to get CCN and INP concentrations at higher altitudes. For example, Figure 7, which shows the retrieved CCN profiles at 0.2%, 0.6%, and 1.2% supersaturation, and INP profiles at -20°C and -25°C . This approach does not rely on fixed scaling factors and can be applied to other field campaigns using similar lidar and aerosol instrumentation without requiring location-specific calibration. Extending our method to situations without surface aerosol measurements is beyond the scope of this work.

We retrieve one aerosol profile for each radiosonde launch using data averaged around the launch time, instead of a full time series. This is because radiosonde data are needed for hygroscopic growth correction, and they are not collected often. Other instruments also need time to collect enough data—CCN counters take 30 minutes to scan supersaturations, and INP samples are collected over longer periods. MiniMPL data also need about an hour of averaging to reduce noise, especially when there is cloud. Because of these limits, our method focuses on getting reliable, meaningful profiles rather than capturing short-term changes. Studying how CCN and INP profiles change over time is still important and could be explored in future campaigns with more advanced lidar systems.

To further clarify our method, we include more detailed explanations in the manuscript. Page 8, line 166 (revised page 8, line 169; tracked page 9, line 190). The text now reads: “Each profile is retrieved from data collected over a one to three hour period centered around radiosonde launch time.”

At page 8, line 167 (revised page 8, line 174; tracked page 8, line 196), the text now reads: “This method addresses the challenge that aerosol size distribution, composition, particle shape, and hygroscopic growth, all of which influence backscatter, are not directly measured by the micropulse lidar and must be inferred. By assuming that surface aerosol properties are representative of those of the whole column, the dry backscatter coefficient becomes approximately linearly proportional to aerosol volume concentration. We therefore could scale the time-averaged surface aerosol, CCN, and INP measurements with the lidar-derived dry backscatter profile to obtain their vertical distributions.”

A new paragraph is added after page 15, line 312 (revised page 16, line 330; tracked page 17, line 370): “For each retrieval, aerosol, CCN, and INP measurements were averaged over the same one to three hour window as the lidar data used for backscatter profile retrieval. This averaging period reflects the operational constraints of each instrument: the CCN counter requires approximately 30 minutes to complete a full scan over the range of supersaturations, and INP samples were collected over one to two hour periods (Thompson et al., 2025).

At page 20, line 428 (revised page 21, line 461; tracked page 23, line 521). A new sentence is added: “One profile each for aerosol, CCN, and INP is retrieved for each time-averaging period.”

Reply to referee #1 specific comments:

Referee #1 comment 1: Lines 78-79: Another commonly considered aerosol type is marine aerosol.

Authors’ response: The three aerosol types mentioned in the text refer to the aerosol types mentioned in a study that did not consider the marine aerosol (Lv et al., 2018).

Page 3, line 77 (revised page 3, line 77; tracked page 3, line 86), the text now reads: “The first approach involves using multiwavelength lidar to retrieve aerosol concentrations by classifying them into different aerosol types (urban, biomass burning, and dust) and then using the prescribed hygroscopicity parameter of each aerosol type to estimate the CCN concentration (Lv et al., 2018).”

Referee #1 comment 2: Lines 124-126: You mention that models and observations often rely on assumptions that introduce biases. Could you provide references to support this statement?

Authors’ response: We appreciate the reviewer’s comment. Upon review, we recognized that the original statement lacked clear meaning and sufficient support from the literature. In response, we have deleted this statement.

Page 5, line 123 (revised page 5, line 124; tracked page 5, line 137) now reads: “Despite advancements in understanding aerosol–cloud interactions, significant uncertainties remain in accurately characterizing aerosol vertical distributions and their impact on cloud processes, requiring more comprehensive and vertically resolved measurements.”

Referee #1 comment 3: Line 166: You scale the aerosol backscatter to CCN and INP concentrations at ground level. However, how does this scaling evolve over time? What is the scaling factor? This crucial aspect is missing from the discussion.

Authors’ response: As discussed previously, we do not use a prescribed scaling factor. Rather, we use the measured CCN and INP measurements collected on the ground to scale the MPL backscatter profile. We estimate the vertical profile of CCN concentration at a given supersaturation by scaling the lidar-derived dry aerosol backscatter profile relative to its surface value and applying it to the surface CCN measurement. Similarly, we estimate the vertical profile of frozen INP concentration by scaling the aerosol profile using the measured surface INP concentration and the INP concentration at a given temperature measured on the ground. For this study, the limiting factor in time resolution is the frequency of ROAM-V radiosonde launches,

from which humidity profiles are observed. We retrieve one aerosol profile for each radiosonde launch, representative of the time average of surface aerosol and lidar measurements over the ~2 hour period surrounding the radiosonde launch.

Page 7, line 165 (revised page 8, line 178; tracked page 8; line 191) now reads: “The resulting dry aerosol backscatter coefficient profile is used to linearly scale time-averaged surface aerosol concentration, CCN concentration, and INP concentration measurements to estimate their vertical distributions.”

Referee #1 comment 4: Equation (2): Please use \exp instead of exp.

Authors’ response: We have edited this in the main text. The equation 2 now is:

$$\beta_1(R) + \beta_2(R) = \frac{\text{NRB}(R) \cdot e^{-2(S_1-S_2)} \int_{R_C}^R \beta_2(r) dr}{\frac{\text{NRB}(R_C)}{\beta_1(R_C) + \beta_2(R_C)} - 2S_1 \int_{R_C}^R \text{NRB}(r) \cdot e^{-2(S_1-S_2)} \int_{R_C}^r \beta_2(r') dr' dr} \quad (2)$$

Referee #1 comment 5: Figures 4e, 7, and 8: The profiles exhibit a steady increase in signal and backscatter products from 3 to 8 km. Is this a systematic artifact? Please address this pattern, which is visible in most presented profiles. Could it be associated with the overlap correction or other corrections or filtering?

Authors’ response: Yes, it is likely that the steady increase in aerosol backscatter from 3 to 8 km is a systematic artifact. There are two probable causes for this pattern. The first, as suggested by the referee, is that an overestimated overlap correction at near range may have led to underestimation of the lidar signal at lower altitudes. Although the overlap correction was carefully implemented following established procedures, some residual uncertainty may remain, especially near the instrument’s full-overlap height. The second possible cause is a positive bias in the noise floor at higher altitudes, which can artificially elevate the apparent signal and backscatter coefficients in the upper portion of the profile.

Based on the case studies presented in the paper, the magnitude of the artificial increase in aerosol backscatter at higher altitudes appears to be closely related to the noise level in the raw lidar signal. All three cases (Case 1, 2, and 3) use a total averaging period of at least two hours. However, Case 3 (31 August 2022, now Case 1 after revision) is entirely cloud-free, allowing for more profiles to be averaged. This results in a smoother signal with lower noise and the smallest observed artifact. In contrast, Case 2 (26 August 2022, now Case 3 after revision) contains only a few cloud-free profiles suitable for averaging, which leads to a higher noise level and the most prominent artifact, particularly between 5 and 6 km altitude. These patterns support the second explanation—that the MiniMPL signal noise at higher altitudes may have a small positive bias. As a result, MPL-derived aerosol profiles above 4 km should be interpreted with caution. We acknowledge this issue and will clarify it in the revised manuscript.

At the method section 2.5, line 440 (revised page 22, line 483; tracked page 24, line 548), the text now reads: “It is important to acknowledge that lidar-derived aerosol profiles may be affected by the artificial increase in aerosol backscatter at higher altitudes. As seen in Figure 7a, b, the aerosol backscatter coefficient shows a steady increase with height above 4 km. This apparent increase is likely a systematic artifact related to lidar signal noise at higher altitudes. As a result, the retrieved aerosol profile above 4 km should be interpreted with caution.”

