Response to Review #1

The authors developed an operational algorithm to retrieve the aerosol effective height (AEH) using the slant column density of the oxygen dimer (O2-O2) at 477 nm from the Geostationary Environment Monitoring Spectrometer (GEMS). This algorithm was applied in GEMS observation domain from January to June 2021 and provided important aerosol vertical height information for severe dust plumes over East Asia and anthropogenic aerosol pollutants over India. GEMS AEH product was also compared with CALIOP and TROPOMI aerosol layer height in this study. Although this product provides important data source for diurnal variation of aerosol vertical distribution information and deserves to be published, there are many unclear descriptions in the manuscript and the presentation quality, especially the English writing style needs to be improved. The detailed comments are as follows:

Ans) Thank you for your great response. We appreciated to the reviewer with valuable comments and suggestions to improve the overall quality of our manuscript. We have carefully checked and revised the manuscript based on the reviewer's comments. Details of our responses are listed below to each comment.

1. Line 72: "Because cloud optical properties are relatively simple" is mentioned here. I don't think "simple" is an accurate description. The cloud optical properties also depend on droplet size, cloud phase, etc. This sentence needs to be re-worded to better describe the distinctions between cloud and aerosol optical properties.

Ans) We also agreed the reviewer's comment. We deleted the word 'simple' in all of the revised manuscript to describe more carefully. Also, the commented sentence was deleted during the modification of Introduction section. As a result, the first half of Introduction section is simply written to the literature studies of aerosol/cloud retrieval algorithms in the revised manuscript.

2. Line 81-90: The objective of this paragraph is not clear. The aerosols vertical distribution retrievals from multiple sensors have been introduced in last paragraph. Then, at the beginning of this paragraph, the satellite retrieval of aerosols properties were introduced. Later on, TROPOMI aerosol layer height retrieval was mentioned again. I think it's better to move this introduction to the above paragraph and the connection between these paragraphs needs to be improved. It is not smooth for the readers.

Ans) To improve the readability, we revised the paragraphs in the Introduction section. After introducing the environment satellite sensors, we introduced the cloud/aerosol algorithms. After, the algorithm related to the vertical information of aerosol is listed in the revised manuscript.

3. Introduction: I suggest to add some introduction about the AEH or ALH, since that is the single parameter to describe the aerosol vertical profiles, differing from measurements of lidar.

Ans) To describe the difficulty of description of the aerosol vertical profiles by the passive sensors, we

added the sentences in lines 91-97 in the revised manuscript.

"Veihelmann et al. (2007) showed that the number of degrees of freedom of signal for aerosol is 2~4 for most of satellite observation conditions by the ozone monitoring instrument (OMI). It means that the number of information for aerosol vertical distribution have a limitation. Because of limitation for describing the aerosol vertical information, aerosol layer height (ALH) (Nanda et al., 2018) or aerosol effective height (AEH) (Park et al., 2016) were defined to retrieve the aerosol vertical information from the passive satellite sensors."

4. Line 122-123: The definition of AEH described here is hard to understand. Think about rewording this sentence.

Ans) To describe the definition of AEH, the paragraph is modified in lines 126-139 in the revised manuscript.

"AEH is a layer height parameter that considers the penetration of photons into the aerosol layer. In this study, the AEH product from GEMS is defined as the height with aerosol extinction integrated from the surface of (1-exp-1) × AOD, and a detailed definition of AEH was introduced by Park et al. (2016). Numerous previous studies have used the aerosol top layer height (Kohkanovsky and Rozanov, 2010) or middle layer height (i.e. ALH) (e.g., Sanders et al., 2015; Nanda et al., 2020) as the aerosol vertical layer parameter. AEH is similar to the aerosol top layer height but with a slight bias. For AEH retrieval, the vertical distribution assumption is also important. The Gaussian Density Fitting (GDF) distribution, which is a modified Gaussian distribution structure, is assumed for AEH retrieval. The full-width at half-maximum (FWHM) of the aerosol layer is 1 km. Based on the assumptions about the aerosol vertical distribution, the AEH value is greater than the peak height of the Gaussian distribution and lower than the aerosol top layer height. Detailed description of AEH and other aerosol vertical parameters are shown in Figure 1."

In addition, we added the Figure 1 to illustrate the difference between ALH and AEH in the revised manuscript.

5. Line 128-130: I think a figure showing the different values of AEH, peak height and top height for the same GDF aerosol profile will help demonstrate the conclusion here.

Ans) Figure was added to describe the definition difference between AEH and ALH in Figure 1 in the revised manuscript. Also, we added the sentences to explain the details of parameters for aerosol layer heights in the above paragraph.

