

Reply to the comments of Reviewers

RC1: 'Comment on amt-2023-235', Anonymous Referee #1:

This study reports initial validation of the world's first space borne HSRL lidar, launched by China. Results show overall high consistency with ground-based Raman lidar and CALIPSO satellite measurements, which proves the reliability of the HSRL lidar technique in retrieving aerosol profiles in space. The findings are valuable and the study is timely. However, I have a few concerns, mainly about data availability, and feel some improvements are needed.

Response: We would like to thank the reviewer for providing constructive suggestions and comments. We have revised the manuscript based on the reviewer's comments by providing the following point-by-point responses.

Specific comments:

1. In the acknowledgement the authors indicated that the space HSRL data is not publicly available at the time of submission. I wonder if the data is available now? This is important since the results of the paper cannot be verified or repeated if the data cannot be accessed.

Response: Thanks for your question. Data are publicly available, although they not yet released to the public, but have been shared with relevant teams for retrieval algorithms and validation. Some research articles have already been published by these teams (Liu et al., 2019; Ke et al., 2022; Dai et al., 2023; Hu et al., 2023; Zha et al., 2023; Wang et al., 2023). Data from our manuscript may be politely requested from the corresponding author if the readers need it.

Reference:

Dai, G., Wu, S., Long, W., Liu, J., Xie, Y., Sun, K., Meng, F., Song, X., Huang, Z., and Chen, W.: Aerosols and Clouds data processing and optical properties retrieval algorithms for the spaceborne ACDL/DQ-1, *Aerosols/Remote Sensing/Data Processing and Information Retrieval*, <https://doi.org/10.5194/egusphere-2023-2182>, 2023.

- Hu, J., Wang, X., Zhao, S., Wang, Z., Yang, J., Dai, G., Xie, Y., Zhu, X., Liu, D., Hou, X., Liu, J., and Chen, W.: Spaceborne High Spectral Resolution Lidar for Atmospheric Aerosols and Clouds Profiles Measurement, *Acta Optica Sinica*, 43, 18, 10.3788/AOS231153, 2023.
- Ke, J., Sun, Y., Dong, C., Zhang, X., Wang, Z., Lyu, L., Zhu, W., Ansmann, A., Su, L., Bu, L., Xiao, D., Wang, S., Chen, S., Liu, J., Chen, W., and Liu, D.: Development of China's first space-borne aerosol-cloud high-spectral-resolution lidar: retrieval algorithm and airborne demonstration, *PhotonIX*, 3, 17, <https://doi.org/10.1186/s43074-022-00063-3>, 2022.
- Liu, D., Zheng, Z., Chen, W., Wang, Z., Li, W., Ke, J., Zhang, Y., Chen, S., Cheng, C., and Wang, S.: Performance estimation of space-borne high-spectral-resolution lidar for cloud and aerosol optical properties at 532 nm, *Opt. Express*, 27, A481, <https://doi.org/10.1364/OE.27.00A481>, 2019.
- Wang, J., Liu, D.: Comparison and Analysis of Payloads Performance for Active and Passive Spaceborne Atmospheric Detection, *Acta Optica Sinica*, 43, 18, 10.3788/AOS231153, 2023.
- Zha, C., Bu, L., Li, Z., Wang, Q., Mubarak, A., Liyanage, P., Liu, J., and Chen, W.: Aerosol Optical Properties Measurement using the Orbiting High Spectral Resolution Lidar onboard DQ-1 Satellite: Retrieval and Validation, *Atmos. Meas. Tech. Discuss.* [preprint], <https://doi.org/10.5194/amt-2023-219>, in review, 2023.

2. Although reasonable agreement is reached between HSRL and Raman lidar results, remarkable differences still show up in some cases and in the scatter plots such as Figure 13, especially for the depolarization ratio. It is therefore necessary to discuss the sources of uncertainties or causes of the differences. However, I did not seem to notice these discussions in the paper;

Response: Thanks for your suggestion. The discrepancies in the comparison of aerosol and cloud between ACDL and ground-based lidar measurement are possible because of the several factors such as different lidar system parameters, the difference in detection distance between spaceborne and ground-based systems, various aerosols

and clouds distribution, the inhomogeneity of the atmosphere and also can be due to the uneven terrain in the northwest region of China. Furthermore, even though the measurements are simultaneous, if the observation points are not at the same location, it can lead to discrepant comparison results (Chiang et al., 2011).

