

Responses to RC1

General Remarks

This manuscript presents a valuable long-term study, using an elastic backscatter lidar (532 nm) to evaluate the influence of particle hygroscopic growth on aerosol optical depth (AOD) over central China. The authors have compiled an extensive observational dataset spanning 2010-2024, which enables an analysis of trends related to emission reduction policies. Hygroscopic growth is a critical factor governing AOD, and the authors try to quantify the difference between ambient and dry-condition AOD across different years and seasons. The manuscript provides important new results on this topic, is well and clearly written, and is suitable for publication in Atmospheric Chemistry and Physics. I have just several technical comments.

Response: We appreciate your thoughtful review and valuable comments on our manuscript. In response, we have added a discussion on the influence of hygroscopic growth on lidar ratio, and have conducted a sensitivity analysis to assess the uncertainties in AOD_{dry} introduced by variations in the lidar ratio. In addition, we have also discussed the deliquescence nature of aerosol. Point-by-point responses are provided below, and the manuscript has been revised accordingly.

Specific comments

Comment: Authors use Fernald approach for calculation of the backscattering coefficient and lidar ratio of 50 sr to obtain the extinction coefficient. However, lidar ratio strongly depends on RH, so this issue should be discussed. I recommend the recent publication:

Haarig, M., Engelmann, R., Baars, H., Gast, B., Althausen, D., and Ansmann, A.: Discussion of the spectral slope of the lidar ratio between 355 nm and 1064 nm from multiwavelength Raman lidar observations, EGU sphere [preprint], <https://doi.org/10.5194/egusphere-2025-449>, 2025.

Response: Thank you very much for pointing this out. Relevant statements have been added as follows “**As mentioned in Section 2.1, the particle backscatter (or extinction) coefficient is retrieved using the Fernald method with an assumed fixed lidar ratio of 50 sr for anthropogenic aerosols. However, it should be noted that the lidar ratio varies with ambient RH and can increase notably under high RH conditions. For example, Haarig et al. (2025) reported that the lidar ratio of continental aerosols measured by Raman lidar at 532 nm was 48.1 ± 7.4 sr at 70-80% RH, and increased to 65.3 ± 9.9 sr at 85-92% RH.**” (please see lines 173-179) The resulting uncertainties in AOD_{dry} introduced by different lidar ratios will be assessed and discussed in the following response.

Comment: Lidar ratio even for low RH presents significant variations. Corresponding uncertainties should be discussed. May be AERONET data can be used, to support the choice of lidar ratio of 50 sr (AERONET allows to reconstructs lidar ratio).

Response: Thank you for the reviewer’s valuable suggestions. However, as Wuhan does not have an AERONET site, we adopted typical lidar ratio values for anthropogenic aerosols from existing literature. Previous studies have reported a fixed LR of 50 sr as an average value derived from combined lidar and sun photometer measurements (Takamura et al., 1994) or Raman lidar observations (Müller et al., 2007) for urban aerosols in the ambient troposphere.

Nevertheless, a sensitivity analysis is conducted to assess the uncertainty of applying a fixed lidar ratio of 50 sr for all conditions. A LR-RH relationship from Zhao et al. (2017) is adopted for the sensitivity analysis:

$$LR = LR_0 \times (0.92 + 2.5 \times 10^{-2}(RH - 40) - 1.3 \times 10^{-3}(RH - 40)^2 + 2.2 \times 10^{-5}(RH - 40)^3) \quad (1)$$

Since the RH in the lower troposphere over Wuhan ranges approximately from 40% to 70% (see Figure 7b of our manuscript), we set $LR_0=47$ sr in Eq. (1); this assigns a LR of 50 sr to RH conditions around 50-55%. As derived from Eq. (1) (Zhao et al., 2017), if RH=40%, $LR=LR_0 \times 0.92=43.24$ sr, which will be applied at RH<40%.

Taking the case on 2 August 2023 as an example, LR can reach up to 70 sr when RH exceeds 80% (Figure 1R(a)), resulting in a rapid increase in the extinction coefficient at corresponding altitudes (figure 1R(b)). After removing the influence of hygroscopic growth, the extinction coefficient is lower than that obtained using the original LR=50 sr (Figure 1R(c)). The corrected AOD_{dry} is 0.082, representing a 15.5% decrease from the original value of 0.097. A sensitivity analysis was further conducted for 10 cases in 2023 ($\gamma=0.6$), covering a range of pollution levels and RH conditions (Table 1R). The results indicate that when considering the effect of hygroscopic growth on lidar ratio, corrected AOD_{dry} values generally decrease by 10-25%. This sensitivity analysis and the corresponding discussions have been added as an appendix section in the revised manuscript. (please see lines 373-394)

