

Dear editor and reviewer #1,

Thank you very much for processing and considering our manuscript "[No.: egosphere-2025-6302] Vertical Structure and Driving Mechanism of PM<sub>2.5</sub> and PM<sub>10</sub> 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<sub>2.5</sub> and PM<sub>10</sub> 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<sub>2.5</sub> and PM<sub>10</sub> 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  $PM_{10}$  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<sub>2.5</sub> and PM<sub>10</sub> 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<sub>2.5</sub> pollution events were conducted in winter, while PM<sub>10</sub> 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<sub>2.5</sub> and PM<sub>10</sub> pollution episodes.

*Line 183-184: “It should be noted that we focused on PM<sub>2.5</sub> and PM<sub>10</sub> concentrations during winter and spring, respectively. All comparisons between PM<sub>2.5</sub> and PM<sub>10</sub> 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<sub>2.5</sub> and PM<sub>10</sub>. Data corresponding to winter were used for PM<sub>2.5</sub>-related analyses, and data for spring were used for PM<sub>10</sub>-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.

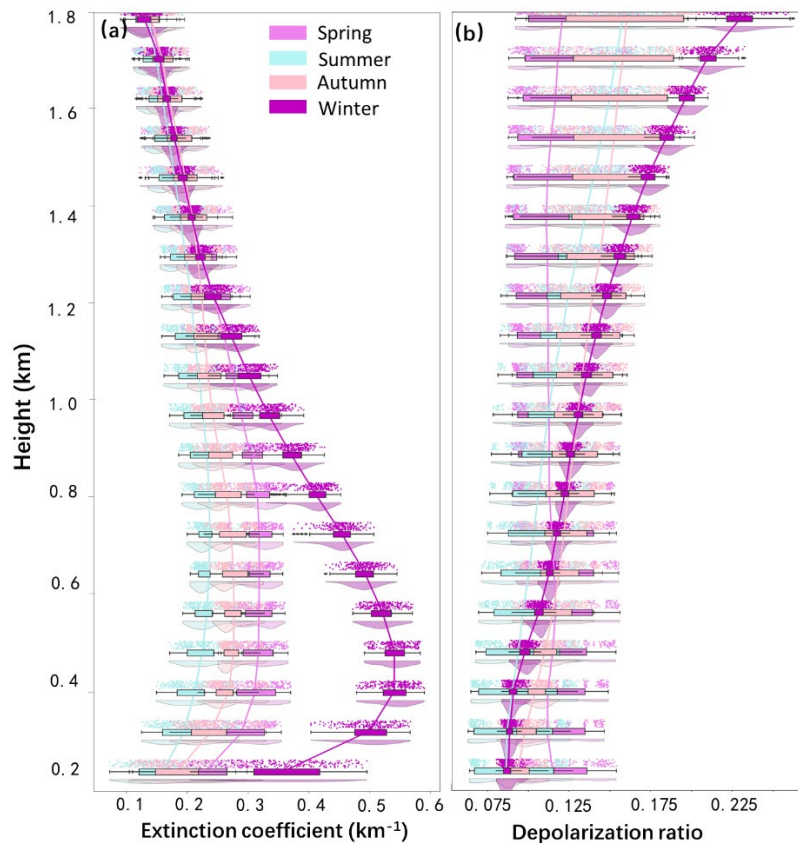
Response: change applied. The extinction coefficient quantifies total light attenuation by atmospheric particles and molecules. Near the surface, high concentrations of anthropogenic and natural aerosols

(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>.

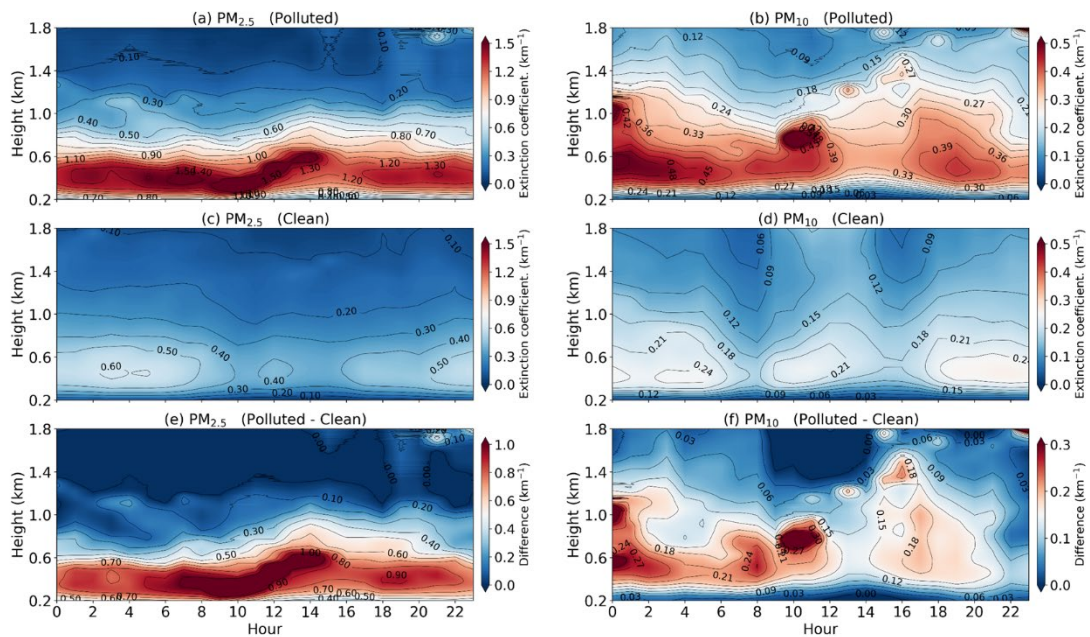
13. Figure 5: Why does the aerosol layer rise at noon? What is the reason for this vertical uplift?

