



Satellite–Ground Intercomparison between EarthCARE/ATLID and the China Aerosol Raman Lidar Network (CARLNET): Part I. Case Studies

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Abstract. The Atmospheric Lidar (ATLID) aboard the Earth Cloud Aerosol and Radiation Explorer (EarthCARE) provides vertical aerosol profiles at 355 nm, which should be verified by other instruments. Here, we use ground-based Raman and polarization measurements from the China Aerosol Raman Lidar Network (CARLNET) as an independent ground-based reference for spaceborne products validation. We compare the particle backscatter coefficient, particle extinction coefficient, particle lidar ratio, and particle linear depolarization ratio from the ATLID aerosol product (A-AER) and the ATLID extinction, backscatter, and depolarization product (A-EBD). We also compare processing baselines for the same overpasses. For each case and product, we analyze both the ATLID profiles closest to each station and the quality-screened mean profiles of ATLID within 50 km of that station. Four cases at three ground stations were analyzed in detail. In the case of the Minfeng lidar station on 25 April, the layer-mean difference in the A-EBD particle extinction coefficient relative to the CARLNET lidar changes from -21.33% in baseline AE to +18.06% in baseline BA. The corresponding difference in the particle lidar ratio changes from -43.33% to +1.20%. In the Changdao-lidar case on 25 March and the Minfeng-lidar case on 31 March, A-EBD retains more within-layer peaks and troughs that correspond to those observed by CARLNET. A-AER yields smoother profiles with broader layers. In the Sheyang-lidar case on 30 May, cloud-classified bins affect the extremely high values in the low-altitude A-EBD profiles for baseline AF. Excluding these bins reduces the high values, but they remain above those in baseline BA and the CARLNET lidar observations. The Minfeng case on 31 March further shows that the particle extinction coefficient and particle lidar ratio are markedly low at low altitudes in baseline BA for both data products. Together, the four case studies demonstrate that CARLNET can provide independent reference values for ATLID aerosol optical data products over China. These four case studies also identify the products, parameters, and altitudes at which ATLID and CARLNET values differ. The effects of processing baselines vary by event and altitude. The baselines therefore cannot be ranked consistently by accuracy according to their release order.



30 1 Introduction

The vertical distribution of aerosols, particularly their position relative to clouds, influences their radiative effects and interactions with clouds (Vuolo et al., 2014; Costantino and Bréon, 2013). Passive satellite remote sensing provides broad horizontal coverage but generally cannot resolve complex aerosol vertical structures independently. Ground-based lidars can continuously observe atmospheric evolution above fixed sites but cannot provide global coverage alone. Spaceborne lidars are therefore needed to establish global observations of aerosol and cloud vertical distributions, while ground-based lidars provide independent vertically resolved references for evaluating spaceborne-lidar signals and products (Winker et al., 2009; Illingworth et al., 2015).

EarthCARE (Earth Cloud Aerosol and Radiation Explorer) is a joint mission of the European Space Agency (ESA) and the Japan Aerospace Exploration Agency (JAXA) and was launched on 29 May 2024. The satellite carries four instruments: the Atmospheric Lidar (ATLID), the Cloud Profiling Radar (CPR), the Multi-Spectral Imager (MSI), and the Broad-Band Radiometer (BBR) (ESA, 2024). The synergistic observations from these active and passive remote sensing instruments provide insights into the interactions among aerosols, clouds, precipitation, and radiation (Wehr et al., 2023). ATLID is a linearly polarized high-spectral-resolution lidar operating at 355 nm. By separating molecular Rayleigh scattering from particulate Mie scattering and measuring the cross-polarized return, ATLID provides the observations needed to retrieve particle backscatter coefficient, particle extinction coefficient, particle lidar ratio, and particle linear depolarization ratio from space (do Carmo et al., 2021). The EarthCARE science processing chain converts calibrated Level-1 signals into single-instrument Level-2a and synergistic Level-2b products. The ATLID Profile Processor (A-PRO) generates the aerosol and cloud optical and classification products considered in this study (Eisinger et al., 2024; Donovan et al., 2024). EarthCARE completed commissioning in late 2024 (ESA, 2025a; JAXA and NICT, 2025). By March 2025, ESA–JAXA in-orbit validation activities included Level-1 data and Level-2a retrieval products (ESA and JAXA, 2025). For ATLID, product evaluation cannot be reduced to whether satellite and ground-based lidar profiles exhibit consistency upon visual inspection. Instrument calibration, background noise, feature detection, cloud-aerosol boundaries, horizontal and vertical smoothing, a priori constraints, multiple-scattering effect, and product quality status can all affect the final lidar profiles. At the same time, an instantaneous along-track satellite sample and a time-averaged observation above a fixed lidar ground site generally do not represent exactly the same atmospheric volume (van Zadelhoff et al., 2023; Donovan et al., 2024). Satellite-ground differences of the lidar profiles may therefore arise from the satellite product data-processing chain, the ground-based retrieval results, differences in observing response, or genuine spatiotemporal variability of atmospheric conditions. These comparison conditions must be checked before a satellite–ground difference is interpreted as a possible error in an ATLID product (Amiridis et al., 2025).

Long-term coordination between the Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation (CALIPSO; NASA, n.d.) mission and the European Aerosol Research Lidar Network (EARLINET; EARLINET, n.d.) established a methodological basis for this task (Pappalardo et al., 2010). Coordinated overpass measurements, cloud screening, profile matching, case



diagnostics, and network analyses showed that standardized ground-based lidars can reveal systematic issues in spaceborne-lidar signals and products (Mona et al., 2009; Pappalardo et al., 2010, 2014; Grigas et al., 2015; Papagiannopoulos et al., 2016).
65 They also showed that collocation distance, weather, horizontal continuity of aerosol layers, and the effective resolutions of the two systems can change the comparison substantially (Mamouri et al., 2009; Gimmestad et al., 2017). Ground-based validation of CALIPSO observations over China and validation of the DQ-1 Aerosol and Carbon Detection Lidar (ACDL; Dai et al., 2024) atmospheric profiles further demonstrate that Chinese ground-based lidar observations can provide regional independent references for spaceborne backscatter, extinction, lidar ratio, and depolarization profiles (Wu et al., 2011; Liu et al., 2024; Dai et al., 2024; Zha et al., 2024). DQ-1 and ATLID differ in wavelength and product design, so their reported error ranges cannot be transferred directly; however, their collocation, scene-screening, and discrepancy-diagnosis strategies remain methodologically relevant. Baars et al. (2026) analyzed seven EarthCARE overpasses by comparing the geometrically closest ATLID profile with observations from PollyNET (TROPOS, n.d.) and using the ground-based time-height evolution and the ATLID along-track scene to characterize the atmospheric context of each comparison. Floutsi et al. (2026) examined
75 CALIPSO-PollyXT comparisons at Mindelo on São Vicente Island, Cabo Verde, in the eastern tropical Atlantic, focusing on how spatial separation and horizontal aerosol inhomogeneity affect whether the two instruments sample comparable atmospheric conditions. Zhang et al. (2026) compared total attenuated backscatter profiles from DQ-1/ACDL and the Asian Dust and Aerosol Lidar Observation Network (AD-Net; NIES, n.d.) at three coastal sites in Japan and related the observed differences to variations in aerosol and cloud layers and meteorological conditions. Despite these methodological advances,
80 independent case-based evaluations of the EarthCARE ATLID Level-2a data using ground-based lidar observations in China remain limited. CARLNET (China Aerosol Raman Lidar Network) provides the observational basis for filling this regional and scene-dependent gap. The network was established by the China Meteorological Administration; its published network papers describe a development phase comprising 49 co-designed multiwavelength polarization Raman lidars (Shao et al., 2025; Bu et al., 2026). According to the author team's operating records, the network is expanding rapidly, and over 100 systems are
85 projected to be deployed by the end of 2026. The sites cover plateaus, deserts and desert margins, grasslands, plains, and coastal environments; the updated station distribution as of September 2025 is shown in Fig. 1.



Distribution of CARLNET Stations (as of September 2025)

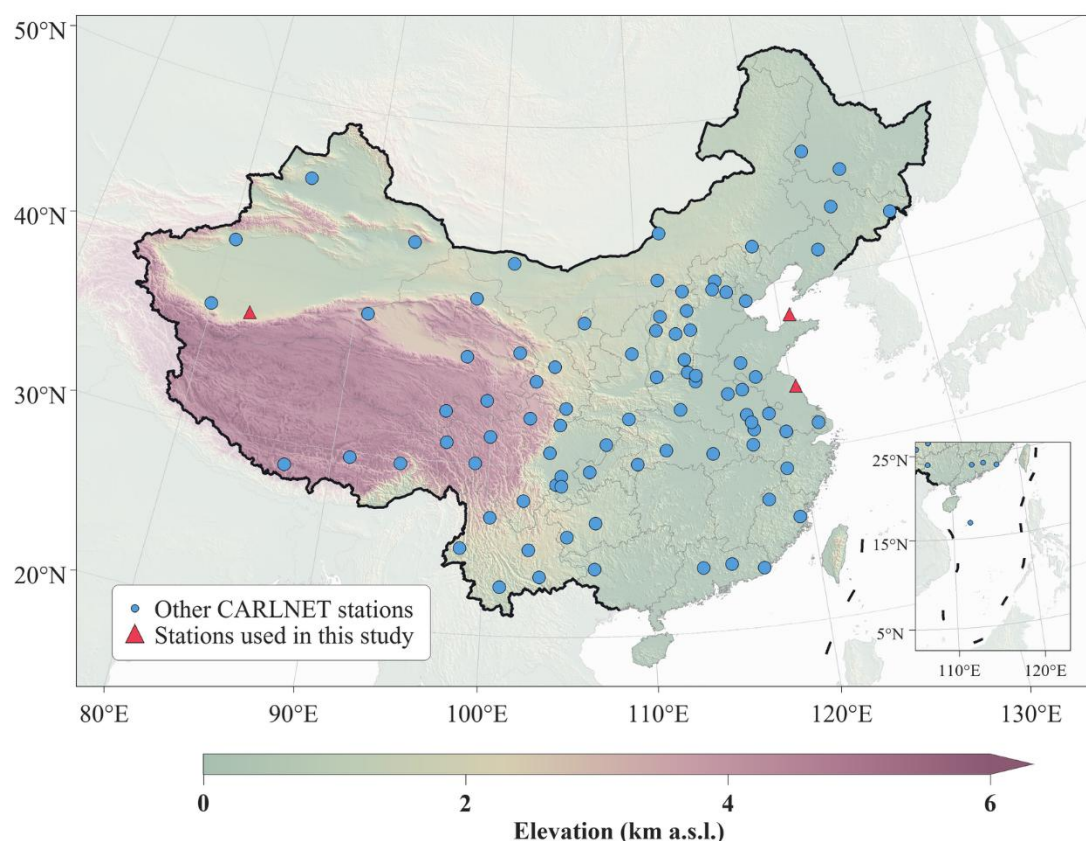


Figure 1. Distribution and site altitude of CARLNET stations as of September 2025. Red triangles mark the stations used in this study, while blue circles represent the other CARLNET stations. The background colors indicate altitude (km a.s.l.), and the inset shows the South China Sea region.

CARLNET's 355 nm elastic, nitrogen Raman, and polarization channels allow retrieval of the particle backscatter coefficient, particle extinction coefficient, particle lidar ratio, and particle linear depolarization ratio at the same nominal wavelength as ATLID. With stations distributed across China, CARLNET continuously observes the evolution of aerosol and cloud layers before and after EarthCARE overpasses under a wide range of atmospheric conditions. CARLNET's value lies not in assuming error-free ground-based lidar profiles of atmospheric conditions (mainly in the context of aerosol particles and clouds), but in using an independent observing geometry and retrieval chain to determine which structures ATLID observations preserve and in which situations anomalous behavior of measured profiles appears.

To address the limited availability of independent evaluations of EarthCARE ATLID Level-2a products using ground-based lidar observations in China, this study analyzes four nighttime EarthCARE overpasses in 2025 for which concurrent CARLNET observations were available. For each overpass, profiles of the particle backscatter coefficient, particle extinction coefficient, particle lidar ratio, and particle linear depolarization ratio from the A-AER and A-EBD products are compared with the corresponding CARLNET profiles. The analysis is organized around three questions. First, under close collocation



and temporally persistent atmospheric conditions, to what extent are ATLID Level-2a A-AER and A-EBD product profiles consistent with CARLNET observations in layer position, vertical structure, and retrieved aerosol optical properties? Second, how sensitive are the observed satellite-ground differences to the use of the nearest ATLID profile or a local along-track mean? Third, for the same overpass and spatial support, how do the observed differences vary among optical variables, between the linked A-AER and A-EBD products, and between available processing baselines? The analysis combines event-specific profile comparisons with a cross-case examination of recurring features among the four selected overpasses. Section 2 describes the observations and comparison strategy, Section 3 presents the cases, Section 4 discusses the results, and Section 5 summarizes the findings.