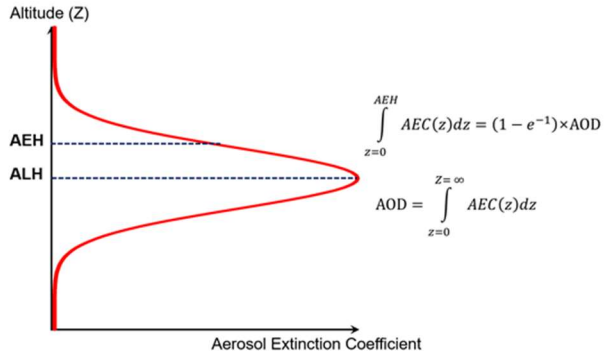


Figure 1. Description of difference between AEH and ALH in idealized aerosol vertical distribution.

6. Figure 1: There is a repeated box for ”simulated radiance” in the flowchart.

Ans) We revised the flowchart figure in Figure 2 in the revised manuscript.

7. Section 2: I think some descriptions about DOAS fitting are needed here. Although it may have been introduced in the previous paper (Park et al., 2016), it becomes hard for the readers to follow the details related to DOAS fitting, such as Table 1. I don’t understand what the fitting parameters mean and which parameters represent setting information, similar as the information about polynomial orders and offset in Table 2.

Ans) Thank you for the comment. To describe the details of fitting, we modified the paragraph in lines 181-194 in the revised manuscript.

“For AEH retrieval, the basic method is the identification of changes in optical path length caused by effective aerosol layer height variation. To measure the optical path length change, O2-O2 slant column density (SCD) retrieved by the differential optical absorption spectroscopy (DOAS) method was used. In the GEMS product, the O2-O2 SCD at 477 nm absorption band is most useful absorption band because this absorption band is strongest absorption band within the GEMS spectral observation range. Detailed DOAS fitting parameter and setting information is provided in Table 1 for the estimation of O2-O2 SCD from both the simulation and observation data. For the O2-O2 SCD estimation at 477 nm, the fitting window is ranged from 460 to 486 nm to cover the full absorption structure of O2-O2. Within the fitting window, the absorption is significantly affected by the absorptions of NO2 and O3. To describe these two absorption materials, temperature dependent cross section information are adopted. The temperature dependent cross section setting considers the stratosphere and troposphere, simultaneously.”

To demonstrate the importance of fitting parameters for DOAS fitting, we revised the paragraph in lines 199-207 in the revised manuscript as below:

"To minimize the noise effect and improve fitting quality, the optimal settings for fitting were also analyzed. Table 2 shows ratios of SCD error to the SCD for various polynomial and bias orders from observed radiance. The polynomial and offset are basic fitting parameters for the DOAS fitting. Both two parameters describe the broadband spectral feature of radiance. The ratio between SCD error and the SCD of O2-O2 is important to determine the AEH retrieval quality. When the fitting error increase, the uncertainty of AEH is also enhanced during the retrieval. Although the fitting quality was good overall, the setting with 2nd order of polynomial and none offset was used for the O2-O2 SCD estimation from the GEMS radiance due to the smallest fitting error."

8. Line 203-204: I don't think the "optical reflection" is a professional description here and I don't understand why it is large for absorbing aerosols.

Ans) To clarify the manuscript, we revised the sentences in lines 223-230 in the revised manuscript as

"The O2-O2 SCD sensitivity is enhanced at high AOD and absorbing dominant aerosol cases. In addition, the contrast of O2-O2 SCD is greater for absorbing dominant aerosols than non-absorbing aerosols. During the radiance passing through the aerosol layer, the absorbing dominant aerosol is more efficiently absorbed the radiance. For this reason, the effective optical path length is significantly shorter for absorbing aerosols. Based on the changes in sensitivity observed for optical path length, aerosol type (in particular in terms of SSA) and AOD are considered as input parameters for AEH retrieval."

9. Table 3: The AOD and imaginary refractive index are both at 440 nm in this table, but the retrieval band used is 477 nm. Is the wavelength dependence considered when creating the look-up-table? If so, how to convert from 440 nm to 477 nm? If not, this needs to be emphasized in the manuscript.

Ans) Thank you for your comment. We agreed that the spectral dependence of aerosol optical properties will affect the radiance simulation. However, in this study, we assumed that the discrepancy of wavelength (440/477 nm) is ignored. To clarify the assumption, we added the sentence in lines 214-217 in the revised manuscript as:

"During the radiative transfer model simulation, the SSA and AOD is assumed to be 440 nm. Although the center of O2-O2 absorption is 477 nm, the spectral discrepancy between model assumed wavelength and center wavelength of O2-O2 absorption is assumed to be ignored in this study."

