Dear editor and reviewer #1,

Thank you very much for processing and considering our manuscript "[No.: egusphere-2025-6302] Vertical Structure and Driving Mechanism of $PM_{2.5}$ and PM_{10} Aerosols in Hefei Based on LiDAR Observations (2021–2023)".

Overall, reviewer provided insightful comments and suggestions on our manuscript. We have addressed all the reviewer's comments and provided a detailed explanation of our changes as attached below. Apart from the minor editing changes marked in the main text, the major changes to the manuscript in five aspects have been summarized as below:

a. As suggested by the reviewer, the abstract has been condensed to highlight the core research content, key methods, and main findings.

b. The ambiguous terms and inappropriate expressions have been revised to ensure accuracy in description and terminology.

c. As suggested by the reviewer, redundant descriptions and overly detailed discussions have been simplified to improve readability and fluency.

d. We have supplemented clear physical explanations for key vertical profiles and correlation results in response to the reviewer's questions.

e. We have supplemented the physical mechanism for the noon vertical uplift of the aerosol layer.

We highly appreciate all the feedback from the reviewer. We sincerely believe that these changes in response to the review comments have greatly improved the overall quality of the manuscript. The manuscripts in revised and clean versions are included in this resubmission for your reference. We look forward to hearing from you soon.

Black: Comments from the reviewers

Blue: Responses from the authors

Green: Changes in the main text

Comments from reviewers:

Comments to the Author

This study investigates the vertical distribution characteristics of atmospheric aerosols in Hefei using a ground-based aerosol lidar system. It effectively compares optical properties between $PM_{2.5}$ and PM_{10} pollution events with sufficient data support. The authors systematically present on the advantages and limitations of the aerosol LiDAR. The integration of LiDAR observations with surface particulate matter monitoring and meteorological data (e.g., vertical wind shear, temperature inversion, relative humidity) strengthens the rigor of the analysis, allowing for a comprehensive exploration of the links between aerosol vertical properties and pollution formation mechanisms.

The research design is reasonable, and the conclusions are scientific and reliable. The results reveal the formation mechanisms of the two types of pollution and fill the research gap in aerosol vertical distribution, providing valuable insights for air quality research in eastern China. This study could enhance our understanding of how vertical aerosol dynamics regulate surface air quality, which is critical for improving air quality forecasting and formulating targeted pollution control strategies. In the context of increasingly frequent regional air pollution events in eastern China, the detailed vertical profile data and comparative analysis of $PM_{2.5}$ and PM_{10} presented here provide a new perspective for distinguishing the distinct drivers of fine and coarse particulate pollution.

The supplementary materials are highly valuable for readers to further understand the observational data and analytical results. Nevertheless, several minor issues still need to be addressed to improve readability. The font size in some figures is too small to distinguish clearly, which affects reading efficiency. In addition, a few technical terms are used inappropriately in certain contexts, and some descriptions are unnecessarily repetitive across different sections. These redundant expressions can be further condensed and polished to enhance the conciseness and fluency of the manuscript. I favor publishing this manuscript in Atmospheric Measurement Techniques after minor revisions.

Response: Thank you very much for your positive comments and valuable suggestions on our manuscript. We have addressed all the concerns in the following responses and manuscript.

Specific comments

1. The abstract is overly lengthy and lacks conciseness. Please condense it to highlight the core issue, key methodologies, and most critical findings, ensuring it meets the standard word count for the journal.

Response: change applied. The abstract has been carefully condensed and streamlined to emphasize the core scientific issue, key methodologies, and main findings of this study.