Typically, the main source of uncertainty in the depolarization ratio is the systematic errors in the optical setup of the lidar systems (Belegante et al., 2018). In particular, different field of view (FOV) can lead to different multiple scattering effects. The FOV of ACDL is 0.2 mrad, the pulse energy is 150 mJ and telescope aperture is $\Phi 1000$ mm (Dong et al., 2018; Liu et al., 2019). The FOV of ground-based lidar is 0.5 mrad, the pulse energy is 100 mJ and telescope aperture is $\Phi 200$ mm. The experiment found that by changing the field of view angle, the lidar and the aerosol remain unchanged, resulting in different depolarization ratios. This is due to the multiple scattering effects, which are more pronounced in the clouds (Hu et al., 2006).

The random noise in the ACDL profiles is much higher than the ground-based lidar profiles due to their much longer measurement range and shorter integration times, and the daytime noise level is higher than nighttime due to the statistical fluctuations associated with solar background light. Reducing the noise to the required level requires averaging profiles along the ground track (Gimmestad et al., 2017). However, spatial aerosol inhomogeneities introduce systematic error into the averages. The Zhangye and Dunhuang lidar station is located at 1454 m a.s.l. and 1142 m a.s.l. with a complex topography of the surrounding area (Figure R1) that makes very difficult the comparison in the planetary boundary layer with satellite data acquired with imperfect spatial coincidence. Overall, the observation comparison results between the ACDL and ground-based lidar are acceptable.

In the end of Section 3, we added “*The discrepancies in the comparison between ACDL and ground-based lidar measurement are possible because of the several factors such as different lidar system parameters, the difference in detection distance between spaceborne and ground-based systems and also can be due to the inhomogeneity of the atmosphere (Chiang et al., 2011; Belegante et al., 2018). Overall, the observation comparison results between the ACDL and ground-based*

lidar are acceptable.” in lines 285-290. And we have changed the distance details in Figure 2.

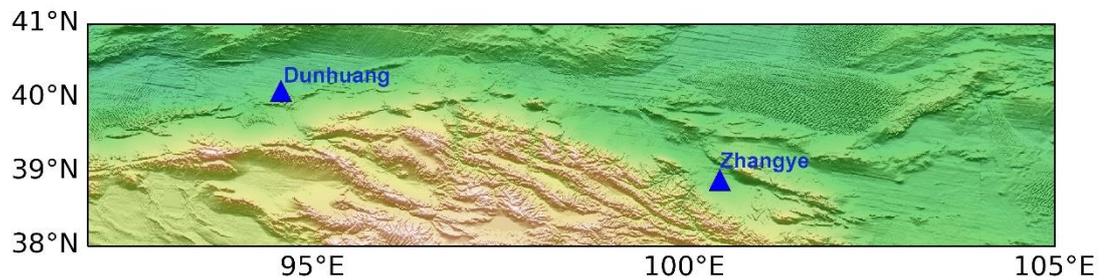


Figure R1. Topographic characteristics of the location of ground-based lidar.

Reference:

Belegante, L., Bravo-Aranda, J. A., Freudenthaler, V., Nicolae, D., Nemuc, A., Ene, D., Alados-Arboledas, L., Amodeo, A., Pappalardo, G., D’Amico, G., Amato, F., Engelmann, R., Baars, H., Wandinger, U., Papayannis, A., Kokkalis, P., and Pereira, S. N.: Experimental techniques for the calibration of lidar depolarization channels in EARLINET, *Atmos. Meas. Tech.*, 11, 1119–1141, <https://doi.org/10.5194/amt-11-1119-2018>, 2018.

Chiang, C.-W., Kumar Das, S., Shih, Y.-F., Liao, H.-S., and Nee, J.-B.: Comparison of CALIPSO and ground-based lidar profiles over Chung-Li, Taiwan, *Journal of Quantitative Spectroscopy and Radiative Transfer*, 112, 197–203, <https://doi.org/10.1016/j.jqsrt.2010.05.002>, 2011.

Dong, J., Liu, J., Bi, D., Ma, X., Zhu, X., Zhu, X., and Chen, W.: Optimal iodine absorption line applied for spaceborne high spectral resolution lidar, *Appl. Opt.*, 57, 5413, <https://doi.org/10.1364/AO.57.005413>, 2018.

Hu, Y., Liu, Z., Winker, D., Vaughan, M., Noel, V., Bissonnette, L., Roy, G., and McGill, M.: Simple relation between lidar multiple scattering and depolarization for water clouds, *Opt. Lett.*, 31, 1809, <https://doi.org/10.1364/OL.31.001809>, 2006.

Gimmestad, G., Forrister, H., Grigas, T., and O’Dowd, C.: Comparisons of aerosol backscatter using satellite and ground lidars: implications for calibrating and validating spaceborne lidar, *Sci Rep*, 7, 42337, <https://doi.org/10.1038/srep42337>, 2017.