10. Line 256-257: The ”insignificant diurnal variation” is mentioned here. I don’t know how many kilometers the diurnal variation is and why it is not significant.

Ans) This expression is confusing. For this reason, we deleted the sentence in the revised manuscript.

11. Figure 2: Add the CALIOP tracks used in later analysis in the map here, and also in Figure 5.

Ans) We modified the figures for adding the CALIOP tracks in Figures 4 and 7 in the revised manuscript.

12. Line 280-282: How is the ”0.5 km” overestimation in an ideal case concluded?

Ans) To explain the details of overestimation, we revised the sentences in lines 303-308 in the revised manuscript as:

“Given the difference in definition for the aerosol height parameters between ALH and AEH, relatively high height values were retrieved from GEMS compared to TROPOMI. In an ideal case under symmetric gaussian distribution with a width of 1 km, the AEH from GEMS was around 0.5 km higher than the peak height of aerosol layer. The ALH expresses the center (or peak) height, thus, the AEH from GEMS was overestimated by around 0.5 km relative to the ALH from TROPOMI.”

13. Figure 4: When comparing GEMS AEH with CALIOP, I notice that for the same CALIOP AEH, the GEMS AEH shows large variation. For example, for those pixels with 2 km AEH from CALIOP, the GEMS AEH changes from 0.2 km to 5 km. What is the reason for this phenomenon? Maybe adding figures showing CALIOP aerosol extinction profiles helps. How is the correlation between CALIOP and GEMS AEH? What do the black dots and error bars in panel (b) represent?

Ans) Thank you for your comment. We checked the statistical results in these cases and found that some collocated pixels are overlapped. Although these overlapped pixels can be averaged during the statistical process, the comparison result are estimating from different pixels. Except to the effect of overlapped comparison results, the retrieval around the 2 km AEH from CALIOP is not from single plume regions. In addition, the captions of Figures 5 and 8 were revised to explain the black dots and error bars in panel (b).

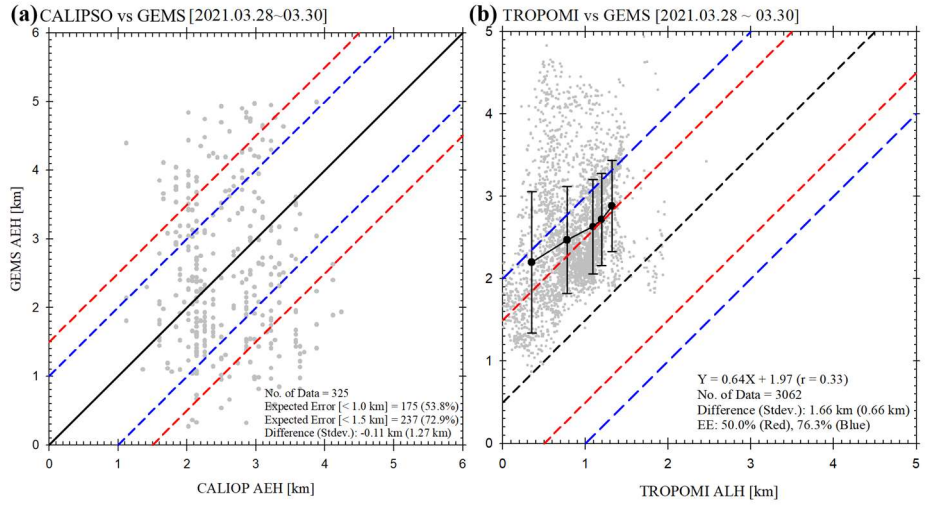


Figure 5. Intercomparison of (a) AEH between CALIOP and GEMS and (b) ALH from TROPOMI and AEH from GEMS (black dot and error bar is mean and standard deviation in 20% interval of each TROPOMI ALH) over the period from March 28 to 30, 2021.

