Dear editor and reviewer #2,

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)".

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_{10}-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 $PM_{2.5}$ and PM10 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 $PM_{2.5}$ and PM_{10} 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 $PM_{2.5}$ and PM_{10} 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 $PM_{2.5}$ and PM_{10} 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

1. -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., $PM_{2.5}$ 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 $PM_{2.5}$ and PM_{10} 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 $PM_{2.5}$ and PM_{10} 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.

2. -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 $PM_{2.5}$- and PM_{10}-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 $PM_{2.5}$ 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

3. -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.

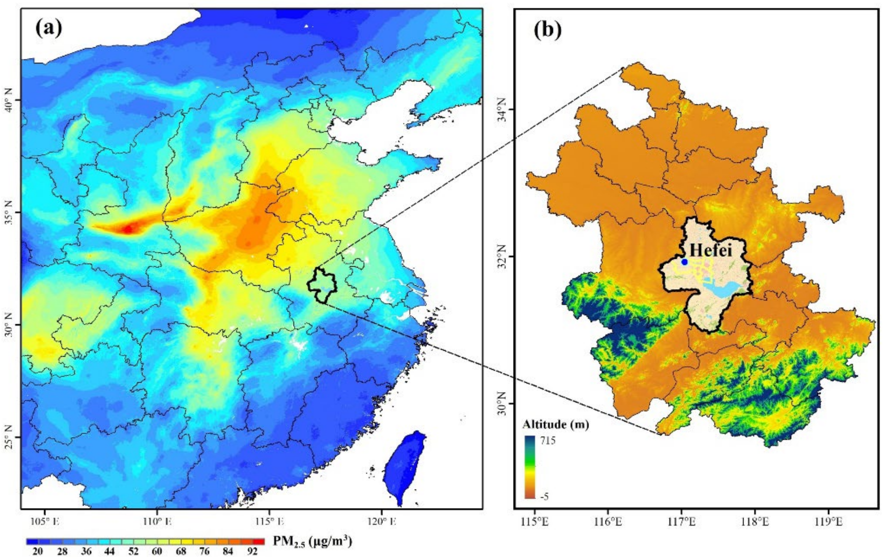

Figure 1. The spatial distribution of (a) the averaged $PM_{2.5}$ concentration during winter from 2021 to 2023(Ministry of Environmental Protection in China, https://air.cnemc.cn:18007/) and (b) the location of the study area (Hefei, China). The digital elevation model (DEM) data are derived from the 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.

4. -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."

5. -L173- Are $PM_{2.5}$ and PM_{10} 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_{10} and $PM_{2.5}$ 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_{10} and the LGH-01B for $PM_{2.5}$, both of which apply the beta attenuation method."

6. -L171- The authors mention "hourly concentrations of major air pollutants ($PM_{2.5}$ and PM_{10})". Since only $PM_{2.5}$ and PM_{10} 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 $PM_{2.5}$ and PM_{10} were adopted.

Response: change applied. This study focuses only on $PM_{2.5}$ and PM_{10}; 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 $PM_{2.5}$ and PM_{10} 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.

7. -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."

8. -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

9. -L270- The concentration of clean days is in the range of 50–70 μg/m³ is not sufficiently accurate, as the pollutant concentration on clean days can vary over a wide range and even reach around 100 μg/m³ 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 μg/m³ 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 PM_{10} concentrations (50–70 μg/m³) with minor fluctuations."

