

Responses to reviewer 1:

The authors would like to express the gratitude for the efforts that the anonymous reviewers dedicated to provide constructive comments and suggestions which help us to improve the quality of the manuscript. Below we provide detailed response to each of the comments of the reviewers:

General comments:

The article deals with retrievals of spectral AOD and surface properties from a AHI image on board of geostationary satellite HIMAWARI-8 using GARSP software. Generally detailed properties with high temporal resolution are of great demand for atmosphere modelling community and article is within the scope of AMT. It seems that GARSP have never been applied to geostationary satellite so from its point it is a rather novel topic, although it is not fully clear if any modifications or improvements to already existing software were made to apply perform the retrievals. Article is well written, properly illustrated and referenced with good logical organization and structure, validation results are quite impressive not only by results (as opposed to the existing JAXA product) but also by sheer number of points used to gather statistics.

I'd recommend this article for publication with minor revision, below I enlist some points that in my opinion authors should consider improving.

Answer: We are grateful for overall positive evaluation of our paper.

The point-by-point responses:

Major comments:

Part of AHI+MPL retrieval is rather novel, I can't recall if anyone did anything similar, and I do understand the desire of authors to share these results, although they outstanding a little from the paper and not emphasized in the title. It looks more like a proof-of-concept study, although well described, it provides significantly lower amount of observation. I'm not completely against having it in the paper, but I'd recommend authors to provide a better introduction to this part to emphasize the points I mentioned.

Answer: Authors are grateful for this valuable feedback. We agree that the AHI+MPL synergistic retrieval part serves primarily as a proof-of-concept study with a limited number of observations. To address your suggestion, we have added some description in the Section 3.4 (Lines 753-760), emphasizing the novelty of the approach, its nature of proof-of-concept, and its potential to guide future synergistic retrievals using collocated passive and active sensors.

- Lines 753-760: "Although the synergistic retrieval of AHI/Himawari-8 with MPL measurements was performed at only one single site - Beijing-PKU, yielding a limited number of data points, this study represents the first attempt in combining high-frequency observations of MPL and geostationary sensors and performing the simultaneous retrievals. Thus, despite the limited data in the analysis, the study serves as a valuable proof of concept, demonstrating the effectiveness and potential advantages of such synergistic approach, providing insights and practical examples for future efforts in synergistic retrievals of collocated passive and active, such as the MSI (Multi-Spectral Imager) and ATLID (the

ATmospheric LiDAR) on board of EarthCARE (Earth Cloud Aerosol and Radiation Explorer) satellite mission (Wehr et al., 2023).”

In the Introduction, the only algorithms described and compared are GRASP and JAXA/AHI one, consider adding an overview of other GEO based algorithms, or ones applied to GEO observations, it feels like general overview of remote sensing algorithms for GEO observation will improve readers awareness of state-of-the art in the field, and why some algorithms are considered more “next-generation” than others. I can suggest Dark Target by Remer et al., 2020 e.g. (<https://dx.doi.org/10.3390/rs12182900>) and MAIAC by Zhang et al., 2011 (<https://acp.copernicus.org/articles/11/11977/2011/>) for e.g., but I believe take that there are so many GEO satellites out there, they should have a more excessive algorithm reference list. And I strongly believe making an overview of comparison between different GEO approaches will make the paper stronger, at least it won’t make it feel that GARSP is the only algorithm that can be applied to both LEO and GEO observations.

Answer: We thank the reviewer for this valuable suggestion. We agree that providing a broader overview of existing aerosol retrieval algorithms applied to geostationary satellite specifically Himawari-8 will improve the manuscript. We have expanded the Introduction to include more algorithms applied to Himawari-8 retrievals. The relevant section has been added to the Introduction (Lines 46–52) and the reference list has been revised accordingly.

- Lines 46-53: “A number of studies have been focusing on inverting aerosol properties from AHI/Himawari-8 observations using a variety of retrieval algorithms and methodologies, such as the Dark target (DT)-like algorithm (Ge et al., 2008; Gupta et al., 2019; Gao et al., 2021), MAIAC algorithm (She et al., 2019), machine learning based approach (Tang et al., 2025; She et al., 2020; Fu et al., 2023) as well as other notable contributions (Lim et al., 2018; Zhang et al., 2018;) aiming to improve the aerosol retrieval accuracy from AHI/Himawari-8 observations. The JAXA has also released its operational products based on an optimal estimation method developed by Yoshida et al. (2018).”