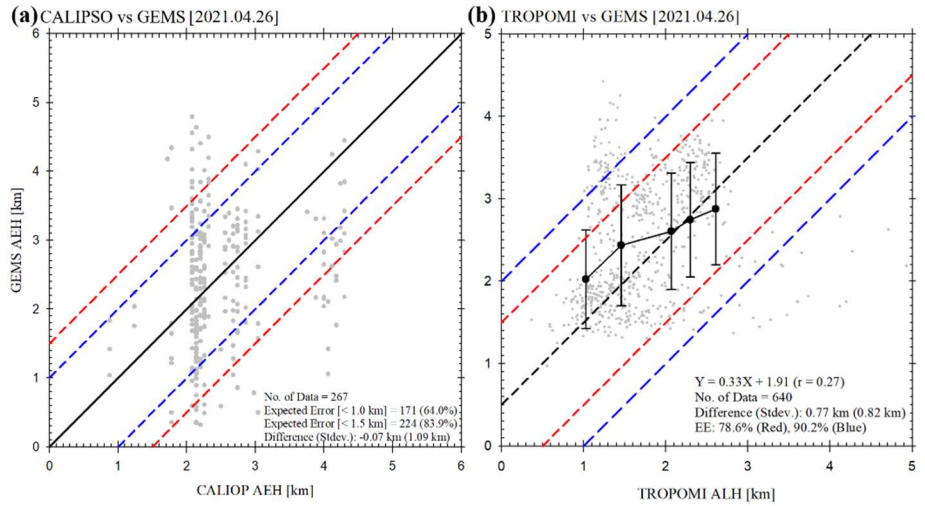


Figure 8. Intercomparison of (a) AEH between CALIOP and GEMS, and (b) ALH from TROPOMI and AEH from GEMS (black dot and error bar is mean and standard deviation in 20% interval of each TROPOMI ALH) on April 26, 2021.

Response to Review #2

The paper introduces the newly developed GEMS aerosol effective height product. This is an interesting new product. Aerosol vertical profile and height products are scarse and satellite instruments that monitor aerosol height are needed to constrain models. Global products are few, notably the CALIOP instrument which resolves the aerosool vertical profile, albeit in a small swath, the TROPOMI instrument with global coverage which retrieves an effective height for global average aerosol properties, and the GOME-2 instruments, which retrieves an effective height for dense absorbing aerosol plumes. At present, no aerosol height product from a geostationary satellite is available, and the results from GEMS are very interesting scientifically.

Ans) Thank you for your great response. We appreciated to the reviewer with valuable comments and suggestions to improve the overall quality of our manuscript. We have carefully checked and revised the manuscript based on the reviewer's comments. Details of our responses are listed below to each comment.

General comments:

The paper presents some technical details of the retrieval algorithm and validation results from a limited but well-chosen intercomparison. However, at present the presentation quality of the paper and the scientific results are not sufficient to warrant publication. My main issue is that the level of detail is poor and seems rather arbitrary. From the manuscript, it cannot be deduced what methods were used, and even a definition and derivation of the AEH, the main product, is missing. On the other hand, some very detailed information of tests are presented, of which the results are not given and referred to in other papers.

The second major issue is that the presentation quality should be increased. At present, the manuscript is poorly structured, with results of tests in the algorithm section, paragraph describing different subjects than indicated, and numerous unjustified qualitative statements, like "good", and especially the overused word "significant". This should be improved by restructering the manuscript and quantifying statements. The use of English should be improved.

The scientific relevance is "significant", so I recommend that the manuscript be published eventually, but only after major revisions have been made. First, I recommend that the manuscript be completely restructured, following a normal setup including Introduction, Method and Data, Results, Conclusions and Discussion section, with all text strictly confined to their proper section, and with the specific comment detailed below included. Second, I recommend a full new review, because the manuscript in its present form cannot be reviewed for content.

Ans) Thank you for your comments. During the revision, we reconstructed the overall of manuscript including introduction, algorithm, and data sections (Section 1~3) including the reviewer's suggestions. Also, detailed description for the methodology setup, specifications of instruments, and explanations of results have been modified. In addition, unjustified statements were modified to the quantified word in the revised manuscript. Finally, all parts of the manuscript were updated.

Specific comments:

Introduction:

l. 53-58. It is suggested here that UVAI is retrieved for atmospheric correction of gaseous species retrievals. This is not true. The UVAI has been retrieved as a ozone absorption residual, which turned out to be mainly due to absorbing aerosols. As such it has been useful for the detection of absorbing aerosols, but only ever in a qualitative way. These sentences should be changed to eitehr properly describe atmospheric correction or properly describe the function of the UVAI (and scattering AI).

Ans) Thank you for your comments. To clarify the manuscript, we modified the in lines 51-60 in the revised manuscript as:

"However, these column-integrated amounts and associated surface concentrations have uncertainty due to simultaneous changes in optical path length associated with the vertical distribution of target species and amounts of scattering materials (clouds and aerosols) present.

