

Response to the Referee 2's Comments

October 05, 2026

Accurate characterization of key aerosol optical properties—such as the complex refractive index (CRI), single scattering albedo (SSA), and lidar ratio (LR)—is paramount for assessing aerosol radiative impacts. However, observational constraints and limitations in retrieval theories introduce substantial uncertainties, making precise radiative evaluations a persistent challenge. To address this issue, the authors present a clear retrieval framework based on field observations collected in Slovenia in April 2016 (including SMPS–OPC size distributions, AE33-derived absorption coefficients, and ambient relative humidity data). Using this approach, they successfully derive dry-state homogeneous-equivalent CRIs alongside RH-corrected, lidar-relevant SSAs and LRs across three key wavelengths (355, 532, and 1064 nm). This work provides a viable bridge connecting dry in situ CRI retrievals with ambient, multi-wavelength aerosol optical products relevant for lidar applications. This manuscript presents an interesting approach, but there are several questions that remain to be addressed. My comments are listed as follows:

Response: We thank the reviewer for the time and effort, which have made a significant contribution to the improvement of the paper.

Major Comments:

Comment 1: The practical utility of the proposed retrieval framework requires further elaboration. In the Discussion section, the manuscript notes that "because the framework is constrained by near-surface in situ observations, its products are most directly applicable as local lidar constraints for near-surface or well-mixed lower-boundary-layer conditions, rather than as direct representations of the full vertically resolved aerosol column." Given that the retrieved aerosol optical parameters are primarily representative of near-surface conditions, could the authors clarify how this framework meaningfully advances the evaluation of aerosol radiative effects? Since radiative forcing assessments generally require column-integrated or vertically resolved profile data, near-surface results alone appear insufficient for this purpose. For example, a key purpose of determining the lidar

ratio is to constrain lidar inversions when retrieving extinction coefficient profiles. However, since the current framework yields only near-surface lidar ratios, these values are not readily applicable to solving vertical extinction coefficient profiles.

Response 1: We thank the reviewer for this important comment. We agree that the spatial representativeness of the retrieved optical properties must be distinguished from their potential role in lidar and radiative applications. The present framework directly derives aerosol optical properties constrained by near-surface in situ observations; it does not independently retrieve a vertically resolved aerosol profile.

Importantly, however, this does not restrict the retrieved quantities to purely point-level interpretation. Ground-based optical constraints can contribute to vertically resolved lidar retrievals when they are combined with independent information on the vertical atmospheric structure. For example, Liu et al. (2024) used ground-based particle-size and composition measurements together with vertically resolved meteorological information to estimate boundary-layer aerosol optical profiles and showed that representative lidar ratios can be obtained from surface observations under sufficiently well-mixed boundary-layer conditions.

Beyond this conditional role in lower-boundary-layer lidar retrievals, a complementary future application is the evaluation of aerosol-type-dependent LR priors. For example, Miffre et al. (2026) developed a laboratory method combining 180° backscatter and cavity ring-down extinction measurements to determine the LR of controlled aerosol samples and to evaluate light-scattering models. Such laboratory measurements could complement ambient, multiwavelength estimates from the present framework.

Accordingly, the LR retrieved in the present study is interpreted first as a local, aerosol-state-dependent constraint on the lidar ratio. It can be used to evaluate the physical plausibility of an assumed LR at the surface and, when independent observations establish sufficient vertical representativeness, can provide an additional constraint for lower-boundary-layer lidar retrievals. The present study does not perform this vertical coupling because suitable collocated vertically resolved observations are not available for an independent evaluation of that step.

The radiative relevance is analogous. The retrieved CRI, SSA, and associated optical properties constrain the local aerosol optical state required by radiative-transfer calculations, whereas column radiative-effect estimates additionally require independent information on the vertical or column aerosol distribution. We have revised the manuscript to distinguish clearly between the direct local products of the framework and their conditional use as constraints in vertically resolved lidar or radiative applications.

Comment 2: Limitations of Data Timeliness and Sample Size: The main conclusions of this manuscript appear to be constrained by significant data limitations. First, using decade-old observations raises questions regarding data timeliness and present-day relevance. Second, a dataset spanning merely ten days represents a severely restricted temporal sample.

It remains doubtful whether such a brief snapshot is statistically sufficient to yield generalizable or robust atmospheric insights. The authors must clarify how a ten-day regional dataset can support broader, universal claims, or reframe the study's scope to reflect its site-specific and short-term nature.

Response 2: We thank the reviewer for raising this important issue. We agree that the temporal scope of the April 2016 Vipava observations limits their use for characterizing long-term or present-day aerosol conditions at the site. We have therefore clarified the scope of the manuscript. The primary contribution of this Technical Note is methodological: the field observations are used to develop and evaluate the decoupled retrieval framework under real mixed-aerosol conditions, rather than to establish an aerosol climatology for the Vipava Valley.