In the result section 3.1, at page 22, line 471 (revised page 26, line 554; tracked page 28, line 634), the text now reads: “The increase of the dry aerosol backscatter profile as well as the aerosol concentration profile between 6 and 8 km is likely a systematic artifact related to the lidar noise at high altitude.”

In the result section 3.2, after page 23, line 497 (revised page 28, line 595; tracked page 31, line 697), a new paragraph is added: “The increase in the dry aerosol backscatter and aerosol concentration between 5 and 7 km is a systematic artifact likely caused by high lidar signal noise, as shown in Figure 10a above 5 km. The magnitude of this artifact is likely amplified by the high noise level, which is caused by the limited number of cloud-free profiles available for averaging during this period, as compared to the previous case, where more cloud-free profiles led to reduced noise and less pronounced artifacts.”

In the result section 3.4, at page 25, line 532 (revised page 29, line 619; tracked page 34, line 742), the text now reads: “The miniMPL overestimates aerosol backscatter coefficients between 6 km and 8 km compared to the MPL, suggesting that the miniMPL-derived profiles may be less reliable at higher altitudes.”

Referee #1 comment 6: Line 379: You assume a refractive index value. How does this assumption impact the humidity-effect correction? How much would your results change if the real part varied between 1.35 and 1.55? What about variations in the imaginary part?

Authors’ response: It is common practice to assume the refractive index of ammonium sulfate when the exact aerosol composition is unknown (Zieger et al., 2013; Ghan and Collins, 2004). In our approach, we compute the aerosol’s refractive index at each relative humidity (RH) by taking a volume-weighted average of the dry aerosol (ammonium sulfate) refractive index and that of water, and assuming the imaginary part of the refractive index is considered as 0 in all cases. It appears that this has a small effect on our calculations of the lidar hygroscopic growth correction factor, as illustrated below (Figure 4). However, this assumption represents a limitation of our analysis, as real atmospheric aerosols can have various refractive indices depending on their chemical composition and mixing state. In reality, aerosol mixtures often include absorbing species and complex internal or external mixing, making the effective refractive index difficult to constrain.

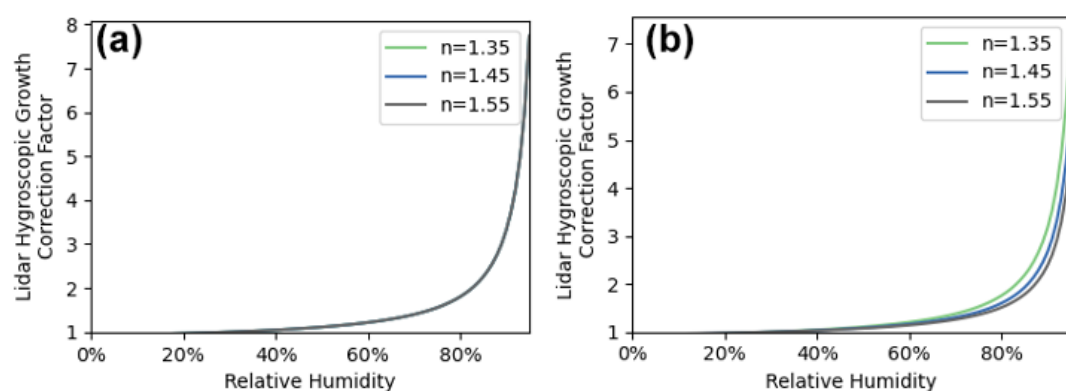


Figure 4 Lidar hygroscopic growth correction factor calculated with constant refractive with humidity (a), and with volume-weighted average of the dry aerosol refractive index and that of water.

At page 18, line 379 (revised page 19, line 404; tracked page 20, line 435), the text now reads: “In the absence of detailed aerosol composition data, the refractive index of ammonium sulfate is frequently adopted as a representative value in aerosol optical calculations, as it provides a reasonable approximation for non-absorbing, hygroscopic particles (Zieger et al., 2013; Ghan and Collins, 2004).”

Referee #1 comment 7: The step of computing aerosol size growth once the kappa value is determined is critical. I recommend including more details about this calculation beyond citing Petters and Kreidenweis (2007), such as providing the corresponding expression(s) or procedures.

Authors’ response: To determine the wet diameter at each RH value, we solve for the point at which the saturation ratio predicted by the κ -Köhler theory matches the specified environmental saturation ratio. This is done through an iterative root-finding approach, using the dry diameter as the initial guess. Essentially, we solve for the aerosol wet diameter given the saturation ratio and the aerosol dry diameter.

At page 17, line 365 (revised page 18, line 386; tracked page 20, line 436), the text now reads: “Thus, the problem becomes finding the κ corresponding to a given $D_{p,c}$ as the dry diameter, to

match a specific SS_c as the output. The κ is then numerically determined using an iterative root-finding method to match the measured SS_c - $D_{p,c}$ pairs.”

Referee #1 comment 8: Line 376: Please describe the Mie simulations in more detail. Which Mie package or code was used? Including the corresponding mathematical expressions would also be beneficial.

Authors’ response: The MiePython package is used to calculate the aerosol extinction coefficient at each RH value (Prah1, 2023). Since this is an open-source software and is a standard Mie scattering code, we chose to leave the mathematical expressions out of the text.

The revised text at page 17, line 377 (revised page 19, line 402; tracked page 20, line 452), the text now reads: “Once the aerosol size is known as a function of RH, the MiePython package is then used to calculate the aerosol extinction coefficient at each RH value (Prah1, 2023).”

Referee #1 comment 9: Line 381: Do you mean that aerosol size distributions are measured under dry ambient conditions? I assume the particles are dried before size distribution measurements, making the process independent of air humidity. Please clarify.

Authors’ response: Yes. The inlet air is dried below 30% RH which we measure with an RH meter.

At page 18, line 381 (revised page 19, line 411; tracked page 20, line 462), the text now reads: “During the field campaign, aerosol size distribution measurements are made after the sample air is dried to below 30% RH, as measured by an RH sensor.”

Referee #1 comment 10: Line 391: The choice between the extinction and backscatter coefficient is important. While a constant lidar ratio holds for a given humidity, varying humidity also alters the lidar ratio, affecting the growth correction factor differently for the extinction and backscatter coefficients. Additionally, since the backscatter coefficient is the robust retrieved

property, your Mie calculations should consider the backscattering cross-section instead of the extinction cross-section.

Authors' response: The reviewer is correct that in lidar measurements, the backscatter coefficient is the more robustly retrieved property. This is why we use the backscatter coefficient as the primary aerosol optical property in our analysis. However, when doing Mie scattering calculations, the extinction cross-section is usually more robust. The extinction cross-section is smoother and less sensitive to small changes in refractive index or size distribution. The reason is that the extinction cross-section integrates over the entire scattering angle, thus it's less noisy and has less angular dependence. Backscatter cross-section, on the other hand, depends heavily on the exact phase function at 180° , making it more sensitive to size, refractive index, and numerical precision, thus less robust in Mie calculations, as noted in a previous study (Geisinger et al., 2017). In addition, the extinction cross-section calculation is only used to compute the relative change in aerosol backscatter coefficient. Extinction can be used because the relative growth due to humidity is similar for both extinction and backscatter for real atmospheric aerosols, as noted in previous studies (Ghan and Collins, 2004; Ghan et al., 2006). The extinction-derived lidar hygroscopic growth correction factor $f(RH)$ offers a stable and physically reasonable correction for lidar backscatter profiles.