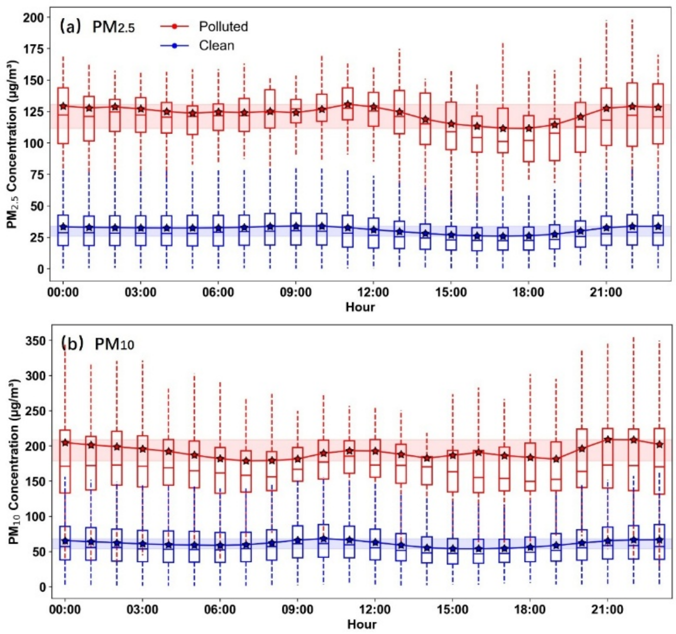

Figure 3. Hourly mean (a) $PM_{2.5}$ and (b) PM_{10} concentrations on polluted and clean days (Beijing time, BJT = UTC + 8 h). The blue and red shaded areas represent the ranges of mean concentration values for polluted and clean days, respectively. The whiskers and boxes represent the 95th, 75th, 50th, 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.

10. -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_{10}-polluted days is attributed to midday boundary layer growth and frontal dust transport, elevating non-spherical coarse particle concentrations."

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

Response: change applied.

*Line 489-490: "However, the depolarization ratio of $PM_{2.5}$-polluted days was markedly decreased during this peak period (**Fig. 10c**)."*

12. -L465- The depolarization ratio of $PM_{2.5}$-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 $PM_{2.5}$-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 $PM_{2.5}$ event, leading to increased extinction and decreased depolarization."

13. -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 ($PM_{2.5}$ ≤75 μg/m³, PM_{10} ≤150 μg/m³) and became higher on polluted days."

14. -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."

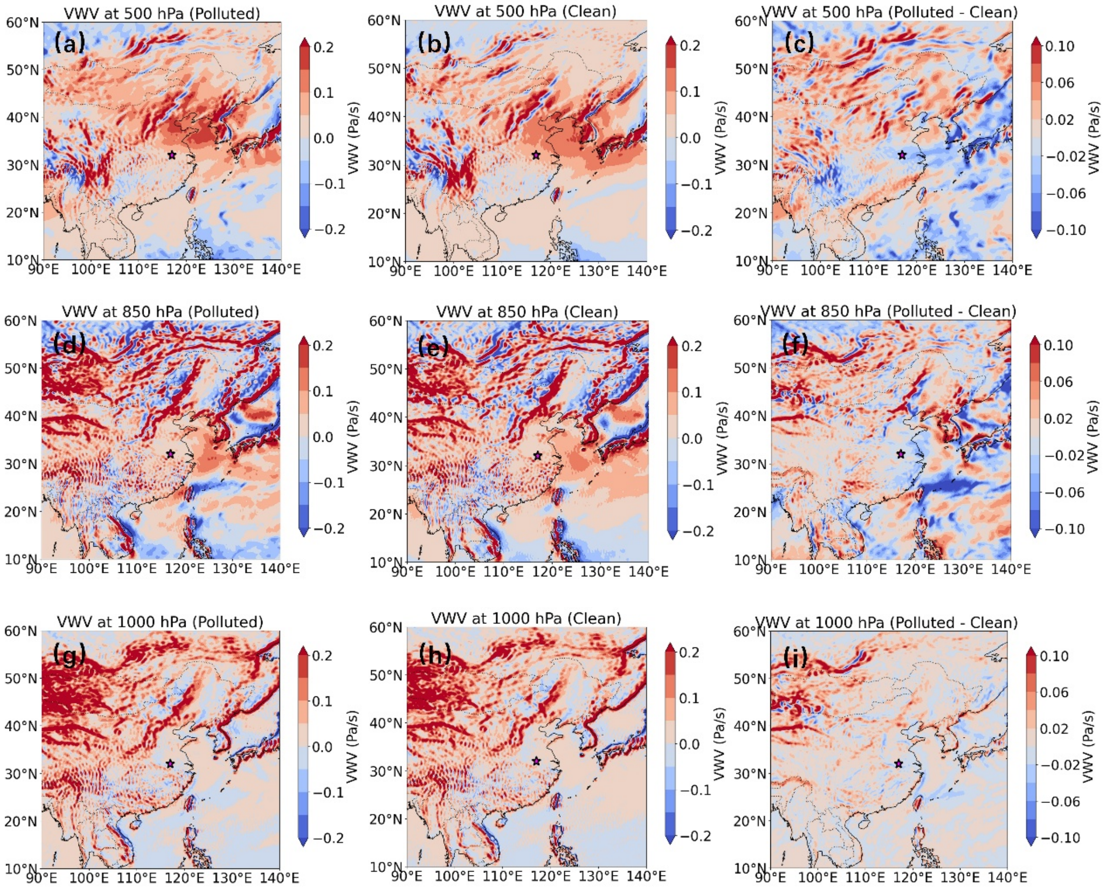

Figure 14. Spatial distribution of the vertical wind velocity (VWV) at three pressure levels (500 hPa: a–c; 850 hPa: d–f; 1000 hPa: g–i) on $PM_{2.5}$-polluted (left column), clean (middle column) days and the difference between them (right column), respectively. The areas highlighted with a red star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

