Response to Reviewer 2

Manuscript number: egusphere-2026-4536

Manuscript title: High-Resolution Boundary-Layer Detection Lidar for Spaceborne Applications: Parameter Design, Theoretical Simulation, and Airborne Validation

We thank the reviewer for the careful review of our manuscript and the constructive suggestions. For clarity, the reviewer's comments are shown in **bold black text**, our point-by-point responses in blue, and quotations from the revised manuscript in red.

We appreciate the reviewer's positive assessment of the combined use of numerical simulations and airborne experiments and its value for instrument development. Below, we address the comparison between the two systems, the identification of surface returns, and the interpretation of the Hainan daytime observations.

1: Table 2 in Section 3.1 compares the equivalent signal strengths and background noise levels of the spaceborne system and the airborne prototype. Are these quantities compared on a per-pulse basis or over a specified accumulation interval? Please explain how the comparison accounts for the different pulse repetition frequencies of the two systems.

We thank the reviewer for asking us to clarify the basis of the comparison. The equivalent signal strengths in Table 2 are compared on a single-pulse basis. Specifically, the signal equivalence parameter is calculated as ED^2/R^2, where E is the single-pulse laser energy, D is the receiving telescope diameter, and R is the observation range. Neither the pulse repetition frequency nor the number of accumulated pulses is included in this calculation. The airborne-to-spaceborne signal ratios of approximately 1.3 and 1.5 therefore represent the relative backscattered signal strengths per transmitted pulse.

For background noise, Table 2 compares the receiver parameter $D^2\theta^2\Delta\lambda$, where θ is the receiver field of view and $\Delta\lambda$ is the filter bandwidth. For a given background radiance and receiver efficiency, this parameter describes the relative background photon count rates. According to Eq. (3), multiplying the background count rate by the sampling time associated with a range bin, $2\Delta z/c$, gives the expected background photon count per pulse and per range bin. Thus, for the same range-bin width, this background scaling relationship also applies to the background photon counts per pulse and per range bin.

Pulse accumulation is treated separately in the subsequent simulations and profile comparisons. For a given number of accumulated pulses, N_{acc}, the integration time is $T = N_{acc}/f_{rep}$, where f_{rep} is the pulse repetition frequency. For example, the theoretically simulated profiles and the measured airborne profiles compared in Fig. 13b both use 250 accumulated pulses and a vertical resolution of 30 m. Accumulating 250 pulses corresponds to a temporal resolution of 0.125 s for the airborne system operating at 2000 Hz and 0.25 s for the spaceborne system operating at 1000 Hz. Under the orbital conditions considered in this study, the latter corresponds to an along-track integration distance of less than 2 km, or an along-track resolution finer than 2 km. The equivalence assessment therefore uses the single-pulse signal as its reference. In the subsequent comparisons using the same number of accumulated pulses, the respective repetition frequencies are used to determine the corresponding integration times and spatial resolutions.

Comment 2: In Section 3.3, the authors use surface returns to express the airborne profiles in terms of height above ground level. Please describe how the surface return is identified. When terrain variations broaden the return or produce multiple peaks, how is the range to the ground determined?

We thank the reviewer for this question. The surface position is identified from the sharp signal change associated with the hard-target surface return. Specifically, photon counts are first accumulated over 0.125 s intervals and 30 m height bins to form profiles. Counts from the two detection channels

are added, and the mean background is subtracted. We then calculate the signal gradient along the height coordinate for each profile and select the range gate with the maximum positive gradient. The height of this gate, where the signal increases most steeply with height, is used as the surface reference height, h_g. The profile is converted to height above ground level using $h_{AGL} = h - h_g$, aligning the surface positions of the profiles along the flight track. Surface identification is therefore performed after the profiles have been formed by pulse accumulation.

The same maximum positive gradient criterion is applied to all profiles. For a broadened surface return, the position of the steepest signal increase with height is used as the surface reference. The same criterion is used for returns with multiple peaks, without additional peak separation or selection procedures.