Line 15-42: Aerosol pollution remains a significant environmental concern in China. However, the vertical structure and evolution of particulate matter are poorly understood due to the lack of long-term, high-resolution observations. In Hefei, the aerosols during the study period were dominated by a mixture of fine particulate matter ($PM_{2.5}$) and coarse particulate matter (PM_{10}), mainly originating from urban traffic emissions, industrial activities, and regional transport, with significant contributions from secondary inorganic aerosols and occasional dust events. To address the knowledge gap in aerosol vertical distribution during different pollution episodes, this study employed an aerosol LiDAR system with 532 nm band to investigate the vertical profile characteristics of aerosols, with a focus on comparing the stratification differences of optical properties between $PM_{2.5}$ and PM_{10} pollution events over Hefei. The seasonal and diurnal variations of aerosol profiles were investigated on polluted and clean days. The relationship between near-surface particulate matter concentrations and aerosol stratification was analyzed, alongside the dynamic evolution of aerosol layers during typical pollution events. Our results demonstrated that the extinction coefficient (532 nm) of $PM_{2.5}$-polluted days below 0.6 km was approximately three times that of PM_{10}-polluted days. In contrast, the depolarization ratio of PM_{10}-polluted episodes remains consistently higher than that of $PM_{2.5}$-polluted cases throughout the entire observed altitude range. The differences in extinction between polluted and clean days for $PM_{2.5}$ were most pronounced below 0.9 km and subsequently decreased as altitude increased, whereas the differences in PM_{10} remained significant below 1.2 km. For $PM_{2.5}$, the strongest enhancement appeared between 7:00 and 14:00 (Beijing time, BJT). A subtle lifting with height was observed around midday. PM_{10}-polluted days were characterized by a greater vertical extension of high aerosol extinction (up to ~1.2–1.4 km) but a shorter duration of strong extinction. In contrast, $PM_{2.5}$-polluted days exhibited a persistent but vertically confined aerosol layer. The vertical wind shear (VWS) was weaker on $PM_{2.5}$-polluted days compared to clean days. On PM_{10}-polluted days, the VWS in the near-surface layer (1000–900 hPa) was significantly stronger than that on clean days, especially during the early morning and evening periods. The $PM_{2.5}$ pollution in Hefei was mostly contributed by temperature inversion and high relative humidity, while PM10 pollution was driven by long-range transport of aerosol particles under the cold front system and dry conditions. These findings reveal *complex interactions between aerosol optical properties, boundary-layer dynamics, and synoptic conditions, providing new insights into the vertical air quality processes in eastern China.*

2. Line 23: "The relationship between near-surface particulate matter concentrations and aerosol stratification was analyzed, alongside the dynamic evolution of aerosol layers during typical pollution events." Please clarify whether the analysis of the aforementioned relationship is presented in Figure 8 or 9 of the manuscript. Note that "aerosol stratification" is an appropriate expression if the analysis corresponds to Figure 8, which divides the atmosphere into three distinct vertical layers: 0.2-0.5 km, 0.5-1.0 km, and above 1.0 km. However, this term is not suitable for Figure 9, which shows continuous vertical variations. For Figure 9, a description referring to aerosol properties at different heights would be more accurate.

Response: change applied. We have revised the expression "aerosol stratification" to "aerosol vertical properties at different heights" in the manuscript, as the analysis corresponds to Figure 9, which presents continuous vertical variations of aerosols rather than distinct stratified layers.

Line 24-26: "The relationship between near-surface particulate matter concentrations and aerosol vertical properties was analyzed at different heights, alongside the dynamic evolution of aerosol layers during typical pollution events."

3. Line 82-84: The authors mention that polarization-sensitive aerosol LiDAR can retrieve extinction coefficients and depolarization ratios, which indicate aerosol concentration, morphology, and type, and note that most previous LiDAR-based studies are limited to short-term campaigns or individual pollution episodes lacking spatial and temporal representativeness. Please clarify whether the present study uses polarization-sensitive LiDAR. Additionally, the authors use the term "spatial and temporal representativeness / spatiotemporal" at Lines 91 and 104, but ground-based LiDAR observations inherently have strong advantages in temporal continuity and vertical resolution, not in spatial coverage. It is recommended that the authors revise this phrasing to more accurately reflect the actual strengths and limitations of LiDAR data (e.g., by emphasizing "long-term temporal continuity and seasonal representativeness" rather than "spatial and temporal representativeness"), to avoid overstating the spatial representativeness of single-site LiDAR measurements.

Response: change applied. We confirm that the present study employs a polarization-sensitive aerosol LiDAR. We have supplemented this key information in **Section 2.2 Aerosol LiDAR data** to explicitly state this instrument capability. We have revised the relevant sentences to accurately reflect the strengths of single-site ground-based LiDAR observations, emphasizing long-term temporal continuity and vertical resolution instead of overstating spatial representativeness.