Liu, D., Zheng, Z., Chen, W., Wang, Z., Li, W., Ke, J., Zhang, Y., Chen, S., Cheng, C., and Wang, S.: Performance estimation of space-borne high-spectral-resolution lidar for cloud and aerosol optical properties at 532 nm, *Opt. Express*, 27, A481, <https://doi.org/10.1364/OE.27.00A481>, 2019.

3. It is not clear how the space lidar and surface lidar are collocated? And how space HSRL and CALIPSO are collocated? Lidar orbit tracks are typically narrow and there may be certain distances between the lidar orbit and the surface lidar. Also, it is not clear how lidar signals are averaged spatially (vertical and horizontal) and temporally? The ground lidar data presented seem to have lower vertical resolution so it seems some averaging is performed.

Response: We thank you for raising the question. In order to better illustrate the collocating of ACDL and ground-based lidar, we have made a schematic diagram (Figure R2). Collocating is centered around the location of the ground-based lidar (red star in the Figure R2), with a radius of 50 km drawn as a circle (the circle represented by the black dashed line in the Figure R2). The observation trajectory of ACDL is very narrow, so we can approximate it as a line (green line in the Figure R2). If this line intersects with the drawn circle, we believe that the observation results of the two could be compared. The orange dashed line in the Figure R2 represents the observation distance between the ACDL and ground-based lidar. The trajectory matching method of CALIPSO is the same as ACDL, and the collocate between CALIPSO and ACDL is derived from their distances from ground-based lidar. In the case of July 10, 2022, the nearest position of CALIPSO ground track is 97 km away from Zhangye ground-based lidar station and 69 km away from ACDL, which we think is a comparable range.

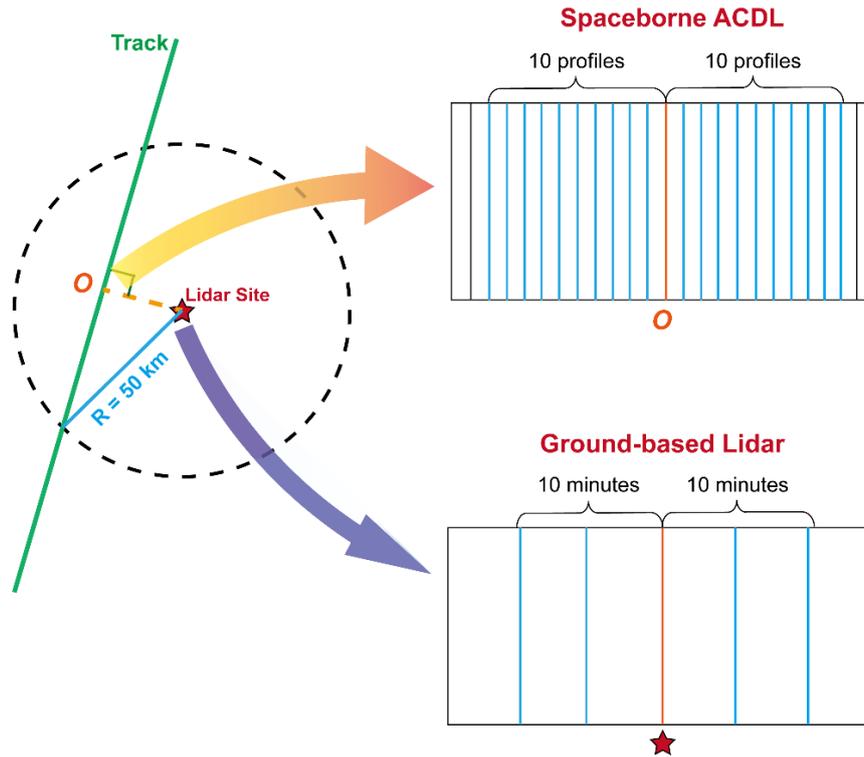


Figure R2. Schematic diagram of position matching and data selection for spaceborne and ground-based lidar.

We use moving average to smooth the vertical signals of both spaceborne and ground-based lidars. To reduce the random error of instrument observation, we use the location nearest the ground-based lidar position in the ground track of the spaceborne lidar (point O in Figure R2) as the center. We take 10 profiles before and after it (a total of 21 profiles) for averaging. The relevant schematic diagram is located in the upper right corner of Figure R2. For ground-based lidar, we take the satellite observation time corresponding to point O as the overpass time of the spaceborne lidar. Based on this time, we select 10 minutes of data before and after the overpass time and average them (the time resolution of the ground-based lidar is 5 minutes, so there is a total of 5 profiles). The relevant schematic diagram is located in the lower right corner of Figure R2. In Section 3, we added “*Selecting satellite ground tracks passing within a 50 km radius centred on ground-based lidar for validation.*”. And we moved “*In order to further quantify and visually compare the observed discrepancies between ACDL and ground-based lidar, and to eliminate the uncertainties such as random noise generated by the observations, 21 profiles were averaged in ACDL (i.e., take the*

profile at the closest distance to the ground site is taken as the centre, and ten profiles are averaged before and after) and 5 profiles were averaged in the ground-based lidar (i.e., the overpass time was centered and averaged by taking a 10-minute profile before and after each).” in Section 3.1 to Section 3.

