Author's Response : Anonymous Referee # 1

Dear, referee

We would like to thank the referee for your valuable feedback and suggestions. Below are our responses to the comments provided.

Comment 1:

"Abstract first line: "The atmospheric visibility in South Korea has not improved despite decreasing concentrations of particulate matter (PM)2.5." Please specify number or mass concentrations"

Author's Response:

We appreciate the reviewer's valuable suggestion. Accordingly, we have revised the first line of the abstract to read: "The atmospheric visibility in South Korea has not improved despite decreasing mass concentrations of particulate matter (PM)2.5."

Comment 2:

"Please include uncertainties in measurements of PM concentrations and subsequent calculation of rate of decrease"

Author's Response:

We sincerely appreciate your valuable suggestion regarding the inclusion of uncertainties in the PM concentration measurements and the subsequent calculation of the rate of decrease. The PM concentration data used in this study are finalized data validated through a rigorous process. After being measured according to official test methods, the data underwent a primary validation by the Seoul Metropolitan Air Quality Management Office and the Korea Environment Corporation, followed by a secondary validation conducted by the National Institute of Environmental Research (NIER), after which the final validated data were released. As such, specific uncertainty information for these data has not been provided, and we respectfully ask for your understanding that we are unable to offer additional details on this matter. However, given that the data are finalized by highly credible institutions, we have conducted our analysis based on the reliability of this data.

In addition, we used the Mann-Kendall (MK) test to assess uncertainties in the increasing and decreasing trends of PM, MEE, relative humidity, and Ångström exponent. This explanation is provided in lines 225-230, where z-scores and p-values are used to evaluate the extent of uncertainty

associated with the calculated rates of increase or decrease. Thank you very much for your insightful feedback

Comment 3:

"Instead of looking at monthly trends, the authors could try to look at seasonal trends. It would be easier to attribute changes to sources/processes that are widespread across a season rather than a month"

Author's Response:

We sincerely appreciate the reviewer's insightful suggestion to examine seasonal trends for a clearer attribution of changes. In response, we conducted an analysis of seasonal trends in both Seoul and Ulsan. However, in both locations, we found that the seasonal trends did not show significant differences from the monthly trends already presented in the manuscript. Additionally, due to data limitations in certain months, particularly in Ulsan, seasonal trends could not be adequately represented, making it less suitable for this approach. As such, we decided not to include these additional analyses in the manuscript to maintain focus and clarity in the results section. We are grateful for the opportunity to further validate our findings.

Comment 4:

"It is very evident from an aerosol size distribution that the smaller particles have a negligent impact on mass of the aerosols. Isnt the conclusion of the study very obvious or similar to the already known facts. How is this study contributing in understanding something new or the gaps of the knowledge we already have? This study feels like use of multiple statistical approaches to come round an already known fact that smaller size aerosols donot contribute to mass distributionThe study needs more scientific backing."

Author's Response:

Thank you for your valuable question regarding the scientific contribution of this study. While it is widely recognized that smaller aerosol particles contribute minimally to the total aerosol mass, our study brings new insights by quantifying the impact of particle size on mass extinction efficiency (MEE) specifically in the context of Northeast Asia, with a focus on South Korea. The increase in PM2.5 MEE despite reductions in PM2.5 mass concentrations highlights a critical issue: that smaller particles, although contributing little to mass, significantly affect visibility due to their high scattering efficiency.

Our study also addresses an important gap in the current understanding by using lidar data to examine the trends in PM2.5 MEE, relative humidity, and the Ångström exponent, which is indicative of particle size. These analyses allow us to attribute the observed trends in MEE to reductions in particle size rather than to overall mass concentration. This approach provides a detailed understanding of visibility trends, which have not shown improvements proportional to the reductions in PM mass concentrations. These findings emphasize the need for policy measures targeting not only mass reduction but also the composition and size of particles to improve air quality and visibility effectively.

We believe that this approach strengthens the scientific understanding of the optical properties of aerosols in the region, contributing valuable knowledge on how fine-mode particles influence public perception and environmental policies.

Comment 5:

"It is interesting to note that the authors attribute increase in relative humidity to increase in MEE due to hygroscopic growth. My question is: doesn't hygroscopic growth of particles increase the size and eventually contribute to mass? Again the authors mention a reduction in particle size result in larger MEE. It's a bit confusing if the hygroscopic growth is increasing MEE or the reduction in particle size"

Author's Response:

Thank you for your insightful question regarding the impact of hygroscopic growth and particle size reduction on mass extinction efficiency (MEE). To clarify, both hygroscopic growth and smaller particle sizes contribute to higher MEE, but they do so through slightly different mechanisms.

When relative humidity increases, hygroscopic particles absorb moisture, causing them to grow in size. This growth leads to an increase in their scattering cross-section, meaning they scatter more light without a significant increase in their dry mass. As a result, MEE increases because more light is scattered per unit of particle mass under humid conditions.

Similarly, when particle sizes are intrinsically smaller, the overall scattering cross-section in the same mass concentration is larger compared to having a few large particles. This is because a collection of smaller particles, with a greater surface area-to-mass ratio, scatters light more effectively than a single larger particle of the same total mass, leading to a higher MEE.

In summary, MEE increases both when particles grow due to hygroscopic effects (under higher humidity) and when particles are smaller in dry conditions, as both situations enhance the scattering

cross-section relative to the mass concentration. We hope this explanation addresses your question and clarifies the mechanisms by which both hygroscopic growth and particle size reduction impact MEE.

Additionally, we have included the following statement in our paper on lines 326-328 to further clarify this point: " Both hygroscopic growth, which increases particle size and scattering cross-section under high humidity, and the presence of smaller particles, which scatter light more efficiently per unit mass, contribute to the increase in MEE."

Comment 6:

"Why is the monthly trend of relative humidity increasing? Can you associate it with any atmospheric/anthropogenic process happening in that region?"

Author's Response:

Thank you for your thoughtful question regarding the trend of relative humidity observed in our study. Upon careful review, our findings indicate that the monthly trends in relative humidity do not exhibit a statistically significant increase. The results from the Mann-Kendall test, along with the associated p-values, do not support a conclusive upward trend. While our analysis reveals some slight month-to-month fluctuations, these variations do not constitute a clear or statistically supported long-term trend. As for potential atmospheric or anthropogenic processes that could influence relative humidity, we recognize that factors such as temperature changes, local and regional weather patterns, and urbanization can play a role. However, given the lack of a statistically significant trend in our data, we are cautious about drawing speculative associations with these factors. We sincerely appreciate your attention to this detail.

We appreciate your thorough feedback and have implemented the suggested revisions to improve the clarity and accuracy of the manuscript.