2 Data and methods

2.1 EarthCARE ATLID products

We use three ESA EarthCARE ATLID single-instrument Level-2a A-PRO products: ATL_AER_2A, the ATLID Aerosol Inversion (A-AER) product; ATL_EBD_2A, the ATLID Extinction, Backscatter and Depolarization (A-EBD) product; and the ATLID Target Classification (A-TC) product for scene interpretation. A-AER applies feature-guided adaptive horizontal and vertical averaging according to target type and signal strength, followed by a relatively direct high-spectral-resolution lidar retrieval of particle backscatter coefficient, particle extinction coefficient, particle lidar ratio, and particle linear depolarization ratio. Its results also provide layer structure, classification, and optical starting values or prior information to A-EBD (Donovan et al., 2024; Donovan and van Zadelhoff, 2025a).

A-EBD uses a column-wise, layer-based optimal-estimation framework that accounts for multiple scattering in the forward model and provides high-, medium-, and low-resolution outputs for weak targets. We used the low-resolution A-EBD output profiles throughout because their stronger horizontal averaging reduces noise-related variability in weak aerosol layers and provides a stable basis for comparison across the selected cases, albeit with broader horizontal support (Donovan et al., 2024; Baars et al., 2026). A-EBD is not a second blind retrieval independent of A-AER but is linked to it within A-PRO. Presenting the two products together therefore allows us to assess whether a feature is already present in the upstream A-AER result or is modified or retained during A-EBD optimal estimation, rather than to determine which product is superior or inferior (Donovan et al., 2024; Donovan and van Zadelhoff, 2025b). We compare the 355 nm particle backscatter coefficient, particle extinction coefficient, particle lidar ratio, and particle linear depolarization ratio. Along-track A-TC classes identify aerosol, ice cloud, liquid cloud, attenuation, and surface scenes; they are used as contextual classifications rather than as optical-profile measurements (Irbah et al., 2023).

EarthCARE data products are released under two-letter processing-baseline identifiers that denote the version of the processing chain used to generate them. Within a baseline series, the second letter changes for incremental updates (e.g., AE to AF), whereas a major update intended for full-record reprocessing advances the first letter and resets the second to A (e.g., BA; Baars et al., 2026). Baseline BA reprocesses EarthCARE observations from August 2024 to September 2025, covering all



135 cases analyzed here. We therefore use BA for the primary cross-case comparisons so that all cases are examined using the same processing version; earlier AE or AF products are used only in paired comparisons of the same overpass. BA is not treated as a truth standard or assumed to be superior for every variable and altitude.

2.2 CARLNET ground-based observations

Each CARLNET lidar emits at 355, 532, and 1064 nm and receives the corresponding elastic signals, polarization components
140 at 355 and 532 nm, nitrogen Raman signals near 387 and 607 nm, and a water-vapor Raman signal near 407 nm (Shao et al., 2025; Bu et al., 2026). For this study, we use nighttime observations from the 355 nm elastic channel, the 387 nm nitrogen Raman channel, and the parallel and perpendicular polarization channels at 355 nm. Nighttime measurements reduce solar-background interference in the nitrogen Raman channel and permit an independent vibrational-Raman retrieval of particle extinction coefficients. Particle backscatter coefficients are obtained from the elastic-to-Raman signal ratio, particle lidar ratios
145 from the ratio of independently retrieved extinction and backscatter coefficients, and particle linear depolarization ratios after correction for the relative gain between the parallel- and cross-polarized receiver channels (Ansmann et al., 1992; Pappalardo et al., 2004; Wandinger, 2005; Freudenthaler et al., 2009; Freudenthaler, 2016). However, similar instrument configurations and established raw-signal quality-control procedures do not replace a dedicated assessment of the quantitative consistency of retrieved products among stations. The present study therefore uses only CARLNET profiles that pass case-level quality
150 screening as independent ground-based references for ATLID products. These profiles are used to diagnose agreement and mismatch in representative scenes, rather than to infer network-wide consistency within CARLNET or the overall statistical performance of ATLID products from a limited number of cases.

For every case, we examined time-height curtains of the 355 nm range-corrected signal (RCS) and 355 nm volume linear depolarization ratio (VLDR). RCS was used to assess the temporal evolution of aerosol layers and clouds, while VLDR
155 indicated the presence of nonspherical particles. Both ground-based curtains (RCS and VLDR) are displayed as height above ground level (a.g.l.). The CARLNET optical profiles are averaged over the ground-based period matched to the satellite overpasses and converted to altitude above sea level (a.s.l.). In each case-study figure, the profile-comparison panels show the ATLID and CARLNET profiles together with their reported uncertainties. The same panels contain horizontal lines marking the CARLNET station altitude and the altitude above which the CARLNET lidar reaches full overlap. Ground-based values
160 below the displayed full-overlap altitude are removed.

2.3 Case selection and satellite-ground matching

All four cases have nighttime CARLNET Raman observations and A-AER and A-EBD profiles suitable for comparison. The Minfeng case on April 25 is used for a detailed comparison of baselines AE and BA. The Changdao case on March 25 examines the within-layer structure and altitude grids of the two products. The Sheyang case on May 30 examines classification, samples,
165 and mid-altitude discrepancies for baselines AF and BA. The Minfeng case on March 31 tests whether the baseline relationship



observed in the Minfeng case on April 25 also appears during another overpass at the same station. Table 1 lists the stations, times, and baselines. The case order follows the sequence of the analysis in this study.

Table 1. Overview of the three CARLNET stations and four EarthCARE/ATLID overpasses used in this study.

Case	CARLNET Location (°E, °N)	CARLNET Elevation (m a.s.l.)	Overpass (UTC)	Integration Time (UTC)	Nearest distance	Baselines
Minfeng 25 Apr 2025	82.69, 37.07	1408.9	20:05:25	19:30-20:30	1.08 km	BA/AE
Changdao 25 Mar 2025	120.70, 37.99	66.0	17:33:33	17:00-18:00	11.15 km	BA/AE
Sheyang 30 May 2025	120.30, 33.75	3.0	17:36:04	17:00-18:00	21.07 km	BA/AF
Minfeng 31 Mar 2025	82.69, 37.07	1408.9	20:05:22	19:30-20:30	7.73 km	BA/AE

2.3.1 Closest ATLID Product Profile and 50 km Mean Profile

170 We calculate the distance from each station to the geolocation of each ATLID product profile. We select the closest profile as the primary satellite–ground matchup. This preserves the most direct pairing and is comparable to the use of the closest available ATLID profile in previous EarthCARE ground-based case studies (Baars et al., 2026).

Inspection of along-track classifications and neighboring profiles showed that adjacent product profiles could vary markedly even when the closest profile was near the station. Thus, a comparison based only on the ATLID product profile closest to the station may be affected by retrieval noise in that profile or by horizontal heterogeneity in aerosol distribution along the track. It also cannot show whether the satellite–ground difference persists in neighboring profiles. As a result, it may not accurately describe product behavior along the nearby track. Thus, for all four cases, we also calculate the arithmetic mean of retrieved product profiles within 50 km of the station at each altitude level.

For cases in which the closest ATLID product profile is within 50 km of the station, we retain A-AER and A-EBD values with a quality status of 0 (“Good: Nominal”) or 1 (“Likely Good but possibly degraded or affected by a low signal-to-noise ratio”), as defined in the corresponding product definition documents (Donovan and van Zadelhoff, 2025a, b). The mean describes the aggregate profile along the nearby track. It also tests whether a difference in the closest profile persists after spatial averaging. Distance is thus used as an initial geometric descriptor rather than as sufficient evidence of scene representativeness, consistent with previous CALIPSO- and Aeolus–EARLINET comparisons (Mamouri et al., 2009; Abril-Gago et al., 2022).

185 2.3.2 Vertical coordinates, uncertainty representation, and comparison methods

ATLID product heights are used as altitudes above sea level (a.s.l.). CARLNET optical profiles are shown at the corresponding ATLID altitude levels, without interpolation across invalid-data gaps. A common nominal altitude grid does not imply the same effective vertical resolution. Local peaks and sharp layer boundaries must therefore be interpreted in light of the smoothing and retrieval methods used for each profile. In the 50 km mean-profile plots, the ATLID shading is drawn around



the mean profile using the arithmetic mean, at each altitude, of the uncertainties reported for the valid contributing product profiles. Neighboring product profiles are not statistically independent, and the product files do not provide the inter-profile covariance needed to propagate their uncertainties. The shading summarizes the reported uncertainties of the contributing profiles. It is neither the uncertainty of the mean profile nor the standard deviation among profiles. We assess satellite–ground differences first from profile shape and values over the common valid altitude range. Overlapping shaded bands alone do not demonstrate agreement between the ATLID and CARLNET profiles. For specified altitude layers, relative differences use CARLNET as the reference and follow the sign convention $100\% \times (\text{ATLID} - \text{CARLNET}) / \text{CARLNET}$. Positive values indicate higher ATLID values; negative values indicate lower ATLID values. We use layer-mean differences only for the specified layers and parameters of each case. We do not pool values from different stations, events, or neighboring product profiles as independent samples for an overall statistical analysis. The closest product profile and the 50 km mean profile have different spatial supports, so we report their results separately.

3 Results

Table 2. Comparison focus and main findings for four overpasses of EarthCARE. The data products are the ATLID aerosol product (A-AER) and the ATLID extinction, backscatter, and depolarization product (A-EBD).

Case	Main finding
Minfeng on April 25, 2025	Baseline BA in both products reduced the underestimation of the particle extinction coefficient and particle lidar ratio relative to CARLNET seen in baseline AE.
Changdao on March 25, 2025	A-EBD retained more detail within the aerosol layer.
Sheyang on May 30, 2025	The extremely high low-altitude A-EBD values in baseline AF were sensitive to cloud-classified bins and remained high after removing them. Baseline BA improved the low-altitude result, but the particle extinction coefficient and particle lidar ratio at mid-altitudes remained higher than CARLNET.
Minfeng on March 31, 2025	Both data products in baseline BA underestimated the low-altitude particle extinction coefficient and particle lidar ratio. The nominal 50 km mean of A-EBD/AE was instead closer to CARLNET results.

Table 2 summarizes the main finding of each case. The following sections present the closest ATLID product profiles and the 50 km mean profiles for the three CARLNET lidar stations.

3.1 Minfeng on April 25, 2025: Changes in the particle extinction coefficient and particle lidar ratio across processing baselines

Figure 2 shows that EarthCARE passed near Minfeng at 20:05:25 UTC. The center of the closest ATLID product profile was 1.08 km from the Minfeng station. The ground-based signal used for retrieval of the optical parameters was accumulated from 19:30:00 to 20:30:00 UTC. As shown in Figures 2b and 2c, the main aerosol layer extended from near the station surface at about 1.4 km above sea level (a.s.l.) to about 3.5 km a.s.l. Particle linear depolarization ratios of about 0.28–0.32 within the main layer, together with the desert-margin setting of Minfeng, are consistent with dust, i.e., nonspherical mineral particles.

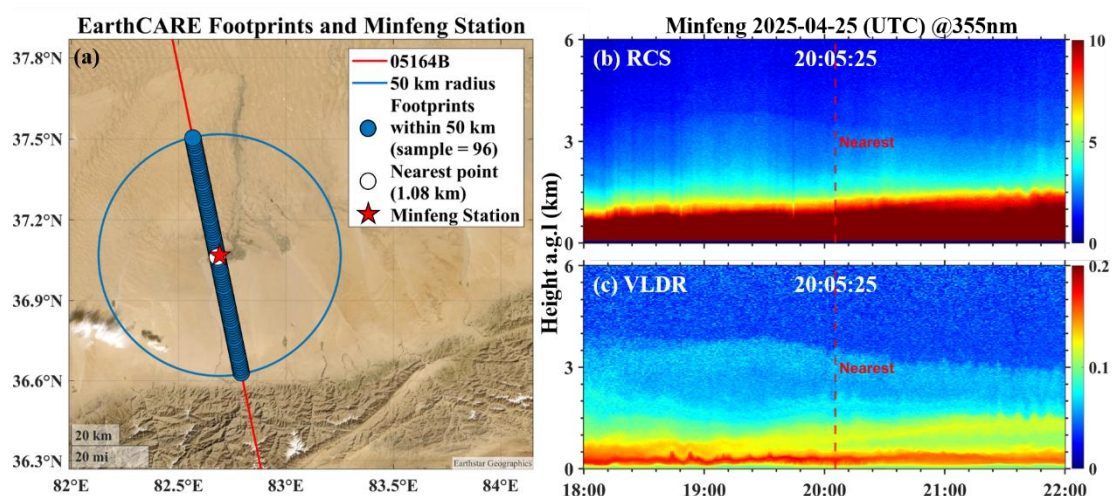


Figure 2. EarthCARE overpass near the Minfeng station on April 25, 2025. (a) Map showing the CARLNET station and the EarthCARE ground track; (b) ground-based 355 nm range-corrected signal (RCS); and (c) ground-based 355 nm volume linear depolarization ratio (VLDR). The time–height plots cover 18:00–22:00 UTC. The nearest satellite overpass occurred at 20:05:25 UTC.