Line 149-150: "As a polarization-sensitive system, it can retrieve extinction coefficients and depolarization ratios to characterize aerosols in the atmosphere."

Line 93-95: "These attempts often lack the long-term temporal continuity and seasonal representativeness necessary for climatological or process-level understanding, particularly in regions subject to strong seasonal and meteorological variability."

Line 105-107: "LiDAR technology provides high temporal resolution and fine vertical resolution measurements of aerosol and meteorological variables, including aerosol extinction, backscattering, and wind profiles."

4. Line 143-144: The authors state that the LGJ-05 LiDAR operates at 355 nm, 532 nm, and 1064 nm wavelengths. Please clarify whether all three bands were used in this study, or only the 532 nm channel was employed. If only 532 nm data were analyzed, the description of the other two wavelengths is unnecessary and should be removed to avoid misunderstanding.

Response: change applied. We clarify that **only the 532 nm channel was used for aerosol retrieval and analysis in this study**. The 355 nm and 1064 nm bands were not utilized in the presented results, so we have removed the description of these two wavelengths from the manuscript to avoid confusion as below:

Line 146-148: "The LGJ-05 aerosol LiDAR combines traditional radar technology and modern laser technology with 532 nm as detection light sources. Measurements at 532 nm were utilized exclusively for this study."

5. Line 143& Line 162: Line 143 and Line 162 both describe the LGJ-05 LiDAR and its three laser wavelengths (355 nm, 532 nm, 1064 nm). These two descriptions are duplicated and redundant.

Response: change applied. Thank you for this helpful reminder. We have identified the duplicate description of the LGJ-05 LiDAR wavelengths, and have removed the redundant content at Line 162 to streamline the manuscript and avoid repetition.

Line 167-169: "~~The LGJ-05 aerosol LiDAR accomplishes all these operations using a laser as the light source. The laser system generates high-energy light beams at wavelengths of 532 nm, 355 nm, and 1064 nm. The three-wavelength laser beams are emitted into the atmosphere through a broadband mirror and undergo Mie scattering with aerosols.~~ Since the instrument is capable of receiving data *below 30 km, the effective detection range of the aerosol LiDAR can cover 0.2-6 km and 0.2-15 km for daytime and nighttime, respectively. It offers a vertical spatial resolution of 7.5 meters and a temporal resolution of 10 minutes. The observations were conducted at the National Meteorological Observation Station in the northwest of Hefei (117.06°N, 31.96°E) from March 2021 to May 2023. "*

6. Line178: The study includes observations from two seasons: winter and spring. Please clearly state which seasons are used in the analysis, and specify whether the comparisons between $PM_{2.5}$ and PM_{10} pollution episodes are based on winter, spring, or both seasons. It is recommended to use the word "respectively" to clearly define the corresponding relationship between seasons and pollution types in the text.

Response: change applied. In this study, $PM_{2.5}$ pollution events were conducted in winter, while PM_{10} pollution events were dominant in spring; such a seasonal classification helps avoid confusion caused by mixed pollution episodes and ensures clear identification of the respective pollution types. We have revised the sentence to clearly specify the seasons and clarify the comparison basis for $PM_{2.5}$ and PM_{10} pollution episodes.

Line 183-184: "It should be noted that we focused on $PM_{2.5}$ and PM_{10} concentrations during winter and spring, respectively. All comparisons between $PM_{2.5}$ and PM_{10} pollution episodes were conducted across both seasons."

7. Line 198: The ERA5 reanalysis data used in this study covers the period 2021–2023, while the surface pollutant data only includes winter and spring during 2021–2023. Please clarify whether the ERA5 data were extracted and analyzed for the same period (winter and spring) as the pollutant data. This information should be clearly stated in the data and methodology section.

