Response to Albert Ansmann' comments

MS No.: amt-2023-219
MS type: Research article
Title: Aerosol Optical Properties Measurement using the Orbiting High Spectral Resolution Lidar onboard DQ-1 Satellite: Retrieval and Validation
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We greatly appreciate Dear Dr. Albert Ansmann's valuable time reviewing our research paper and providing feedback/suggestions. The comments are valuable and helpful for improving our paper. We have studied all comments carefully and have made major revisions to our manuscript. We sincerely thank the Editor and the reviewer for their valuable suggestions in improving the previous version of our manuscript.

Report #1
The manuscript describes the performance of the Chinese aerosol space lidar DQ-1 HSRL. This manuscript will be probably one of the fundamental papers on DQ-1 HSRL. Therefore, the quality of the manuscript must be improved. Much more information about the quality of the measured signals, about calibration and quality assurance efforts, about cross talk in the different measurement channels needs to be provided.
Major revision is thus recommended.

Response: We are grateful to the reviewer for acknowledging our efforts. We have followed your suggestions carefully and revised the manuscript accordingly, we highlighted the revised text with red font. The corrections have been made in the revised manuscript. Thank you for your suggestions.

General comments and major points

Point 1: What is the meaning of DQ-1 (DQ stands for…?, should be explained…).
Response 1: DQ-1 stands for atmospheric environment monitoring satellite, also called DaQi-1, We have changed the introduction in the abstract. Relevant changes have been made in the revised version of the manuscript at:

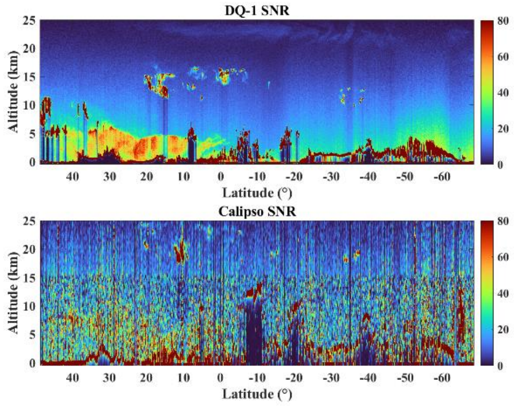
Line 13 The Atmospheric Environment Monitoring Satellite (AEMS), also called DaQi-1 (DQ-1), was launched in April 2022.

Point 2: I would suggest not to use dB to characterize signal-to-noise ratios or the cross talk impact. Just use signal ratios such as P1/P2 instead of Q = 10 log (P1/P2) in dB.
Response 2: Thank you for pointing out this issue. We will accept your suggestion and use P1/P2 to characterize signal-to-noise ratios in this manuscript. The corresponding modifications have been made to the manuscript at:

L19: The results have shown a continuous profile alignment between the two datasets, with DQ-1 describing an improved signal-to-noise ratio.

L220: While the value of CALIPSO's aerosol signal SNR varied from 10 to 40, the SNR of DQ-1's aerosol signal exceeded 40. Additionally, DQ-1 has maintained a high-altitude molecular scattering SNR above 20, whereas CALIPSO's high-altitude molecular scattering signal SNR has a value of less than 20.

Line 550 Figure 4 (c), (d):



Point 3: In the abstract, R^2 0.803, you mean R^2=0.803?

Response 3: Yes, it is. And we apologize for the negligence of the wording here, we have revised the wording to be clearer. The corresponding revised sentences are:

Line 24: …were correlated and yielded a value of R^2 equal to 0.803.

Point 4: The shortcomings of airborne (and spaceborne) observations could also be mentioned: They deliver snapshot-like observations, compared to ground-based (GB) observations. GB remote sensing may allow to study life cycle processes, evolutions, developments.

Response 4: Thank you for your comments. Considering your suggestion, we have added corresponding modifications to the manuscript regarding the advantages and disadvantages of airborne (and spaceborne) observations to our manuscript. The revised sentences are:

Line 37: There are several advantages of ground-based lidar: easy maintenance of the instrument, accurate results, and long-term observation. The life cycle and evolution process of aerosols can be studied through ground-based lidar systems.

Line 54: Nevertheless, the system's observations are limited by factors such as flight paths and meteorological conditions to prevent prolonged data collection, and low spatiotemporal resolution making it impossible to observe the microscale system.