Figure 3 shows that both A-AER and A-EBD identify the main aerosol layer under both processing baselines. In baseline AE, the particle backscatter coefficient profiles from both products have a broad peak near 2.4 km a.s.l., similar to the peak shown in the profile obtained with the CARLNET lidar, with a peak value of about $7.5 \text{ Mm}^{-1} \text{ sr}^{-1}$. A-EBD/AE also has a local minimum near 2.0 km a.s.l. that is well below the CARLNET backscatter profiles. This dip is absent in the profile obtained with BA. The BA particle backscatter coefficient profiles of both data products are also smoother than those obtained with AE. Larger baseline differences occur in the particle extinction coefficient and particle lidar ratio. Within and above the main layer to about 4.0 km a.s.l., both parameters in A-EBD/AE remain low and separate from the uncertainty range reported for the CARLNET lidar profiles at several altitudes. Both parameters increase substantially in A-EBD/BA and are closer to the results obtained with CARLNET. Their reported uncertainty ranges overlap with the CARLNET profiles over more continuous altitude intervals. A-AER shows the same direction of change from AE to BA data processing. For the particle linear depolarization ratio, the closest A-EBD/AE profile has low values within the main layer and a comparably broad uncertainty range. This result indicates limited quantitative discrimination for this parameter in A-EBD/AE. Results obtained with BA are closer to the CARLNET-profile value of about 0.3. The two A-AER baselines differ less in the particle linear depolarization ratio. Thus, the clearest improvement with BA in this case concerns the particle extinction coefficient and particle lidar ratio, not a comparable improvement in all four parameters.

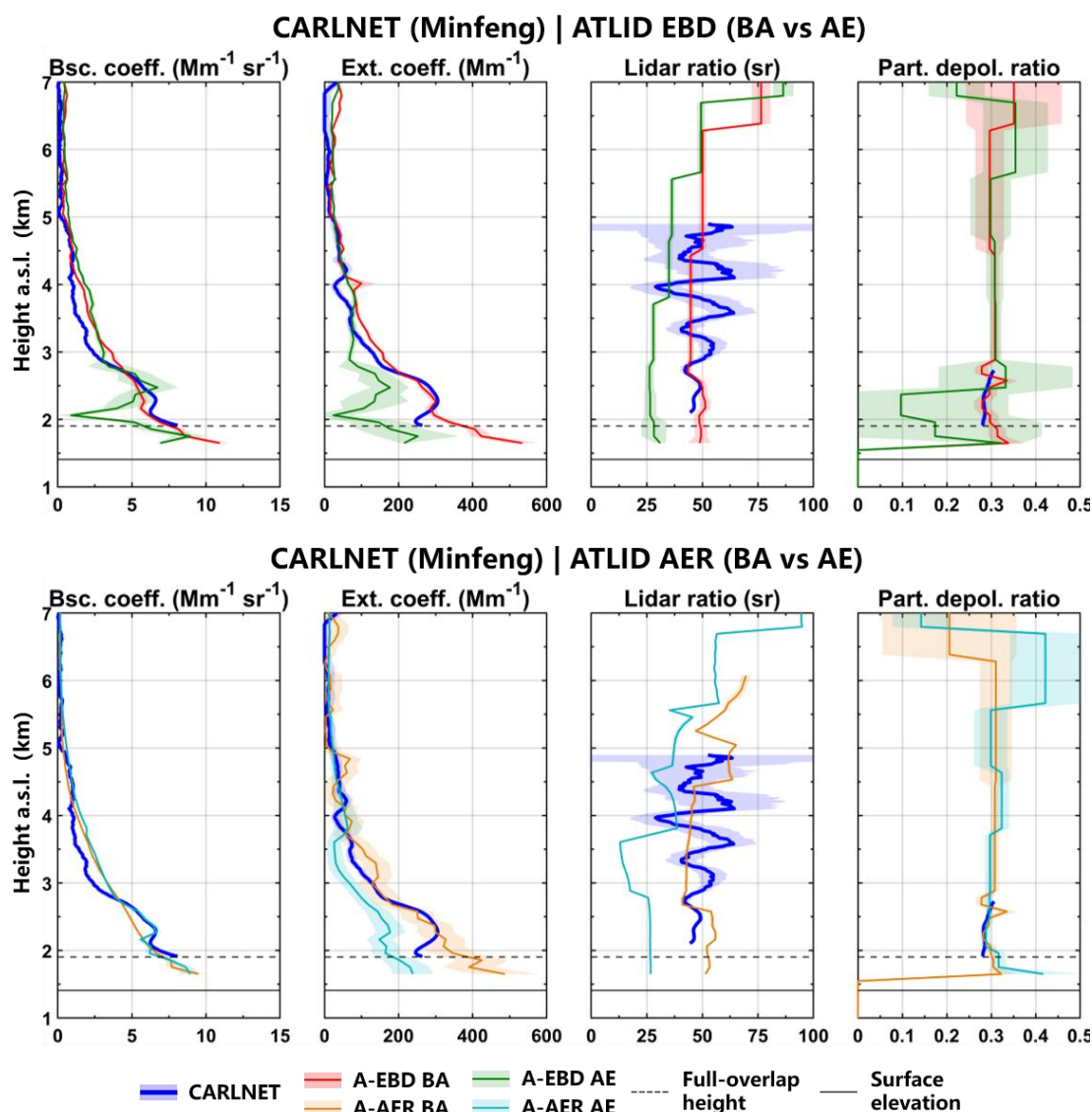


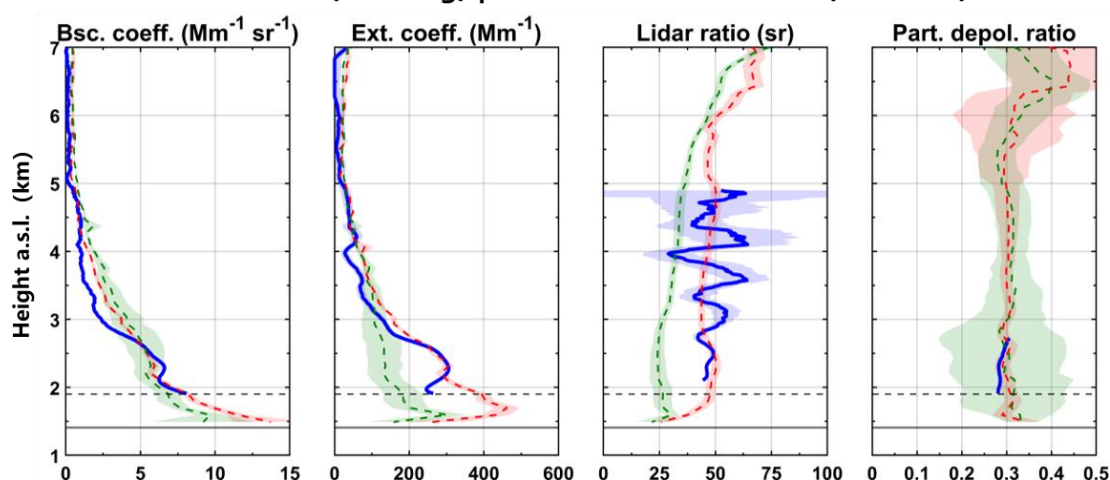
Figure 3. Particle optical parameters for the closest ATLID product profile at Minfeng on April 25, 2025. The nearest satellite overpass occurred at 20:05:25 UTC. Ground-based lidar signals from 19:30:00 to 20:30:00 UTC were used for the optical retrievals. Results from baselines BA and AE for A-EBD and A-AER are compared with results obtained by the CARLNET lidar. The shaded ranges show the uncertainties reported for the individual profiles.

To reduce the possible influence of an anomalous individual satellite track point on the BA–AE difference, we averaged quality-screened valid data from 96 along-track locations within 50 km of the station. Figure 4 shows that the baseline differences in the particle extinction coefficient and particle lidar ratio seen in Figure 3 persist after data averaging. The central A-EBD/AE profile of the particle linear depolarization ratio no longer shows the pronounced low values seen in Figure 3. However, below 3.5 km a.s.l., the arithmetic mean of the reported uncertainties across contributing profiles remains large. For the 1.9–3.5 km aerosol layer, the layer-mean relative difference in the A-EBD particle extinction coefficient against the

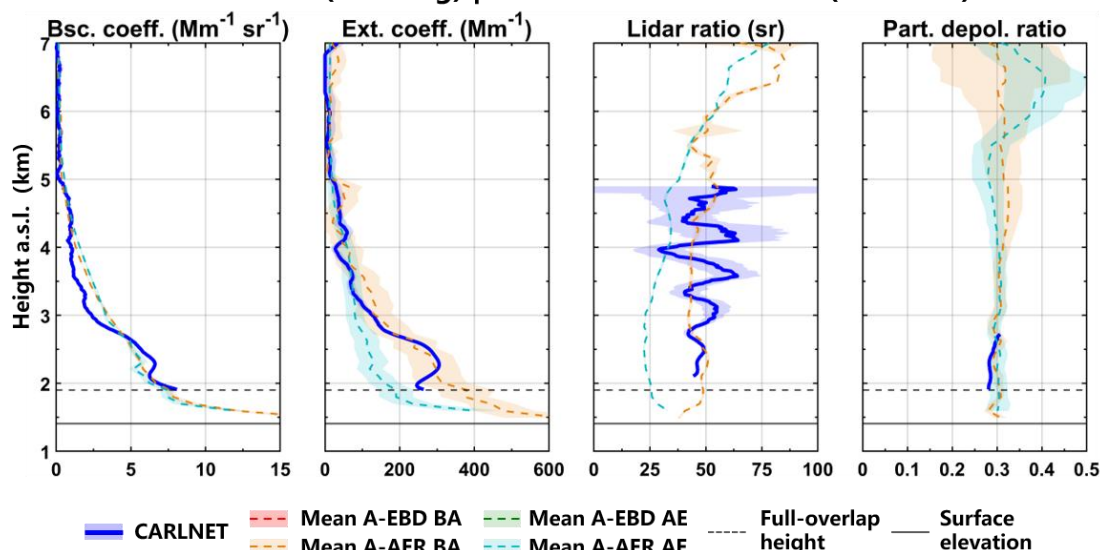


CARLNET profile changes from -21.33% in AE to +18.06% in BA. For the particle lidar ratio, it changes from -43.33% to +1.20%. The corresponding A-AER differences change from -41.26% and -48.86% to +14.80% and +0.20%, respectively. In contrast, the 50 km mean particle backscatter coefficient profile shows no marked change from the closest profile in Figure 3, and the particle linear depolarization ratio is also mostly close to the CARLNET profile within the aerosol layer. The baseline differences in the particle backscatter coefficient and particle linear depolarization ratio are less pronounced than those in the particle extinction coefficient and particle lidar ratio.

CARLNET (Minfeng) | Mean 50km ATLID EBD (BA vs AE)



CARLNET (Minfeng) | Mean 50 km ATLID AER (BA vs AE)



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Figure 4. Mean particle optical parameters within a 50 km radius of the Minfeng station on April 25, 2025. The nearest satellite overpass occurred at 20:05:25 UTC. Ground-based lidar signals from 19:30:00 to 20:30:00 UTC were used for the optical retrievals. Results from baselines BA and AE are shown for A-EBD and A-AER. The shaded ranges show the arithmetic mean of the uncertainties reported for the validated contributing product profiles.



255 These results show that BA changes the layer-mean relative difference in the particle extinction coefficient from negative to slightly positive in both data products, while reducing the markedly negative difference in the particle lidar ratio to near zero. The particle lidar ratio is defined as the ratio of the particle extinction coefficient to the particle backscatter coefficient. Because the baseline difference in the particle backscatter coefficient is small, the difference in the particle lidar ratio is mainly driven by the particle extinction coefficient. The changes that occur in the particle extinction coefficient and particle lidar ratio when
 260 changing from AE to BA have the same direction in the A-AER and A-EBD data products. A-EBD uses the layer structure, particle lidar ratio prior, and initial particle extinction coefficient estimate from A-AER. This baseline sensitivity may therefore already be present in the upstream A-AER result and remain after the subsequent optimal-estimation retrieval in A-EBD (Donovan et al., 2024).