Response: change applied. We have clarified the temporal coverage of ERA5 reanalysis data to ensure consistency with the surface pollutant and LiDAR datasets. Specifically, ERA5 data were extracted and analyzed only for winter and spring during 2021–2023, consistent with the periods of polluted and clean days for $PM_{2.5}$ and PM_{10}. Data corresponding to winter were used for $PM_{2.5}$-related analyses, and data for spring were used for PM_{10}-related analyses, matching the time periods of aerosol LiDAR-based pollution case studies.

Line 206-207: "The data were extracted for winter and spring during 2021–2023, consistent with the periods of the surface pollutant and aerosol LiDAR observations."

8. Line 207-208: It is mentioned that outliers were removed according to the parameter intervals

provided by the instrument. However, what specific normal value ranges or thresholds were applied for each parameter (extinction coefficient and depolarization ratio) remains unclear.

Response: change applied. We have supplemented the specific thresholds used for quality control of the extinction coefficient and depolarization ratio. Specifically, outlier removal and data reliability checks were performed based on the signal-to-noise ratio (SNR) thresholds of the parallel (P) and perpendicular (S) channels, as detailed in the following description.

Line 214-219: "Outlier detection was conducted to eliminate all records outside the normal value range according to the parameter intervals provided by the instrument, with specific thresholds applied based on the signal-to-noise ratios (SNR) of the parallel (P) and perpendicular (S) channels. The extinction coefficient at 532 nm was calculated using data from the P channel, which was considered reliable only when the corresponding SNR exceeded three. The depolarization ratio was derived from the P and S channels, and data were accepted only when both channels had SNRs greater than three."

9. Line 233: The term VWS bulk is used in the study, but it is not clearly defined or explained.

Response: change applied. We appreciate the reminder. The term "bulk wind vector" refers to the overall horizontal wind vector including both zonal and meridional components at a given pressure level. To avoid ambiguity and improve readability, we have removed the expression "VWS bulk" and revised the definition to use a clearer and more intuitive description..

Line 242-245: "The vertical wind shear (VWS) is a crucial factor in characterizing the change in wind velocity with height. It is defined as the variation of wind vector across atmospheric layers, quantified by the magnitude of the difference between upper and lower levels."

10. Line 248: Clarify the referent of "the $PM_{2.5}/PM_{10}$ ratio" by adding a modifier (e.g., "the local $PM_{2.5}/PM_{10}$ ratio in Hefei") to improve the accuracy of expression.

Response: change applied. We have revised the sentence as below:

Line 258-259: "The episodic PM_{10} peaks observed in spring 2022–2023 coincided with a pronounced decrease in the $PM_{2.5}/PM_{10}$ ratio in Hefei."

11. Line: What is the physical reason for the decreasing extinction coefficient and increasing depolarization ratio with increasing altitude in Figure 4? Please provide a clear physical explanation and cite relevant literature to support this observed vertical profile pattern.

Response: change applied. The extinction coefficient quantifies total light attenuation by atmospheric particles and molecules. Near the surface, high concentrations of anthropogenic and natural aerosols (e.g., sulfate, organic matter, dust) accumulate within the planetary boundary layer (PBL), leading to strong light extinction (Wang et al., 2021). As altitude increases, vertical mixing, gravitational sedimentation, and dilution rapidly reduce aerosol number concentrations, causing a monotonic decrease in extinction. Above the PBL, molecular scattering becomes the dominant contributor to extinction, which is much weaker than aerosol scattering, further driving the decline in the extinction coefficient.

The depolarization ratio is a sensitive indicator of particle non-sphericity. Near the surface, fine-mode aerosols dominate, resulting in low depolarization ratios (typically <0.1 at 532 nm). With increasing altitude, the fractional contribution of non-spherical particles (e.g., mineral dust, ice crystals in cirrus clouds) increases significantly (Wang et al., 2020b). These non-spherical particles exhibit much higher depolarization ratios (0.1–0.4) than spherical aerosols. Even as total aerosol loading decreases, the relative enrichment of non-spherical particles leads to a steady increase in the depolarization ratio with height. We have supplemented a clear physical explanation for the vertical trends of extinction coefficient and depolarization ratio in the manuscript, along with relevant literature support.