Line 57: Although satellite observations have the drawbacks of low temporal and spatial resolution, as well as long revisit period, they can obtain global aerosol optical parameters

Point 5: lines 66-68: The text is confusing, please rephrase.

Response 5: We are very sorry for our incorrect writing and thanks for your suggestion. The revised sentence is:

Line 66: As a new-generation lidar, high spectral resolution lidar avoids the assumption during retrieval steps, resulting in more precise results.

Point 6: Furthermore, one could mention other activities such as the AEOLUS and the EarthCARE space lidar missions, in support to CALIPSO. line 79: … to be launched…when?

Response 6: Thank you for pointing out this issue. We have added the introduction of the two space lidar missions and their support to Calipso. We are sorry for this incomplete sentence, this satellite is expected to be launched in 2024, and we have made corresponding revisions to the manuscript. The revised sentence is

Line 75: This satellite is anticipated to be launched in 2024. In addition, the Atmospheric Laser Doppler Instrument (ALADIN) lidar loaded on the AEOLUS provides results of global aerosol optical parameters retrieved by L2A data which had performed the comparison with the ground-based lidar product."

Point 7: line 112: There are three signal channels: cross-polarized (particle+Rayleigh), co-polarized (particle+Rayleigh), and HSRL channel (Rayleigh). Please add this information on particles and Rayleigh contributions;

DQ-1 detects co and cross-polarized Rayleigh and particle backscatter components. We need to know, how large the contribution of these four signal components is in the three measurement channels? Is all the cross talk considered and corrected for in the different product retrievals? How are the transmission and reflection properties of the optical elements in the receiver unit, between the telescope and the detector. What is the contribution of the four signal elements to the detected signal counts in the three channels.

All potential cross talk effects must be considered in the retrieval. So, please discuss the contribution of the four backscatter components in the three channels.

Response 7: Thank you for pointing out these important issues. We have added the functions of each optical channel to the manuscript, we also analyzed the proportion of Mie scattering and Rayleigh scattering in each channel.

Figure 1 illustrates the schematic of the three optical channels in the DQ-1 receiving system. The function of high spectral channels is to separate the Mie scattering and Rayleigh scattering in the signal. In this channel, the Mie scattering is mostly filtered out, leaving behind molecular Rayleigh scattering. The ratio of these two scattering signals can be determined by comparing the high spectral channel signal with the parallel channel signal. After filtering, only 0.2% of the Mie scattering signal will remain in the high spectral channel. The remaining Mie scattering signal will be discussed in Response 8.

The function of parallel channels and perpendicular channels is to obtain polarization information of the target. A Polarization Beam Splitter (PBS) separates the perpendicular polarized and parallel polarized signals in the echo signal, and by comparing the ratio of these two channels, the polarization information of the target object can be obtained. For parallel (perpendicular) channels, PBS can filter out most of the perpendicular (parallel) polarized signals, making the proportion of vertical (perpendicular) polarized signal received in PMT less than 0.01%, considering the polarization retrieval results of aerosol signals, this crosstalk will not affect the retrieval of aerosols (Hair et al., 2008).

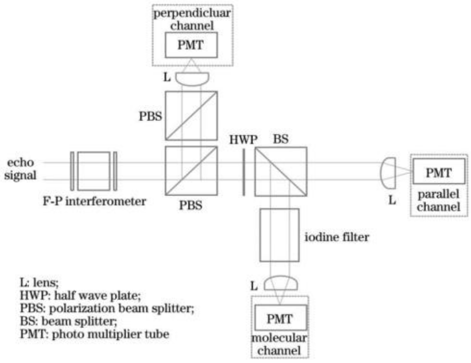


Figure 1 Schematic of HSRL receiving system.

The corresponding revision has been made to the manuscript at:

line 113: The parallel and perpendicular channels serve the function of obtaining polarization information of the aerosol, a Polarizing Beam Splitter (PBS) is placed to reduce polarization cross talk. The high spectral channels function to separate Mie scattering and Rayleigh scattering in the signal, obtaining the molecular scattering profile.