This case also examines classification and valid sample counts. Among 96 candidate ATLID profiles, each product contains
 265 about 1,404–1,405 quality-accepted altitude–track bins in 1.9–3.5 km a.s.l. In AE, 78 bins are classified as ice cloud; in BA, 10. The differences are concentrated at the top of the main layer. We selected altitude bins between 1.9 and 2.83 km a.s.l. that were classified as valid aerosol in both baselines. Over these same bins, the mean particle extinction coefficients were about 280 Mm^{-1} for A-EBD/BA and 137 Mm^{-1} for A-EBD/AE. The mean particle lidar ratios are about 48 and 25 sr, respectively. The corresponding CARLNET lidar-profile values at the same altitudes are about 260 Mm^{-1} and 44 sr. The change in
 270 classification at the layer top affects the included sample but does not account for the entire BA–AE difference within the main layer. This differs from the Sheyang case on May 30, in which many low-altitude AF bins are classified as cloud.

Overall, in the Minfeng dust case on April 25, the BA-processed ATLID profiles agree relatively well with CARLNET retrievals in the vertical variation and overall values of the four particle optical parameters within the target layer. Relative to AE, the cumulative data processing changes from AE to BA markedly reduce the differences in the particle extinction
 275 coefficient and particle lidar ratio against the CARLNET results in both products. The height of the main aerosol layer and the overall structure of the particle backscatter coefficient profiles vary little between the baselines and broadly agree with CARLNET observations. The closest profile and the 50 km mean support the same baseline-related changes in the particle extinction coefficient and particle lidar ratio. Under conditions of a short satellite–station separation and persistence of the target aerosol layer around the overpass, this shows that CARLNET can serve as an independent reference for case-level
 280 evaluation of ATLID Level 2a aerosol products.

3.2 Changdao on March 25, 2025: Representation of within-layer peaks and troughs by the A-AER and A-EBD data products

Figure 5 shows that EarthCARE passed near Changdao at 17:33:33 UTC, and the closest ATLID product profile was 11.15 km away from the station. The ground-based signal was accumulated from 17:00:00 to 18:00:00 UTC. Figures 5b and 5c show
 285 multiple aerosol layers at about 1.6–4.7 km a.s.l. over Changdao. These layers persisted before and after the overpass, and their overall vertical distribution changed little over time. The particle linear depolarization ratio retrieved by the CARLNET lidar is about 0.22–0.26, indicating that nonspherical particles dominate this layer. Aerosols are also present near the surface



at 0–1 km above ground level (a.g.l.). However, the lower part of this layer is below the full-overlap altitude of the Changdao lidar. This case therefore focuses on the aerosol layer at 1.6–4.7 km a.s.l.

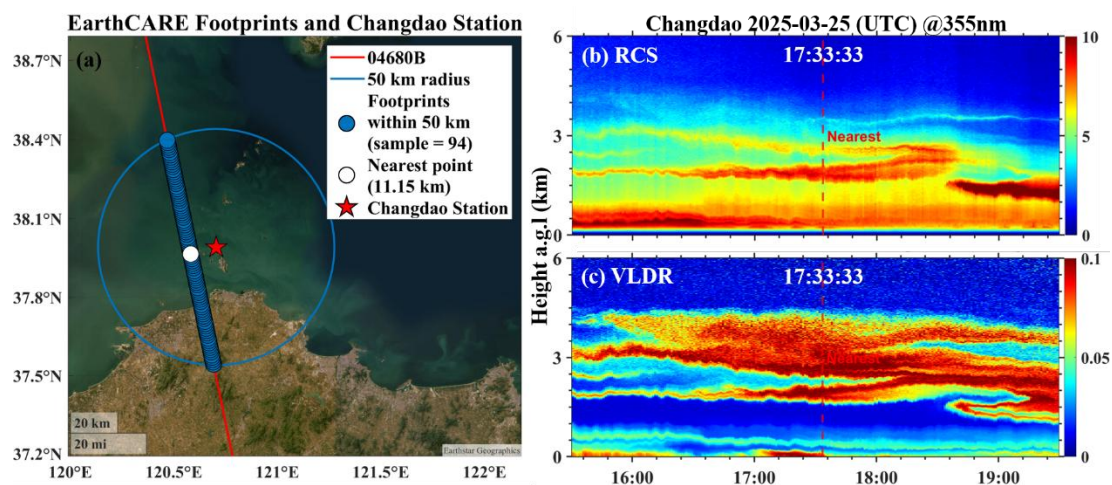


Figure 5. EarthCARE overpass near the Changdao station on March 25, 2025. (a) Map showing the CARLNET station and the EarthCARE ground track; (b) ground-based 355 nm range-corrected signal (RCS); and (c) ground-based 355 nm volume linear depolarization ratio (VLDR). The time–height plots cover 15:30–19:30 UTC. The nearest satellite overpass occurred at 17:33:33 UTC.

Figure 6 shows that data products from A-AER and A-EBD identify the main aerosol layer, but differ in within-layer details. The CARLNET particle backscatter coefficient and particle extinction coefficient profiles show adjacent peaks and troughs near 2.0, 2.7, and 3.5 km a.s.l. A-EBD/BA retains this alternating structure, although some extrema are about 0.2–0.4 km higher than in the respective CARLNET profile. The overall A-EBD/AE profile structure resembles the one obtained with BA, but has more fluctuations and wider uncertainties at 3.0–4.5 km a.s.l. In both baselines, the A-AER profiles show a smoother, broader layer in which several neighboring CARLNET profile-extrema are markedly subdued. In the main aerosol layer, the particle lidar ratio and particle linear depolarization ratio in both data products are generally within the range of the CARLNET values. The local profile shape in BA is closer to the ground-based result.

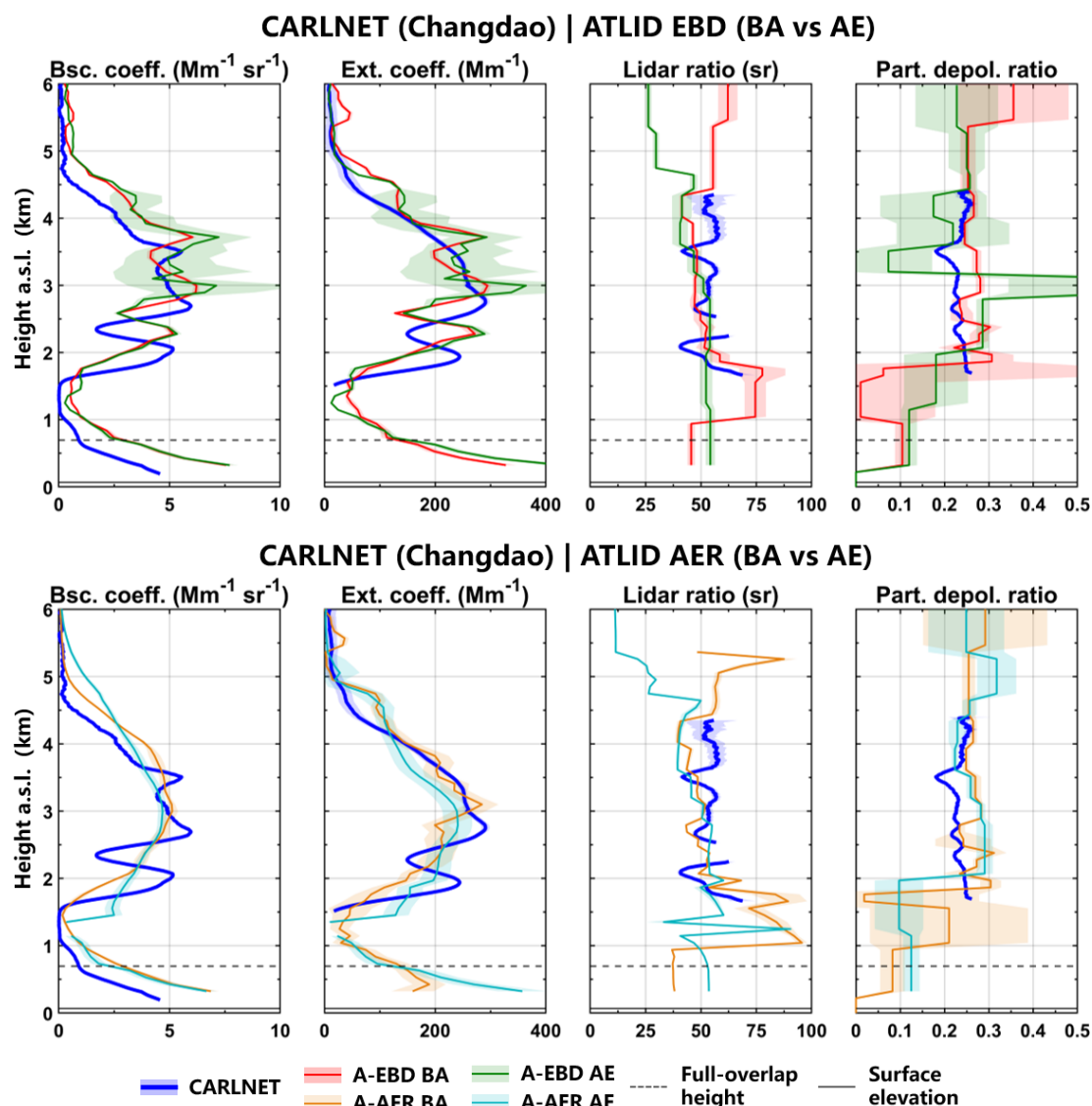


Figure 6. Particle optical parameters for the closest ATLID product profile at Changdao on March 25, 2025. The nearest satellite overpass occurred at 17:33:33 UTC. Ground-based lidar signals from 17:00:00 to 18:00:00 UTC were used for the optical retrievals. Results from baselines BA and AE for A-EBD and A-AER are compared with results obtained by the CARLNET lidar. The shaded ranges show the uncertainties reported for the individual profiles.

In their ground-based comparison at Leipzig, Germany, Baars et al. (2026) reported that a software issue in the EarthCARE Joint Standard Grid (X-JSG) auxiliary product could shift the height array of individual profiles by one vertical bin. This issue produced artificial undulations in a particle extinction coefficient time–height plot without changing the optical parameter values. In Figure 7, a few profiles adjacent to the closest Changdao profile also show an altitude step of about 0.1 km. The closest profile itself has no such inter-profile jump. This local feature resembles the Leipzig time–height plot, but there is no evidence that it originates from the same software issue. A one-bin step also cannot explain the full 0.2–0.4 km difference in

peak height in Figure 6. The 11.15 km spatial separation, as well as the different vertical sampling and smoothing of the two sets of profiles, may affect peak shape and altitude. The specific cause of the peak-height difference requires a dedicated test which is not part of the present study.