A justification for using extinction calculation is included in the text.

At page 18, line 388 (revised page 19, line 418; tracked page 21, line 470), the text now reads, "The extinction coefficient σ , rather than the backscatter coefficient, is used because the extinction coefficient is more stable numerically than the backscatter coefficient in Mie scattering calculations, exhibiting lower sensitivity to uncertainties in particle size distribution and refractive index (Geisinger et al., 2017)."

Referee #1 comment 11: Lines 429-431: The quadratic fitting used to extend the retrieval beyond blind ranges appears to be an extrapolation. Could you provide more details on how this step works?

Authors' response: Yes, the quadratic fitting is an extrapolation. No direct lidar measurements are available in the blind zone (0-100 m for MiniMPL and 0-200m for MPL). To estimate the aerosol backscatter coefficient profile below the lidar's blind zone, we perform a second-degree polynomial fit to the dry aerosol backscatter profile from up to 300 m AGL down to the edge of the blind zone. This fitted curve is then extrapolated into the blind zone. Since the aerosol profile is later linearly scaled by the dry backscatter profile, having a physically reasonable estimate in the blind zone is necessary to ensure that the scaling reflects realistic near-surface conditions. The extrapolated portions of the dry backscatter coefficient profile within the blind zone are shown as dotted lines in Figure 7a. The manuscript has been revised to explain in more detail.

At page 20, line 429 (revised page 21, line 463; tracked page 23, line 523), the text now reads: "To estimate the aerosol backscatter coefficient profile within the lidar's blind zone, we perform a second-degree polynomial fit to the dry aerosol backscatter profile from up to 300 m AGL down to the edge of the blind zone. This fitted curve is then extrapolated into the blind zone. Since the aerosol profile is later linearly scaled by the dry backscatter profile, having a physically reasonable estimation of the aerosol profile in the blind zone is necessary to ensure that the scaling reflects realistic near-surface conditions. The extrapolated portions of the dry backscatter coefficient profile within the blind zone are shown as dotted lines in Figure 7a."

Referee #1 comment 12: Figure 7c, 8d, 9d, 10d: I find it difficult to interpret these profiles. While I understand that you scale to different INP values at different temperatures, the approach differs from CCN concentrations, where supersaturation determines the number. Since INP concentration depends on air temperature, there should be a single INP profile based on the dry backscatter value and temperature. However, this relationship has not been discussed in the manuscript. Further analysis or clarification is needed for the INP retrievals.

Authors' response: As described above, CCN concentrations are measured at the surface at different supersaturations and linearly scaled using the dry aerosol backscatter profile to generate vertical profiles of CCN concentration at corresponding supersaturations. Similarly, INP concentrations are measured at the surface at different temperatures and linearly scaled using the dry aerosol backscatter profile to generate vertical profiles of INP concentration. As a result,

both CCN and INP profiles follow the shape of the dry aerosol backscatter profile and can be implemented in models where they are transported and interact with clouds.

Additional explanation is now added to page 20, line 439 (revised page 22, line 476; tracked page 24, line 541): “CCN concentration profiles are presented at different supersaturations, and INP concentration profiles are presented at different activation temperatures. Presenting CCN and INP profiles this way is useful for modeling applications, as it allows the model to compute CCN and INP activation dynamically when the particles are transported to conditions supportive of cloud condensation or ice nucleation within the modeled convection (or other atmospheric processes of interest).”

Referee #1 comment 13: Lines 533-534: You attribute differences between the two systems to slight misalignment. Could you clarify which misalignment you are referring to? Since MPL systems typically have a transceiver configuration, how would misalignment affect the near-range signal but not the far-range? These differences might instead stem from errors in the overlap function used to correct the signals. The increased signal between 6 and 8 km in the MiniMPL lidar suggests possible system artifacts (Fig. 11). When presenting the lidar analysis, I recommend including signals before and after overlap correction, as well as the overlap function itself. Additionally, how stable is this function over time?

Authors’ response: Thanks for pointing out the increased signal with height between 6 and 8 km in the MiniMPL lidar. This increase in signal is related to the previously discussed artifact. By “misalignment”, we meant that the shape of the profile seems to have a vertical offset. Since ‘misalignment’ could be misinterpreted, it is changed to ‘offset’ in the main text. Secondly, we like the Referee’s suggestion of including signals before and after overlap correction, and we have added them to Figure 11, as discussed in an earlier comment.

After page 25, line 532 (revised page 30, line 623; tracked page 34, line 747), the text now reads: “The miniMPL and MPL profiles exhibit a slight vertical offset below 4 km, which may result from residual errors introduced during the afterpulse, background, or overlap corrections.”

Referee #1 comment 14: Reference List: The absence of URLs for each reference makes reading and reviewing more difficult. Additionally, some journal names are incomplete.

Author's response: Thanks for helping identify issues in the reference section. The URL for the DOI has been added, and the missing journal names have been completed in the updated manuscripts.

RC2: 'Comment on egusphere-2024-3363', Anonymous Referee #2, 08 Jul 2025

Summary: This paper uses ground-based in situ observations of CCN and aerosol concentrations in combination with lidar profiles to create vertical profiles of CCN, aerosol, and INP concentrations. The focus of the analysis is correcting the lidar backscatter profiles observed at varying levels of RH to dry backscatter profiles to avoid the disconnect between optical properties and aerosol concentrations at high RH. The paper is well-written and the methods seem thorough. However, the paper is missing more discussion on the other factors that can cause optics to not be linearly correlated with aerosol concentrations, as well as a discussion of the implications of the time averaging done to retrieve aerosol/CCN concentrations from a single backscatter profile.

Authors' response: We appreciate the Reviewer's perspective. It was not our intent for the manuscript to be overly focused on RH corrections. However, that correction process became quite detailed and lengthy. Based on this comment and a similar comment from Reviewer 1, we have now expanded the description of other factors, including near-ground uncertainties in lidar signal and time averaging of lidar data. Please see our response to Reviewer 1 for additional details.

Referee #2 Major Comments:

Referee #2 comment: If I'm understanding correctly (Line 194-196), all cloud-free profiles from 2-4 hours of lidar observations are averaged into a singular backscatter profile used to retrieve the aerosol/CCN/INP profiles. More discussion of the implications of this step would strengthen the analysis, because it seems like a long time to average over.

Authors' response: Thank you for this comment. In reviewing the original text, we see that it contains an error. It should have said all cloud-free profiles were averaged for 1-3 hours rather than 2-4.

There are several reasons why 1-3 hours of total averaging time are used. First, the derivation of the CCN and INP vertical profiles requires ground-based measurements of aerosol size,

concentration, CCN, and INP activity. During TRACER, the CCN instruments only completed a full supersaturation scan about every 30 minutes, and the INP analysis was performed on hourly impactor samples.

To demonstrate the sensitivity of our retrieval method to the time averaging window, we use the figure below to compare the aerosol and CCN concentration profile collected on 28 August using three averaging windows—2 hr 40 min, 1 hr, and 30 min—each centered on the 17:28 UTC radiosonde launch. The three averaging windows comprise 131, 55, and 29 individual lidar profiles, respectively. The overall shape and magnitude of aerosol concentration profiles remain largely consistent across all three averaging windows. However, small differences still appear, reflecting short-term variability in the aerosol field. The 30-minute average (Figure 1c) is also noticeably noisier and has more uncertainties at higher altitudes.

