Response to Reviewer Comments

We thank the reviewer for the constructive comments and suggestions, which helped us improve the clarity and quality of the manuscript. In this response letter, we provide point-by-point responses. Our replies to the reviewers' comments are presented **in blue font**, while the corresponding revisions in the manuscript are indicated **in blue italics with yellow highlights, together with the updated line numbers**.

General comments

This study presents a unique dataset of aircraft measurements of BC and its microphysical properties over the Yellow Sea, consistently conducted throughout several years. The results will be useful for constraining the assumptions and parameterizations of size-distribution and mixing state of BC in aerosol-climate models and in aerosol remote sensing. I can recommend publication after incorporating the following comments.

Response: We sincerely thank the reviewer for the positive assessment and constructive feedback. The manuscript has been carefully and thoroughly revised in accordance with these comments.

Major comments

Comment:

In Section 1 or Section 3, the authors should add references of observational studies on the relationship between the microphysical properties and wet removal efficiency of BC in the same region, for example, https://doi.org/10.1029/2012GL052034. It should help the interpretation of the decrease of rBC MMD with APT or altitude observed in this study.

Response:

We appreciate this valuable suggestion. There have been several insightful studies which deal with BC's properties in relation to APT and transport efficiency (TE).

Moteki et al. (2012) found, from aircraft observations over the Yellow and East China Seas, that as BC TE decreases, larger-mass BC particles are preferentially removed, resulting in a smaller count median diameter (CMD) during uplift from the planetary boundary layer to the free troposphere. An analysis of the relationship between BC TE and APT revealed a significant negative correlation (R^2 = 0.88) at altitudes above 2 km, and TE decreased with increasing APT as altitude increased (Oshima et al., 2012). In line with these studies, seasonal differences in precipitation and uplift strongly influence BC concentrations, and TE decreases as APT increases, indicating that the seasonal variability of BC is largely controlled by the seasonality of wet deposition (Kondo et al., 2016).

In the revised manuscript, we have incorporated the aforementioned references and expanded the discussion on the relationship between BC microphysical properties and wet removal efficiency based on these studies.

L 65–76:

"Recent aircraft-based observations have revealed diverse vertical and regional characteristics of BC particles. For example, BC particle diameters were found to be smaller near the surface over urban areas (Lamb et al., 2018), whereas in rural regions, BC tended to decrease in size with increasing altitude (Lu et al., 2019). Regional differences in BC mass concentration have also reported between the Atlantic and Pacific Oceans (Katich et al., 2018), and substantial removal of up to 98 % of BC was observed in Asian summer monsoon outflow (Berberich et al., 2025). These findings provide valuable insight into combined effects of emission characteristics, meteorology, and removal processes under real-world atmospheric conditions. More specifically, aircraft observations over the Yellow and East China Seas revealed that BC transport efficiency (TE) declines during uplift from the planetary boundary layer (PBL) to the free troposphere (FT), preferentially removing large-mass BC particles and thus reducing the count median diameter (CMD) (Moteki et al. (2012). At altitudes above 2 km, TE showed a strong negative correlation with accumulated precipitation along air mass trajectory (APT), with R^2 = 0.88 (Oshima et al., 2012). Building on this, Kondo et al. (2016) demonstrated that

seasonal variations in precipitation and uplift patterns strongly modulate BC concentrations."

L 369–370:

"Seasonal differences in precipitation and uplift significantly influence BC concentrations (Kondo et al., 2016) and physical properties (Moteki et al., 2012)."

Individual comments

L17: refractive BC → refractory BC

It has been corrected.

L18: height-dependency → height-dependence

It has been corrected.

L24: reduction → decrease

It has been corrected.

L25: These findings emphasize → These observations reflect

It has been corrected.

L26: You can remove "We believe that"

It has been removed and revised as follows.

L25–26:

"These findings provide valuable observational constraints for improving model representations of the size distribution and mixing state of ambient BC particles in the outflow regions."

L27: “the physical realism of models”: Please be more specific.

It has been revised to the following sentence.

L 25–26:

“These findings provide valuable observational constraints for improving model representations of the size distribution and mixing state of ambient BC particles in the outflow regions.”

L34: “IPCC WG1 AR6”: Is this an accepted style for referencing the IPCC report? Please check. Should it be “First Author name YYYY”?

Thank you for pointing this out. The IPCC report citation was previously given as “IPCC WG1 AR6,” and the correct citation was inadvertently omitted during sentence revision. We have corrected this to **(Masson-Delmotte et al., 2021)** in accordance with ACP reference style.