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<sub>2.5</sub> 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<sub>2.5</sub> 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<sub>2.5</sub> 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<sub>2.5</sub> 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  $\mu\text{m}$ ) that is comparable to the wavelength of visible light (0.4–0.7  $\mu\text{m}$ ). 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 ( $\leq 2.5 \mu\text{m}$ ) and visible light ( $0.4\text{--}0.7 \mu\text{m}$ ), 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<sub>2.5</sub> and PM<sub>10</sub> concentrations" instead of "PM<sub>2.5</sub> and PM<sub>10</sub>"

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<sub>2.5</sub> and PM<sub>10</sub> concentrations"*

18. Line 438: It is stated that the depolarization ratio was negatively correlated with PM<sub>2.5</sub> 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<sub>2.5</sub>.

Response: change applied. Thank you for the valuable question. On PM<sub>2.5</sub>-polluted days, fine-mode spherical particles dominate the aerosol population below 0.9 km. As PM<sub>2.5</sub> 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<sub>2.5</sub> concentration in this layer. We confirm that the statement refers to the negative correlation coefficient ( $r < 0$ ) between DR and PM<sub>2.5</sub>, not that the correlation becomes more negative with increasing PM<sub>2.5</sub>. We have revised the text to explicitly state that DR and PM<sub>2.5</sub> 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<sub>2.5</sub> concentration below 0.9 km on polluted days, as elevated PM<sub>2.5</sub> 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<sub>2.5</sub> 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<sub>2.5</sub> 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<sub>2.5</sub> 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<sub>2.5</sub>-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<sub>2.5</sub>-polluted days."*

Dear editor and reviewer #2,

Thank you very much for processing and considering our manuscript "[No.: egosphere-2025-6302] Vertical Structure and Driving Mechanism of PM<sub>2.5</sub> and PM<sub>10</sub> Aerosols in Hefei Based on LiDAR Observations (2021–2023)".

We greatly appreciate the constructive and insightful comments from the reviewer, which have significantly helped improve the quality and clarity of our manuscript. All comments have been carefully addressed and thoroughly revised accordingly. Besides minor revisions in the main text, the major improvements are summarized in the following four aspects:

a. As suggested, we have revised the vague statements about prior studies, explicitly specifying the focus of existing research and highlighting the novelty of our long-term LiDAR-based vertical observation.

b. In response to the reviewer's questions, we have added clear physical interpretations for the noon peak in depolarization ratio during PM<sub>10</sub>-polluted days.

c. We explained that their apparent inverse pattern reflects different aerosol types, and supplemented the physical meaning of these two key optical properties.

d. We have corrected inconsistent terms, grammatical issues, and unit capitalization errors, removed redundant words and redundant figure titles.

We are confident that the revisions have substantially enhanced the quality and presentation of the manuscript. Both the revised and clean versions of the manuscript are included with this resubmission for your evaluation. We look forward to your positive response.

**Black: Comments from the reviewers**

**Blue: Responses from the authors**

**Green: Changes in the main text**

## **Comments from reviewer #2:**

### **Comments to the Author**

Manuscript #egusphere-2025-6302 titled “Vertical Structure and Driving Mechanism of PM<sub>2.5</sub> and PM<sub>10</sub> Aerosols in Hefei Based on LiDAR Observations (2021–2023)” employs the long-term aerosol LiDAR datasets, integrated with ground-based particulate matter monitoring, meteorological observations, and ERA5 reanalysis data, to investigate the vertical profile features and formation mechanisms of PM<sub>2.5</sub> and PM<sub>10</sub> pollution episodes in Hefei over 2021–2023. It examines the seasonal and diurnal evolution of key aerosol optical properties (extinction coefficient and depolarization ratio) across altitude layers, and contrasts the vertical distribution patterns between polluted and clean conditions for both fine and coarse particulate matter.

The multi-source data integration (LiDAR + ground monitoring + reanalysis) enables a robust exploration of how thermodynamic, dynamic, and synoptic-scale meteorological factors differentially modulate PM<sub>2.5</sub> and PM<sub>10</sub> pollution. This comparative approach effectively highlights the unique vertical dynamics and driving factors of fine versus coarse particles, offering a nuanced perspective on regional air pollution in eastern China. The research design is well-structured, and the analytical framework is scientifically sound. The findings provide actionable insights for targeted air quality management and forecasting in the Yangtze River Delta region, particularly in distinguishing the distinct pathways of PM<sub>2.5</sub> and PM<sub>10</sub> pollution formation. Overall, the manuscript meets the standards of this journal and delivers meaningful contributions to the field of aerosol vertical observation and pollution mechanism research. I recommend acceptance for publication subject to minor revisions.