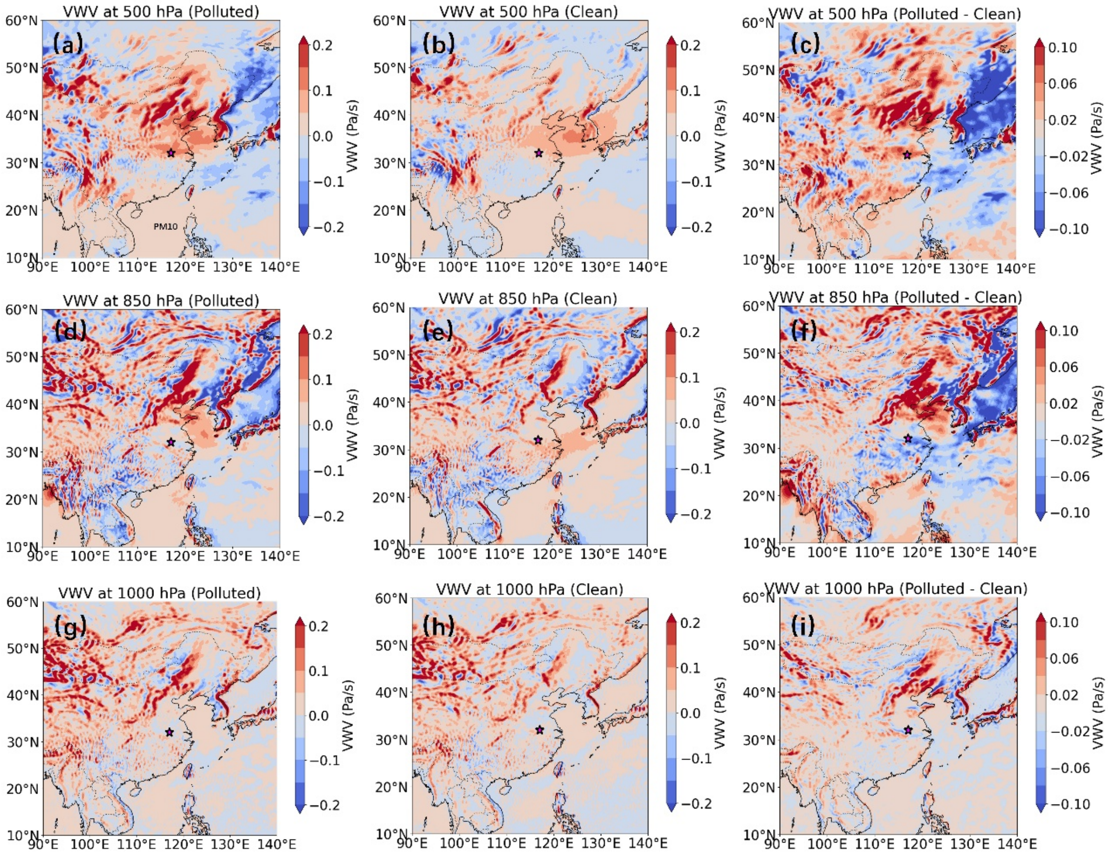

Figure 15. Same as Fig. 14, but on PM_{10}-polluted (left column), clean (middle column) days and the difference between them (right column), respectively.

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

Response: change applied.

