Dear Editors and Reviewers,

Thanks very much for taking your time to review this manuscript. We really appreciate all your detailed valuable comments on our manuscript of “egusphere-2025-435”. These suggestions have been so helpful that we have incorporated them into the newly revised manuscript. And we hope that the reviewers and the editors will be satisfied with our responses to the ‘comments’ and the revisions for this manuscript. Please find our itemized responses in below and my revisions in the re-submitted files.

Yours Sincerely,

Yong Xue

Response for Reviewer #1:

This manuscript presents a novel algorithm for retrieving black carbon (BC) surface concentrations by synergizing MODIS and AERONET data, integrating K-means clustering, Maxwell-Garnett effective medium approximation (MG-EMA), 6SV2.1 radiative transfer modeling, and MERRA-2-based vertical conversion. Seasonal aerosol modeling via K-means clustering and the MG-EMA significantly improves the representation of internally mixed aerosols. Validation against AE33 in-situ measurements (R = 0.727, RMSE = 0.353) demonstrates strong agreement, while comparison with MERRA-2 BC data effectively highlights the algorithm's superior performance. Besides, the uncertainty analysis confirms that the algorithm performs better in conditions of high AOD.

Overall, the manuscript is well-structured and scientifically sound. Due to MODIS having continuous long-term observational data (1999 to present), the results of this study contribute to obtaining a more accurate and long-term series of BC surface concentration datasets, providing richer reference information for climate change and air quality research. Therefore, I suggest accepting the manuscript for publication with slight modifications. Please find my specific suggestions below.

Overall, the method used in this manuscript is unique and innovative. The above are my comments and opinions. I look forward to the author's reply.

Response: Thank you very much for these positive comments and please find our detailed responses below to all your suggestions.

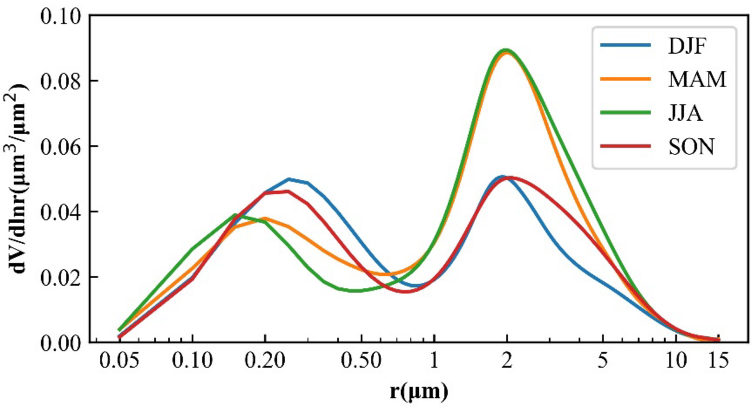
Specific Comments:

1. In section 1, the introduction on satellite platform inversion of BC only lasts until 2023. It is recommended to supplement the latest research progress in this field.

Response: Thank you for your suggestion. We have added new research literature the Introduction part of the manuscript.

2. In Fig.3(a), it is difficult to distinguish the particle size distribution of each season in the fine mode region using equidistant radius r scales. It is recommended to use logarithmic scales to increase discrimination.

Response: Thank you for your suggestion. We have changed the radius (r) coordinate scale of Fig.3 (a) to log.



3. In Fig.4, the spelling of ‘reteieval’ is incorrect and needs to be changed to 'retrieval'.
Response: Thank you very much for pointing out this issue. We have already replaced ‘reteieval’ in Fig. 4 with ‘retrieval’.

4. In section 3.4, there are aerosol optical property data for DJF, MAM, JJA, and SON. Why choose DJF for sensitivity analysis?
Response: The reasons for choosing the DJF period's aerosol model for sensitivity analysis in the manuscript are as follows: (1) The black carbon concentration is relatively high in winter, making the data of this period more representative for the sensitivity analysis of the inversion algorithm. (2) The BAs constructed based on AERONET V3 daily data show significant differences in different seasons, and the absorption characteristics of DJF are more obvious, which is conducive to revealing the performance of the model, especially when the aerosol concentration is high.

5. In section 3.4, only the sensitivity of surface reflectance less than 0.1 is analyzed, and most bright surfaces (such as deserts) are not included. It is recommended to expand the numerical range and set the threshold below 0.3.
Response: Thank you for your suggestion. We have adjusted the contents in Fig. 5, analyzed the performance at surface reflectance of 0.20 and 0.30, and revised the expressions in the text. “As shown in Fig. 5(a)-(d), the sensitivity analysis results indicate that as AOD increases, the estimated TOA standard deviation under different surface conditions gradually increases, suggesting that the theoretical inversion accuracy is higher under high aerosol loading conditions. However, when ρ_s = 0.10 and the aerosol loading is high (AOD > 1.0), if the BC fraction is high ($f_{BC} \geq 0.04$), the TOA will basically not change with the increase of AOD, which will lead to an unsatisfactory inversion effect under such conditions. In Fig. 5(e), as the BC fraction increases, the SSA, which is independent of aerosol load, decreases notably, suggesting that BC content has a substantial impact on the overall aerosol absorption properties. Additionally, under low f_{BC} conditions, the standard deviation of the estimated TOA for dark surfaces is higher, while under high f_{BC} conditions, the standard deviation of the estimated TOA for bright surfaces is higher. This indicates that bright surfaces are more sensitive to absorbing aerosols and are more conducive to estimating strongly absorbing BC particles.”

