Dear Meng,

Thank you very much for your careful handling of our manuscript and for providing us with the opportunity to revise and improve our work. We sincerely appreciate your time, effort, and valuable guidance throughout the review process. We are also grateful to the referees for their thorough and constructive comments on our manuscript entitled “A Multi-Angle and Polarization-Based Retrieval Algorithm for Aerosol Layer Height of Smoke and Dust.”

The detailed comments and suggestions from the referees have been extremely helpful in improving the clarity, scientific rigor, and overall quality of the manuscript. We have carefully considered all comments and have incorporated corresponding revisions into the revised manuscript. We hope that the revised manuscript and our point-by-point responses adequately address the concerns raised during the review process and meet your expectations.

Please find our detailed responses to all comments and suggestions below.

Yours sincerely,

Yong Xue

The manuscript by Pei et al. presents a comprehensive analysis of retrieving aerosol layer height (ALH) using observations from NASA's PACE HARP2 instrument. The authors provide a thorough information content analysis of the contributions from spectral, polarization, and angular measurements under different surface brightness conditions and aerosol layer heights. The proposed retrieval algorithm, based on the HARP2 blue band and the full Stokes components (I, Q, and U), demonstrates encouraging performance when compared with TROPOMI and EarthCARE observations. Overall, I found this to be a well-executed and valuable study.

I would also like to draw the authors' attention to the current NASA operational HARP2 aerosol products (FastMAPOL), which include an aerosol layer height (ALH) product derived from HARP2 multi-angle polarimetric observations. These products may be useful for comparison in future studies. The product description is available at https://pace.oceansciences.org/data_table.htm?id=1, and the data can be accessed through the NASA Earthdata Cloud (DOI: https://doi.org/10.5067/PACE/HARP2/L2/MAPOL_OCEAN/3.0). The expected ALH uncertainty is discussed in Gao et al. (2023; https://doi.org/10.5194/amt-16-5863-2023), where the theoretical RMSE is approximately 0.94 km (Figs. 5 and 6), which is very close to the ~1 km validation uncertainty reported in the present study. In addition, this study showed that the ALH uncertainty decreases with increasing aerosol optical depth (Fig. 7), which is also consistent with the findings presented in this manuscript.

Response:

We are truly grateful for your careful evaluation of our manuscript and for your constructive suggestions. Your recognition of the value of this work means a great deal to us, and we very much appreciate your insightful comments on the relationship between our retrieval framework and the operational HARP2 aerosol products. Following your suggestions, we have revised the manuscript by adding discussions on the existing HARP2 ALH products, clarifying the differences between our approach and the operational retrieval algorithm, incorporating relevant references, correcting the PACE L1C spatial resolution, and further discussing the retrieval uncertainty in relation to the theoretical uncertainty.

As I can gather here, the algorithm presented in this study differs from the operational algorithm in several aspects, including the selection of one key spectral band, direct use of the I, Q, and U Stokes components, the incorporation of external aerosol information, and the focus of one retrieval parameter rather than a dozen of aerosol microphysics. These design choices appear to simplify the retrieval process while making it more robust to current calibration uncertainties. Based on the reported validation results, the retrieval performance appears reasonable and robust. You may also make this clear.

Response:

We thank you for highlighting the important differences between the proposed framework and the operational HARP2 aerosol retrieval algorithm. In the revised manuscript, we have added a discussion in the Introduction to explicitly describe the major design choices of our approach. Specifically, the proposed method focuses on ALH as the primary retrieval parameter rather than simultaneously retrieving multiple aerosol microphysical properties. It utilizes a selected key spectral band (441 nm), directly incorporates multi-angle full linear Stokes components (*I*, *Q*, and U), and adopts externally constrained aerosol optical depth information to reduce parameter coupling. These modifications clarify the motivation and advantages of the proposed ALH-focused retrieval strategy.