Environmental satellite sensors, in particular those that measure UV-visible wavelength range, have been used to detect aerosol and cloud signals by using the aerosol index (e.g., Buchard et al., 2015; Herman et al., 1997; Torres et al., 1998, 2002; Prospero et al., 2000; de Graaf et al., 2005) and scattering radiative index values (Penning de Vries et al., 2009, 2015; Kooreman et al., 2020; Kim et al., 2018), although these indices only have qualitative characteristics and limitations to identify aerosol amounts."

l. 55. cloud signals are not used to derive UVAI. In fact, aerosol signals are not used to derive UVAI as such, but aerosol (absorption) affects the reflectance in the UV measured by a satellite compared to a cloud-free and aerosol-free atmosphere, which can be computed. Clouds affect the reflectance in a different way, which can also be expressed in terms of the UVAI. Please, rephrase and be concise and be specific about the message here.

l 58-60. AOD and clouds are not specifically retrieved from the UV, more often in the visible (aerosols) and the near IR and IR for clouds. What is the purpose of this sentence about UV wavelengths here?

Answer to above 2 comments) We agreed the reviewer's comments, which the cloud signals are not used to derive UVAI and the cloud is more often used in IR. To clarify the manuscript for describing the purpose of aerosol/cloud retrieval in UV, we rephrased and modified the overall of introduction section. Detailed modification points are marked in blue-color in the revised manuscript. The first half of Introduction section is simply written to the literature studies of aerosol/cloud retrieval algorithms in the revised manuscript.

l. 78-80. and because of the generally much smaller signal from aerosols compared to clouds.

Ans) Thank you for your comments. During the revision, we removed sentences in the revised manuscript.

2. AEH retrieval algorithm

Main comments:

* Please, introduce the AEH here. Only a reference is given to the paper by Park et al (2016). The reader should have some knowledge of the subject of the current paper, without having to search for other papers.

Ans) Thank you for your comments. For the readability, the introduction of AEH is shown in Introduction section in lines 87-98 in the revised manuscript (instead of beginning of Section 2). During the revision, we include why we adopted the representative aerosol vertical distribution parameter from passive remote sensing satellites.

"However, the vertical distribution of aerosol is difficult to assess because of its large spatio-temporal variability. Although the Cloud-Aerosol Lidar with Orthogonal Polarization (CALIOP) provided the aerosol vertical distribution with high vertical resolution (Omar et al., 2009), other satellites for passive sensors are only able to estimate the representative parameter of aerosol height. Veihelmann et al. (2007) showed that the number of degrees of freedom of signal for aerosol is 2~4 for most of satellite observation conditions by the ozone monitoring instrument (OMI). It means that the number of information for aerosol vertical distribution have a limitation. Because of limitation for describing the aerosol vertical information, aerosol layer height (ALH) (Nanda et al., 2018) or aerosol effective height (AEH) (Park et al., 2016) were defined to retrieve the aerosol vertical information from the passive satellite sensors."

* A GEMS instrumentation and data section is missing.

Ans) In the revised manuscript, we added the detailed specification of GEMS in lines 146-154 in the revised manuscript as:

"The GEMS is onboard the Geostationary Korea multipurpose satellite 2B (GK2B) as orbiting at 128.2^{o}E, and scans from 145^{o}E to 75^{o}E with north-south coverage of 5^{o}S~45^{o}N. The GK2B observation schedule shares the GEMS and the Geostationary Ocean Color Imager 2 (GOCI2). For this reason, the GEMS scan the 30 minutes duration from every hour from 45 minutes to 15 minutes during daytime. The standard spatial resolution of GEMS is 7 × 8 km. The spectral resolution and sampling are respectively 0.6 nm with full-width and half-maximum (FWHM) and 0.2 nm with spectral range of 300~500 nm."

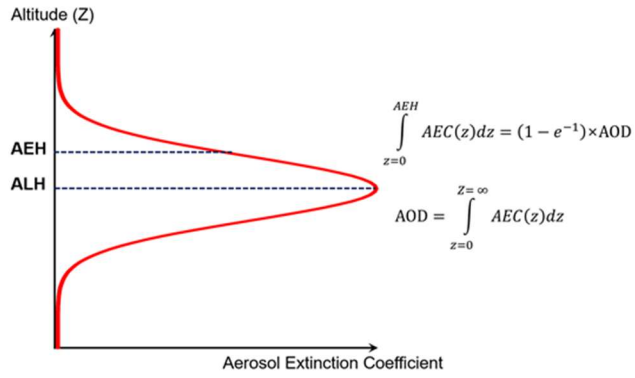
* A product description is missing. Please, provide some guidance with the presented flowchart.

Ans) We agreed the reviewer's comment. We modified Figure 2, and the explanation of flowchart is modified in lines 158-179 in the revised manuscript. During the revision, we added and modified descriptions of retrieval algorithm used to the input parameters.

l. 122: The AEH is apparently something with (1-1/e)* AOD. Please, give a definiition and/or derivation of the product.