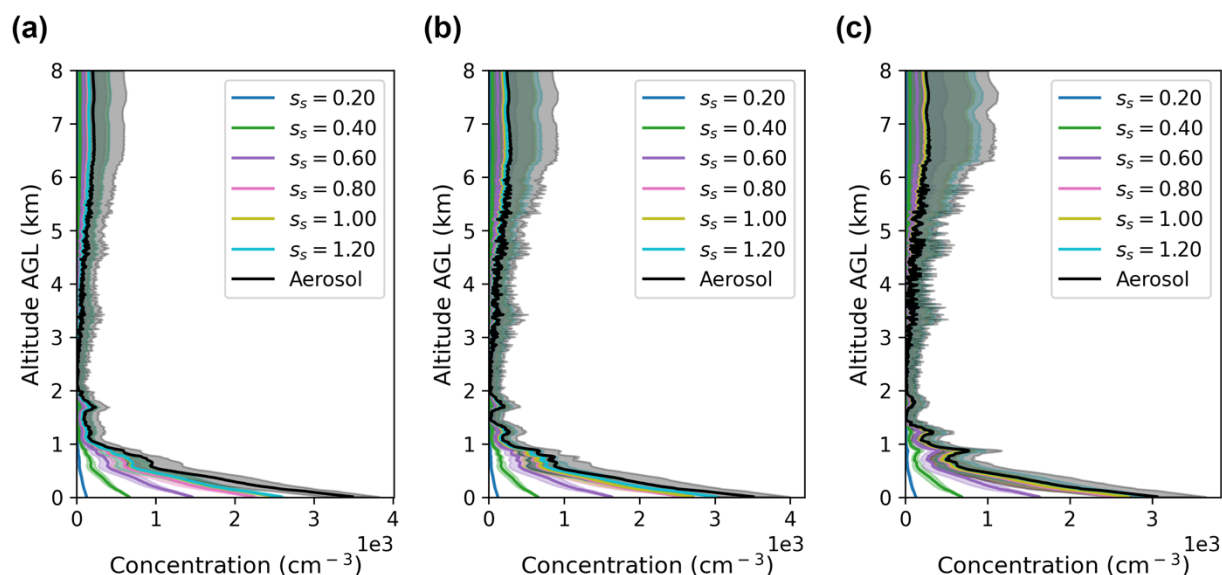


Figure 5 Comparison of aerosol concentration profile among three time-averaging periods for the example case on August 28 2022 (a) 2 hr 40 min averaging time (b) 1 hr averaging time (c) 30 minute averaging.

The figure and the following texts have been added to the supplement.

Supplement, revised page 5, line 72 now reads: “To demonstrate the sensitivity of our retrieval method to the time averaging window, we compare the aerosol and CCN concentration profile

collected on 28 August using three averaging windows—2 hr 40 min, 1 hr, and 30 min—each centered on the 17:28 UTC radiosonde launch. The three averaging windows comprise 131, 55, and 29 individual lidar profiles, respectively. The overall shape and magnitude of aerosol concentration profiles remain largely consistent across all three averaging windows. However, small differences still appear, reflecting short-term variability in the aerosol field. The 30-minute average (Figure 1c) is also noticeably noisier and has more uncertainties at higher altitudes.”

The following changes have been made to the main text:

Page 9, line 195 (revised page 10, line 207; tracked page 11, line 234) now reads: “The NRB profiles of cloud-free columns, typically between 0.5 to 1.5 hours before and after the radiosonde launch time (for a total of about one to three hours), are time-averaged.”

Page 15, line 312 (revised page 16, line 330; tracked page 17, line 370) now reads: “The aerosol, CCN, and INP measurements were averaged over the same one to three hour window as the lidar data used for backscatter profile retrieval. This averaging period reflects the operational constraints of each instrument: the CCN counter requires approximately 30 minutes to complete a full scan over the range of supersaturations, and INP samples were collected over one to two hour periods (Thompson et al., 2025).”

Referee #2 comment: On average, how many profiles are included in a 2-4 hour average?

Authors’ response: The TAMU miniMPL records raw data at 1 min. However, on average, approximately one-third of the profiles were removed due to the presence of clouds. Thus, 40-120 individual profiles are included for 1-3 hours averaging period.

Referee #2 comment: Is homogeneity of the aerosol profile over this time scale in this region a good assumption?

Authors’ response: Yes. In each case, we first examined the lidar attenuated backscatter time series (at 1-minute resolution) to identify time periods with relatively consistent aerosol

structures. In the original text, these time series were shown in figures 8a, 9a, and 10a in the manuscript. For emphasis, we have now added the discussion below:

Page 24, line 508 (revised page 24, line 502; tracked page 24, line 569) now reads: “The NRB timeseries in Figure 8a shows a persistent layer of high backscatter, visible below approximately 1 km. In addition, intermittent layers of high backscatter are observed between 1 and 3 km.”

Page 21, line 454 (revised page 28, line 535; tracked page 30, line 607) now reads: “The NRB time series in Figure 9a shows limited temporal variation in attenuated backscatter profiles during the cloud-free period.”

Page 29, line 485 (revised page 28, line 570; tracked page 30, line 655) now reads: “The NRB time series in Figure 10a shows some temporal variation in the attenuated backscatter profile, with a layer of high backscatter slowly decreasing from around 2 to 1 km AGL.”

Referee #2 comment: How does the standard deviation associated with time averaging compare to the backscatter uncertainty already shown on the figures?

Authors’ response: The uncertainty associated with time averaging is comparable to the backscatter uncertainty of the backscatter coefficient profile, as shown in the figure below, where we use the interquartile range to represent the uncertainty.

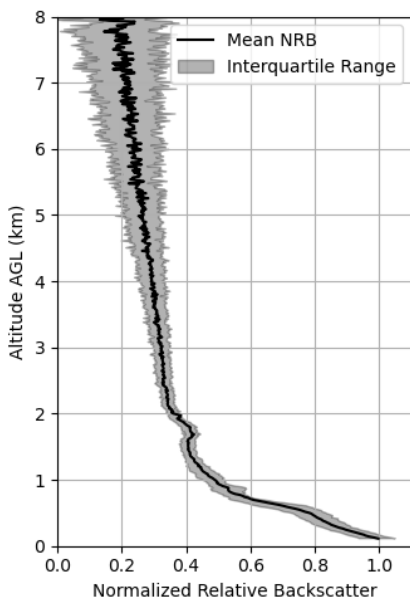


Figure 6 Mean (solid black line) and interquartile range (gray area) of NRB profiles for the example case on August 28, 2022.

The figure and discussion below are included in Section 4 of the Supporting Information.

Supporting Information, revised page 4, line 61 now reads: “We assess the uncertainty associated with temporal variability of attenuated backscatter by calculating the interquartile range (25th–75th percentile) of the 1-minute NRB profiles within the averaging window. For the example case (in the Method section) on 28 August shown in the figure above, the relative magnitude of temporal variability in NRB is comparable to the retrieval uncertainty presented in Figure 4b of the main manuscript. Because range-dependent noise grows with height, the temporal average of NRB shows greater variability aloft; the backscatter coefficient profile retrieval steps apply smoothing to reduce this noise, so the retrieved backscatter profile has lower uncertainty at those heights.”

Referee #2 comment: In lines 569-574, there is discussion of the spatial heterogeneity of aerosol vertical profiles between Galveston and LaPorte, which are only 46km apart. Given the potential for air mass transport over tens of kilometers during a 2-4 hour time frame, the assumption of temporal heterogeneity may lead to some vertical features being washed out. A

quantitative assessment of the temporal variability would enhance confidence in the resultant aerosol profile retrievals.