**Response:** We sincerely appreciate the reviewer’s positive comments and valuable feedback on our manuscript. As suggested by the reviewer, we have carefully revised the manuscript with minor adjustments to further improve its quality, including optimizing the clarity of descriptions, refining the logical coherence of the analytical process, and ensuring the accuracy of key expressions.

## Major queries:

### 1. Abstract and Introduction

24. -L52- The statement “most studies have focused on surface-level air pollution data obtained from ground monitoring networks” is somewhat vague. It would strengthen the context if the authors could briefly specify which types of pollutants or regions these prior studies primarily focused on (e.g., PM<sub>2.5</sub> in eastern China, urban air quality in megacities), to better highlight the specific knowledge gap that the present study aims to address regarding aerosol vertical distribution.

Response: change applied. We have revised the statement to specify that previous studies mainly focused on surface PM<sub>2.5</sub> and PM<sub>10</sub> in eastern China and urban areas, which helps to more clearly emphasize the knowledge gap regarding aerosol vertical distribution addressed by this study.

*Line 54-56: “To date, most studies have focused on surface-level air quality, with particular attention to individual PM<sub>2.5</sub> and PM<sub>10</sub> event in eastern China and urban agglomerations from ground monitoring networks (He et al., 2021).”*

He, G., Deng, T., Wu, D., Wu, C., Huang, X., Li, Z., Yin, C., Zou, Y., Song, L., Ouyang, S., Tao, L., & Zhang, X. (2021). Characteristics of boundary layer ozone and its effect on surface ozone concentration in Shenzhen, China: A case study. *Science of the Total Environment*, 791, <https://doi.org/10.1016/j.scitotenv.2021.148044>.

25. -L114- The authors clearly listed four detailed research objectives of this study. It is suggested to briefly state the novelty or main contribution of this work compared with previous studies in the same region, so that readers can more clearly understand the importance of the present study.

Response: change applied. We have added a statement highlighting the novelty of this study compared with previous research, emphasizing the long-term comparative analysis of PM<sub>2.5</sub>- and PM<sub>10</sub>-dominated pollution vertical structures, which has been rarely reported in local studies.

*Line 91-95: “However, most previous studies using such measurements have been limited to short-term campaigns or case studies of individual pollution episodes (Chen et al., 2022; Zhong et al., 2018). 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 108-110: “This capability makes LiDAR particularly suitable for investigating aerosol evolution and transport within the ABL and lower troposphere. Nonetheless, long-term time series analyses based on continuous LiDAR measurements remain limited in the literature.”*

Line 113-114: “This study fills the observational gap in the long-term vertical characteristics of both fine and coarse particulate pollution over this region.”

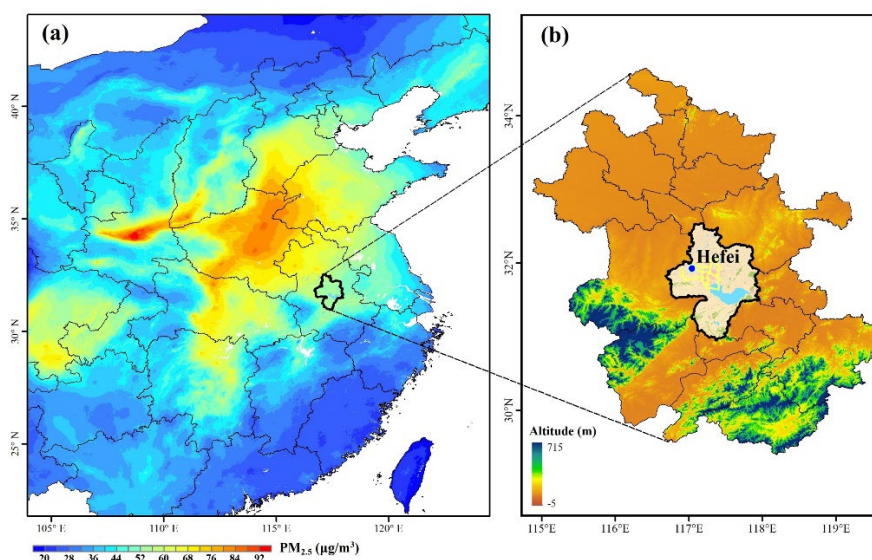
Chen, C., Song, X., Wang, Z., Chen, Y., Wang, X., Bu, Z., Zhang, X., Zhuang, Q., Pan, X., Li, H., Zhang, F., Wang, X., Li, X., & Zheng, R. (2022). Calibration methods of atmospheric aerosol lidar and a case study of haze process. *Frontiers in Physics*, 10, <http://doi.org/10.3389/fphy.2022.942926>.

Zhong, J., Zhang, X., Dong, Y., Wang, Y., Liu, C., Wang, J., Zhang, Y., & Che, H. (2018). Feedback effects of boundary-layer meteorological factors on cumulative explosive growth of PM<sub>2.5</sub> during winter heavy pollution episodes in Beijing from 2013 to 2016. *Atmospheric Chemistry and Physics*, 18, 247-258, <http://doi.org/10.5194/acp-18-247-2018>.