Ans) In the revised manuscript, we added the definition of products with adding the Figure 1.

"Detailed description of AEH and other aerosol vertical parameters are shown in Figure 1."



l. 121: "(...) the aerosol vertical layer parameter, which represents the highest altitudes with existing effective aerosol extinction sensitivity." Please, rephrase. This sentence has no meaning. Which "highest altitudes"? What "existing sensitivity"?

Ans) During the revision, we removed sentences.

l. 125: specify the GDF and the FWHM of the assumed aerosol layer profile.

Ans) We specify the aerosol vertical distribution in lines 127-136 in the revised manuscript.

" In this study, the AEH product from GEMS is defined as the height with aerosol extinction integrated from the surface of (1-exp-1) × AOD, and a detailed definition of AEH was introduced by Park et al. (2016). Numerous previous studies have used the aerosol top layer height (Kohkanovsky and Rozanov, 2010) or middle layer height (i.e. ALH) (e.g., Sanders et al., 2015; Nanda et al., 2020) as the aerosol vertical layer parameter. AEH is similar to the aerosol top layer height but with a slight bias. For AEH retrieval, the vertical distribution assumption is also important. The Gaussian Density Fitting (GDF) distribution, which is a modified Gaussian distribution structure, is assumed for AEH retrieval. The full-width at half-maximum (FWHM) of the aerosol layer is 1 km."

l. 135.: "Because the spectral coverage is limited to 300-500 nm, .." Does this refer to GEMS? Why is it limited?

Ans) As shown in lines 146-154 in the revised manuscript, we clarify that the GEMS spectral range is 300-500 nm. For this reason, the GEMS AEH algorithm used the O2-O2 absorption band at 477 nm.

l. 136 -140: repetition of information, merge with introduction.

Ans) During the revision, these sentences were moved and added sentences in Section 1 (lines 104-114).

l. 142: ".. considering THE aerosol types .." What aerosol types? This is not clear at this point. Please, provide a methods section, in which the aerosol models are introduced which are used by the algorithm. Merge with the information provided later on aerosol properties/LUT calcalutions.

Ans) Thank you for your comment. In the manuscript, aerosol types are defined parameters from L2AERAOD algorithm from GEMS. To clarify the aerosol type datasets, and detailed methodology to adopt the AEH calculation as an input parameter, we added sentences in lines 158-167 in the revised manuscript.

"The GEMS Level 2 aerosol operational algorithm (L2AERAOD) retrieves the aerosol index (AI) values for UV and visible wavelengths, as well as AOD and SSA with considering the aerosol types (National Institute of Environmental Research, 2020a). The aerosol types are defined as absorbing, non-absorbing, and dust types by using the classification methods based on the UV and visible AIs (e.g., Go et al., 2020). Park et al. (2016) noted that the error budget of AEH is significantly affected by uncertainty in AOD and SSA and by the misclassification of aerosol types, which is directly related to the optical property and size information. Main error sources for AEH retrieval can be obtained from the L2AERAOD results. Therefore, the L2AERAOD results for AOD and SSA at 550 nm were adopted as input data for aerosol properties."

In addition, we modified Table 3 and sentences in lines 222-230.

"O2-O2 SCD decreases with increasing AEH for all aerosol types and AOD (Park et al., 2016). The O2-O2 SCD sensitivity is enhanced at high AOD and absorbing dominant aerosol cases. In addition, the contrast of O2-O2 SCD is greater for absorbing dominant aerosols than non-absorbing aerosols. During the radiance passing through the aerosol layer, the absorbing dominant aerosol is more efficiently absorbed the radiance. For this reason, the effective optical path length is significantly shorter for absorbing aerosols. Based on the changes in sensitivity observed for optical path length, aerosol type (in particular in terms of SSA) and AOD are considered as input parameters for AEH retrieval."

l 143-144: Repetition of information. Merge with an accuracy assessment section.

Ans) We added sentences related to the accuracy in lines 108-112 in the revised manuscript as:

"Park et al. (2016) conducted theoretical sensitivity testing of AEH retrieval using solely the O2-O2 absorption band along with aerosol and surface properties. Overall, the sensitivity of AEH retrieval was strongly affected by SSA, AOD, and aerosol types including optical and size properties, and the error budget for AEH retrieval using the O2-O2 band was 739 ~ 1276 m."

In addition, sentences for essential input parameters are added in lines 162-167.