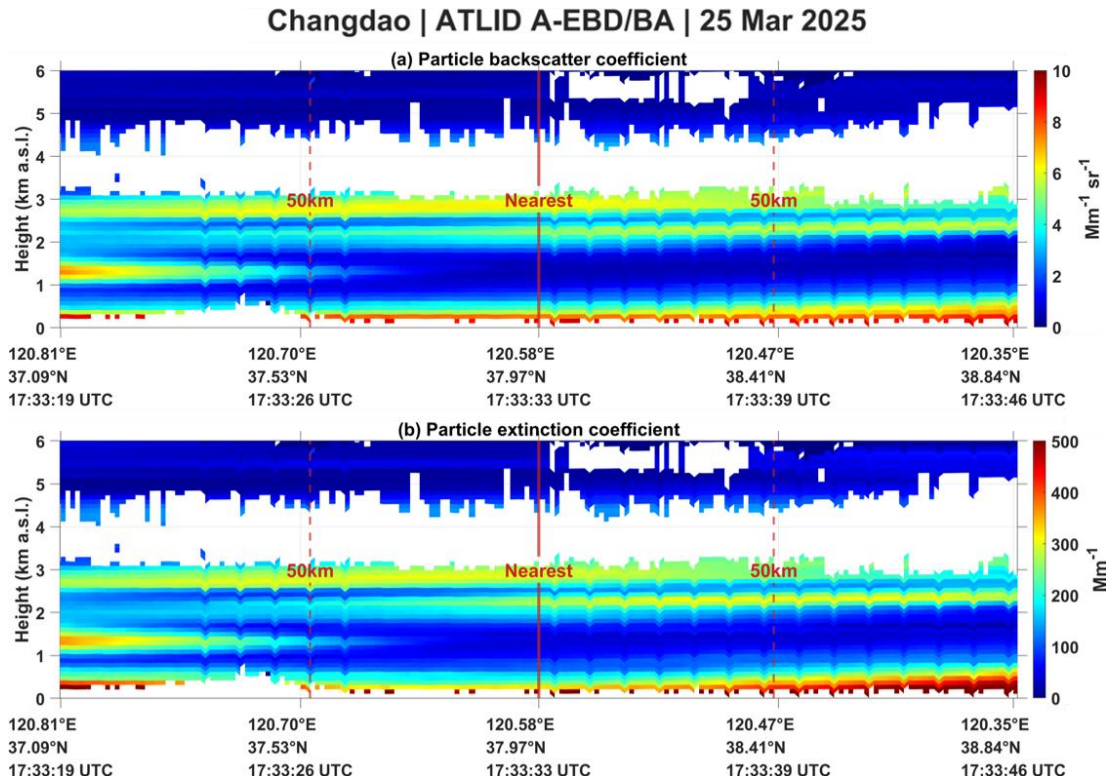
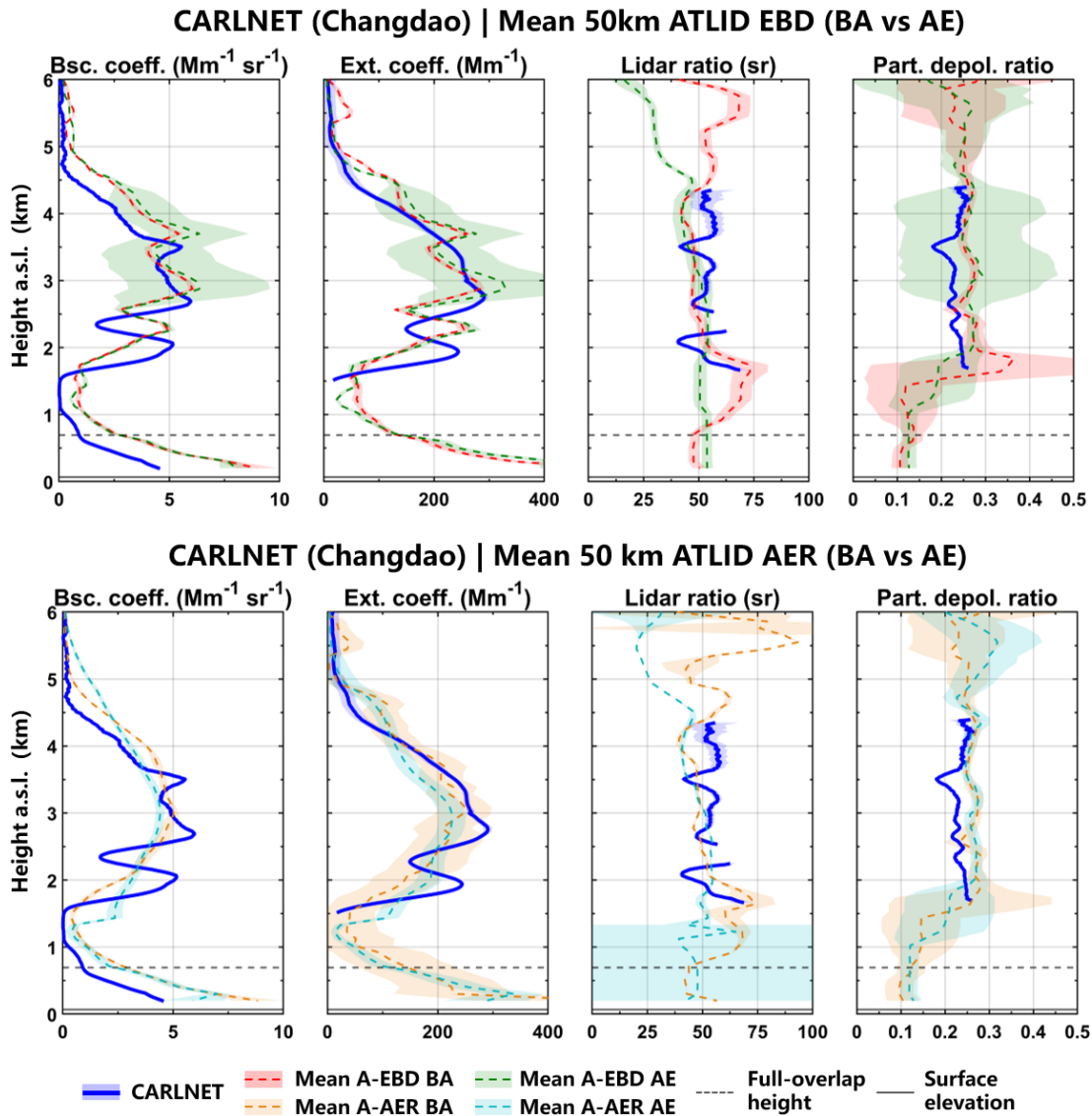


Figure 7. Along-track distribution of A-EBD/BA near Changdao on March 25, 2025. The particle backscatter coefficient and particle extinction coefficient over an approximately 200 km track segment are shown. The closest product profile to the Changdao station and the area within 50 km of the station are marked.

Figure 8 shows that quality screening and the 50 km mean profiles reduce the local A-EBD/AE fluctuations at 3.0–4.5 km a.s.l. The AE particle backscatter coefficient and particle extinction coefficient profiles move closer to the profiles obtained with BA at most altitudes in the main layer. The AE-profile spike in the particle linear depolarization ratio near 3 km height in the closest profile also becomes less evident, although the shaded uncertainty band around the mean profile remains wide. The mean A-AER profiles remain smoother than A-EBD. Spatial averaging does not restore the multiple CARLNET profile peaks and troughs in A-AER. This is consistent with the processing sequence of the two data products: A-AER averages weak signals before direct retrieval, whereas A-EBD uses the A-AER layer structure and prior estimates for optimal-estimation retrieval at a higher horizontal resolution. It then uses selective horizontal smoothing to produce medium- and low-resolution profiles of the particle extinction coefficient, particle backscatter coefficient, and particle linear depolarization ratio (Donovan et al., 2024). In this case, A-EBD retains the within-layer multipeak structure more completely, while A-AER shows a broader-layer shape.

Quality screening excludes values that do not meet the selected quality criteria. Averaging the remaining values at each altitude smooths local fluctuations in the AE profiles along the nearby track.



335 Figure 8. Mean particle optical parameters within a 50 km radius of the Changdao station on March 25, 2025. The nearest satellite overpass occurred at 17:33:33 UTC. Ground-based lidar signals from 17:00:00 to 18:00:00 UTC were used for the optical retrievals. Results from baselines BA and AE are shown for A-EBD and A-AER. The shaded ranges show the arithmetic mean of the uncertainties reported for the validated contributing product profiles.

3.3 Differences in classification between baselines and low-altitude retrieval differences

3.3.1 Sheyang on May 30, 2025: Low-altitude classification differences in baseline AF and persistent mid-altitude overestimation in baseline BA

The Sheyang case on May 30 examines how classification and sample selection relate to the high low-altitude A-EBD values in baseline AF. This case study also tests whether the A-EBD particle extinction coefficient and particle lidar ratio remain higher than the CARLNET values at middle altitudes under baseline BA.

Figure 9 shows that EarthCARE passed near the Sheyang station at 17:36:04 UTC. The center of the closest ATLID data product profile was 21.07 km away from the CARLNET lidar station. Ground-based lidar signals from 17:00:00 to 18:00:00 UTC were used for the optical retrievals. The CARLNET lidar observed a persistent low-altitude aerosol layer at about 0.5–1.8 km a.s.l. and a weaker layered structure at about 3.4–5.0 km a.s.l. The ATLID target classification (A-TC) product classified the strong scattering structure at about 8–9 km a.s.l. as high cloud. The CARLNET particle backscatter coefficient shows a sharp peak in this high-altitude structure, whereas the Raman-derived particle extinction coefficient has a broader, smoother peak. The two ground-based retrievals have different effective vertical smoothing lengths. We use this high-altitude structure to assess the scene, but not to evaluate aerosol optical parameters.

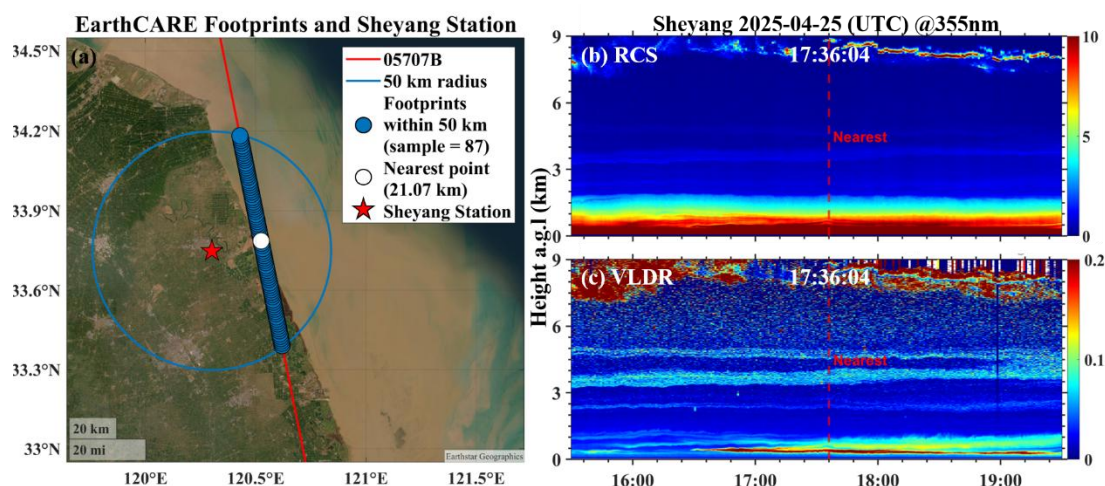


Figure 9. EarthCARE overpass near the Sheyang station on May 30, 2025. (a) Map showing the CARLNET station and the EarthCARE ground track; (b) ground-based 355 nm range-corrected signal (RCS); and (c) ground-based 355 nm volume linear depolarization ratio (VLDR). The time–height plots cover 15:30–19:30 UTC. The nearest satellite overpass occurred at 17:36:04 UTC.

Figure 10 shows that the A-EBD particle backscatter and particle extinction coefficients obtained by baseline AF are markedly higher than those from the baseline BA data processing chain at 0.5–1.8 km a.s.l. In contrast, the A-AER particle backscatter coefficients from both baselines are lower than the respective values measured by the CARLNET lidar in this layer, while their particle lidar ratios are correspondingly higher. Thus, the two data products have the same classification but different values relative to CARLNET. At about 3.4–4.0 km a.s.l., the particle extinction coefficients and particle lidar ratios from both



baselines of both data products exceed the CARLNET-lidar values. The positive differences are generally larger in baseline AF. The A-AER particle extinction coefficient also has short-scale fluctuations at altitudes of about 5–7 km where scattering signals were comparably weak. No corresponding continuous structure appears in the particle backscatter coefficient of the ATLID profile or CARLNET profile. The narrow, isolated peaks associated with the fluctuations in the A-AER particle extinction coefficient profile are consistent with residual retrieval noise under weak-signal conditions. They should not be interpreted as additional aerosol layers. A similar pattern appears during the Karamay overpass on June 9, 2025 (Fig. A1).