## 2. Data and methods

26. -L140- “The monitoring station is marked by the blue dot.” Where is the blue dot?

Response: change applied. We thank the reviewer for this careful reminder. We acknowledge that the description of the blue dot was incomplete in the original manuscript. We have added the location of the blue dot in the manuscript to avoid ambiguity in the revised manuscript.



**Figure 1.** The spatial distribution of (a) the averaged PM<sub>2.5</sub> concentration during winter from 2021 to 2023 (Ministry of Environmental Protection in China, <https://air.cnemc.cn:18007/>) and (b) the location of the study area (Hefei, China). The digital elevation model (DEM) data are derived from the NASA Shuttle Radar Topography Mission (SRTM) 30 m product (<https://glovis.usgs.gov/>), and the land use map of the study area is obtained from the 30 m resolution annual China Land Cover Dataset (CLCD) dataset. The monitoring station is marked by the blue dot.

27. -L144- Please clarify whether the present study solely relies on the 532 nm band for aerosol retrieval and analysis. If the data presented in the manuscript are exclusively derived from the 532 nm channel, any discussion of the 355 nm and 1064 nm channels should be removed from the text, as these additional bands do not contribute to the reported results. This will ensure the accuracy and integrity of the methodological description.

Response: change applied. This study exclusively uses the 532 nm channel for aerosol analysis. We have removed all descriptions related to the 355 nm and 1064 nm channels from the manuscript to ensure the accuracy and conciseness of the methodology.

*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."*

28. -L173- Are PM<sub>2.5</sub> and PM<sub>10</sub> both obtained from the LGH-01B monitor? The description of the instrument is repetitive and wordy.

Response: change applied. We have revised the description to clarify that PM<sub>10</sub> and PM<sub>2.5</sub> were measured by the LGH-01E and LGH-01B monitors, respectively.

*Line 178-180: "These pollutant data were obtained from professional monitoring instruments, with the LGH-01E aerosol mass concentration monitor used for PM<sub>10</sub> and the LGH-01B for PM<sub>2.5</sub>, both of which apply the beta attenuation method."*

29. -L171- The authors mention "hourly concentrations of major air pollutants (PM<sub>2.5</sub> and PM<sub>10</sub>)". Since only PM<sub>2.5</sub> and PM<sub>10</sub> are used and analyzed in this study, please clarify whether other air pollutants were also included in the analysis. If no other pollutants were used, the word "major" is inappropriate and misleading, and the description should be revised to clearly state that only PM<sub>2.5</sub> and PM<sub>10</sub> were adopted.

Response: change applied. This study focuses only on PM<sub>2.5</sub> and PM<sub>10</sub>; No other air pollutants were included in the analysis. We have removed the inappropriate and misleading word "major" and revised the description to clearly state as below:

*Line 176-178: "Hourly concentrations of PM<sub>2.5</sub> and PM<sub>10</sub> were obtained from ground-based monitoring stations in Hefei, which are operated and maintained by the China National Environmental Monitoring Centre (CNEMC) (Liu et al., 2017)."*

Liu, T.T., Gong, S.L., He, J.J., Yu, M., Wang, Q.F., Li, H.R., Liu, W., Zhang, J., Li, L., Wang, X.G., Li, S.L., Lu, Y.L., Du, H.T., Wang, Y.Q., Zhou, C.H., Liu, H.L., & Zhao, Q.C. (2017). Attributions of meteorological

and emission factors to the 2015 winter severe haze pollution episodes in China's Jing-Jin-Ji area. *Atmospheric Chemistry and Physics*, 17, 2971-2980, <http://doi.org/10.5194/acp-17-2971-2017>.

30. -In Section 2.5. Quality control, what is the temporal resolution (hourly or minute-level) of the LiDAR and ground-based data after quality control for the subsequent analysis in this study?

Response: change applied. The original LiDAR data have a temporal resolution of 10 minutes. After quality control, we averaged these data to hourly resolution to ensure consistency with the hourly-resolution ground-based pollutant measurements used in this study.

*Line 223-225: "The original LiDAR data have a 10-minute temporal resolution. After quality control, these data were averaged to hourly resolution to be consistent with the hourly ground-based pollutant observations."*

31. -L217- For the efficient detection ranges of the extinction coefficient and depolarization ratio, it is suggested to retain 1 or 2 decimal places for the numerical values.

Response: change applied.