Line 295-298: "Vertically, extinction coefficients were highest near the surface and gradually decreased with altitude in all seasons. This vertical decline arises from rapid reductions in aerosol loading due to vertical mixing, gravitational sedimentation, and dilution with increasing height, as well as the dominance of weaker molecular scattering above the planetary boundary layer (Wang et al., 2021)."

Line 306-309: "With increasing altitude, the contribution of non-spherical particles increases, leading to a steady rise in depolarization ratio. This is attributed to the fact that non-spherical particles exhibit stronger anisotropic light scattering than nearly spherical fine-mode aerosols that dominate near the surface (Wang et al., 2020b)."

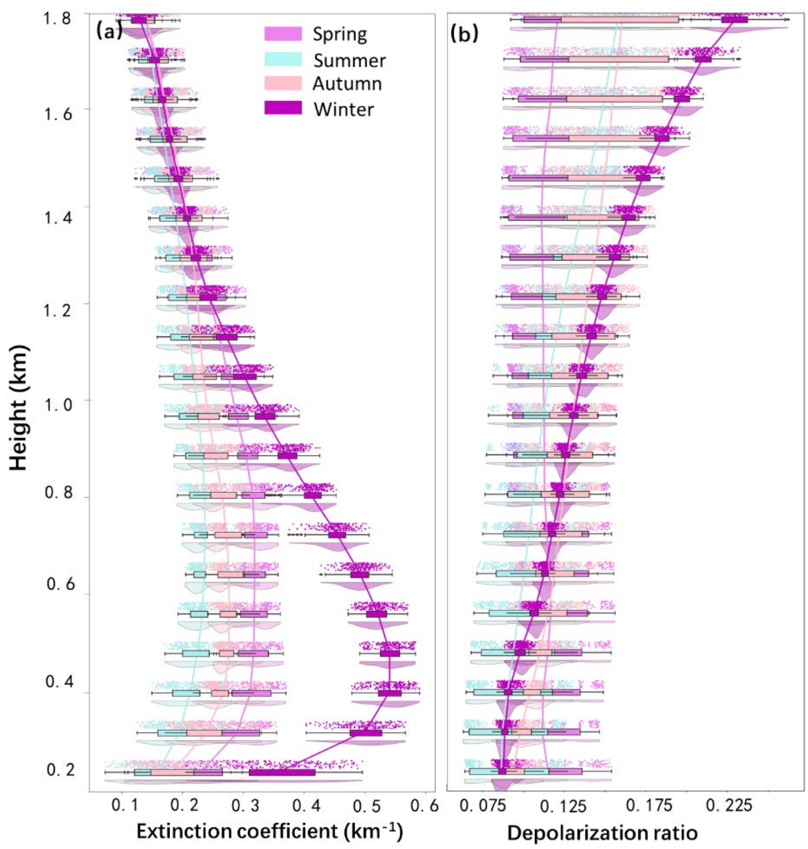

Figure 4. Seasonal variation of vertical aerosol (a) extinction coefficient and (b) depolarization profiles at 532 nm from LiDAR measurements. The whiskers represent the 90th and 10th percentiles, respectively. The shaded areas represent the 25th-75th percentiles. The connected lines depict the trend of mean values across different heights.

[1] Wang, Z., Liu, C., Hu, Q.H., Dong, Y.S., Liu, H.R., Xing, C.Z., & Tan, W. (2021). Quantify the Contribution of Dust and Anthropogenic Sources to Aerosols in North China by Lidar and Validated with CALIPSO. Remote Sensing, 13, https://doi.org/10.3390/rs13091811.

[2] Wang, Z., Liu, C., Xie, Z.Q., Hu, Q.H., Andreae, M.O., Dong, Y.S., Zhao, C., Liu, T., Zhu, Y.Z., Liu, H.R., Xing, C.Z., Tan, W., Ji, X.G., Lin, J.N., & Liu, J.G. (2020b). Elevated dust layers inhibit dissipation of heavy anthropogenic surface air pollution. Atmospheric Chemistry and Physics, 20, 14917-14932, https://doi.org/10.5194/acp-20-14917-2020.

12. Line 324: The phrase “During this period…” is ambiguous in this sentence. It is unclear which specific period you are referring to.