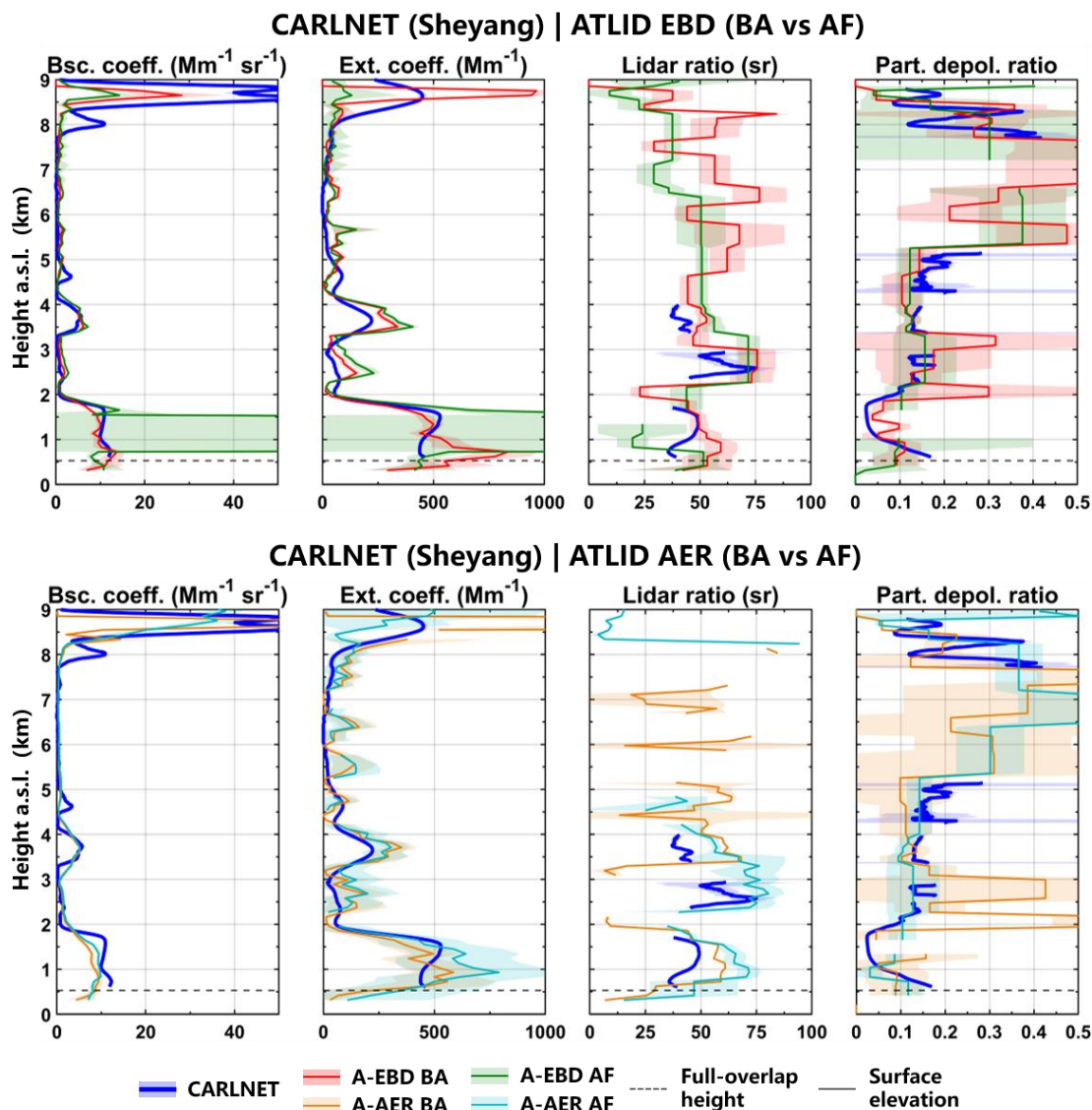


Figure 10. Particle optical parameters for the closest ATLID product profile at Sheyang on May 30, 2025. The nearest satellite overpass occurred at 17:36:04 UTC. Ground-based lidar signals from 17:00:00 to 18:00:00 UTC were used for the optical retrievals. Results from baselines BA and AF for A-EBD and A-AER are compared with results obtained by the CARLNET lidar. The shaded ranges show the uncertainties reported for the individual profiles.



Figure 11 shows that, after quality screening and averaging within 50 km distance, the low-altitude A-EBD particle backscatter and particle extinction coefficients in baseline AF remain higher than in baseline BA. An inspection of the A-EBD classifications contributing to the mean profiles shows that baseline BA has 328 valid altitude–track bins at 0.8–1.7 km a.s.l., all classified as aerosol. Baseline AF has 266 quality-qualified bins, of which 113 are classified as liquid cloud. These cloud labels are inconsistent with the persistent low-altitude aerosol observed by the CARLNET lidar. After cloud-classified bins are excluded, 153 bins remain in baseline AF. For A-EBD/AF, the layer-mean particle extinction coefficient decreases from about 1116 to about 665 Mm^{-1} , and its particle backscatter coefficient decreases from about 31.8 to about 12.8 $\text{Mm}^{-1} \text{sr}^{-1}$. Both data-product values remain higher than the corresponding values in baseline BA, for which the numbers are about 487 Mm^{-1} and 9.3 $\text{Mm}^{-1} \text{sr}^{-1}$, and the CARLNET-lidar values of about 485 Mm^{-1} and 10.7 $\text{Mm}^{-1} \text{sr}^{-1}$. After cloud-bin exclusion, the particle lidar ratio in baseline AF rises from about 42 to about 52 sr, which is close to the baseline BA value of about 52 sr. Cloud-classified samples clearly affect the extremely high values in the baseline AF retrieval procedure. The particle extinction and particle backscatter coefficients nevertheless remain high after these bins are excluded.

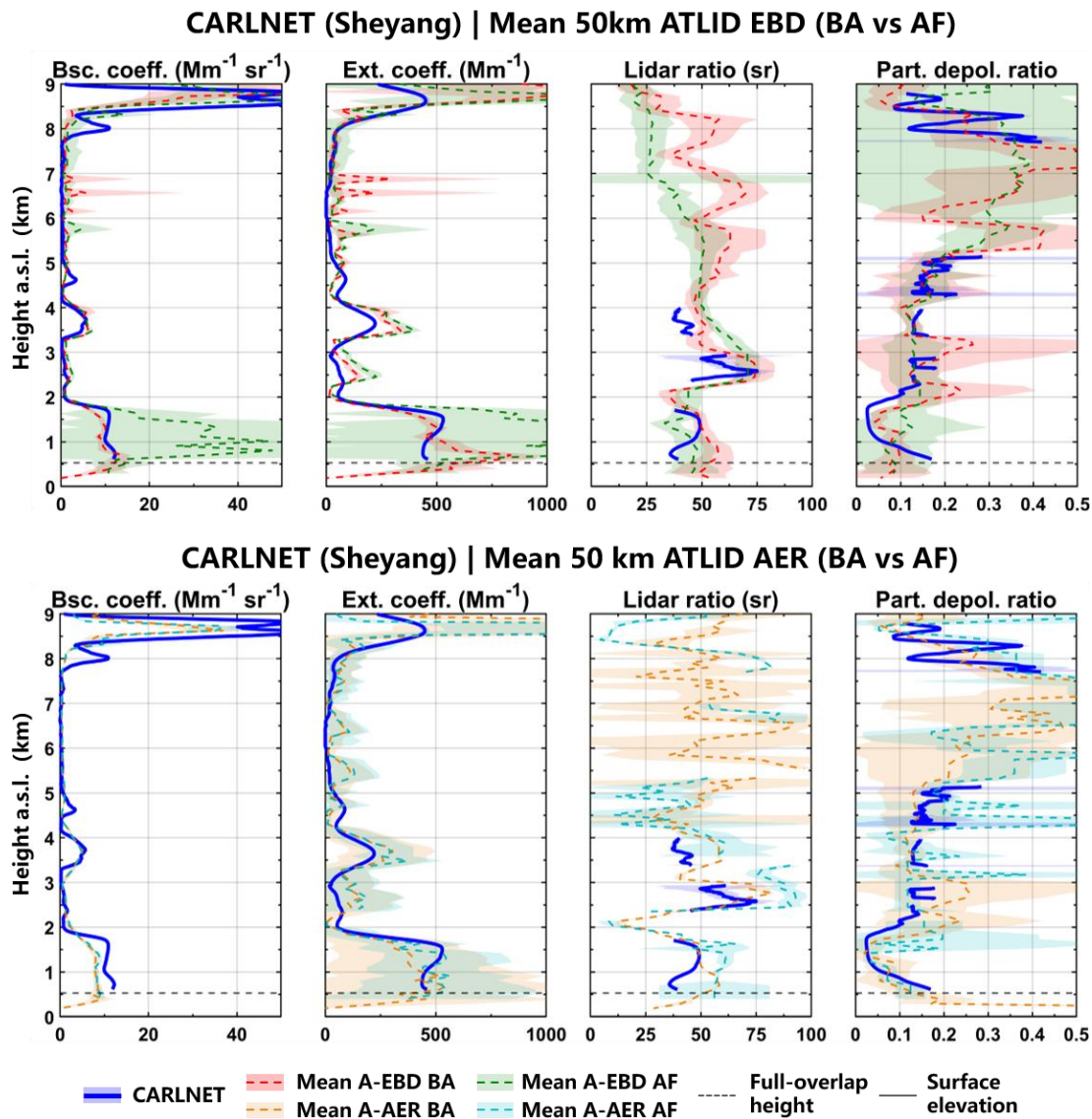


Figure 11. Mean particle optical parameters within a 50 km radius of the Sheyang station on May 30, 2025. The nearest satellite overpass occurred at 17:36:04 UTC. Ground-based lidar signals from 17:00:00 to 18:00:00 UTC were used for the optical retrievals. Results from baselines BA and AF are shown for A-EBD and A-AER. The shaded ranges show the arithmetic mean of the uncertainties reported for the validated contributing product profiles.

In the same altitude layer, only 9 A-AER bins in baseline AF pass the quality screening, compared with 266 A-EBD bins in baseline AF. The two mean data-product profiles therefore contain samples of different sizes and composition. A-AER does not show similarly high values. However, this does not establish that A-AER is insensitive to the cloud–aerosol classification differences described above. In the processing chain, A-AER averages the input signals before a direct retrieval. A-EBD also uses the A-AER layer structure, classification, and optical priors in an optimal-estimation retrieval (Donovan et al., 2024).



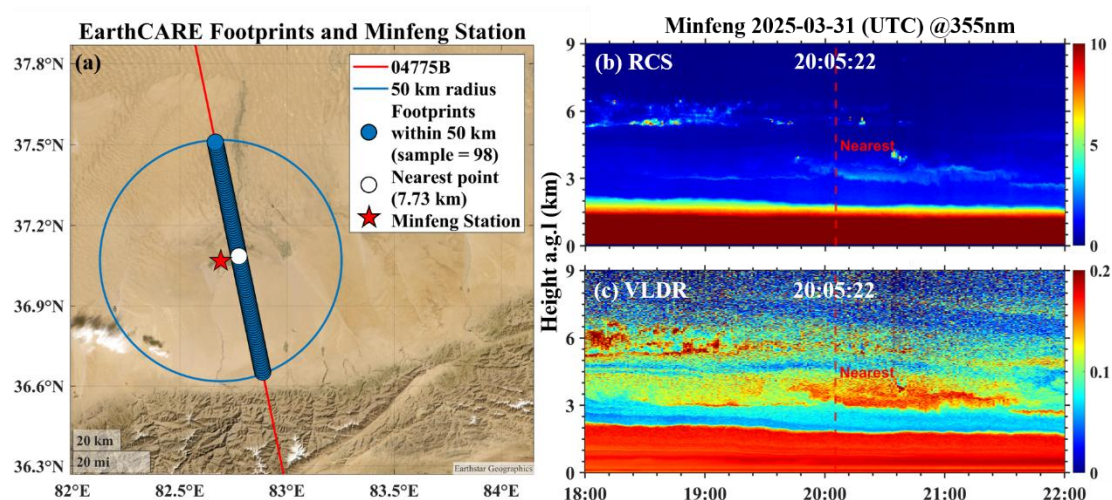
395 This product-chain relationship provides a possible path for the differences to propagate. The direct evidence points first to substantial changes in classification and sample composition.

At 3.4–4.0 km a.s.l., the particle extinction coefficients and particle lidar ratios obtained by A-EBD and A-AER in baseline BA remain higher than the corresponding values measured by the CARLNET lidar. Baars et al. (2026) reported overestimation in the same direction at Leipzig, Germany. In that case, the authors of that study traced the anomaly to one profile from the nominal ATLID measurements (A-NOM) product that entered the A-AER smoothing procedure. The target layer in the
400 baseline BA A-NOM data along the Sheyang track has no flagged noise spike. The data checks performed here found no corresponding evidence. The mid-altitude particle extinction coefficient and particle lidar ratio at Sheyang remain higher than corresponding data from the CARLNET lidar in baseline BA.

In summary, the low-altitude classification in baseline BA is more consistent with the aerosol observed by the CARLNET
405 lidar, and its A-EBD optical values are closer to the ones measured by the CARLNET instrument than those in baseline AF. However, baseline BA does not eliminate the mid-altitude overestimation of the particle extinction coefficient and particle lidar ratio.

3.3.2 Minfeng on March 31, 2025: Low-altitude underestimation in both baseline BA products

This case study tests whether the better agreement between baseline BA and CARLNET found at Minfeng on April 25, 2025,
410 recurs during the EarthCARE overpass at Minfeng on March 31, 2025, when dust was present. Figure 12 shows that EarthCARE passed near the Minfeng station at 20:05:22 UTC. The closest ATLID product profile was 7.73 km away from the station. Ground-based lidar signals from 19:30:00 to 20:30:00 UTC were used for the optical retrievals. Low-altitude aerosol extended from near the surface to about 3.3 km a.s.l. A separate mid-altitude structure was present at about 4.4–5.3 km a.s.l., and a strong high-altitude scattering structure at about 6.7–7.7 km a.s.l. The particle linear depolarization ratio of about 0.3 in
415 the low-altitude layer is consistent with dust aerosol. A sharp high-altitude peak in the particle backscatter coefficient occurs alongside a broader, smoother peak in the particle extinction coefficient. The interpretation is the same as for the high-altitude structure at Sheyang on May 30 and is not repeated here.