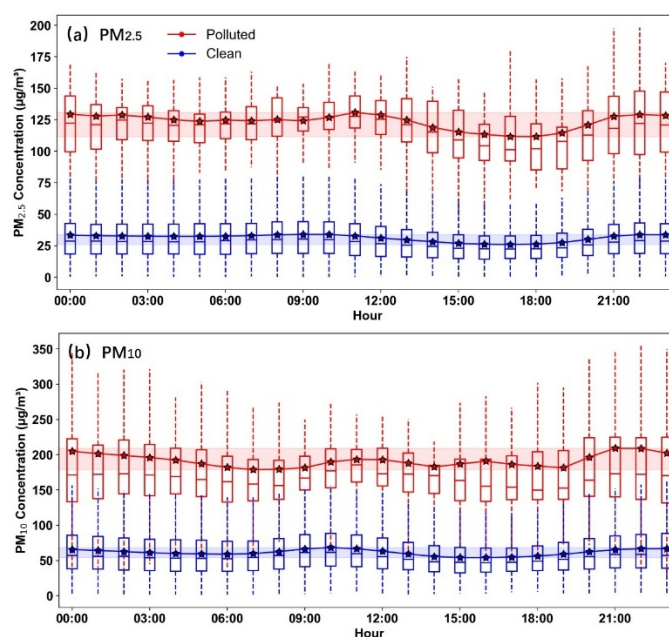
*Line 228: "Based on the criterion of a 60% valid data availability rate, the efficient detection ranges for the 532 nm of the extinction coefficient and depolarization ratio were 0.2~1.8 km."*

### **3. Results and discussion**

32. -L270- The concentration of clean days is in the range of 50–70  $\mu\text{g}/\text{m}^3$  is not sufficiently accurate, as the pollutant concentration on clean days can vary over a wide range and even reach around 100  $\mu\text{g}/\text{m}^3$  in some cases. Do you mean the hourly mean concentration (the solid line in Fig.3b) by this range description? Please clarify and revise the relevant textual expression for accuracy.

Response: change applied. The concentration range of 50–70  $\mu\text{g}/\text{m}^3$  refers to the hourly mean values shown by the solid lines in Fig. 3b, and we have revised the relevant description in the manuscript for greater accuracy and clarity.

*Line 279-280: "Clean days maintained relatively low hourly mean  $\text{PM}_{10}$  concentrations (50–70  $\mu\text{g}/\text{m}^3$ ) with minor fluctuations."*



**Figure 3.** Hourly mean (a)  $PM_{2.5}$  and (b)  $PM_{10}$  concentrations on polluted and clean days (Beijing time, BJT = UTC + 8 h). The blue and red shaded areas represent the ranges of mean concentration values for polluted and clean days, respectively. The whiskers and boxes represent the 95th, 75th, 50th, 25th, and 5th percentiles, respectively. The stars represent the mean values of the pollutant concentrations. The solid lines connect the hourly mean values to show the diurnal variation trends.

33. -The results presented in Figures 5 and 6 are very informative and clearly illustrate the vertical distribution of aerosols during different periods. However, in Figure 6, why does the depolarization ratio for  $PM_{10}$ -polluted days show a distinct peak at noon? Please provide a clear physical explanation for this diurnal pattern.

Response: change applied. The distinct noon peak in the depolarization ratio during  $PM_{10}$ -polluted days can be physically explained by the combined effects of enhanced boundary layer development and frequent frontal activity. At noon, strong solar radiation drives vigorous vertical mixing and expansion of the planetary boundary layer, while frequent cold front or squall line events during the afternoon to early evening intensify horizontal and vertical transport. These frontal processes are accompanied by strong temperature gradients and elevated wind speeds, which effectively enhance dust loading and increase the concentration of non-spherical mineral dust in the vertical column. Meanwhile, the warmer, drier conditions at midday minimize hygroscopic growth and wet deposition, preserving the non-spherical shape of these coarse dust particles and maintaining elevated depolarization ratio values. We have supplemented this concise explanation in the revised manuscript

to clarify this diurnal pattern.

*Line 367-368: “The increased depolarization ratio at noon during PM<sub>10</sub>-polluted days is attributed to midday boundary layer growth and frontal dust transport, elevating non-spherical coarse particle concentrations.”*

34. -L462- change "showed reduced values" to "was markedly decreased"

Response: change applied.

*Line 489-490: “However, the depolarization ratio of PM<sub>2.5</sub>-polluted days was markedly decreased during this peak period (Fig. 10c).”*

35. -L465- The depolarization ratio of PM<sub>2.5</sub>-polluted days showed reduced values at the peak of the extinction coefficient. Does this indicate an inverse relationship between the extinction coefficient and the depolarization ratio? The manuscript lacks a clear, detailed explanation of the physical meaning of these two key aerosol optical properties.

Response: Change applied. The extinction coefficient represents the total attenuation of light caused by aerosol scattering and absorption, and its magnitude is physically determined by the aerosol number concentration, size distribution, and the refractive index of the particles. The depolarization ratio quantifies the degree to which backscattered light loses its original polarization state and governed by particle morphology. For spherical particles, the symmetry of the particle geometry preserves the polarization state of the incident light, resulting in a low depolarization ratio. In contrast, non-spherical particles break this symmetry and generate a significant cross-polarized component, leading to a high depolarization ratio. During PM<sub>2.5</sub>-polluted episodes, fine particles typically exhibit spherical or near-spherical shapes, particularly when they are composed of hygroscopic species such as sulfates and nitrates that undergo deliquescence under ambient humidity. Hence, as the concentration of these fine particles increases, the extinction coefficient rises due to enhanced light attenuation, while the depolarization ratio remains low or even decreases further because the scattering population is dominated by spherical particles. This observed inverse relationship is therefore not a direct physical law but rather a manifestation of the dominant particle morphology under pollution conditions. We have added the new text to **Results and discussion-3.4** as below:

*Line 491-493: “Physically, the extinction coefficient scales with aerosol concentration and size, while the depolarization ratio is governed by particle morphology. Spherical fine particles such as hygroscopic sulfates and nitrates dominating this PM<sub>2.5</sub> event, leading to increased extinction and decreased depolarization.”*

36. -L491- All physical quantities should be explicitly labeled with their corresponding units to ensure standardization in data presentation.