Authors' response: Some features may indeed vary on the time scale of our analysis, but a more detailed quantitative assessment of variability is difficult given the time resolution of the ground-based measurements. Nevertheless, aerosol vertical profiles remained distinctly different between Galveston and La Porte, even after 2 h 40 min of temporal averaging, as shown in Figure 12 in the main text.

Referee #2 comment: I would recommend replacing “accurate” with “realistic” in Line 585 and elsewhere in the paper, because “accurate” implies validation against independent observations, which is not presented here. “Realistic” better reflects that the profiles follow expected physical behavior. Additionally, additional discussion of the scenarios in which this method will not work would strengthen the final section. It is alluded to earlier in the paper (Line 409) that the approach only holds for well-mixed aerosol layers, but I think this needs to be reiterated here. As soon as the aerosol chemical composition or size distribution differs from what is measured at the surface, there will be errors introduced as the exact relationship between aerosol/CCN concentration and optical properties changes. It may also be beneficial (if you have a number) to discuss how often such well-mixed aerosol layer cases for which this method holds were observed in the TRACER campaign.

Authors' response: We thank the reviewer for the thoughtful suggestions. We agree that “realistic” is a more appropriate term than “accurate” and have changed the wording everywhere in the text. We note that the discussions of the method’s limitations due to the assumption of the well-mixed aerosol column are included in the Method section 2.5 and the fourth paragraph of the Conclusions.

Reply to referee #2 specific comments:

Referee #2 comment 1: Line 30: Can you clarify why the focus here is on convective processes? Assuming because it’s mostly what is observed in the Houston area, but this makes it sound like aerosols don’t also impact stratocumulus cloud processes.

Authors' response: The referee is right to point out that the non-convective clouds could be included in the introduction. We initially focused on the convective clouds since it is the focus of the TRACER project. However, aerosols affect both convective and non-convective clouds.

On Page 2, line 29 (revised page 2, line 29; tracked page 2, line 35), the text now reads:
“Consequently, changes in aerosol concentrations could influence many cloud properties and processes (Tao et al., 2012; Fan et al., 2016; Twohy et al., 2005).”

Referee #2 comment 2: Line 81: “multiwavelength” not capitalized

Authors' response: Thank you. We have corrected this.

Referee #2 comment 3: Line 85: “relationship between”

Authors' response: Corrected.

Referee #2 comment 4: Line 105: Clarify what exactly “dry” ambient conditions mean for this case

Authors' response: The literature we cited here assumes ambient conditions of less than 50% relative humidity are dry. For clarity, this has been added to the text.

Page 4, line 105 (revised page 4, line 105; tracked page 4, line 117) now reads: “Their results show that CCN concentration at 0.3% supersaturation in dry ambient conditions (where $RH \leq 50\%$) strongly correlates with the HSRL-2 measured extinction and backscatter.”

Referee #2 comment 5: Line 145: “first” not capitalized

Authors' response: Corrected.

Referee #2 comment 6: Line 145: What defines an enhanced operation day? Is it dependent on atmospheric conditions or just a pre-determined day to deploy additional platforms?

Authors' response: Enhanced operation days were defined from field-campaign forecasts indicating a strong sea breeze and atmospheric conditions favorable for isolated deep convection. On these days, the TRACER team launched additional radiosondes. In hindsight, this terminology was unclear to readers, so we have removed the term “enhanced operation day” and instead describe the forecast criteria explicitly.

Page 6, line 145 (revised page 6, line 147; tracked page 6, line 165) now reads: “During the IOP, when forecasts indicated a strong sea breeze and conditions favorable for isolated deep convection, the TAMU ROAM-V was deployed at Seawolf Park in Galveston, Texas, and at several inland sites (Rapp et al., 2024).”

Referee #2 comment 7: Fig 2: Can you write out what NRB stands for? Since I don't think it's a super common acronym, this could be confusing for someone scrolling through the figures first before reading.

Authors' response: Good point. NRB stands for Normalized Relative Backscatter. Figure 2 in the manuscript has been updated as shown below:

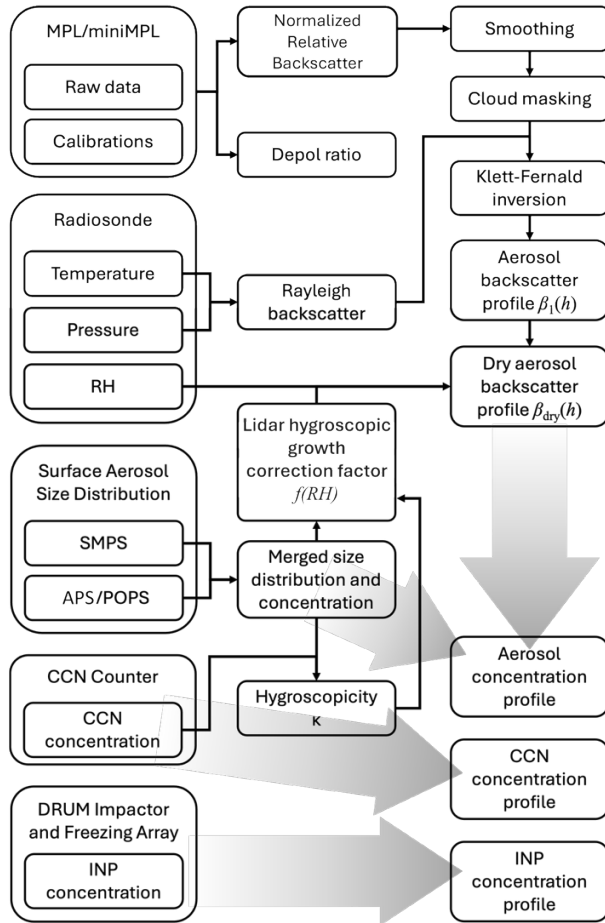


Figure 7 Updated figure 2 in the manuscript: An overview of the aerosol, CCN, and INP profile retrieval routine.

Referee #2 comment 8: Line 245-249: I am assuming this is expected in this region due to a primarily polluted urban boundary layer but maybe state it a little more explicitly if this is what you're implying.

Authors' response: This section of the manuscript aims to convey that the total backscatter coefficient above 2 km closely matches the Rayleigh backscatter from air molecules, indicating that the atmosphere at these altitudes is relatively clean with minimal aerosol presence. This agreement also serves as a quality check for the Fernald retrieval, as the Rayleigh backscatter is calculated independently and not retrieved. Matching profiles suggest that the retrieval is well constrained and performed correctly.

Page 12, line 244 (revised page 13, line 259; tracked page 14, line 291) now adds: “The total backscatter coefficient profile closely follows the molecular (Rayleigh) backscatter profile above 2 km AGL, indicating that aerosol contributions are minimal at these altitudes and that the backscatter is dominated by scattering from air molecules. This consistency also suggests that the Fernald inversion is performing well, since the molecular backscatter is independently calculated and provides a reference baseline.”

Referee #2 comment 9: Fig 6: Can you make panel (a) wider? The numbers on the top really run together and are difficult to read

Authors’ response: Thank you for this comment. We have edited the figure and updated the figure description to clarify the constant κ lines.