420 **Figure 12. EarthCARE overpass near the Minfeng station on March 31, 2025. (a) Map showing the CARLNET station and the EarthCARE ground track; (b) ground-based 355 nm range-corrected signal (RCS); and (c) ground-based 355 nm volume linear depolarization ratio (VLDR). The time–height plots cover 18:00–22:00 UTC. The nearest satellite overpass occurred at 20:05:22 UTC.**

Figure 13 shows that A-EBD retains more within-layer detail than A-AER, as also seen in the Changdao case on March 25. The main issue during this overpass, however, is the low particle extinction coefficient in baseline BA at low altitudes. Below
 425 about 3.0 km a.s.l., the A-EBD and A-AER particle extinction coefficients in baseline BA are both markedly lower than the profile values measured by the CARLNET lidar. The particle lidar ratios from both products in baseline BA are also lower than the corresponding CARLNET values. Between about 3.3 and 4.3 km a.s.l., i.e., between the low- and mid-altitude layers, the CARLNET lidar profile shows a lower particle loading. The A-AER particle backscatter and particle extinction coefficients are closer to this low-value region, whereas A-EBD still has elevated signals at some altitudes.

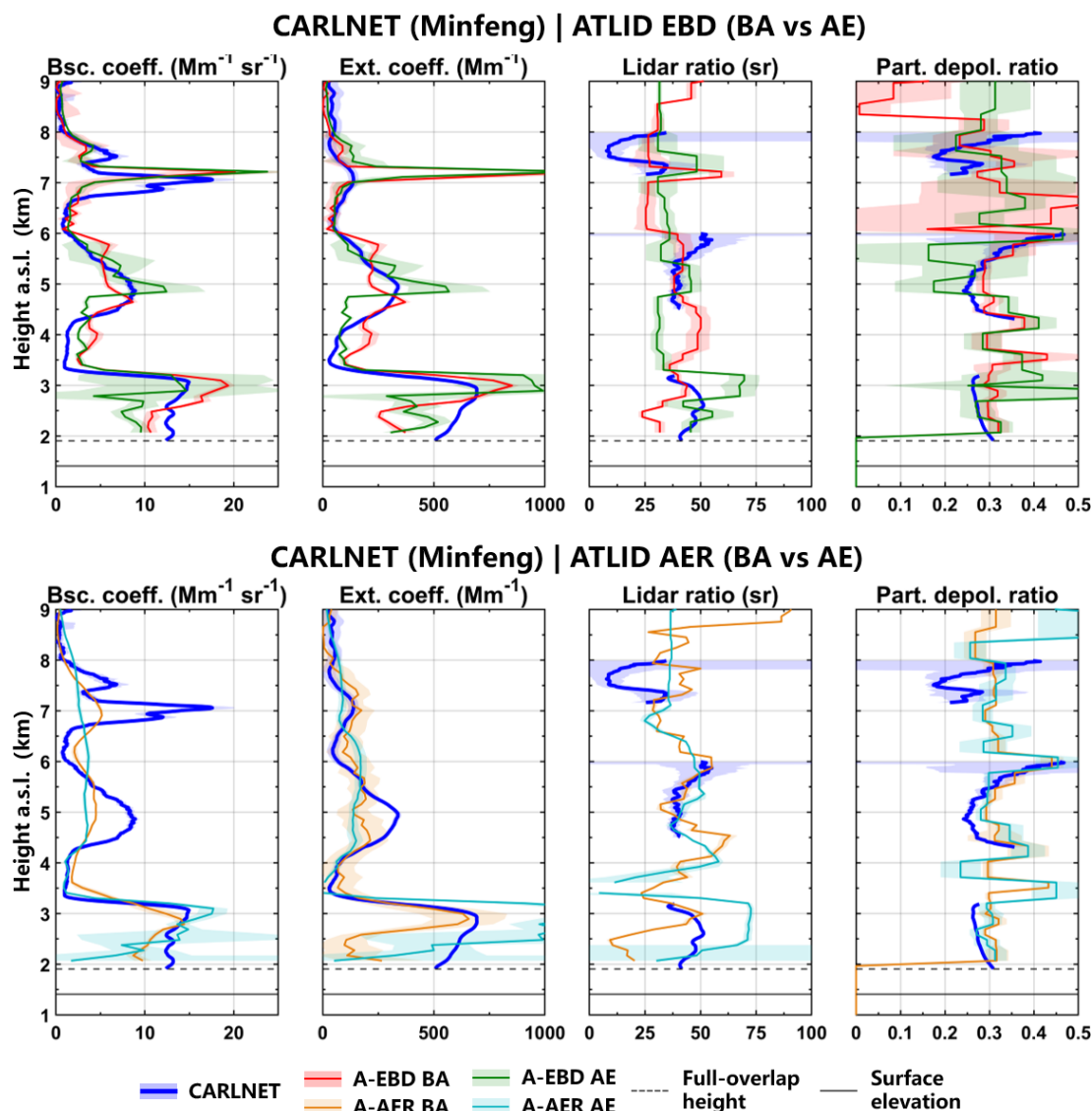


Figure 13. Particle optical parameters for the closest ATLID product profile at Minfeng on March 31, 2025. The nearest satellite overpass occurred at 20:05:22 UTC. Ground-based lidar signals from 19:30:00 to 20:30:00 UTC were used for the optical retrievals. Results from baselines BA and AE for A-EBD and A-AER are compared with results obtained by the CARLNET lidar. The shaded ranges show the uncertainties reported for the individual profiles.

Figure 14 shows that, after quality screening and averaging within 50 km of the CARLNET station, the particle extinction coefficient and particle lidar ratio from both data products in baseline BA remain lower than the corresponding CARLNET values below 3.0 km a.s.l. The analysis of the height layers above the CARLNET lidar's full-overlap altitude and below 3.0 km a.s.l. delivers the following results: The layer-mean differences in the A-EBD particle extinction coefficient and particle lidar ratio in baseline BA relative to the CARLNET lidar are -31.66% and -31.16%, respectively. The corresponding differences for A-AER in baseline BA are -35.71% and -27.64%. For A-EBD in baseline AE, the differences are -19.49% and



+4.59%. In the 50-km mean profiles, the nominal low-altitude A-EBD values in baseline AE are closer to the ones obtained by the CARLNET lidar than those in baseline BA. Thus, baseline BA does not yield mean values closer to the ground-based reference for every case and parameter.

445 The closest profile provides a necessary comparison. In Figure 13, the low-altitude A-EBD particle extinction coefficients in baseline AE are no closer to the extinction coefficients measured by the CARLNET lidar than the values obtained by the baseline BA. Only the particle lidar ratios are relatively closer to each other. Figure 14 shows the arithmetic mean of the uncertainties for the valid baseline AE profiles. This shaded area overlaps extensively with the corresponding area for baseline BA. Thus, the nominal advantage in the 50 km mean does not establish greater accuracy of the baseline AE low-altitude retrieval.

450 The A-AER particle extinction coefficient and particle lidar ratio in baseline AE are high at about 2.3–2.7 km a.s.l. However, only three quality-screened A-AER/AE profiles contribute to the 50 km mean at each altitude in this layer, compared with about 65–77 A-AER/BA profiles. The retained baseline AE bins are classified as aerosol. At bins valid in both baselines and classified as aerosol in both baselines, the baseline AE particle extinction coefficient remains high. The high values here cannot be attributed to cloud-bin inclusion as in the Sheyang case on May 30. The difference in sample numbers alone also cannot
455 explain them.

The low-altitude particle extinction coefficients and particle lidar ratios from A-AER and A-EBD in baseline BA are low in the same direction. Because A-EBD uses the A-AER retrieval results as input, these underestimates cannot be treated as independent evidence of error (Donovan et al., 2024). The two Minfeng overpasses on April 25 and March 31 show different results. In the former, baseline BA markedly reduces the negative differences seen in baseline AE. In the latter, baseline BA
460 remains markedly low at low altitudes. Here, the CARLNET lidar identifies a baseline exception at specific altitudes and for specific parameters, rather than a uniformly better or worse baseline.

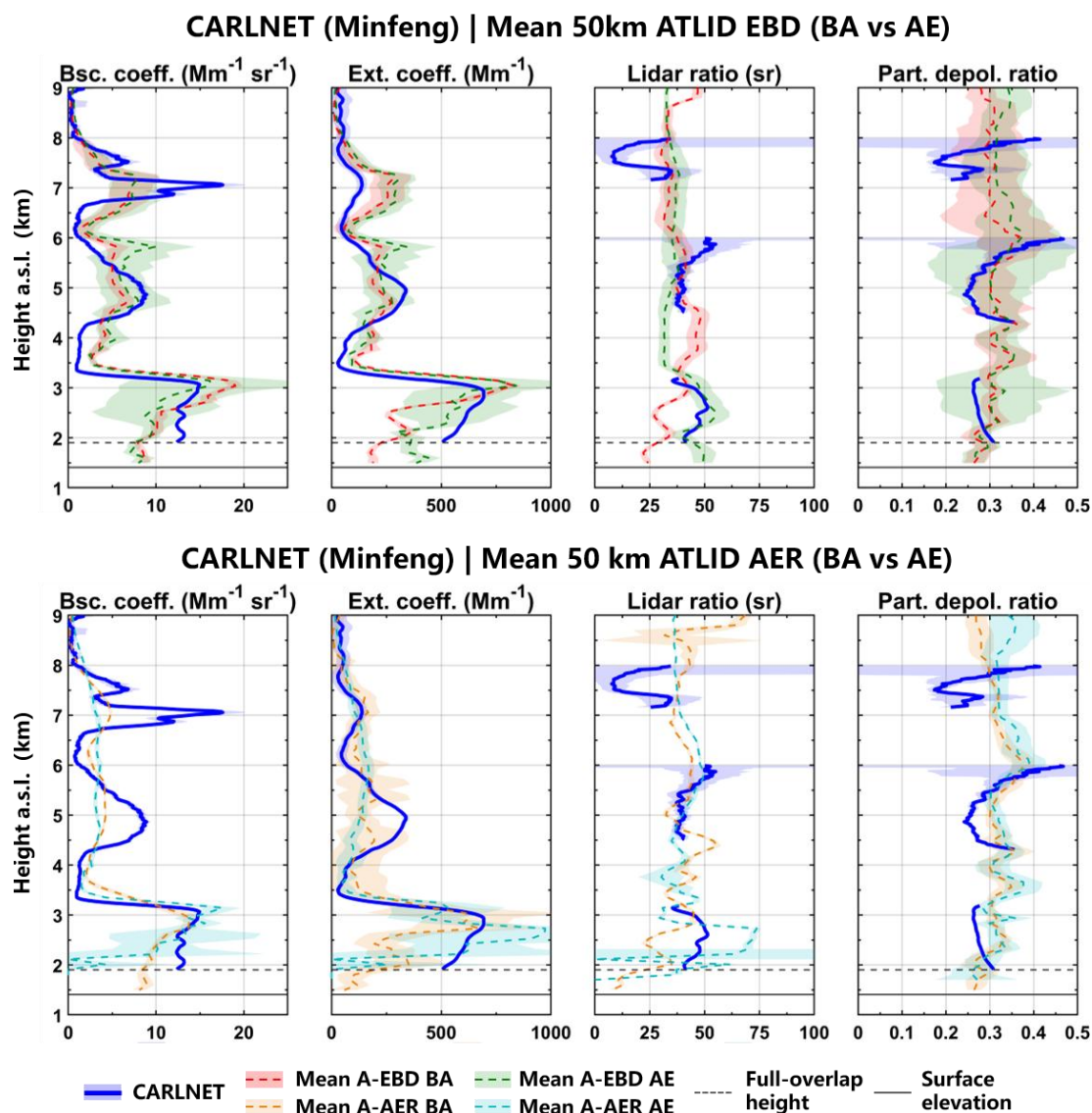


Figure 14. Mean particle optical parameters within a 50 km radius of the Minfeng station on March 31, 2025. The nearest satellite overpass occurred at 20:05:22 UTC. Ground-based lidar signals from 19:30:00 to 20:30:00 UTC were used for the optical retrievals. Results from baselines BA and AE are shown for A-EBD and A-AER. The shaded ranges show the arithmetic mean of the uncertainties reported for the validated contributing product profiles.

3.4 Results common to the four case studies

The four cases show that ATLID can identify an aerosol layer, but this does not mean that the values of all four particle optical parameters agree with the corresponding CARLNET values. The effect of the processing baseline changes by event and altitude.

Baseline BA markedly reduces the differences in the particle extinction coefficient and particle lidar ratio at Minfeng on April 25 and improves the low-altitude A-EBD results at Sheyang on May 30. However, it does not eliminate the mid-altitude



overestimation at Sheyang on May 30 or the low-altitude underestimation at Minfeng on March 31. A-EBD provides more within-layer detail. At some altitudes with low particle loading, A-AER is closer to the ground-based reference. Target classification and quality screening also determine which ATLID data bins from product profiles within 50 km of the station contribute to the mean at each altitude. The number of contributing bins should therefore be reported alongside the mean profile values.