The field campaign covered 7–23 April 2016, although the effective retrieval coverage was reduced by instrument availability, synchronization requirements, and quality-control screening. The retained observations allow the framework to be evaluated across the range of mixed-aerosol conditions encountered during the campaign, including its internal consistency, sensitivity, and aerosol-state-dependent optical response. They are not, however, interpreted as evidence for climatological frequencies, long-term site statistics, or universal aerosol optical relationships.

Accordingly, we have revised the manuscript to distinguish the methodological contribution of the framework from the temporal and regional representativeness of this particular field application. Campaign-derived CRI, SSA, LR, RH responses, and regime-dependent differences are now explicitly interpreted in the context of the aerosol states sampled during the Vipava campaign. The age of the observations therefore limits the present-day environmental representativeness of these results, but does not preclude their use as a field-based demonstration of the retrieval framework. Broader applicability of the framework across aerosol environments requires evaluation with additional datasets from other sites and periods.

Specific Comments:

Comment 1: Sample Size Considerations in Figure 5: Regarding the boxplots presented in Figure 5, are the sample sizes (N) for each individual box roughly comparable? A substantial disparity in sample sizes could skew the statistical distribution and potentially alter the derived conclusions. To ensure statistical rigor and transparency, the authors should explicitly specify the sample count for each box, either annotated directly within the figure or detailed in the caption.

Response 1: Thank you for this helpful suggestion. We have revised the caption of Figure 5 to report the sample counts explicitly for each boxplot group. We also clarified that the compared cases were evaluated on the same post-QC cohort, so the boxplots within each comparison are based on directly comparable sample sets. This revision improves the transparency of the statistical basis of the distributions and helps the reader assess whether differences among

boxplots may be influenced by unequal group sizes.

Comment 2: Figure Sizing and Format Consistency: The dimensions of figures throughout the manuscript should be kept as uniform as possible to ensure ease of reading. Several figures appear overly small (e.g., Figure 10). The authors are advised to adjust figure scales for better visual clarity.

Response 2: Thank you for this suggestion. We re-exported the main-text and supplementary figures using harmonized panel widths, font sizes, axis-label sizes, line widths, marker sizes, and spacing. The detailed regime-resolved analysis formerly associated with Sect. 3.4 was moved to Supplement Sect. S7, where the figures were enlarged and reformatted for improved legibility; the main text retains a concise summary and explicit cross-references.

Comment 3: Marker Visibility in Figure 10: Specifically in Figure 10, the data points/markers are too small to be visually distinguished. Please increase the marker size to improve legibility.

Response 3: Thank you for this helpful suggestion. We condensed Sect. 3.4 and moved the detailed regime-resolved analysis and associated figures to Supplement Sect. S7 (Figs. S6–S10).

We have revised the figure to improve visual readability by increasing marker sizes and enhancing the distinction among different FVF groups. In the revised figure, the three FVF categories are represented using larger and distinct markers, and the corresponding sample numbers are explicitly provided in the legend. We have also added the corresponding AAE values for each FVF group to provide additional context for the absorption-related differences associated with the observed LR spectral variations.

Comment 4: Physical Interpretation of Figure 12c: In Figure 12c, the results indicate that the influence of relative humidity (RH) becomes more pronounced at longer wavelengths. What is the physical mechanism behind this wavelength dependence? Furthermore, why does the behavior at 1064 nm run counter to the trends observed at 355 nm and 532 nm? Further clarification on these optical/hygroscopic mechanisms is needed.

Response 4: Thank you for this comment. The former Figure 12c is now presented as Figure 8c, while the corresponding extinction–backscatter decomposition is shown in Figure 9.

The results show that the RH effect should not be interpreted as increasing monotonically toward longer wavelengths. Hygroscopic water uptake changes both particle size and the effective complex refractive index, and both changes affect extinction and 180° backscatter through the size- and wavelength-dependent Mie response. The particle-size increase shifts the aerosol population across wavelength-dependent Mie size-parameter regimes, while the

accompanying refractive-index dilution modifies the scattering and absorption efficiencies. Because 180° backscatter is additionally sensitive to the angular-scattering response, its relative change need not follow that of extinction. Because $LR = \alpha_{\text{ext}} / \beta_{\text{back}}$, the sign of the LR response depends on the relative changes in extinction and backscatter.

At 355 and 532 nm, the median relative enhancement of extinction exceeded that of backscatter, consistent with positive median paired LR changes of +1.91% and +4.15%, respectively. At 1064 nm, this relationship reversed: the relative enhancement of backscatter exceeded that of extinction, with a median paired LR change of -4.20% . Thus, the opposite 1064-nm response results from the reversal in the relative extinction–backscatter enhancement, rather than from a monotonic strengthening of the RH effect toward longer wavelengths. The extinction–backscatter decomposition is shown in Fig. R1 and has been incorporated as Fig. 9 in the revised manuscript.