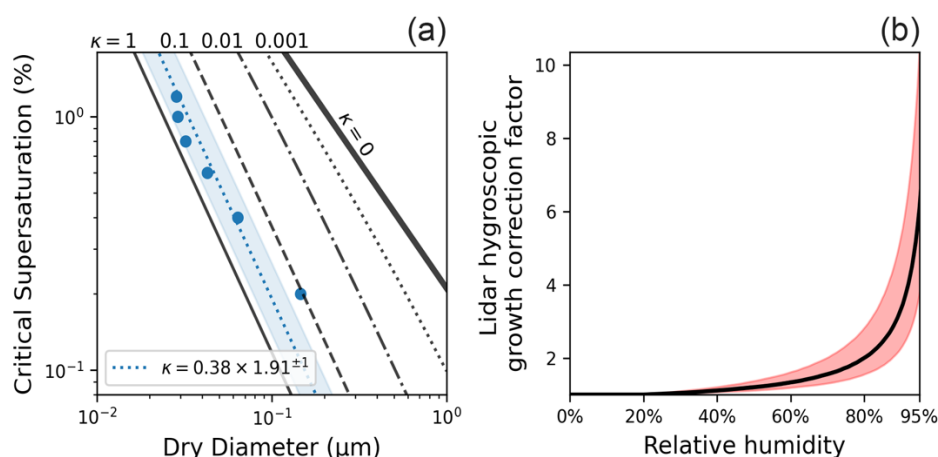


Figure 8 Updated Figure 6 in the manuscript (a) Blue scattered points represent pairs of critical supersaturation and corresponding critical dry diameter derived from aerosol size distribution and CCN measurements. The blue dotted line represents the derived geometric mean of aerosol hygroscopicity κ , and the shaded region represents the one geometric standard deviation of κ . $\kappa = 1$ line is shown in a solid black line; $\kappa = 0.1$ is shown in a dashed line; $\kappa = 0.01$ line is shown in a dash-dotted line; $\kappa = 0.001$ line is shown in a dotted line; and $\kappa = 0$ is shown in a thick solid black line. (b) Lidar hygroscopic growth correction factor as a function of relative humidity. The shaded area represents the uncertainties of the derived κ .

Referee #2 comment 10: Line 379: How does ammonium sulfate compare to/represent the aerosol types typically observed during TRACER? Somewhere when you're describing the campaign can you discuss the typical/dominant aerosol types observed during the campaign?

Authors' response: While the exact refractive index of ambient aerosol during TRACER is not fully characterized in this study, we assume that of ammonium sulfate and compute a volume-weighted average with water at each RH. This choice has limited influence on the hygroscopic scattering enhancement correction, which depends on the relative increase in scattering with RH rather than the absolute backscatter coefficient.

Page 18, line 379 (revised page 19, line 404; tracked page 20, line 455) now reads: "In the absence of detailed aerosol composition data, the refractive index of ammonium sulfate is frequently adopted as a representative value in aerosol optical calculations, as it provides a reasonable approximation for non-absorbing, hygroscopic particles (Zieger et al., 2013; Ghan and Collins, 2004). In reality, aerosols containing sulfate, nitrate, organic compounds, soot, and soil dust were all presented in Houston in varying proportions depending on air mass origin (Thompson et al., 2025; Lei et al., 2025)."

Referee #2 comment 11: Should there be a section in here somewhere (even if brief) about the radiosonde observations and the uncertainty of their temperature/RH profiles?

Authors' response: We agree. Radiosonde information is shown in table 1 in the manuscript. The iMet-4 radiosonde reports temperature uncertainty of ± 1.0 °C, and relative humidity uncertainty of $\pm 5\%$.

Page 19, line 417 (revised page 21, line 449; tracked page 23, line 508) now reads: "The radiosonde has a relatively small uncertainty in relative humidity measurements, specified as $\pm 5\%$."

Referee #2 comment 12: Fig 7: Would a log-scale for the x-axis be helpful? It's hard to see what's going on near the y-axis with all the lines really close together.

Authors' response: We appreciate the reviewer's suggestion to use a log-scale for the x-axis in Figure 7. However, we chose a linear scale to maintain consistency and interpretability across the different panels, which include both backscatter coefficient and aerosol concentration. A log-scale would compress higher values while overemphasizing minor differences at lower values.

Referee #2 comment 13: Fig 8: Could panels b, c, and d be put below panel a so all are larger and easier to read?

Authors' response: We appreciate the feedback. the figure 8, 9 and 10 are edited and shown below. The original section 3.3 has moved to 3.1 based on later comments.

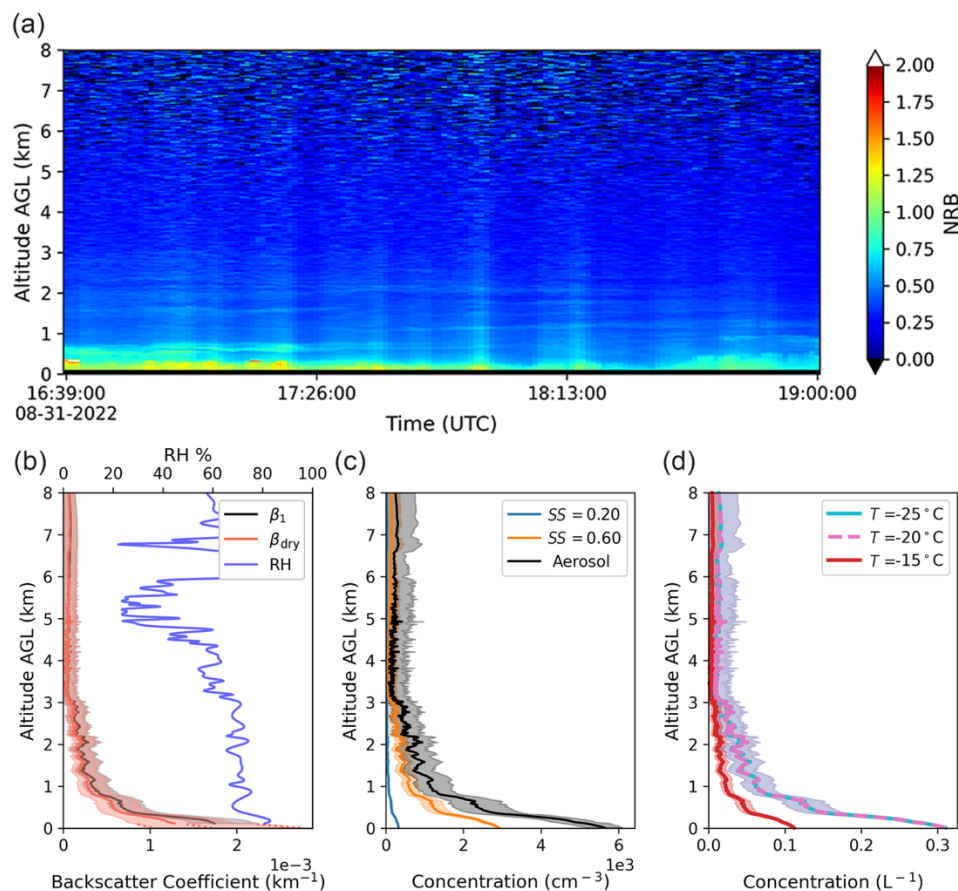


Figure 9 Updated Figure 8 in the manuscript (a) NRB time series data collected on 31 August 2022, from 16:39 to 19:00 UTC, with miniMPL in Galveston, Texas. (b) Aerosol and dry aerosol backscatter coefficient profiles are shown as solid black and red lines, respectively, with a shaded area showing the corresponding uncertainty interval for each profile. The relative humidity profile is shown as a solid blue line. (c) The aerosol profile is shown as a

solid black line. CCN profiles are shown in different colors corresponding to supersaturation levels of 0.2% and 0.6%. CCN data for 1.2% supersaturation were not available. (d) INP profiles at -15°C , -20°C , and -25°C . Note that the -20°C INP profile overlaps with the -25°C INP profile.