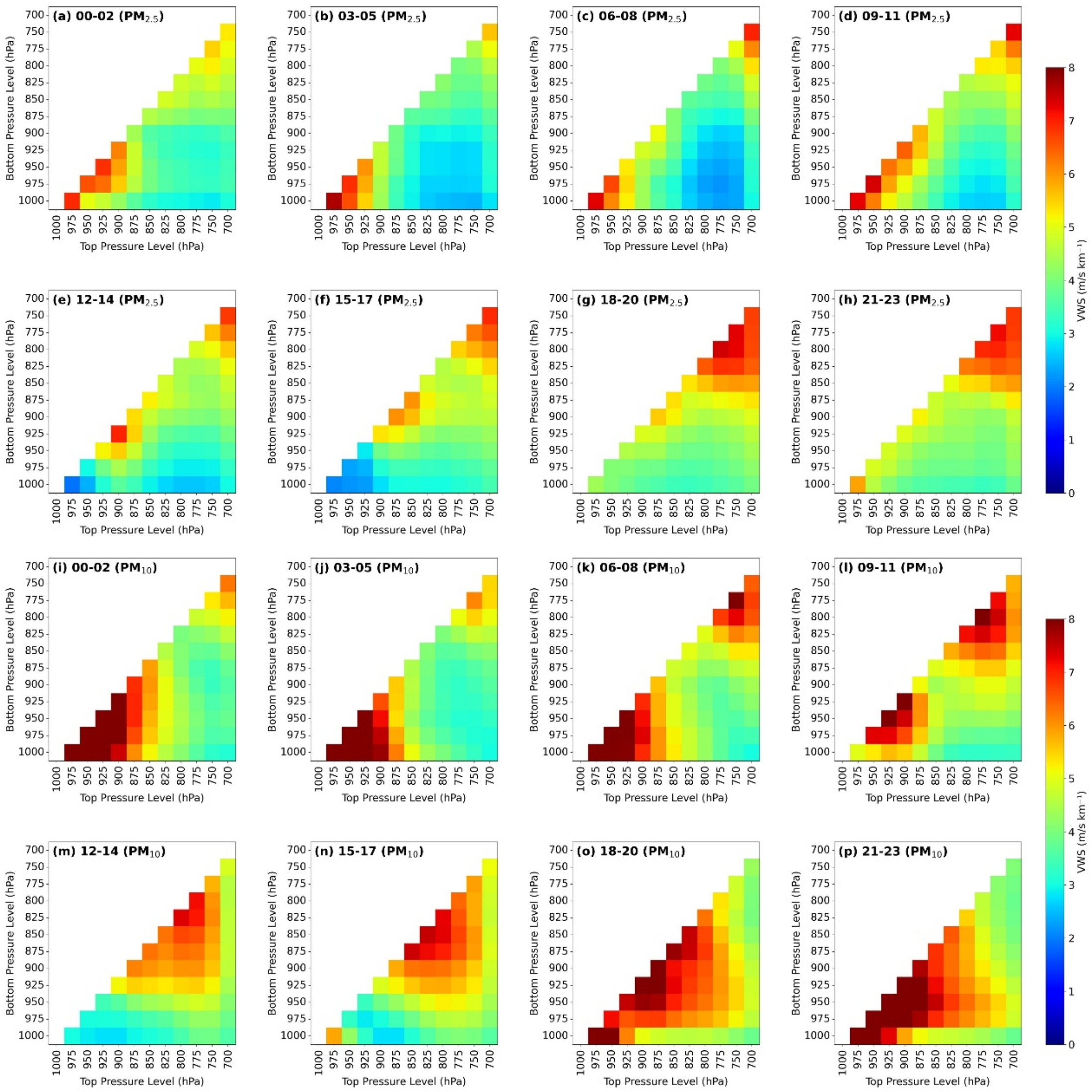

Figure 11. Three-hourly variation of vertical wind shear for (a-h) $PM_{2.5}$ and (i-p) PM_{10} on polluted days in Hefei at (a&i) 00:00–02:00 BJT, (b&j) 03:00–05:00 BJT, (c&k) 06:00–08:00 BJT, (d&l) 09:00–11:00 BJT, (e&m) 12:00–14:00 BJT, (f&n) 15:00–17:00 BJT, (g&o) 18:00–20:00 BJT, and (h&p) 21:00–23:00 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.

16. -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_{10} pollution events, subsidence at 500 hPa is significantly stronger than that on clean days (**Fig. 15**)."*

4. Minor suggestions:

17. -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 $PM_{2.5}$ and PM_{10} (**Fig. 6**)."*

18. -L459- delete "a.m"

Response: change applied.

Line 486-488: "Severe $PM_{2.5}$ pollution was evident at 10:00 on January 2, 2023 (BJT), with the maximum hourly concentration reaching 159.6 μg/m^3."

19. -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 $PM_{2.5}$-polluted days."

20. -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."

21. -change "PM_{10} accumulation" to "the accumulation of" The accumulation of PM_{10}"

Response: change applied.

Line 597-599: "Under such dry and calm conditions, the accumulation of PM_{10} 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.