Point 8: line 117: You mention, the aerosol suppression ratio is more than 25 dB. So, we have less than -25 dB, i.e., less than 0.00316). Is that sufficient to derive extinction profiles? In the case of cirrus backscatter and extinction, you may need 5-6 orders of magnitude suppression to obtain high-quality extinction profiles? But maybe you correct for cross talk? But that should then be explicitly described.

Response 8: Yes, it is sufficient for retrieval. We present the attenuated backscatter signal profiles of cirrus and comparison using molecular backscattering profiles. The filter absorbed the Mie scattering signal of the cirrus, and the signal quality did not affect the results. In our retrieval results of cirrus, the lidar ratio is less than 40, which is consistent with the range of ice crystals in the literature. Other types of aerosols are also consistent with the literature.

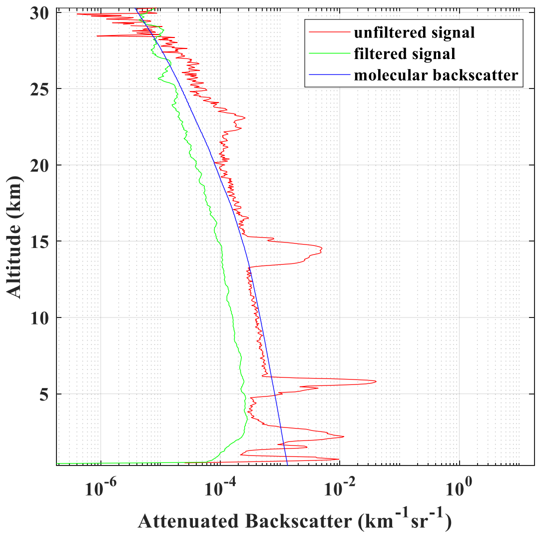


Figure 2 Attenuated backscatter of a cirrus

Figure 2 showcases a cirrus profile. The red line represents the unfiltered signal, the green line represents the filtered signal, and the blue line represents the molecular backscatter signal. The unfiltered signal displays the echo signal of the cirrus at an altitude of 13-15 km. The filtered signal only contains molecular backscatter, without the cirrus signal. Similarly, clouds at 5-6 km are only displayed in the unfiltered signal. At an altitude of 3 km, the signal is unable to penetrate thick cumulus clouds, resulting in signal attenuation below this altitude. The filtered signal is more in line with the molecular scattering, the signals from clouds and aerosols have been filtered out.

Point 9: The Eqs.(2.1)-(2.3) are too simple. No efficiency factor (describing optical and detection efficiency), no cross talk factor. So, Eq.(2.5) does not need any calibration? The depolarization ratio is simply obtained from the ratio of the cross- to- co-polarized channel outputs?

Response 9: We apologize for our negligence. System calibration has been conducted in equations (2.1) – (2.3). We have added and modified the corresponding introduction and formulas to the manuscript, analyzing the system calibration process of signals. The corresponding modifications are:

Line 139:

$$B^{\perp}(r) = \frac{P(r)r^2}{P_0\eta^{\perp}AL}[\beta_m^{\perp}(r) + \beta_a^{\perp}(r)] \times exp\left\{-2\int_0^r [\alpha_m(r) + \alpha_a(r)]\,dr\right\} \quad (2.1)$$

$$B_C^{\parallel}(r) = \frac{P(r)r^2}{P_0\eta_C^{\parallel}AL}[\beta_m^{\parallel}(r) + \beta_a^{\parallel}(r)] \times exp\left\{-2\int_0^r [\alpha_m(r) + \alpha_a(r)]\,dr\right\} \quad (2.2)$$

$$B_H^{\parallel}(r) = \frac{P(r)r^2}{P_0\eta_H^{\parallel}AL}[T_m(r)\beta_m^{\parallel}(r) + T_a(r)\beta_a^{\parallel}(r)] \times exp\left\{-2\int_0^r [\alpha_m(r) + \alpha_a(r)]\,dr\right\} \quad (2.3)$$

Line 144: $P(r)$ represents the power of the laser echo signal at distance r. P_0 represents the pulse energy, η represents the optical-electrical efficiency of the recever in corresponding channel, A represents the aperture of the telescope, and L stands for half of the pulse spatial length, where L is calculated as $L = c\Delta t/2$, with c representing the speed of light and Δt denoting the pulse duration. System correction has been implemented to ensure that the data is solely contingent upon atmospheric conditions. $\beta_m(r)$ and $\beta_a(r)$ represents the backscatter coefficient of molecules and aerosols respectively. The molecular backscatter coefficient and extinction coefficient are calculated by the S6 molecular model using the data of temperature and pressure provided by ERA5.