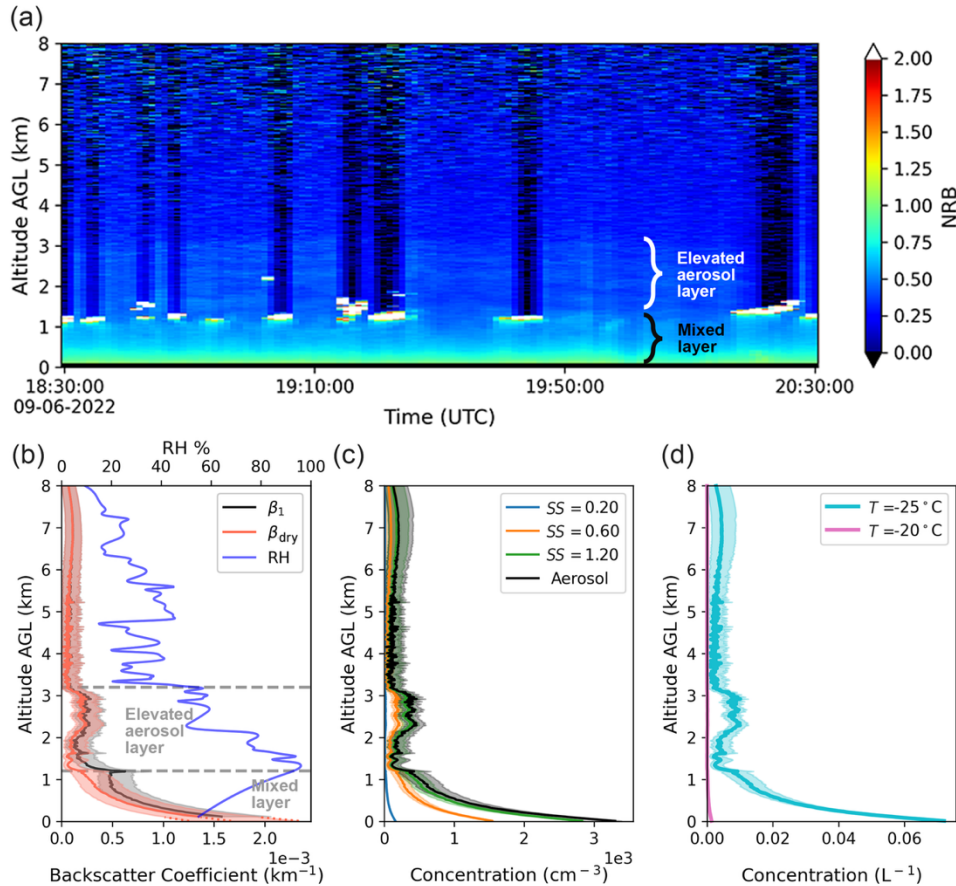


Figure 10 Updated Figure 9 in the manuscript (a) NRB time series data collected on 6 September 2022, from 18:30 to 20:30 UTC, with miniMPL inland at Hockley, Texas. (b) Aerosol and dry aerosol backscatter coefficient profiles are shown as solid black and red lines, respectively, with a shaded area showing the corresponding uncertainty interval for each profile. The relative humidity profile is shown as a solid blue line. (c) The aerosol profile is shown as a solid black line. CCN profiles are shown in different colors corresponding to supersaturation levels of 0.2%, 0.6%, and 1.2%. (d) INP profiles evaluated at -20°C and -25°C . No INP was observed at -15°C .

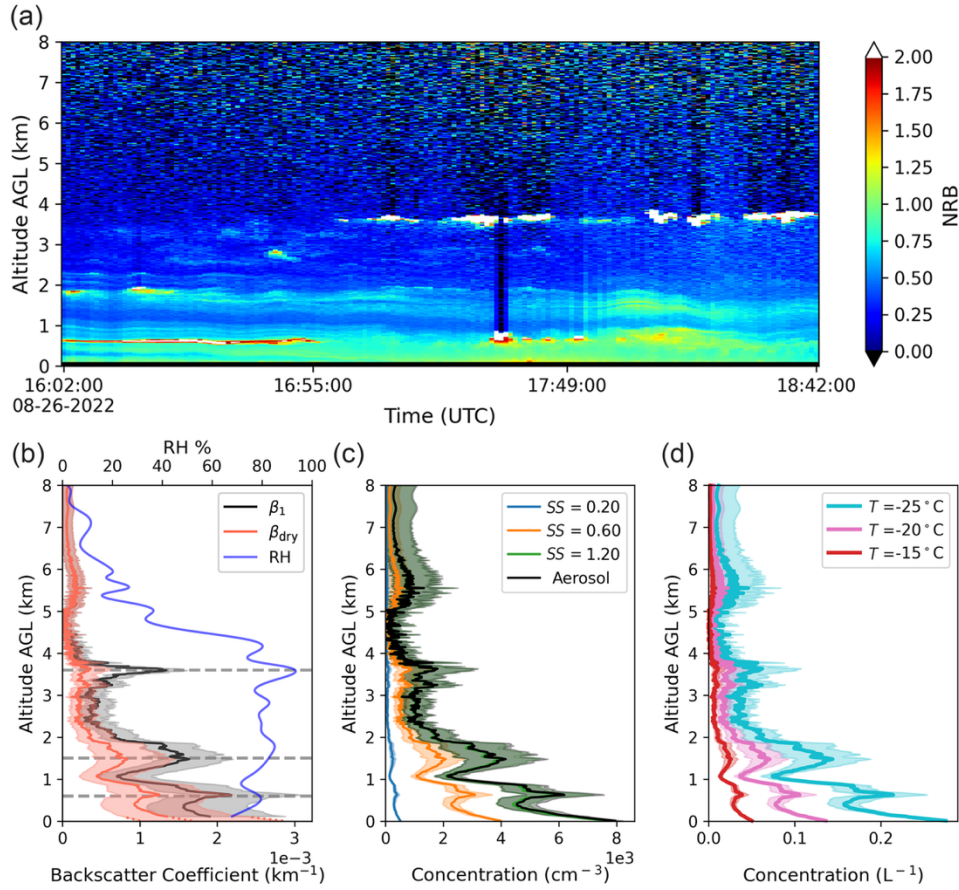


Figure 11 Updated Figure 10 in the manuscript. (a) NRB time series collected on 26 August 2022, from 16:02 to 18:42 UTC, with miniMPL in Galveston, Texas. **(b)** Aerosol and dry aerosol backscatter coefficient profiles are shown as solid black and red lines, respectively, with a shaded area showing the corresponding uncertainty interval for each profile. The relative humidity profile is shown as a solid blue line. Gray dashed lines indicate the cloud level. **(c)** The Aerosol profile is shown as a solid black line. CCN profiles are shown in different colors corresponding to supersaturation levels of 0.2%, 0.6%, and 1.2%. **(d)** INP profiles at -15°C , -20°C , and -25°C .

Referee #2 comment 14: Lines 454, 469-471: Previously, you mention this approach only holds for well-mixed layers, but here you are using an example with an elevated aerosol layer. I would mention that this does not impact the main point of this section, which is demonstrating the hygroscopic growth correction. Either that, or maybe don't even address the elevated aerosol layer or only do it at the end? Right now, it feels like you're picking a bad case right out of the gate immediately after finishing the methodology.