Response: change applied. The phrase now clearly points to the 12:00–15:00 (BJT) midday window mentioned in the preceding text, which aligns with the temporal evolution of boundary layer development and aerosol vertical distribution shown in **Fig. 5a**. We have clarified the ambiguous reference of "During this period" by explicitly specifying the time window it refers to, ensuring clarity for readers.

*Line 342-346: "Hence, strong daytime turbulence promotes the vertical transport of aerosols, resulting in an elevated and vertically expanded aerosol layer (**Fig. 5a**) (Wang et al., 2024). During this period (12:00–15:00 BJT), the enhanced extinction was concentrated around 0.6 km, extending vertically from the surface to this altitude, rather than peaking near the ground."*

[1] Wang, M., Wei, T., Lolli, S., Wu, K., Wang, Y., Hu, H., Yuan, J., Tang, D., & Xia, H. (2024). A long-term Doppler wind lidar study of heavy pollution episodes in western Yangtze River Delta region, China. Atmospheric Research, 310, https://doi.org/10.1016/j.atmosres.2024.107616.

13. Figure 5: Why does the aerosol layer rise at noon? What is the reason for this vertical uplift?

Response: change applied. Specifically, the vertical rise of the aerosol layer at noon (12:00–15:00 BJT) corresponds to the observed decrease in near-surface $PM_{2.5}$ concentrations during this period (**Fig. 3**). The reduction in near-surface pollutant concentrations directly leads to a weakening of the aerosol extinction coefficient, which is particularly sensitive to fine-mode particles. This phenomenon is driven by two key physical processes: a) Enhanced boundary layer development: Strong solar radiation at noon heats the surface, intensifying convective mixing and deepening the planetary boundary layer (PBL). This vertical mixing lifts fine-mode aerosols from the near-surface layer to higher altitudes (up to ~0.6 km), reducing ground-level $PM_{2.5}$ concentrations while expanding the aerosol layer vertically. b) Delayed dispersion effect: Pollutants accumulated in the stable nocturnal boundary layer during the morning are gradually dispersed upward as the PBL grows, leading to a temporary decrease in near-surface $PM_{2.5}$ and a corresponding rise in the aerosol layer altitude. We have added a clarifying sentence in the manuscript to highlight this correspondence and mechanism.

*Line 338-341: "However, extinction values near the surface (below 0.4 km) were relatively low during 12:00-15:00 (BJT), with high values concentrated mainly around 0.6 km. This midday vertical uplift of the aerosol layer corresponds to the decrease in near-surface $PM_{2.5}$ shown in **Fig. 3**, as enhanced convective mixing lifts fine particles upward and weakens near-surface extinction."*

14. In the title of Figure 5, the letter labels are mixed in upper and lower case. Please change (E, F) to (e, f) to keep the notation consistent.

Response: change applied.