Point 9: An Eq.( ) for T_m would be nice. Please state in the manuscript where you found Eq.(2.4). Please provide a reference for Eq.(2.6) and Eq.(2.8). Please, provide reference for Eq.(2.9). What is the solution for Eq.(2.9) if you start from Eq.(2.8) (or Eq.(2.6))?

Response 9: Following your comment, the formula for T_m has been incorporated into the manuscript. The references and the solution of the corresponding formulas have been added:

Line 145:

$$T_m(T,p) = \int F(v)\int R_m(v',T,p)l(v-v')dv'dv \quad (2.4)$$

$$T_a(T,p) = \int F(v)\int R_a(v',T,p)l(v-v')dv'dv \quad (2.5)$$

Line 147: Where $l(v-v')$ represents the spectrum distribution of the laser beam, $F(v)$ represents the normalized transmission spectrum of the iodine filter. $R_m(v',T,p)$ represents the normalized molecular scattering spectrum related to temperature and pressure. $R_a(v',T,p)$ represents the normalized aerosol particles scattering spectrum.

Line 148:

$$\beta_a(r) = \beta_m(r)\frac{[1+\delta(r)]}{(1+\delta_m)}\frac{[T_m(r)-T_a(r)]K(r)}{[1-T_a(r)K(r)]} - \beta_m(r), (Xu\ et\ al., 2020) \quad (2.6)$$

Line 153:

$$\tau(r_0) = \int_0^{r_0}\left(\alpha_a(r)+\alpha_m(r)\right)dr = -\frac{1}{2}ln\left[\frac{\left(1-K(r_0)T_a(r_0)\right)(1+\delta_m)B_H^{\parallel}}{\left(T_m(r_0)-T_a(r_0)\right)}\right], (Xu\ et\ al., 2020) \quad (2.9)$$

Line 159:

$$\alpha_a(r_0) = \frac{\partial\tau(r_0)}{\partial r} - \alpha_m(r_0) = -\frac{1}{2}\frac{\partial}{\partial r}\left\{ln\left[\frac{\left(1-K(r_0)T_a(r_0)\right)(1+\delta_m)B_H^{\parallel}}{\left(T_m(r_0)-T_a(r_0)\right)}\right]\right\} - \alpha_m(r_0), (Xu\ et\ al., 2020) \quad (2.10)$$

Point 10: Please explain all abbreviations when they appear for the first time.

Response 10: We apologize for this carelessness. All abbreviations in the manuscript have been double checked and explained. Revisions are:

Line 21: Optical property profiles from National Aeronautics and Space Administration (NASA) Micro Pulse Lidar NETwork (MPLNET) stations were selected for validation with the DQ-1 measurements

Line 176: The network utilizes the automated sun photometers produced by Cimel Electronique as the primary instrument to observe the atmosphere.

Point 11: line 184: Pappalardo et al. (2014) deal with the EARLINET lidar network, not with the MPLNET. line 191: For HYSPLIT we need a references.

Response 11: We apologize for this oversight, the corresponding reference has been replaced or added. The revised references are:

Line 184: The NASA Micro-Pulse Lidar Network (MPLNET) is a globally distributed network equipped with a polarized Micro-Pulse Lidar (MPL) system that has been operating continuously since 2000 (Welton et al., 2001).

Line 191: The NOAA Hybrid Single Particle Lagrangian Integrated Trajectory (HYSPLIT) model is a widely used atmospheric transport and dispersion model developed by the National Oceanic and Atmospheric Administration (NOAA) (Draxler and Hess, 1997; Stein et al., 2015).

Point 12: line 227: … with a 10^-4 m^-1 values …. What does it mean? What do you want to tell us? line 228: … with a value of 10^-5 m^-1 sr^-1. …. What does it mean? What do you want to tell us? lines 222 and 234: the same … I do not understand.

Response 12: By representing specific values of aerosol optical parameters, the meaning of these values is to introduce the concentration and types of aerosols here, which helps to identify and analyze.