Authors' response: We thank the referee for this suggestion. We agree that it is clearer to show a baseline case first with a simpler atmospheric vertical structure. We have moved the 3.3 case study section to the 3.1 case study section and added further discussion of the results as comment 16 suggests.

Page 21, line 454 (revised page 25, line 533; tracked page 27, line 605) now adds: “Although an elevated aerosol layer exists, it does not affect the correction for the enhanced scattering from hygroscopic growth in the mixed layer.”

Referee #2 comment 15: Fig 9: Is it worth addressing the multiple aerosol layers here? This case also doesn't appear super well-mixed to me.

Authors' response: We appreciate the reviewer's observation regarding the presence of multiple aerosol layers and the degree of vertical mixing in Figure 9. We have added clarifying statements in the revised manuscript to address these points. Specifically, we now note that enhanced backscatter near cloud levels may indicate distinct aerosol layers or a high humidity layer, and that the dry backscatter profile suggests a possible elevated aerosol layer around 1.5 km. We also acknowledge that this feature may reduce the accuracy of retrieved aerosol properties at that level, while the removal of the humidity-induced peak at 3.6 km supports the robustness of our correction method.

Page 22, line 485 (revised page 27, line 569; tracked page 30, line 653) now adds: “The high attenuated backscatter signal near the cloud levels may reflect the presence of distinct aerosol layers or result from higher humidity enhancing aerosol scattering.”

Page 23, line 491 (revised page 28, line 580; tracked page 30, line 666) now adds: “The dry backscatter profile suggests that an elevated aerosol layer may be present near 1.5 km AGL, while the uncorrected peak at 3.6 km AGL is likely dominated by humidity-enhanced scattering rather than a distinct aerosol layer.”

Page 23, line 497 (revised page 28, line 590; tracked page 31, line 692) now adds: “The retrieval of aerosol, CCN, and INP concentrations may be less reliable around 1.5 km due to the possible presence of an elevated aerosol layer. However, the successful removal of the humidity-enhanced scattering peak near 3.6 km is encouraging, suggesting that the applied κ value may be reasonable throughout the column.”

Referee #2 comment 16: Line 498: Could this be the first case study you show? It might be good to show the most straightforward application first to give a reader confidence in your method before you introduce complications of multiple cloud layers or more pronounced hygroscopic growth.

Authors’ response: Yes, we agree, and we have moved case study 3 to case study 1. Previous lines 499-517 are now moved to current lines 490-519. Previous lines 472-497 are moved to current lines 520-555. Previous lines 472-497 are now moved to current lines 556-599.

Referee #2 comment 17: Line 518: The placement of this section between your aerosol profile results felt a little confusing – would it make more sense in the methods section maybe?

Authors’ response: We appreciate the reviewer’s suggestion regarding the placement of this section. However, we chose to keep it in the current location because the Methods section is reserved for describing the procedural details of the aerosol, CCN, and INP retrieval methods. This section serves as a necessary transition that sets up the subsequent comparison between the ARM and TAMU results.

References:

- Fan, J., Wang, Y., Rosenfeld, D., and Liu, X.: Review of aerosol–cloud interactions: Mechanisms, significance, and challenges, *Journal of the Atmospheric Sciences*, 73, 4221–4252, <https://doi.org/10.1175/JAS-D-16-0037.1>, 2016.
- Geisinger, A., Behrendt, A., Wulfmeyer, V., Strohbach, J., Förstner, J., and Potthast, R.: Development and application of a backscatter lidar forward operator for quantitative validation of aerosol dispersion models and future data assimilation, *Atmospheric Measurement Techniques*, 10, 4705–4726, <https://doi.org/10.5194/amt-10-4705-2017>, 2017.
- Ghan, S. J. and Collins, D. R.: Use of in situ data to test a Raman lidar–based cloud condensation nuclei remote sensing method, *Journal of Atmospheric and Oceanic Technology*, 21, 387–394, [https://doi.org/10.1175/1520-0426\(2004\)021<0387:UOISDT>2.0.CO;2](https://doi.org/10.1175/1520-0426(2004)021<0387:UOISDT>2.0.CO;2), 2004.
- Ghan, S. J., Rissman, T. A., Elleman, R., Ferrare, R. A., Turner, D., Flynn, C., Wang, J., Ogren, J., Hudson, J., and Jonsson, H. H.: Use of in situ cloud condensation nuclei, extinction, and aerosol size distribution measurements to test a method for retrieving cloud condensation nuclei profiles from surface measurements, *Journal of Geophysical Research: Atmospheres*, 111, <https://doi.org/10.1029/2004JD005752>, 2006.
- Lei, Z., Peña, T., Thompson, S. A., Chen, B., Matthews, B. H., Li, R., Rapp, A. D., Nowotarski, C. J., and Brooks, S. D.: Aerosol Physicochemical Mixing State and Cloud Nucleation Potential during Tracking Aerosol Convection Interactions Experiment (TRACER) Campaign, *Environmental Science & Technology*, 2025.
- Lv, M., Wang, Z., Li, Z., Luo, T., Ferrare, R., Liu, D., Wu, D., Mao, J., Wan, B., and Zhang, F.: Retrieval of cloud condensation nuclei number concentration profiles from lidar extinction and backscatter data, *Journal of Geophysical Research: Atmospheres*, 123, 6082–6098, <https://doi.org/10.1029/2017JD028102>, 2018.
- Muradyan, P., Cromwell, E., Koontz, A., Coulter, R., Flynn, C., Ermold, B., and O'Brien, J.: Micropulse Lidar (MPLPOLFS). [dataset], <https://doi.org/10.5439/1320657>, 2021.
- Prahl, S.: miepython: Pure python implementation of Mie scattering, Version v2, 5, 2023.
- Rapp, A. D., Brooks, S. D., Nowotarski, C. J., Sharma, M., Thompson, S. A., Chen, B., Matthews, B. H., Etten-Bohm, M., Nielsen, E. R., and Li, R.: TAMU TRACER: Targeted Mobile Measurements to Isolate the Impacts of Aerosols and Meteorology on Deep Convection, *Bulletin of the American Meteorological Society*, <https://doi.org/10.1175/BAMS-D-23-0218.1>, 2024.
- Tao, W. K., Chen, J. P., Li, Z., Wang, C., and Zhang, C.: Impact of aerosols on convective clouds and precipitation, *Reviews of Geophysics*, 50, <https://doi.org/10.1029/2011RG000369>, 2012.
- Thompson, S. A., Chen, B., Matthews, B. H., Li, R., Nowotarski, C. J., Rapp, A. D., and Brooks, S. D.: Characterizing Greater Houston's aerosol by air mass during TRACER, *Journal of Geophysical Research: Atmospheres*, 130, e2025JD044164, <https://doi.org/10.1029/2025JD043353>, 2025.
- Twohy, C. H., Petters, M. D., Snider, J. R., Stevens, B., Tahnk, W., Wetzel, M., Russell, L., and Burnet, F.: Evaluation of the aerosol indirect effect in marine stratocumulus clouds: Droplet number, size, liquid water path, and radiative impact, *Journal of Geophysical Research: Atmospheres*, 110, 2005.
- Zieger, P., Fierz-Schmidhauser, R., Weingartner, E., and Baltensperger, U.: Effects of relative humidity on aerosol light scattering: results from different European sites, *Atmospheric Chemistry and Physics*, 13, 10609–10631, <https://doi.org/10.5194/acp-13-10609-2013>, 2013.