Minor comments:

Eq.19: In regards of height that sometimes is retrieved as a exponent parameter or profile, it is not clear how this equation changes when profile is retrieved, and S_h are not mentioned anywhere in eq19.

Answer: We thank the reviewer for this careful observation. In Eq. 19, S_a represents the matrix containing the coefficients used to calculate the m -th order differences for each pixel. Within each pixel, no single-pixel constraint is applied to the aerosol layer height when it’s retrieved as an exponent parameter. Therefore, the corresponding S_h are zero, which is why S_h did not explicitly appear in Eq. 19.

To generalize the Eq.19 for both cases (retrieving aerosol height as an exponent parameter or as a vertical profile), we have now included S_h in Eq. 19 and clarified this in the text (Lines 362–364, 366-369). Specifically, when aerosol height is retrieved as an exponent parameter, $S_h = 0$, whereas for retrievals with aerosol vertical profiles, $S_h \neq 0$.

- Lines 362-364: “In addition, the $S_h = \mathbf{0}$ because the aerosol layer height is retrieved as an exponent parameter and no single-pixel constraint can be imposed.”

- Lines 366-369: “Similarly, for the synergistic AHI/MPL retrieval, given the significant increase in the number of retrieved parameters, a certain degree of smoothness constraint is also imposed on the aerosol vertical distribution (i.e., $\mathbf{S}_h \neq \mathbf{0}$) to avoid unreasonable and abrupt vertical variation (See Table 3 for details).”

Eq. 21: Δf_i are not described, assuming it is the same as for one pixel, I may conclude uncertainties are set up differently for each pixel however nowhere in text how accuracy is estimated for different pixels, please clarify.

Answer: We thank the reviewer for the helpful comment. The term $\Delta f_1, \Delta f_2 \dots \Delta f_{n_{pix}}$ indicate the uncertainty of the observations associated with each pixel. The uncertainties are estimated to be consistent across all the pixels, based on the assumption that the observation uncertainties don't vary spatially or temporally. We have clarified this in the text Lines 404-407 to enhance the precision and readability.

Line 76: it is not clear if there any community-wide recognized “generations” of the remote sensing algorithms, consider elaborating more what stands out it from the others.

Answer: We thank the reviewer for the comment. While there is no formal and community-wide classification of “generations” of remote sensing algorithm, the term here is used to emphasize its comprehensive and advanced capabilities and flexibilities that could be and have been applied to a wide range of remote sensing instruments. We have rephrased the sentence and elaborated in Lines 85-89.

- Lines 85-89: “GRASP is a state-of-the-art algorithm developed for deriving extensive aerosol and underlying surface properties from diverse space-borne and ground-based instruments. Compared with some earlier retrieval approaches, GRASP allows simultaneous retrieval for a group of spatial or temporal pixels, enhancing the information content and improving the consistency and robustness of the results. It also provides the flexibility to accommodate different type of instruments as well as their synergy, allowing for more accurate and flexible characterization of aerosol and surface properties (Dubovik et al., 2021).”

Line 356: “AHI/MPL retrievals, since aerosol loading is typically very low above 5 km, a prior estimate of $1.0 \cdot 10^{-6}$ is set for the normalized aerosol concentration at the top altitude layer.” It is not clear why this a priori is applied and how, eq. above do not have such explications. In general it seems that there are some differences introduced by the presence of the MPL in the retrieval consider to make it clearer how AHI/MPL and AHI differ.

Answer: We thank the reviewer for this valuable comment. The a priori value of $1.0 \cdot 10^{-6}$ for the normalized aerosol concentration at 5km is applied to constrain the retrieval in the high-altitude, where aerosol loading is typically very low, and in order to describe the aerosol vertical distribution in the whole atmosphere column to be able to perform radiative transfer calculation, the aerosol concentration above 5km was assumed linearly decreasing from C_p at 5km to a value close to zero at TOA, following a similar approach described in Lopatin et al. (2013). Clarification and corresponding modifications have been added in Section 2.4 (Lines 352, 374-377, 385-392) to explain how and why this a priori is applied, as well as to clarify how AHI/MPL synergistic and AHI/Himawari-8 retrieval differs.