CARLNET's independent Raman and polarization measurements provide reference values for ATLID particle optical parameters over China. These comparisons identify the products, processing baselines, parameters, and altitudes at which ATLID and CARLNET values differ. The case analyses also help assess how target classification and the composition of valid ATLID data bins contributing to the 50 km mean affect the comparison. The four case studies of EarthCARE overpasses support validation by atmospheric event, observation altitude, and optical parameter.

4 Discussion

4.1 Comparison of closest and 50 km mean profiles

The ATLID product profile closest to the station provides a clear geometric matchup for the satellite–ground comparison. It also allows comparison with studies that use the closest available ATLID profile (Baars et al., 2026). The closest profile shows the product values nearest the station, but it does not fully describe the product along the nearby track. Neighboring product profiles may still differ locally. Relying on the closest profile alone may therefore make the interpretation depend too strongly on one profile with an unusually high or low value, or a jagged pattern, in an optical parameter.

The 50 km mean provides another spatial support. It tests whether features in the closest profile remain visible after neighboring product profiles are combined. It summarizes quality-screened product profiles within a fixed area around the station and helps assess whether features at the closest location also occur along the nearby track. If an anomalous feature remains after averaging, it is not confined to the closest profile. If the mean is closer to CARLNET, the closest profile and the composition of the valid sample must be examined before this change is interpreted.

The two spatial supports should therefore be interpreted together. The closest profile shows the product at the location nearest the station. The 50 km mean shows the aggregate product values along the nearby track.

4.2 Processing baselines

The four EarthCARE overpasses show that the same processing baseline can produce deviations in different directions in different aerosol layers. The clearest change between baselines occurs in the Minfeng case on April 25. From baseline AE to baseline BA, the particle extinction coefficient and particle lidar ratio from both A-AER and A-EBD become markedly closer to the CARLNET lidar observations, while the overall structure of the particle backscatter coefficient profiles changes little. The Minfeng case on March 31 provides a contrast. In both products, baseline BA still underestimates the particle extinction coefficient and particle lidar ratio at low altitudes. The nominal values of the 50 km mean from A-EBD under baseline AE are



instead closer to the results obtained with CARLNET. In the Sheyang case on May 30, baseline BA reduces the extremely high low-altitude A-EBD values found under baseline AF, but the particle extinction coefficient and particle lidar ratio remain high at middle altitudes. Baseline BA is the common processing reference across the four cases and shows changes in optical parameters in each case. It is not, however, closest to CARLNET lidar profiles at every altitude in every case.

The transition from baseline AE or AF to baseline BA spans several data processing updates, including cumulative changes in calibration and product algorithms (Baars et al., 2026; ESA, 2025b, 2026). The four cases directly establish differences between baselines for the same overpass. The final profiles alone cannot identify which individual update caused a particular numerical change. The direction of the middle-altitude overestimation in the Sheyang case on May 30 matches that reported by Baars et al. (2026) for the observations over Leipzig, Germany. However, no noise spikes were flagged in the A-NOM target layer for the Sheyang case on May 30. The available evidence does not establish that the two cases share the same input anomaly. The common underestimation in the Minfeng case on March 31 also cannot be inferred from the mechanism proposed for overestimation in another event.

The Sheyang case on May 30 also shows that processing baseline updates can change quality-control grades and classification results. Under baseline AF, many low-altitude bins that pass the quality screening are classified as liquid clouds. The corresponding valid bins under baseline BA are all classified as aerosol. The low-resolution A-EBD profiles apply broader horizontal smoothing to aerosol, while cloud features are still reported at higher resolution (Baars et al., 2026). Excluding cloud-classified bins under baseline AF markedly reduces the extremely high low-altitude particle extinction and backscatter coefficients. The remaining values are still higher than those from baseline BA and the CARLNET lidars. Thus, the classification difference explains an important part of the extreme discrepancy, but not all of the overestimation. A-AER and A-EBD under baseline AF also have very different numbers of valid bins. Comparisons of mean values between products or baselines must therefore report quality status, classification, and valid-bin counts together.

4.3 A-AER and A-EBD

A-AER and A-EBD use different retrieval approaches, but they are not independent. As explained before, A-AER first averages the input signal and then directly estimates optical quantities. A-EBD uses layer structure, classification, and optical priors from A-AER, and adjusts the results through optimal estimation (Donovan et al., 2024). In the Changdao case on March 25 and the Minfeng case on March 31, A-EBD preserves more of the peaks and troughs observed by the CARLNET lidars. A-AER instead shows smoother, broader layers. Yet A-AER is closer to the CARLNET results in the low-aerosol-load region between layers in the Minfeng case on March 31. More vertical detail does not necessarily mean closer agreement with CARLNET at every altitude. In the Sheyang case on May 30, the A-AER particle extinction coefficient shows short-scale fluctuations at altitudes where the scattering signal is weak. Similar fluctuations do not appear in the A-AER particle backscatter coefficient and the CARLNET profiles. The short-scale fluctuations are more consistent with residual noise under weak-signal conditions and should not be interpreted directly as new aerosol layers.



535 4.4 The role of CARLNET in validating ATLID over China

CARLNET provides independent 355 nm optical parameter profiles for evaluating ATLID product quality. In these cases, ATLID captures the main layer structure, but the particle extinction coefficient, particle lidar ratio, and within-layer peaks and troughs may still differ from the ground-based results. CARLNET lidars locate these differences by optical parameter and altitude, which allows differences between data products and processing baselines to be examined for each observation and
 540 altitude. Continuous time–height plots are used to check whether the target layer above the station persists before and after the satellite overpass. Together, these two types of evidence support the numerical satellite–ground comparison.

5 Conclusions

We used nighttime 355 nm Raman and polarization profiles from CARLNET as an independent reference to validate EarthCARE ATLID products. We compared four EarthCARE overpasses near three CARLNET lidar stations: Minfeng,
 545 Changdao, and Sheyang. The four case studies show that the effects of processing baseline updates depend on the event and target layer. In the Minfeng case on April 25, baseline BA markedly reduced the negative differences in the particle extinction coefficient and particle lidar ratio found in baseline AE. In the Sheyang case on May 30, baseline BA reduced the extremely high low-altitude A-EBD values in baseline AF, but the mid-altitude overestimation remained. In the Minfeng case on March 31, the low-altitude results from both data products in baseline BA remained markedly low. These findings do not support
 550 ranking the accuracy of processing baselines by release date alone.

In these four cases, neither A-AER nor A-EBD is consistently closer to CARLNET. In the Changdao case on March 25 and the Minfeng case on March 31, A-EBD retained more within-layer peaks and troughs that corresponded to CARLNET lidar profiles. However, A-AER was closer to the ground-based result in the low-aerosol-load region between layers in the Minfeng case on March 31. The Sheyang case on May 30 also shows that classification and the composition of valid samples can
 555 substantially change the 50 km mean profile. The closest product profile and the local mean should be considered together. A mean that is closer to the ground-based result does not, by itself, establish a more trustworthy retrieval. The results show that CARLNET can provide parameter-specific reference values for the ATLID A-AER and A-EBD optical data products over China. It can also identify the product, processing baseline, optical parameter, and altitude at which a difference occurs. These findings apply to four nighttime overpasses at three stations and to comparable altitudes above the full-overlap height
 560 of the CARLNET lidar stations considered in this study. The results are case-level product diagnostics and do not represent the mean error across the CARLNET network in China. During these overpasses, CARLNET lidars provided an independent reference for the optical parameters, allowing specific differences in ATLID products to be examined over China.

Appendix A

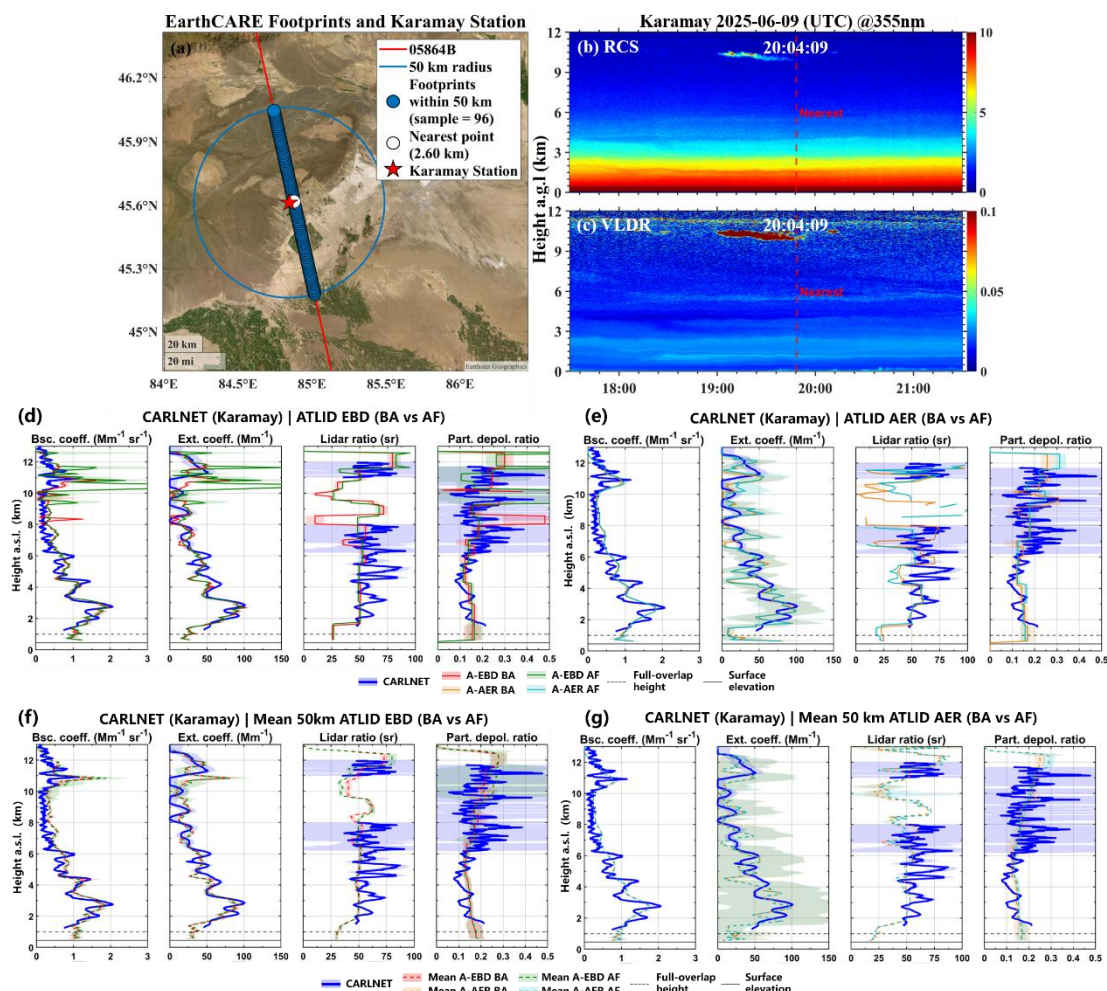


Figure A1. EarthCARE overpass near the Karamay station on June 9, 2025. (a) Map showing the CARLNET station and the EarthCARE ground track; (b) ground-based 355 nm range-corrected signal (RCS); (c) ground-based 355 nm volume linear depolarization ratio (VLDR); (d) particle optical parameters for the closest A-EBD product profiles; (e) particle optical parameters for the closest A-AER product profiles; (f) 50 km mean A-EBD profiles; and (g) 50 km mean A-AER profiles. The nearest satellite overpass occurred at 20:04:09 UTC, and the closest ATLID product profile was 2.60 km from the station. Panels (d)–(g) compare baselines BA and AF with CARLNET. In panels (d) and (e), the shading shows the uncertainties reported for the individual profiles. In panels (f) and (g), the ATLID shading shows the arithmetic mean of the uncertainties reported for the valid product profiles contributing at each altitude; the CARLNET shading shows the reported uncertainty of the ground-based profile.

Data availability

The EarthCARE ATLID Level-2a products used in this study were downloaded from the ESA MAAP Explorer (https://explorer.maap.eo.esa.int/?q=EarthCAREL2Validated_MAAP). The baseline BA products are available through this collection. The baseline AE and AF files used for the comparisons were downloaded earlier and are retained by the authors.



At the time of manuscript preparation, these earlier versions could not be retrieved from the same public collection. The CARLNET observations were provided by coauthors. The CARLNET data provider has not authorized the authors to redistribute the observations or the derived profiles, so these data are not publicly available.

580 **Author contributions**

YW: Conceptualization, Formal analysis, Data curation, Writing – original draft. ZY: Formal analysis, Writing – review & editing. SZ: Writing – review & editing. SM: Methodology. YC: Resources, Data curation. ZB: Resources, Data curation. YD: Resources, Data curation. XW: Conceptualization, Resources, Project administration. DM: Supervision, Writing – review & editing. All authors reviewed and approved the final manuscript.

585 **Competing interests**

The authors declare that they have no conflict of interest.

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Review statement

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