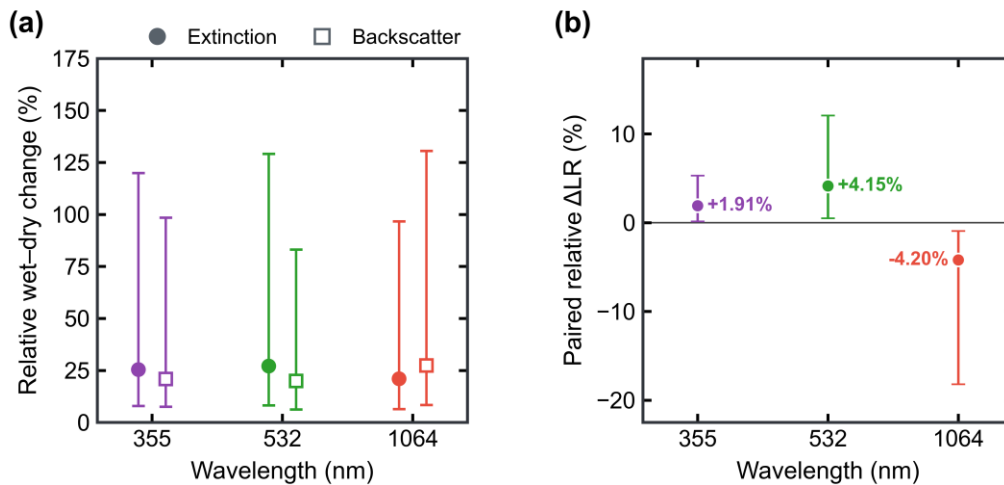


Figure R1. Wavelength-dependent RH effects on aerosol optical properties. (a) Median relative wet-reference changes in extinction and 180° backscatter at 355, 532, and 1064 nm. (b) Median hourly paired wet-versus-reference relative changes in lidar ratio. Markers denote medians and error bars denote interquartile ranges for the 275 RH-active hours from the final 304-hour post-QC cohort. At 1064 nm, lidar ratio decreased in 239 of 275 hours. The same analysis is presented in Fig. 9 of the revised manuscript.

Comment 5: Justification of Literature Comparison in Table 2: In the Discussion, the authors compare their results with previous literature in Table 2. However, the rationale and added value of this comparison require further clarification. Reported lidar ratios (LR) across different studies vary widely depending on retrieval methodologies, observation sites, and spatial representativeness (e.g., the near-surface nature of this study vs. column measurements). In addition, LR is highly sensitive to aerosol type, a factor that is not comprehensively categorized or stratified in this work. Given these fundamental discrepancies, what specific insights does

Table 2 offer, and how does it advance the discussion?

Response 5: Thank you for this important comment. Note that the former Table 2 is now Table 3 in the revised manuscript. In the revised manuscript, we have clarified that Table 3 is intended as a contextual comparison rather than an external validation dataset. The purpose of this comparison is not to demonstrate one-to-one agreement with previous LR retrievals, but to place the retrieved wavelength-dependent LR behaviour within the range of reported multi-wavelength LR behaviours under different observational contexts and to highlight the limited availability of 1064-nm LR information.

We have further revised the discussion to emphasize that the studies included in Table 3 represent different observational conditions, including ground-based lidar observations, vertically resolved aerosol-layer measurements, and operational lidar retrieval schemes. Therefore, aerosol classifications reported in these studies are retained only to describe their original measurement contexts and are not interpreted as direct aerosol-type equivalents of the Vipava Valley aerosol population.

The revised discussion now focuses on wavelength-dependent tendencies rather than absolute LR agreement. Specifically, previous studies showing both increasing and decreasing LR trends with wavelength demonstrate that LR spectral behaviour is not universal, but depends on coupled effects of aerosol microphysical state and observational constraints. This comparison therefore supports the motivation for deriving locally constrained, physically based LR estimates rather than applying fixed empirical LR assumptions across different aerosol environments.

References

- Liu, X., Alves Gouveia, D., Henzing, B., Apituley, A., Hensen, A., van Dinter, D., Huang, R., and Dusek, U.: Aerosol optical properties within the atmospheric boundary layer predicted from ground-based observations compared to Raman lidar retrievals during RITA-2021, *Atmos. Chem. Phys.*, 24, 9597–9614, <https://doi.org/10.5194/acp-24-9597-2024>, 2024.
- Miffre, A., Pacoret-Berenger, C., Genoud, A. P., and Rairoux, P.: A novel laboratory methodology to evaluate the particle extinction-to-backscatter ratio or particle lidar ratio of aerosols, *Sci. Rep.*, 16, 28738, <https://doi.org/10.1038/s41598-026-61997-3>, 2026.