Table 3: I'm a bit confused by 0 and – in the table, does 0 means the constraint is effectively not applied? How's that different from – then?

Answer: We thank the reviewer for the comment. In Table 3, the “–” indicated that the single-pixel constraint cannot be applied because there is only one value retrieved for the parameters, such as C_v , h , δ_{Fr} and σ within a single pixel, without any spectral dependence. In contrast, the value of “0” for the multiple-pixel (spatial) constraints of f_{iso} , f_{vol} and f_{geo} means that the constraints are intentionally not applied, as these surface parameters could vary rapidly in space. This distinction has been clarified in the manuscript Lines 438-439.

- Lines 438-439: “** –: indicates that the constraint cannot be applied or is not meaningful in the given context; it differs from ‘0’, which denotes that the constraint is intentionally not applied.”

Table 4: It seems – have different signification in different columns of the table, consider clarifying it for readers, it is already rather hard to grasp due to excessive math. Consider noting “unitless” for the units column or something different.

Answer: We thank the reviewer for pointing out this ambiguity. The “–” have been replaced with “unitless” in the *Units* column. The remaining “–” symbols in the *Variables* column indicate that these variables are not available. This has been modified in the table and clarified in text Line 452 to improve the clarity and readability of the table.

- Line 452: “** -: products not available.”

Line 431: “at least 5 valid AHI/GRASP retrieval pixels should be available”, please clarify are these spatial or temporal pixels? It is not clear for which group of pixels standard deviation is calculated”

Answer: We appreciate the reviewer's comment. The “5 valid AHI/GRASP retrieval pixels” refer to spatial pixels. The validation is performed by selecting a 3×3 AHI/Himawari-8 retrieval pixel window centered on the AERONET station to calculate the average AOD(λ) value of the satellite retrievals. Within this 3×3 window, at least 5 valid pixels are required. The standard deviation is also calculated based on these spatial pixels within the same 3×3 window. The clarification has been added to text Lines 459-461.

- Lines 459-461: “Additionally, at least 5 valid spatial AHI/GRASP retrieval pixels should be available within the 3x3 pixel window centered on the AERONET station, and the AHI/GRASP AOD standard deviation within the 3x3 pixel window larger than 0.05 for AOD<0.5 and AOD relative standard deviation larger than 0.15 for AOD>0.5 are removed to avoid possible thin cloud contamination induced inhomogeneity (Chen et al., 2020).”

Figure 4: It's a bit hard to interpret this figure, can we have a supplementary table with the same parameters somewhere below?

Answer: Thanks for the suggestion, the supplementary Table S1 has been added with the AHI/GRASP validation statistical metrics R, RMSE, Bias and GCOS at AERONET over land stations for the year 2018 for AOD at 510nm in the supplement material.

Line 574: “Both products have been re-gridded to $0.2^{\circ} \times 0.2^{\circ}$ spatial resolution”, can authors elaborate more or justify why this resolution was chosen?

Answer: Thank you for the comment. The $0.2^{\circ} \times 0.2^{\circ}$ spatial resolution was chosen as a compromise between spatial resolution and computational efficiency. This resolution is sufficiently fine to capture regional aerosol variability while ensuring sufficient collocated data points for statistically robust comparison between the two aerosol products. Additionally, re-gridding to this resolution helps to smooth out possible differences arising from observation geometry and geolocation mismatches between the two products. Similar resolutions have also been commonly adopted in previous aerosol retrieval intercomparison studies (e.g., Chen et al., 2020, 2022, 2024). The clarification has been added in the text Lines 615- 617 to improve the clarity and readability.

- Lines 615 – 617: “... which helps to mitigate the possible differences due to the observation geometry and geolocation mismatch between the two products. Similar resolutions have been commonly adopted in previous aerosol products intercomparison studies (Chen et al., 2020, 2022, 2024).”

Figures 8 and 10: Are there any other AERONET sites that can be marked in these areas?