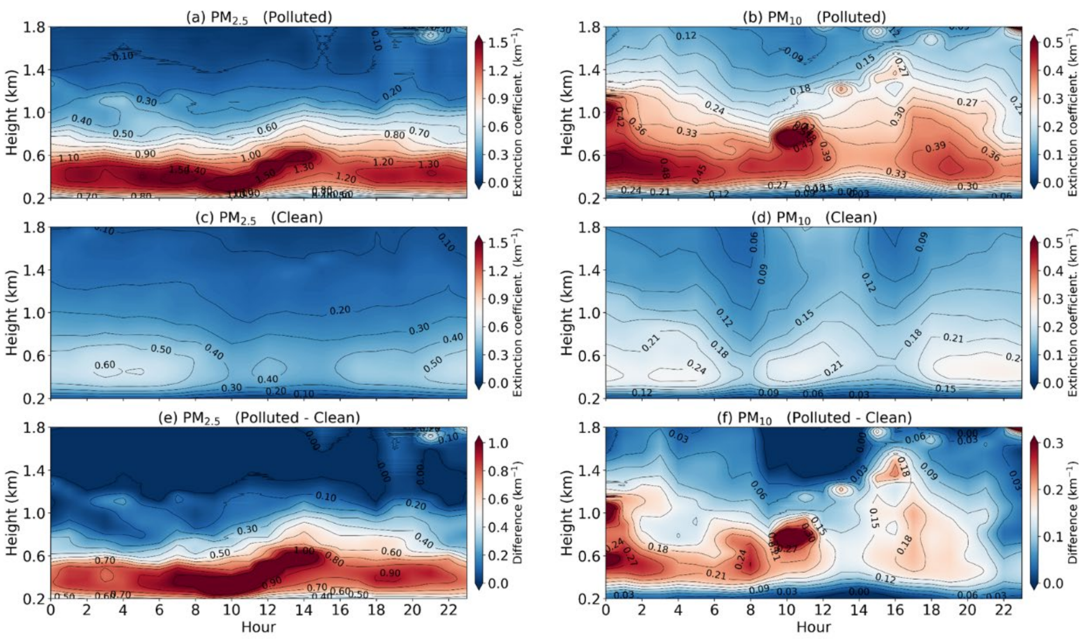

Figure 5. Diurnal variation in the vertical distribution of aerosol extinction coefficient (Winter days for $PM_{2.5}$: First column; Spring days for PM_{10}: Second column) under days with (a, b) polluted, (c, d) clean, and (e, f) the difference between the two. All data are presented in Beijing time (BJT = UTC + 8 h) for the 532 nm channel.

15. Figure 5: Why is the extinction coefficient for PM_{10} smaller than that for $PM_{2.5}$?

Response: change applied. The generally higher extinction coefficient of $PM_{2.5}$ compared to PM_{10} is primarily due to the fact that fine particles ($PM_{2.5}$) have a particle size range (0.1–2.5 μm) that is comparable to the wavelength of visible light (0.4–0.7 μm). According to Mie theory, particles in this size regime exhibit the highest scattering efficiency per unit mass. In contrast, coarse particles ($PM_{2.5-10}$) are much larger than the visible wavelength, resulting in a lower mass-specific extinction efficiency. Additionally, $PM_{2.5}$ is typically enriched with hygroscopic species (e.g., sulfate, nitrate) and light-absorbing carbon (e.g., black carbon), which further enhance both scattering (via hygroscopic growth) and absorption, respectively. In terms of mass-specific surface area, fine particles provide a much larger total surface area for light interaction compared to coarse particles at the same mass concentration. This observation is consistent with the fundamental optical properties of fine and coarse particulate matter reported in previous atmospheric optics studies (Wang et al., 2021; Chen et al., 2023).

Line 329-332: "The extinction coefficient is significantly higher on $PM_{2.5}$-polluted days than on PM_{10} polluted days. This is attributed to the optimal size match between fine-mode particles (≤ 2.5 μm) and visible light (0.4–0.7 μm), as well as their chemical components, which are more efficient at *scattering and absorbing light (Wang et al., 2021; Chen et al., 2023).”*

[1] Wang, Z., Liu, C., Hu, Q.H., Dong, Y.S., Liu, H.R., Xing, C.Z., & Tan, W. (2021). Quantify the Contribution of Dust and Anthropogenic Sources to Aerosols in North China by Lidar and Validated with CALIPSO. Remote Sensing, 13, https://doi.org/10.3390/rs13091811.

[2] Chen, X., Yang, T., Wang, H.B., Wang, F.T., & Wang, Z.F. (2023). Variations and drivers of aerosol vertical characterization after clean air policy in China based on 7-years consecutive observations. Journal of Environmental Sciences, 125, 499-512, https://doi.org/10.1016/j.jes.2022.02.036.

16. Line 413-414: The statement that “extinction values show limited diurnal variability above 1 km” is misleading. The apparent weak variation is likely caused by using a fixed, consistent Y-axis scale across panels, not by genuinely small diurnal changes.

Response: change applied. We appreciate this valuable comment. The visually weak diurnal pattern in the figure is indeed affected by the consistent Y-axis scale. We have revised the misleading statement to avoid ambiguity. The description has been updated to emphasize that extinction coefficients above 1 km are relatively small in magnitude, rather than implying limited diurnal variability.

*Line 439-440: “The extinction values decreased significantly and remained at low levels above 1 km (**Fig. 8e**).”*

17. Line 432: “$PM_{2.5}$ and PM_{10} concentrations” instead of “$PM_{2.5}$ and PM_{10}”

Response: change applied. We have revised the title in the manuscript.