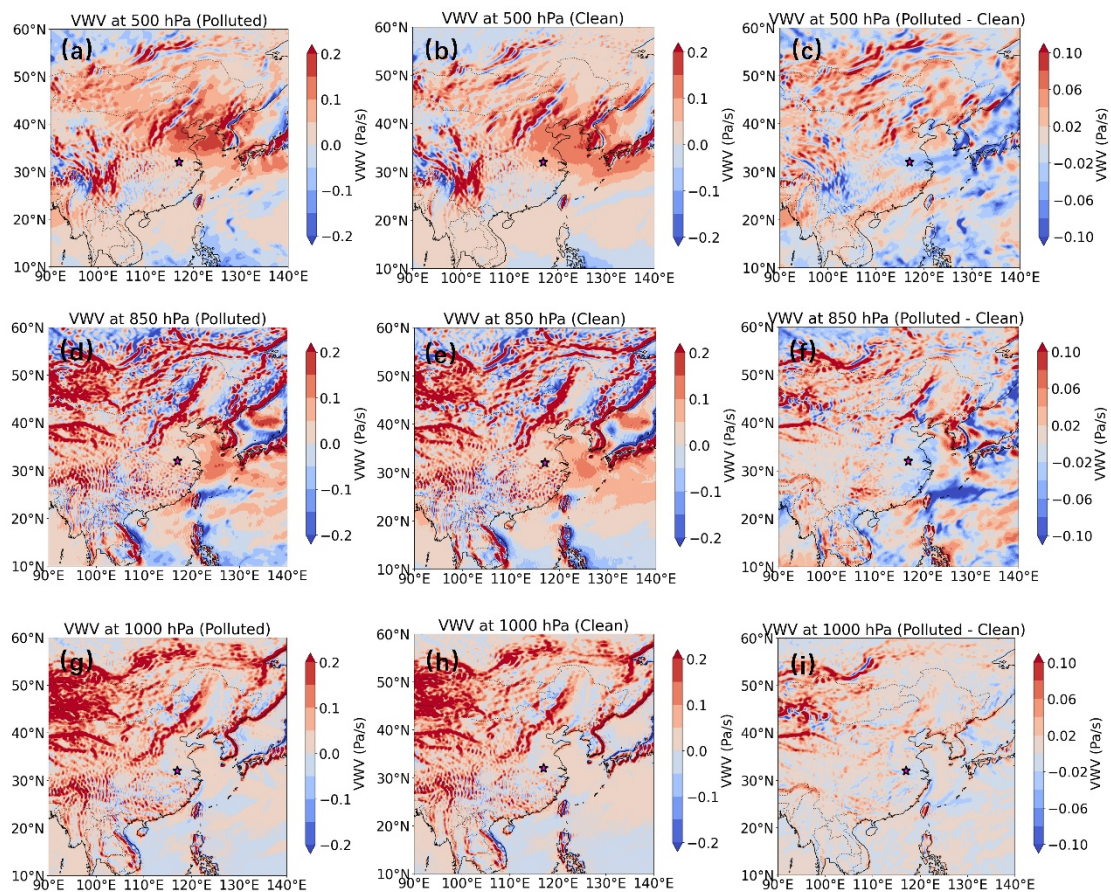
Response: change applied. We have carefully checked the entire manuscript and explicitly supplemented the corresponding units for all physical quantities to ensure standardized and accurate data presentation.

*Line 523-524: “The average pressure values were lower on clean days ( $PM_{2.5} \leq 75 \mu\text{g}/\text{m}^3$ ,  $PM_{10} \leq 150 \mu\text{g}/\text{m}^3$ ) and became higher on polluted days.”*