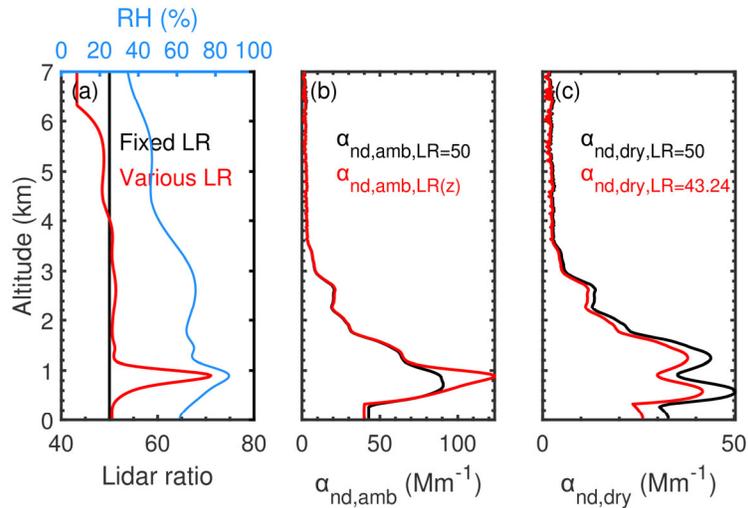


Figure 1R. Profiles of (a) lidar ratio and relative humidity; (b) non-dust extinction coefficient in ambient atmosphere; (c) non-dust extinction coefficient in dry conditions during 1639-1758 LT on 2 August 2023. The Black curves denote the results obtained using the original fixed lidar ratio of 50 sr, while the red curves denote the corrected results.

Table 1R. Comparisons of AOD_{dry}: original LR versus corrected LR.

Date	AOD _{dry,LR=50}	AOD _{dry,LR=43.24}	RH(%)	$(\text{AOD}_{\text{dry,LR=50}} - \text{AOD}_{\text{dry,LR=43.24}}) / \text{AOD}_{\text{dry,LR=50}}$
2023-01-04 0400-0519 LT	0.435	0.367	29±18	15.6%
2023-02-03 1347-1417 LT	0.431	0.345	68±10	20.0%
2023-04-09 1753-1824 LT	0.105	0.092	47±26	12.4%
2023-06-08 0927-1046 LT	0.201	0.181	57±17	10.0%
2023-08-02 1639-1758 LT	0.097	0.082	55±19	15.5%
2023-08-13 0957-1114 LT	0.500	0.373	78±8	25.4%
2023-08-22 1625-1744 LT	0.138	0.120	29±24	13.0%
2023-10-24 0933-1052 LT	0.274	0.234	47±23	14.6%
2023-11-22 2008-2127 LT	0.267	0.231	38±24	13.5%
2023-11-29 1131-1250 LT	0.430	0.348	47±28	19.1%

Comment: When Fernald approach is used, backscattering is calculated only above the height of full overlap. I did not find in the manuscript discussions about extrapolation data to the ground level (sorry if I missed it).

Response: For our lidar system, the lowermost height with complete field-of-view (FOV) observation is 0.3 km. Therefore, particle extinction coefficients below 0.35 km were assumed to be equal to those at 0.35 km (Jing et al., 2025). Relevant statements have been added in Section 2.3 (please see lines 159-161)

Comment: Hanel parametrization is applicable above deliquescence point. Discussion about deliquescence nature of aerosol considered would be useful.

Response: In light of the reviewer's comments, the discussions about deliquescence nature of aerosol have been added as follows "Note that the Hanel parametrization is applicable only above the deliquescence relative humidity (DRH), which is defined as the phase transition point at which a hygroscopic solid transform from the solid phase to the liquid phase at a specific RH (Mauer and Taylor, 2010). Generally, water-soluble inorganic salts exhibit distinct DRH values, e.g., 80% for ammonium sulfate, 75% for sodium chloride, and 61% for ammonium nitrate (Lee et al., 2001; Wise et al., 2007; Zawadowicz et al., 2015). Under ambient conditions, however, the DRH of inorganic salts trends to decrease when they are internally mixed with organic compounds (Brooks et al., 2002; Luo et al., 2020)...." (please see lines 150-156)

Comment: Abstract, ln 11. "both parameters". Probably should be corrected.

Response: We have modified accordingly.

Comment: P.9, ln 207. The use of "annual mean hygroscopic growth parameter" definitely leads to significant uncertainties. Would be good to discuss.

Response: Relevant statements have been added as follows "The standard deviation of the annual mean γ would affect AOD_{dry} , as indicated by the error bars in figure 6a, resulting in an uncertainty of approximately 10%." (please see lines 251-252)

Comment: P.9 ln 210. "These values suggest that hygroscopic growth on average increased AOD by 30.7%...". Keeping in mind uncertainties of approach such accuracy looks excessive.

Response: Thank you very much for your reminder. The relevant statement has been revised as follows "The average AOD_{dry} and AOD_{amb} were measured to be 0.315 ± 0.164 and 0.404 ± 0.219 , respectively, across the period considered in our study. These results indicate that hygroscopic growth on average enhanced AOD by approximately 30% under humid atmospheric conditions." (please see lines 231-234) Additionally, the average AOD_{dry} has been updated from 0.309 to 0.315. The initial value was derived using a constant $\gamma=0.62$ for the entire period, whereas our analysis employs the annual mean γ for each respective year.

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