"Park et al. (2016) noted that the error budget of AEH is significantly affected by uncertainty in AOD and SSA and by the misclassification of aerosol types, which is directly related to the optical property and size information. Main error sources for AEH retrieval can be obtained from the L2AERAOD results. Therefore, the L2AERAOD results for AOD and SSA at 550 nm were adopted as input data for aerosol properties."

l. 151: "long-term GEMS (...) data." What do you mean with long-term? Be specific, if this is relevant at all.

Ans) We agreed that the 'long-term' is not adequate in this sentence. To specify the temporal scale of GEMS data for surface reflectance, we modified the sentence in lines 168-172 in the revised manuscript.

"Although L2AERAOD retrieved their own surface reflectance for accurate separation of surface signals from total reflectance at the top of the atmosphere (TOA), the standard product for surface reflectance (L2SFC) (National Institute of Environmental Research, 2020b) was also independently retrieved from GEMS radiance/irradiance data with specific temporal periods."

l. 167: "From Nanda (...) retrieval." This is irrelevant information in this section. Please, restructure the manuscript to describe the AEH, ALH and the different tests and analyses seprately.

Ans) During the revision, we removed this sentence. In addition, we reconstruct the manuscript to describe the AEH and ALH including the definition as shown in Figure 1.

l. 174-176: Merge this with the actual description of the LUT on page 10.

Ans) Detailed setting of DOAS fitting is important and it is independent process from the LUT calculation to convert from O2-O2 SCD to AEH. Instead of merging the description, therefore, detailed setting description for DOAS fitting is added in lines 188-194 in the revised manuscript as:

"For the O2-O2 SCD estimation at 477 nm, the fitting window is ranged from 460 to 486 nm to cover the full absorption structure of O2-O2. Within the fitting window, the absorption is significantly affected by the absorptions of NO2 and O3. To describe these two absorption materials, temperature dependent

cross section information are adopted. The temperature dependent cross section setting considers the stratosphere and troposphere, simultaneously."

l. 181: "Observed radiance fitting is affected by noise signals during radiance observation." I do not understand what this sentence means. Please, rephrase.

Table 2: It is unclear what is fitted. Please, describe the test and/or the polynomilas and their meaning and the test results.

page 9: Somehow during the description of the AEH algorithm we have entered some fitting testing. It is unclear what the reason and the outcome is. Please, provide an overview of this test, if relevant, and quantatative results.

l184-185: "Although the fitting quality was good overall, the setting with the smallest error was used in this study." I surely hope so! Howveer, as mentioned, the test and results are unclear. Pleasew, remove this statement and provide more useful information.

Answer to above 4 comments) The DOAS fitting quality is one of important factor of AEH retrieval algorithm in this study. For this reason, checking the fitting quality is essential result in this study. To clarify and explain the details of Table 2, we modified the paragraph in lines 199-207 in the revised manuscript as:

"To minimize the noise effect and improve fitting quality, the optimal settings for fitting were also analyzed. Table 2 shows ratios of SCD error to the SCD for various polynomial and bias orders from observed radiance. The polynomial and offset are basic fitting parameters for the DOAS fitting. Both two parameters describe the broadband spectral feature of radiance. The ratio between SCD error and the SCD of O2-O2 is important to determine the AEH retrieval quality. When the fitting error increase, the uncertainty of AEH is also enhanced during the retrieval. Although the fitting quality was good overall, the setting with 2nd order of polynomial and none offset was used for the O2-O2 SCD estimation from the GEMS radiance due to the smallest fitting error."

In the modified paragraph, we also include the purpose of observed radiance fitting test.

The original sentence of "Observed radiance fitting is affected…" is removed in the revised manuscript.

l. 192-197. This information is not about the LUT. Please, put it in a more appropriate section.

Ans) We removed this sentence, and we modified and clarified the description of LUT in the revised manuscript.

l. 201 and 203: Please rephrase the following:

"Thick aerosols"

"the effective scattering layer penetrates more deeply ..."

"dominant aerosols"

Ans) During the revision, we modified the qualitative description.

l. 206: How significantly? This is useless information, please quantify.

Ans) To clarify the information, we modified sentences in lines 224-230 in the revised manuscript as:

"In addition, the contrast of O2-O2 SCD is greater for absorbing dominant aerosols than non-absorbing aerosols. During the radiance passing through the aerosol layer, the absorbing dominant aerosol is more efficiently absorbed the radiance. For this reason, the effective optical path length is significantly shorter for absorbing aerosols. Based on the changes in sensitivity observed for optical path length, aerosol type (in particular in terms of SSA) and AOD are considered as input parameters for AEH retrieval."