Answer: We thank the reviewer for the valuable comment. For the pollution case shown in Figure 8, three other AERONET sites are identified in the polluted area: Bhola (Bangladesh), Lumbini (Nepal), and Pokhara (Nepal). The locations of these sites and the diurnal cycles of AHI/GRASP and AERONET AOD at 510nm during the pollution event on 24th-26th November, 2018 are provided in the supplementary material (Figure. S3- S6) and described in text Lines 576-579. For the pollution case shown in Figure 10, no other AERONET sites with complete diurnal cycles were identified within the polluted area.

- Lines 576-579: “Three additional AERONET sites are also identified within the polluted area: Bhola (Bangladesh), Lumbini (Nepal), and Pokhara (Nepal). The locations of these sites and the diurnal cycles of AHI/GRASP and AERONET AOD at 510nm during this pollution event are shown in Figs. 3-6. Similarly, the diurnal variations of aerosol optical properties are well captured by AHI/GRASP retrievals.”

Section 3.4. The profile analysis for several cases are quite nice, but is it possible to have layer to layer comparisons for all the cases combined on one scatter plot for general overview?

Answer: We thank the reviewer for the suggestion. Layer-to-layer comparison for the cases presented in Section 3.4 has been added to the supplementary figure (Figure S9) and text has been added in manuscript Lines 824-827. As noted in Section 3.4, profiles derived from the Fernald method exhibit some unreasonable oscillations, abrupt spikes, and occasional negative values, which lead to less robust statistics in the comparison. Nevertheless, most points generally scatter around the 1:1 line, indicating overall agreement.

- Lines 824-827: “The layer-to-layer comparison combining all the cases analyzed above is shown in Fig. S9. Despite the oscillation and abrupt spikes present in the profiles derived from the Fernald method, which result in less robust statistics, the majority of the data points still cluster around the 1:1 reference line, indicating overall good agreement between the retrievals.”

Technical comments:

Line 173: I believe it is not final layout, but this one is particularly bad with huge spaces, same for line 301.

Answer: We thank the reviewer for pointing this out. These layout issues have been corrected in the revised manuscript.

Line 186: (<http://www.eorc.jaxa.jp/ptree/index.html>) consider providing the last access date

Answer: We thank the reviewer for the suggestion. The last access date has been added (Lines 196-197).

- Lines 196-197: “(<http://www.eorc.jaxa.jp/ptree/index.html>, last accessed: August 1st, 2025)”

Section 2.4: Consider mentioning somehow the version of the code used in the study.

Answer: We thank the reviewer for the suggestion. The version of the code used in this study (v1.1.2) has now been specified in the manuscript Line 167, ensuring reproducibility of the results.

- Line 167: “As mentioned above, this study is focused on the processing of AHI/Himawari-8 geostationary satellite data using GRASP (version 1.1.2) retrieval platform.”

Eq.16: “For i -th pixel” there’s no i in the equation anywhere, and in eq. 18 i is not explicitly described.

Answer: We thank the reviewer for pointing this out. The phrase “for i -th pixel” in Line 337 has been replaced with “for each pixel” for clarity. Additionally, a description of the index i has been included in the text (Line 347) for Eq. 18 to explicitly indicate that it refers to the i -th pixel.

Line 345: “ S is the matrix” it seems there are multiple matrices S_i .

Answer: We thank the reviewer for the comment. The matrix referred to as “ S ” in the manuscript is S_a . The text has been revised accordingly to clarify this notation in Line 356.

Figures 6, 7, 16, 23-27: Personally I’m not in favor of captions like this, consider copy pasting the full caption, it’s not convenient to scroll up and down all day.

Answer: We thank the reviewer for the suggestion. The captions for Figures 6,7,16, 24-27 have been revised to include the full descriptions.

Figure 8: Found it hard to find a black circle, consider mentioning that it is “circled in black (on the left edge of the map)” same for figure 9.

Answer: We thank the reviewer for the comment. The captions for Figure 8, 10, S1, S2, S3, S4 have been revised to indicate the circled point is “on the left edge of the map” (Figure 8, S1, S2) and “in the upper middle of the map” (Figure 10, S7, S8) to improve the readability.