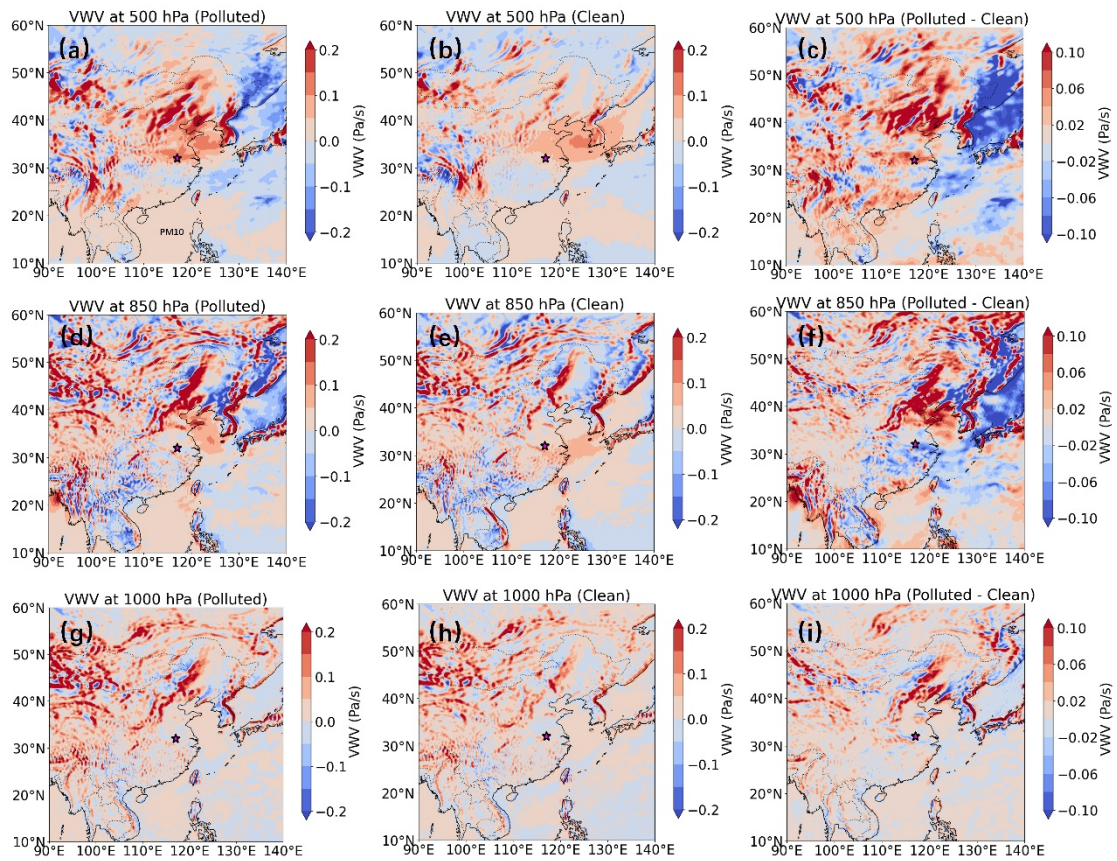
37. -Figure 14- The purpose of calculating the differences between polluted and clean days is not clarified.

Response: change applied. The purpose of calculating the differences between polluted and clean days is to highlight the subtle but critical meteorological anomalies that drive pollution formation and maintenance, which are otherwise obscured by the large-scale, similar background circulation patterns across both conditions. We can clearly identify the specific dynamic and thermodynamic differences that distinguish polluted episodes from clean conditions, thereby providing a more direct mechanistic explanation for the observed pollution events. This approach enhances the interpretability of the meteorological drivers underlying aerosol pollution in our study region. We have supplemented this explanation in the revised manuscript as below:

*Line 605-608: “To better elucidate the meteorological characteristics between polluted and clean conditions, we calculated the differences in vertical velocity between these two scenarios, as their broadly similar large-scale background circulation patterns obscure the subtle but critical dynamic anomalies that drive pollution formation.”*



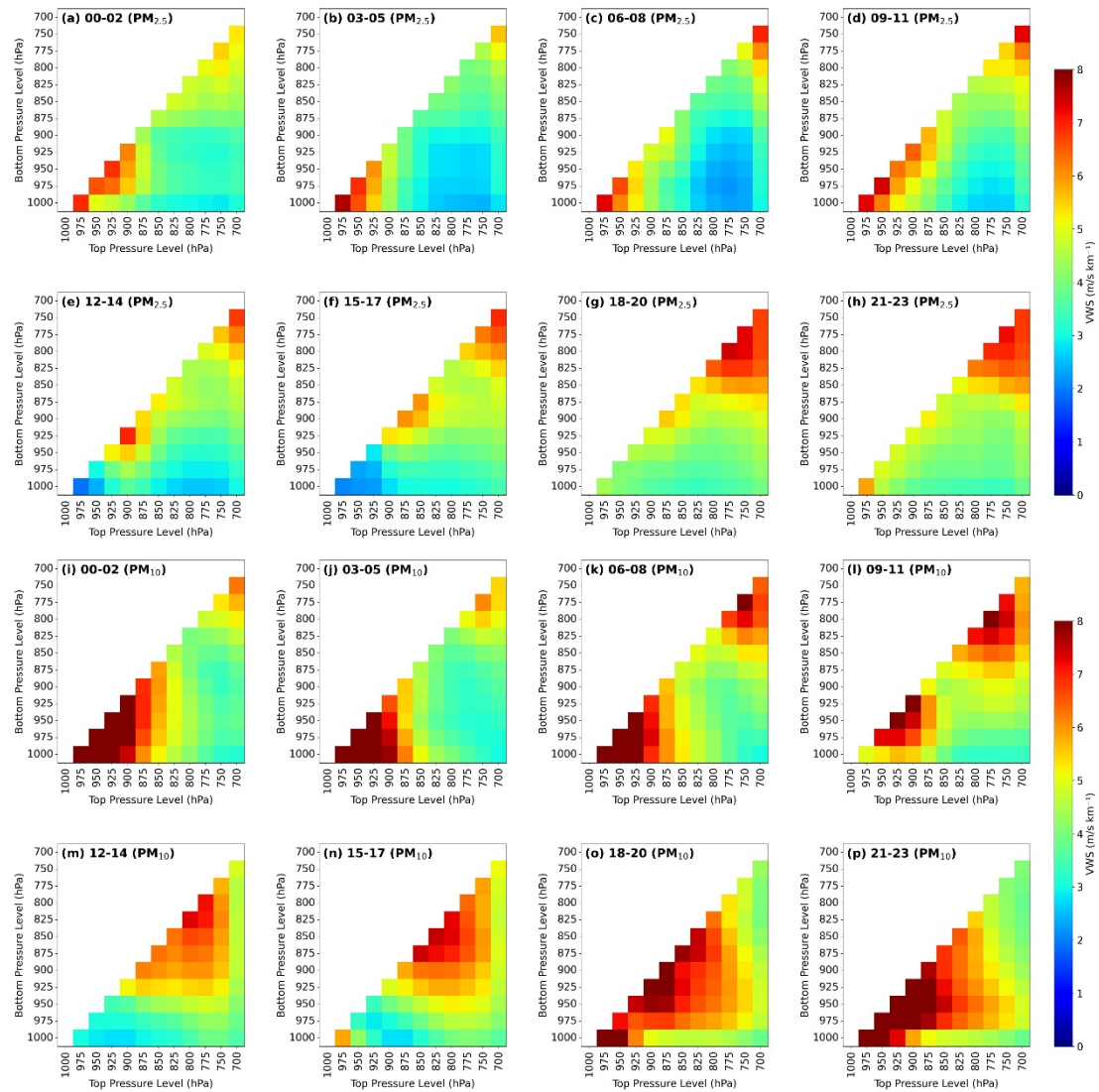
**Figure 14.** Spatial distribution of the vertical wind velocity (VWV) at three pressure levels (500 hPa: a–c; 850 hPa: d–f; 1000 hPa: g–i) on PM<sub>2.5</sub>-polluted (left column), clean (middle column) days and the difference between them (right column), respectively. The areas highlighted with a red star represents the location of Hefei.