L 29–30:

“*The pace of recent climate change has intensified, prompting extensive efforts across scientific, political, and societal domains to curb its impacts (Masson-Delmotte et al., 2021).”*

L 30–32:

“*However, the nonlinear and interconnected nature of the climate system presents substantial challenges to accurately predicting outcomes and implementing effective mitigation strategies (Masson-Delmotte et al., 2021; Steffen et al., 2018).”*

L 35–37:

“*BC is a carbonaceous aerosol that is directly released into the atmosphere from incomplete combustion of biomass, fossil fuels, and biofuels. It absorbs light strongly in the visible and near-infrared spectrum (Masson-Delmotte et al., 2021).”*

L39: “0.14 W m^{-2}”: Please use the minus-sign “−” instead of the hyphen “-“.

We have corrected this case as well as all other instances in the manuscript where the minus sign was typed as a hyphen, ensuring consistency throughout the text.

L39: You need one or more references for the BC radiative forcing "+0.14 W m^{-2}".

We have added the appropriate reference.

L 34–35:

"Black Carbon (BC) is a significant SLCF that contributes roughly 0.14 W m^{-2} of radiative forcing, as assessed in Masson-Delmotte et al. (2021)."

L45: estimated at → estimated to be

It has been corrected.

L47–L50: "Historical trends prior to 2000 show … ECLIPSE inventory.": I couldn't understand this sentence. Please re-word it to be more concise.

It has been revised into two shorter sentences for clarity:

L 44–47:

"BC emissions declined in North America and Europe prior to 2000, based on the Coupled Model Intercomparison Project (CMIP) inventory (Eckhardt et al., 2023). In contrast, the ECLIPSE (Evaluating the Climate and Air Quality Impact of Short-Lived Pollutants) inventory indicates a sustained increase in Asian emissions over the past two decades (Klimont et al., 2017)."

L68: mass distribution → mass concentration

It has been corrected.

L82: "CO/CO_2 ratio below 0.1%": Using % for ratio (not fraction) is uncommon.

We directly calculated CO/CO_2 ratios as 'ppmv/ppmv × 100' and consistently report them in percent. It was initially intended to compare previous studies who reported CO/CO_2

ratios in % over the region including the Yellow Sea (e.g., Halliday et al., 2016). To clarify, we added the following sentence when CO/CO_2 is discussed in the manuscript. We believe this addition resolves potential ambiguity while allowing consistent use of % throughout the text.

L 377–378:

"In this study, CO/CO_2 ratios are expressed in percent (ppmv/ppmv × 100)."

References:

Halliday, H. S., Thompson, A. M., Wisthaler, A., Blake, D. R., Hornbrook, R. S., Mikoviny, T., Müller, M., Eichler, P., Apel, E. C., and Hills, A. J.: Atmospheric benzene observations from oil and gas production in the Denver-Julesburg Basin in July and August 2014, J. Geophys. Res. Atmos., 121, 11,055-011,074, https://doi.org/10.1002/2016JD025327, 2016.

Kondo, Y., Moteki, N., Oshima, N., Ohata, S., Koike, M., Shibano, Y., Takegawa, N., and Kita, K.: Effects of wet deposition on the abundance and size distribution of black carbon in East Asia, J. Geophys. Res. Atmos., 121, 4691-4712, https://doi.org/10.1002/2015JD024479, 2016.

Masson-Delmotte, V., Zhai, P., Pirani, A., Connors, S. L., Péan, C., Berger, S., Caud, N., Chen, Y., Goldfarb, L., Gomis, M. I., Huang, M., Leitzell, K., Lonnoy, E., Matthews, J. B. R., Maycock, T. K., Waterfield, T., Yelekçi, O., Yu, R., and Zhou, B. (eds.): Summary for Policymakers, in: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 3–32, https://doi.org/10.1017/9781009157896.001, 2021.

Moteki, N., Kondo, Y., Oshima, N., Takegawa, N., Koike, M., Kita, K., Matsui, H., and Kajino, M.: Size dependence of wet removal of black carbon aerosols during transport from the boundary layer to the free troposphere, Geophys. Res. Lett., 39, https://doi.org/10.1029/2012GL052034, 2012.

Oshima, N., Kondo, Y., Moteki, N., Takegawa, N., Koike, M., Kita, K., Matsui, H., Kajino, M., Nakamura, H., Jung, J. S., and Kim, Y. J.: Wet removal of black carbon in Asian outflow: Aerosol Radiative Forcing in East Asia (A-FORCE) aircraft campaign, J. Geophys. Res. Atmos., 117, https://doi.org/10.1029/2011JD016552, 2012.