Responses to reviewer 2:

The authors would like to express the gratitude for the efforts that the anonymous reviewers dedicated to provide constructive comments and suggestions which help us to improve the quality of the manuscript. Below we provide detailed response to each of the comments of the reviewers:

General comments:

This paper is highly innovative. As stated by the author, it not only realizes the first application of the GRASP algorithm in the retrieval of geostationary satellite data, but also synergetic retrieval between AHI/Himawari-8 and micro-pulse lidar (MPL). The significance of this article is prominent, as it not only improves the accuracy of aerosol product from geostationary satellites and provides surface parameters synchronously, but also confirms the reliability of the vertical profile of MPL for satellite retrieval accuracy. But there are still some works in this article that need to be improved and perfected:

Answer: We are grateful for overall positive evaluation of our paper.

The point-by-point responses:

1. This article is actually very rich in content, but the title of the paper is relatively weak to generalise all the contents. It is recommended to consider modifying the title of the article to more comprehensively display the content of this article.

Answer: We appreciate the reviewer's insightful comment regarding the title. After careful consideration, we decided to retain the current title with only a minor adjustment - "Retrieval and Validation of Diurnal Properties of aerosol and surface from geostationary satellite Himawari-8 using Multi-Pixel Approach", as we believe it effectively summarises the main approach and focus of our study. Specifically, the title prefers to main novelty of our work - the multi-pixel approach used in both the AHI/Himawari-8 and AHI/MPL retrievals. Aslo it emphasises that the retrieval allows for the characterisation of the aerosol diurnal variations, that make the new retrieval product especially valuable compared to conventional aerosol products. We therefore consider the current title to be representative of the key methodology and objectives presented in the paper.

2. The resolution of some Figures in the article is too low, for example, Figure 21. It is recommended to increase the resolution of these images.

Answer: We thank the reviewer for the comment. The resolution of Figure 21, as well as other figures (Figures. 2,3,4,5,6,7,18) with low resolution have been improved to enhance the clarity and readability.

3. To improve the readability of this article, the author can provide some explanations of professional terms. For example, starting from line 56 of this article, the author discusses the impact of the surface reflectance on aerosol retrieval. line 63-65 introduce the solar geometry condition influence surface albedo. Suggest the author briefly mention the correlation and difference between reflectivity and albedo to improve the understanding of graduate readers.

Answer: We thank the reviewer for this valuable suggestion. To improve the readability for a broader audience, we have added brief explanations in Lines 61-64 clarifying the correlation and difference between surface reflectivity and albedo, and how solar geometry influence the surface albedo in the aerosol retrievals.

- Lines 61-64: “Surface reflectance refers to the fraction of incoming solar radiation that is reflected by the surface at a given wavelength and viewing angle, while surface albedo represents the fraction of total incident light reflected in all directions. The geometry condition, including the solar zenith and azimuth angle, affects the apparent surface albedo observed by the satellite and, in turn, influences aerosol retrieval.”

4. There are many Figures in this article, and the author usually lists each case one by one (day by day, for example Figure 22, 24, 26). Can we consider reducing the number of pictures and integrating and displaying these cases.

Answer: We thank the reviewer for the suggestion. Figures 22, 24, and 26 have now been integrated into as Figure 22 to reduce the number of figures and improve the overall presentation.

5. line 838-839, "the new approach also improves upon the potential issues of non-physical negative values or the abrupt spikes that may occur with the Fernald method." Indeed, for Fernald and Mie scattering lidar (do not like Raman or HSRL), some hypothesis parameters may introduce significant errors. However, the signal emission frequency of MPL is very high, and have more time/opportunity to realize the synchronous observation with geostationary satellites. Did the author attempt to average multiple MPL profiles to smooth out these errors or remove erroneous signals to ensure the validity of MPL data? After all, ground-based observation equipment is usually the reference for satellite.

Answer: We thank the reviewer for the valuable comment. In this study, we did consider the potential errors in MPL observations. The MPL has a temporal resolution of 15 seconds, and during the pre-processing, the profiles are averaged within a 15-minute window centered on the AHI/Himawari-8 measurement time to improve the signal to noise ratio as indicated in Line 241.

- Line 241: “The data is averaged within 15 minutes centered at the satellite observation time, similar to Lopatin et al., (2021,2024);”