Revision:

Lines 158-167: Different from existing operational multi-parameter aerosol retrieval algorithms, this study focuses on ALH as the primary retrieval target to avoid strong coupling among multiple aerosol parameters. To enhance the sensitivity of observations to aerosol vertical structure, the proposed framework directly utilizes multi-angle measurements of the full linear Stokes components (*I*, *Q*, and *U*), which preserve polarization orientation information and provide additional constraints on aerosol scattering characteristics compared with approaches based on radiance and DoLP. Furthermore, externally constrained aerosol optical depth information is incorporated to further reduce the dependence of ALH retrieval on simultaneously retrieved aerosol properties, thereby improving retrieval robustness. Based on these analyses, a joint retrieval strategy is developed within an optimal estimation method to achieve robust ALH retrieval over both ocean and land surfaces.

A few more comments below:

Abstract (Line 25), Table 4, and Conclusion (Line 757):

As mentioned above, the reported ALH RMSE of 1.03 km is in excellent agreement with the theoretical HARP2 retrieval uncertainty reported by the PACE team (Gao et al., 2023). This is very encouraging. It would be worthwhile to mention the agreement.

Response:

We thank you for this valuable suggestion. The comparison between the validation uncertainty obtained in this study and the theoretical HARP2 ALH retrieval uncertainty provides important context for evaluating the retrieval performance. In the revised manuscript, we have added a statement in the Results and Conclusion sections noting that the achieved RMSE of 1.03 km is comparable to the theoretical HARP2 ALH retrieval uncertainty (0.94 km) reported by Gao et al. (2023). This agreement further demonstrates the consistency between the proposed retrieval method and the expected performance of HARP2-based ALH observations.

Revision:

Lines953-958: For all cases combined, the HARP2 retrieval achieves an RMSE of 1.03 km, which is notably lower than that of TROPOMI (1.40 km), with a near-zero mean bias (−0.07 km). The obtained RMSE of 1.03 km is comparable to the theoretical HARP2 ALH retrieval uncertainty (~0.94 km) reported by Gao et al. (2023), indicating good consistency between the validation results of this study and the expected retrieval performance of HARP2-based ALH observations.

Line 56, Line 90, Line 107:

For the polarization-based retrieval approaches, it would be more complete to mention existing HARP2 algorithm and product.

Response:

We have added a brief discussion of the operational HARP2 aerosol products and related retrieval studies in the Introduction section to provide a more complete overview of polarization-based ALH retrieval approaches.

Revision:

Lines 124-130: Meanwhile, polarization observations provide an additional dimension of information for aerosol vertical structure retrieval. Using data from the Research Scanning Polarimeter (RSP), Wu et al. (2016) found that polarization signals in the near-ultraviolet and blue spectral bands exhibit strong sensitivity to ALH. Recently, the NASA operational FastMAPOL product has provided aerosol properties, including ALH, from HARP2 multi-angle polarimetric observations (Gao et al., 2021). These developments demonstrate the potential of multi-angle polarimetric measurements for aerosol characterization.

Line 136:

Xu et al. (2024) is an important reference for ALH retrieval, but it may not be sufficient to describe the HARP2 instrument itself. You may also consider:

Martins, J. V., Fernandez-Borda, R., McBride, B., Remer, L., and Barbosa, H. M. J.: The HARP hyperangular imaging polarimeter and the need for small satellite payloads with high science payoff for Earth science remote sensing, IGARSS 2018, Valencia, Spain, 22–27 July 2018, 6304–6307, https://doi.org/10.1109/IGARSS.2018.8518823.

Response:

Thank you for this suggestion. We have added the recommended reference (Martins et al., 2018) to provide a more comprehensive introduction of the HARP/HARP2 instrument and its capability for multi-angle polarimetric Earth observations.