6. In section 4.1, “This trend is likely related to the region's high population density, developed industry, and low temperatures, which hinder the timely dispersion of emitted BC. From April to June, the overall BC concentration in the study area remains at a relatively low level”. I suggest adding references here to prove that these factors do indeed affect the high values.
Response: Additionally, the presence of the northern and western Alps as well as the southern Apennine Mountains determines weak wind conditions and frequent temperature retrogrades, which hinder atmospheric diffusion and trap pollution on the ground (Renna et al., 2024).

Renna, S., J. Lunghi, F. Granella, M. Malpede, and D. Di Simine, 2024: Impacts of agriculture on PM_{10} pollution and human health in the Lombardy region in Italy. *Front. Environ. Sci.*, **12**, 1369678, doi: 10.3389/fenvs.2024.1369678.

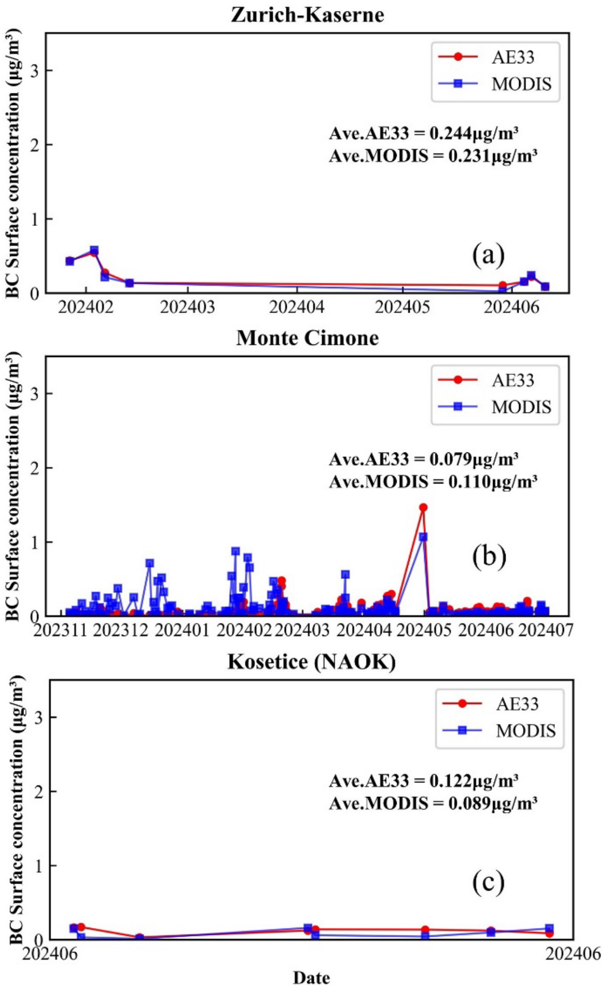
7. In section 4.2, "It is evident that the fluctuation trends of MODIS BC and AE33 BC are generally consistent, although MODIS BC tends to be lower than AE33 BC most of the time." Why is there a trend of underestimation?

Response: This may be related to the MG-EMA model which only considers BC internal mixing state, but there may still be a small amount of fresh and exposed BC externally mixed in the atmosphere (China et al., 2013), which may result in an underestimate of BC.

China, S., C. Mazzoleni, K. Gorkowski, A. C. Aiken, and M. K. Dubey, 2013: Morphology and mixing state of individual freshly emitted wildfire carbonaceous particles. *Nat. Commun.*, **4**(1), 2122, doi: 10.1038/ncomms3122.

8. In Fig.7, the author only presented data from 3 out of 6 AE33 sites, and it may be considered to display data from other sites.

Response: The satellite-ground comparison data of the three AE33 sites (Zurich-Kaserne, Monte Cimone, and Kosetice (NAOK)) are shown in the following figure. The number of valid matching values of Zurich-Kaserne and Kosetice (NAOK) is very small. Although the number of valid matching values of Monte Cimone is large, the BC concentration has remained at a relatively low level, and the degree of change is not as obvious as that of the three sites (ISAC Bologna II, Marseille Longchamp and Milano Pascal) shown in Fig. 7. Therefore, it is not shown in the manuscript.



9. In section 4.3, "suggesting that the algorithm's applicability in bright surface areas still needs improvement. However, it is worth noting that due to the lack of data from AE33 stations in high brightness areas, the surface reflectance of the AE33 stations in this study is below 0.12, and DT AOD accuracy is better in dark surface, so further research is needed to determine the applicability of bright surface reflectance." The surface reflectance here is relatively low, making it difficult to reveal the characteristics of bright surfaces. It is recommended to revise the statement to make it more rigorous.

Response: We have made the following modifications: "When ρ_s >0.08, the uncertainty of the bias increases significantly, suggesting that the algorithm's applicability in relatively high surface reflectance areas still needs improvement. However, it is worth noting that due to the lack of data from AE33 stations in high brightness areas (ρ_s≥0.2), the surface reflectance of the AE33 stations in this study is below 0.12, and when ρ_s > 0.1, the data also is insufficient. Therefore, uncertainty analysis confirms that this retrieval algorithm has better performance under high AOD conditions. However, due to the lack of ground-based AE33 observation data in high-brightness surface areas, the accuracy under this surface condition still lacks effective validation."