We visually inspected the surface identification and alignment results and found no obvious anomalies. No profiles were manually rejected and no surface positions were manually adjusted. This may be related to the relatively uniform local terrain along the flight segments analysed, where return broadening and multiple peaks associated with complex terrain were not apparent. We therefore did not conduct a separate analysis of these effects in this study. We thank the reviewer for drawing attention to this issue. Future spaceborne observations will cover more varied terrain, requiring closer consideration of how broadened and multi-peak surface returns affect the determination of the range to the ground. We will further examine surface-return identification and the associated quality control under complex terrain conditions in our work on processing spaceborne data.

Comment 3: Figure 16 in Section 4.2 presents daytime profiles under different cloud conditions. For each case, please indicate whether near-surface aerosol backscatter can be distinguished and, where it can, whether the signal is sufficient to identify the boundary-layer top. The conclusions could reflect this distinction by stating what the Hainan experiment demonstrates about daytime signal detection and under what conditions height retrieval remains limited.

We thank the reviewer for this suggestion. We agree that detecting near-surface aerosol signals needs to be distinguished from reliably identifying the boundary-layer top. Section 4.2 of the revised manuscript describes the signal characteristics and retrieval limitations under the different cloud conditions in Fig. 16, as detailed below.

(1) Fig. 16a: No usable near-surface aerosol signal is detected, preventing reliable boundary layer height (BLH) retrieval. The revised manuscript states:

> In this case, only the hard target echo from the ground can be clearly identified, whereas the near-surface atmospheric signal did not contain sufficient information for reliable BLH retrieval.

In this case, the optically thick cloud severely attenuates the atmospheric returns from below the cloud. Although the hard-target surface echo remains identifiable, no usable near-surface aerosol backscatter signal could be detected, so the boundary-layer top could not be determined.

(2) Fig. 16b: Near-surface aerosol signals are detectable, but the structure needed to identify the boundary-layer top is insufficiently clear. The revised manuscript states:

> At 07:44:37 LT, corresponding to Fig. 16b, despite the laser intensity being attenuated by clouds at altitudes of 4–5 km, the near-surface aerosol signal was still effectively detected. However, owing to the impact of strong background noise, the effective atmospheric signal remained weak and its structural features were indistinct, making it difficult for the traditional wavelet transform method to reliably retrieve the BLH.

This case shows that the measured profile retains discernible near-surface aerosol information under these cloud conditions. However, the low contrast between the signal and background obscures the gradient features needed to identify the boundary-layer top, making reliable BLH retrieval difficult with the wavelet method used in this study.

(3) Fig. 16c: Layered returns are visible, but low-cloud and aerosol returns overlap. The revised manuscript further explains:

> Although the stratification structure appeared more pronounced in this case, relying solely on the traditional wavelet transform method can lead to considerable BLH retrieval errors by confusing cloud-related and aerosol-related gradients.

Near-surface atmospheric layers can be distinguished in this case, but overlapping low-cloud and aerosol returns limit the independent identification of aerosol structure and make the boundary-layer top ambiguous.

The Hainan experiment shows that near-surface aerosol signals can still be detected after 1 s of accumulation under strong daytime background illumination and some cloud conditions. However, severe attenuation by optically thick clouds, low signal contrast, and the difficulty of distinguishing overlapping low-cloud and aerosol structures continue to limit reliable BLH retrieval. We also recognise that some statements in the original manuscript about the Hainan results were overly optimistic. We have therefore revised Sect. 4.2 and the conclusions to clarify that these observations demonstrate the possibility of acquiring surface and near-surface aerosol signals in selected daytime cases, while also revealing the current limitations of the system in BLH retrieval. The revised manuscript further notes that improvements to the retrieval algorithm alone cannot overcome the lack of atmospheric information caused by severe cloud attenuation. The primary validation of the system's BLH retrieval performance remains the Yulin nighttime experiment.