Line 140:

As mentioned previously, it is interesting to see the retrieval directly using the I, Q, and U Stokes components. The current operational HARP2 Version 3 data still experience some polarimetric calibration challenges. From the operational product, retrievals based only on total intensity and degree of linear polarization (I and DoLP) often exhibit positive AOD biases and large ALH biases. Using the full Stokes vector (I, Q, and U) in this study, which also retains polarization orientation information, may help mitigate some of these calibration-related issues. The use of externally constrained AOD may also improve retrieval robustness by decoupling mutual dependencies between ALH and other aerosol properties.

Response:

We appreciate your insightful comment regarding the use of the full Stokes components in the proposed retrieval framework. In the revised manuscript, we have added a discussion of the potential advantages of directly using the linear Stokes components (I, Q, and U) compared with retrieval approaches based on total intensity and DoLP. Specifically, the full Stokes representation preserves polarization orientation information, which provides additional constraints on aerosol scattering characteristics. In addition, we have clarified that externally constrained AOD is incorporated in our retrieval framework to reduce the coupling between ALH and other aerosol parameters, thereby improving retrieval robustness. These modifications have been added to the Introduction section to better explain the motivation and design choices of the proposed approach.

Revision:

Lines 151-167: Motivated by the above considerations, the present study aims to enhance information content by extending ALH retrieval from a single spectral dimension to a multi-dimensional observational space that integrates spectral, angular, and polarization measurements. This approach provides stronger physical constraints for retrieving aerosol vertical structure from passive remote sensing. Through radiative transfer simulations and sensitivity analysis of the Stokes vector, the response of TOA polarized radiance to aerosol vertical distribution and scale height is systematically evaluated. The variation in information contribution under different viewing geometries is further investigated. Different from existing operational multi-parameter aerosol retrieval algorithms, this study focuses on ALH as the primary retrieval target to avoid strong coupling among multiple aerosol parameters. To enhance the sensitivity of observations to aerosol vertical structure, the proposed framework directly utilizes multi-angle measurements of the full linear Stokes components (I, Q, and U), which preserve polarization orientation information and provide additional constraints on aerosol scattering characteristics compared with approaches based on radiance and DoLP. Furthermore, externally constrained aerosol optical depth information is incorporated to further reduce the dependence of ALH retrieval on simultaneously retrieved aerosol properties, thereby improving retrieval robustness. Based on these analyses, a joint retrieval strategy is developed within an optimal estimation method to achieve robust ALH retrieval over both ocean and land surfaces.

Line 144:

Please note that the PACE Level-1C spatial resolution is approximately 5.2 km, rather than 3.5 km.

Response:

Thank you for pointing out this error. We have corrected the spatial resolution of the PACE/HARP2 Level-1C product from 3.5 km to approximately 5.2 km throughout the revised manuscript.

Line 220:

Retrieval uncertainty propagation has also been investigated for HARP2 observations (Gao et al., 2023). That study found that the theoretical ALH uncertainty agrees well with retrieval uncertainties derived from simulations (see Fig. 9). That means the retrieval uncertainty of 1km may also approach to the optimal performance constrained by measurement uncertainty itself.

Response:

We thank the reviewer for pointing out the uncertainty analysis of HARP2 ALH retrieval reported by Gao et al. (2023), which we have now incorporated into our discussion. In the revised manuscript, we have added a discussion comparing our validation results with the theoretical uncertainty estimated from HARP2 observations. The reported ALH RMSE of approximately 1 km in this study is consistent with the theoretical retrieval uncertainty derived from error propagation analysis in Gao et al. (2023), suggesting that the achieved retrieval accuracy is within the expected uncertainty range of HARP2-based ALH retrievals. The corresponding discussion has been added in the revised manuscript.

Revision:

Lines 953-958: For all cases combined, the HARP2 retrieval achieves an RMSE of 1.03 km, which is notably lower than that of TROPOMI (1.40 km), with a near-zero mean bias (−0.07 km). The obtained RMSE of 1.03 km is comparable to the theoretical HARP2 ALH retrieval uncertainty (~0.94 km) reported by Gao et al. (2023), indicating good consistency between the validation results of this study and the expected retrieval performance of HARP2-based ALH observations.