**Figure 15.** Same as Fig. 14, but on PM<sub>10</sub>-polluted (left column), clean (middle column) days and the difference between them (right column), respectively.

38. -Figure 11- The title contains redundant expressions because three-hourly is used twice. Please revise it.

Response: change applied.



**Figure 11.** Three-hourly variation of vertical wind shear for (a-h)  $PM_{2.5}$  and (i-p)  $PM_{10}$  on polluted days in Hefei at (a&i) 00:00–02:00 BJT, (b&j) 03:00–05:00 BJT, (c&k) 06:00–08:00 BJT, (d&l) 09:00–11:00 BJT, (e&m) 12:00–14:00 BJT, (f&n) 15:00–17:00 BJT, (g&o) 18:00–20:00 BJT, and (h&p) 21:00–23:00 BJT. Beijing Time (BJT) is UTC+8, the local standard time used in this study. The axes indicate the vertical bounds (upper and lower pressure levels) used to compute VWS, where the main diagonal (from top-right to bottom-left) corresponds to self-referential values for single-layer calculations. The color gradient represents the magnitude of VWS between adjacent atmospheric layers.

39. -L576- The comparison is redundant and inconsistent. "Clear days" should be unified with the term "clean days" used elsewhere in the manuscript. Please revise to remove the repetitive comparison (e.g., "subsidence at 500 hPa is significantly stronger than on clean days").

Response: change applied.

*Line 612: “During PM<sub>10</sub> pollution events, subsidence at 500 hPa is significantly stronger than that on clean days (Fig. 15).”*

#### **4. Minor suggestions:**

40. -L332- delete (532 nm

Response: change applied.

*Line 354-355: “For the depolarization ratio, distinct patterns also emerged between polluted and clean days for both PM<sub>2.5</sub> and PM<sub>10</sub> (Fig. 6).”*

41. -L459- delete “a.m”

Response: change applied.

*Line 486-488: “Severe PM<sub>2.5</sub> pollution was evident at 10:00 on January 2, 2023 (BJT), with the maximum hourly concentration reaching 159.6 µg/m<sup>3</sup>.”*

42. -L521- 850 hPa (not 850 hpa)

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<sub>2.5</sub>-polluted days.”*

43. -L577- delete “However,”

Response: change applied.

*Line 613-614: “However, Hefei is located in a unique region defined by upward motion at 850 hPa, with a comparable weak upward movement also observed at 1000 hPa.”*

44. -change “PM<sub>10</sub> accumulation” to “the accumulation of” The accumulation of PM<sub>10</sub>”

Response: change applied.

*Line 597-599: “Under such dry and calm conditions, the accumulation of PM<sub>10</sub> is likely driven by mechanical resuspension or regional dust transport rather than secondary aerosol formation processes enhanced by moisture (Li et al., 2020).”*

Li, H.D., Sodoudi, S., Liu, J.F., & Tao, W. (2020). Temporal variation of urban aerosol pollution island and its relationship with urban heat island. *Atmospheric Research*, 241, <http://doi.org/10.1016/j.atmosres.2020.104957>.