4. The HSRL was launched more than 1.5 years ago, which should have obtained quite large amounts of data. So why only 6 cases are selected? How are they selected?

Response: Thanks for your suggestion. The focus of our work is to evaluate the observation performance of ACDL in the first few months, as stated in the title of the manuscript as “Initial”. Because the quality of data in these months is extremely important for evaluating the observational performance of new launched spaceborne remote sensing instruments. After the instrument starts working, it needs to take some time to reach a stable observation state. Therefore, we selected the data of the Belt and Road lidar network from May to July to match the six best-matched cases in time and space. And these 6 cases include 3 different typical types of clear, dust, and cloudy atmospheric scenes, with observation times also including daytime and nighttime.

The matching method is centered around the location of the ground-based lidar (red star in the Figure R2), with a radius of 50 km drawn as a circle (the circle represented by the black dashed line in the Figure R2). The ground track of ACDL is the green line in the Figure R2. If this line intersects with the drawn circle, we believe that the observation results of the two can be compared. We have changed the sentence in Section 3: *“Herein, we compare six best-matched cases of space-borne ACDL that overpassed the ground-based lidar sites in time and space, which are classified into three weather conditions, including clear sky, dust events, and cloudy conditions.”*.

5. Why not also use EARLINET data? It is publicly available and may increase valid cases.

Response: Thanks for your suggestion. Validation is extremely important for a newly launched spaceborne lidar, especially in different regions, times, and weather conditions. Ground-based lidar data from different networks should be used to evaluate

the performance of ACDL. However, in order to evaluate the initial observation performance of ACDL as soon as possible, we firstly used the self-developed multi-wavelength Raman polarization lidar network data and CALIPSO data. In the future, we hope to use more data with other teams around the world (such as EARLINET, ADNET, MPLNET) to evaluate the observational performance of ACDL in other places.

6. Some technical basics of the HSRL, such as signal to noise ratio, calibration method, data quality control, should be described.

Response: Thanks for your suggestion. The manuscript only provides a brief description of HSRL technology. For more details, please refer to Dai et al. (2023) published article. We added “*For specific data processing methods such as signal-to-noise ratio processing, calibration method and data quality control, please refer to relevant published articles (Liu et al., 2019; Ke et al., 2022; Dai et al., 2023; Zha et al., 2023).*” in section 2.4.4 High spectral resolution lidar (HSRL) retrieval method from ACDL.

Reference:

Dai, G., Wu, S., Long, W., Liu, J., Xie, Y., Sun, K., Meng, F., Song, X., Huang, Z., and Chen, W.: Aerosols and Clouds data processing and optical properties retrieval algorithms for the spaceborne ACDL/DQ-1, *Aerosols/Remote Sensing/Data Processing and Information Retrieval*, <https://doi.org/10.5194/egusphere-2023-2182>, 2023.

Ke, J., Sun, Y., Dong, C., Zhang, X., Wang, Z., Lyu, L., Zhu, W., Ansmann, A., Su, L., Bu, L., Xiao, D., Wang, S., Chen, S., Liu, J., Chen, W., and Liu, D.: Development of China’s first space-borne aerosol-cloud high-spectral-resolution lidar: retrieval algorithm and airborne demonstration, *PhotoniX*, 3, 17, <https://doi.org/10.1186/s43074-022-00063-3>, 2022.

Liu, D., Zheng, Z., Chen, W., Wang, Z., Li, W., Ke, J., Zhang, Y., Chen, S., Cheng, C., and Wang, S.: Performance estimation of space-borne high-spectral-resolution lidar for cloud and aerosol optical properties at 532 nm, *Opt. Express*, 27, A481, <https://doi.org/10.1364/OE.27.00A481>, 2019.

Zha, C., Bu, L., Li, Z., Wang, Q., Mubarak, A., Liyanage, P., Liu, J., and Chen, W.:
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Resolution Lidar onboard DQ-1 Satellite: Retrieval and Validation, *Atmos. Meas.
Tech. Discuss.* [preprint], <https://doi.org/10.5194/amt-2023-219>, in review, 2023.