Point 13: line 245: CALIPSO does not measure the lidar ratio. The lidar ratio is an input value in the CALIPSO data analysis. The lidar ratio has to be set. line 247: In case of CALIPSO measurements of marine particles the lidar ratio is set to 20 sr. What about the measured lidar ratios (DQ-1 HSRL), measured within the cirrus at 15 km height? Please discuss the values. This is one of the important new products of a spaceborne HSRL, compared to the CALIPSO products. Should be highlighted.

Response 13: We apologize for the oversight regarding the CALIPSO lidar ratio. We have acknowledged this issue in the relevant section of the article. The lidar ratio of DQ-1 has been compared only to CALIPSO to a limited extent. Besides, we have added an analysis of the lidar of cirrus, showcasing highlights of DQ-1. The revised sentences are:

Line 244: The advantage of the DQ-1 HSRL system is that it can retrieval the lidar ratio without assumptions, which is significantly different from CALIPSO. DQ-1 indicate that the lidar ratio of aerosol particles is around 40 sr, describing the characteristics of mixed dust aerosols, consistent with Calipso's aerosol type. For cirrus at altitude of 10 to 15 km, the retrieved lidar ratio of DQ-1 is less than 40 sr, indicating the characteristics of ice crystals. Due to the proximity of the CALIPSO orbit to oceanic regions, below 3 km altitude and at a latitude below 18°N, CALIPSO identified sea salt aerosols, with numerical values representing a lidar ratio of 20 sr.

Point 14: The lidar ratio dimension is sr and not sr^-1.

Response 14: Thank you for pointing this out and we are sorry about our mistake. The corresponding dimension has been corrected to "sr" in the manuscript.

Point 15: Regarding cirrus and specular reflection. Is the lidar zenith or off-zenith pointing?

Response 15: lidar is off-zenith pointing at a specific angle. We have added the corresponding introduction about off-zenith pointing in the manuscript:

Line 108: The laser is with two distinct pulses, pulse A and pulse B, to observe the atmosphere practically, the laser beam is off-zenith pointing at a specific angle.

Point 16: line 313: You mean top height of 8 km or base height of 8 km? Please, specify.

Response 16: We're sorry for the wording issue here. The meaning we want to express is the top height of the dust. The revised sentence is:

line 313: DQ-1 observed a top height of 8 km for the aerosol layer

Point 17: Figure 1: One should indicate the different channels (B, B_C, B_H)

Response 17: we have added this information to the title of figure 1, the revised title are:

Line 535: The actual measured transmittance spectra of the on-board iodine vapor filter of the DQ-1 satellite. The subfigure in the lower right corner displays the transmittance spectrum in 1110 line. The red solid line delineates the spectral of the echo signal prior to filter (parallel channel), the blue solid line delineates the spectral of the echo signal after the filter (high spectral channel).

Point 18: Figure 4e: Please mention that mean profiles for 20-22°N (longitudes…?) are shown.

Response 18: Thank you for pointing out this issue. We have mentioned the latitude and longitude range of the mean profiles. The revised title is:

Line 563: (i) Comparison of particulate depolarization mean profile of 20°N to 22°N; (j) Comparison of aerosol backscatter coefficient mean profile of 20°N to 22°N. (k) Comparison of aerosol extinction coefficient mean profile of 20°N to 22°N. (h) Aerosol lidar ratio mean profile of 20°N to 22°N.

Point 19: Figure 5: the color range should be improved. We have mostly dark blue, sometimes light blue (or cyan) and sometimes yellow. Figure 5: The advantage of DQ-1 HSRL is that lidar ratios can be measured. But lidar ratio results are not shown in Figure 5 (i:backscatter, j: extinction, why not k: lidar ratio). and also, what about depolarization ratio results?