Line 457-458: “3.3 Role of aerosol extinction coefficient and depolarization ratio at different altitudes on ground-based $PM_{2.5}$ and PM_{10} concentrations”

18. Line 438: It is stated that the depolarization ratio was negatively correlated with $PM_{2.5}$ concentration below 0.9 km on polluted days. Why does a negative correlation exist in this layer, and clarify whether you mean the correlation coefficient becomes more negative (i.e., a stronger negative correlation) with increasing $PM_{2.5}$.

Response: change applied. Thank you for the valuable question. On $PM_{2.5}$-polluted days, fine-mode spherical particles dominate the aerosol population below 0.9 km. As $PM_{2.5}$ concentration increases, the proportion of non-spherical coarse particles (e.g., dust) decreases, leading to a reduction in depolarization ratio. This inverse relationship results in a negative correlation between depolarization ratio (DR) and $PM_{2.5}$ concentration in this layer. We confirm that the statement refers to the negative correlation coefficient ($r < 0$) between DR and $PM_{2.5}$, not that the correlation becomes more negative with increasing $PM_{2.5}$. We have revised the text to explicitly state that DR and $PM_{2.5}$ exhibit a negative linear correlation below 0.9 km on polluted days, avoiding ambiguity about the trend in correlation strength.

Line 463-465: "A negative correlation was observed between the depolarization ratio and $PM_{2.5}$ concentration below 0.9 km on polluted days, as elevated $PM_{2.5}$ levels corresponded to a higher fraction of fine, spherical particles with low depolarization."

19. Line 497: The phrase "Henan, and even further north" lacks clarity regarding the administrative scope. Please add "Province" to specify the region.

Response: change applied. We have revised the sentence as below:

Line 529-531: "The cities of northern Anhui Province, Henan Province, and even further north were characterized by dense industrial activities and frequent wintertime heating emissions, which contribute to elevated $PM_{2.5}$ levels (Qian et al., 2024; Shi et al., 2018)."

[1] Qian, Z., Li, L., Lin, X., Sun, R., & Chen, Y. (2024). Spatial and temporal variation of $PM_{2.5}$ and the influence of vegetation in the Yangtze River Delta region. Atmospheric Pollution Research, 15, http://doi.org/10.1016/j.apr.2024.102266.

[2] Shi, C.N., Yuan, R.M., Wu, B.W., Meng, Y.J., Zhang, H., Zhang, H.Q., & Gong, Z.Q. (2018). Meteorological conditions conducive to $PM_{2.5}$ pollution in winter 2016/2017 in the Western Yangtze River Delta, China. Science of the Total Environment, 642, 1221-1232, http://doi.org/10.1016/j.scitotenv.2018.06.137.

20. Line 457-502: The relationships between meteorological factors (temperature, pressure, humidity, wind) and pollutant concentrations have been widely reported in previous studies. Although these factors are necessary for analyzing the driving mechanisms, the detailed description is not required. Simplify this section to make it more concise.

Response: change applied. We have carefully reviewed and simplified the section by removing redundant descriptions of the well-documented relationships between meteorological factors (temperature, pressure, humidity, wind) and pollutant concentrations. The revised text now focuses more directly on the key findings and driving mechanisms specific to our study, while retaining only the essential context needed to interpret our results, thus improving the conciseness and readability of the manuscript.

21. Line 508: " was " instead of " WAS "

Response: change applied.

22. Revise the non-standard pressure unit "hpa" to the normative "hPa" (capital P).

Response: change applied.

Line 554: "From 00:00 to 11:00 (BJT), the VWS in the upper layer (850 hPa-700 hPa) gradually increases on $PM_{2.5}$*-polluted days."*

23. Line 556: "00:00 am" is inappropriate in academic writing. "00:00" inherently denotes midnight, so "am" is redundant.

Response: change applied.

Line 554: "From 00:00 to 11:00 (BJT), the VWS in the upper layer (850 hPa-700 hPa) gradually increases on $PM_{2.5}$*-polluted days."*