Response 19: Thank you for pointing out this issue. We have changed the colormap used in the manuscript to display data features more clearly. And we have considered your comments and added the results of the corresponding lidar ratio to the depolarization ratio in Figure 5. The modified figures are:

Figure 5e:

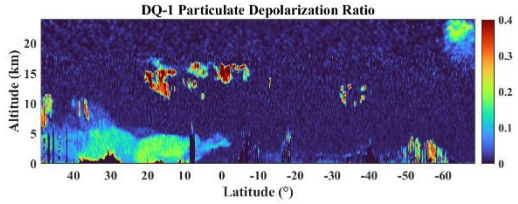
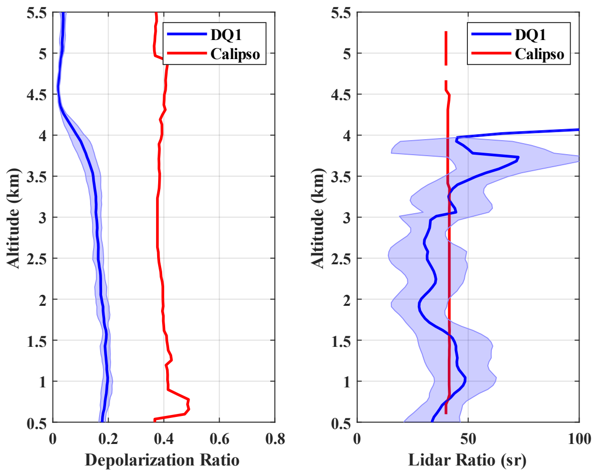


Figure 5i, 5h:



Point 20: Figure 6: MPL retrievals can only deliver particle backscatter profiles. If extinction profiles obtained with MPL and DQ-1 HSRL match then this is just the hint that the lidar ratio was around 50 sr, as assumed in the MPL retrieval. What about depolarization profiles.

Figure 7: Again, only backscatter can be compared.

Response: Thank you for pointing out this issue. We have removed the results comparing with the extinction coefficient of MPL and replaced them with the results comparing with the depolarization ratio in Figures 6 and 7. The modified figures are:

Figure 6a, 6d ,and 6g:

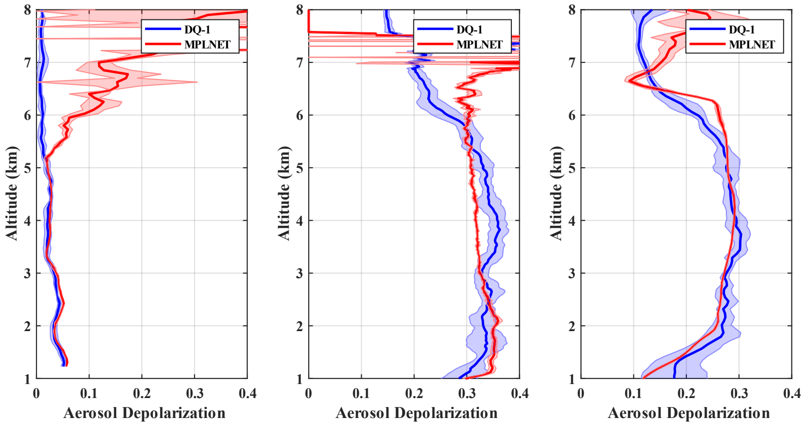
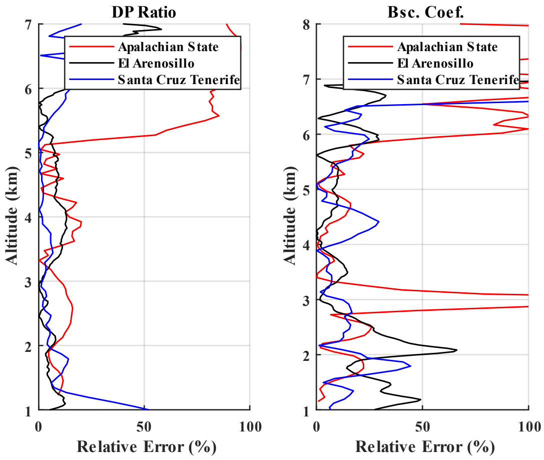


Figure 7:



The above is the complete response to your comments. We look forward to hearing from you regarding our responses. We would be glad to respond to any further questions and comments you may have.

References

Hair, J. W., Hostetler, C. A., Cook, A. L., Harper, D. B., Ferrare, R. A., Mack, T. L., Welch, W., Izquierdo, L. R., and Hovis, F. E.: Airborne High Spectral Resolution Lidar for profiling aerosol optical properties, Appl. Opt., 47, 6734-6752, 10.1364/AO.47.006734, 2008.