Table 3: Please, provide the real part of the refractive index as well for the various aerosol models, and I suggest to add a separate section on aerosol models used.

Ans) We added the real part of the refractive index for respective aerosol types in Table 3.

l. 216: "...(AER_LH) retrieves vertically localized aerosol layers in free troposphere .." This is not true. Do you mean in cloud free scenes?

Ans) After we checked the reference of de Graaf et al. (2022), the description of AER_LH product from TROPOMI retrieves the localized aerosol layer height information. To clarify the considering the cloud free scenes, we modified the sentence in lines 239-242 in the revised manuscript as:

"The aerosol layer height product from TROPOMI (AER_LH) retrieves vertically localized aerosol layers in free troposphere with cloud free condition by using the level 1b earth radiance measurements from 758 to 770 nm (de Graaf et al., 2022)."

l. 218-219: "Spectral fit estimation of reflectance around the O2-A band is based on a neural network for the forward model calculation." This is not true. The spectral fit is the optimal estimation of the retrieval part, mentioned in l. 220. The forward model consists of a simulated spectrum provided by the neural network.

Ans) Thank you for your comment. To describe the spectral fitting both forward and inverse methods independently, we modified sentences in lines 243-247 in the revised manuscript.

"Spectral fit estimation of reflectance around the O2-A band is based on a neural network for the forward model calculation for simulated condition. After cloud masking to avoid the cloud affected pixels, an optimal estimation method was used to retrieve the aerosol layer height parameters for the inversion method from observation."

l. 221-223: "During the radiance fitting, AOD is also used as the main fitting parameter, but other aerosol parameters, such as SSA and scattering phase function, are assumed to be fixed values (Nanda et al., 2020)." ALH and AOD are (currently the only) fitted parameters, the aerosol model is assumed (SSA, g and aerosol layer thickness are fixed).

Ans) We modified the sentence in lines 247-250 in the revised manuscript as:

"During the radiance fitting, the ALH and AOD are fitted parameters, but other aerosol parameters, such as SSA, layer thickness, and scattering phase function, are assumed to be fixed values (Nanda et al., 2020)."

l. 241-242 "(..) layer height parameter is estimated by using the vertical profile of extinction coefficient at 532 nm. ". How is this done? Do you calculate an effective height? How? Or use the top and bottom aerosol layer products? Please, specify.

Ans) Yes. We calculated the AEH, directly. The CALIOP Aerosol Profile product (APro) provides the vertical distribution of aerosol extinction coefficient at 532 nm with fine vertical resolution. By vertical integration of aerosol extinction coefficient, we can calculate the AOD at 532 nm, and aerosol vertical parameters (AEH and ALH). To clarify the process of AEH calculation from the CALIOP, we added the sentence in lines 266-268 in the revised manuscript.

"Representative layer height parameters (ALH and AEH) are directly estimated by using the vertical profile of aerosol extinction coefficient at 532 nm."

l. 248. "Based on the retrieval sensitivity of AEH (...)". Which sensitivity? Please, show this in this paper, or repeat the conclusions from another.

Ans) We modified the sentence in lines 274-276 in the revised manuscript as:

"From Park et al. (2016), thin AOD pixels have large AEH uncertainty due to weak aerosol scattering information. For this reason, only AEH retrieval results with AOD greater than 0.3 are shown in this study."

l. 255: "Although the AOD and SSA for these plumes are differed significantly, their AEH results were similar. " Improper English, please rephrase. Why would you assume a correlation?

Ans) Thank you for your comment. This sentence can be misreading. To clarify the explanation of case result, we modified the sentence in lines 281-283 in the revised manuscript as:

"Although the AOD and SSA for these plumes are differed significantly, the retrieved AEH results from these different plumes show similar ranges. For both plumes, AEH shows around 1.0~2.0 km in this case."

l. 256. " (...) the retrieved AEH values exhibited insignificant diurnal variation (..)"
What is insignificant? Can you show this in e.g. a line plot?

Ans) Thank you for your comment. This sentence is inadequate. For this reason, we removed the sentence in the revised manuscript.

Figure 2: These small plots are not readable. Please, device a better way to show the case, it's diurnal variation and the correlations you try to show. 21 plots just won't do it. The caption is insufficient

Ans) In the main text, these figures cannot be size up. We added the original figure files by the supplements.

l. 266: "siginficant". What does this mean?

Ans) To clarify the mean of "significant" in the original sentence, we modified and added sentences in lines 291-294 in the revised manuscript as:

"Therefore, the aerosol plume with high AOD and low SSA (high absorbing) was a result that actually exists, and it was not a result with high uncertainty due to edge of GEMS observation field. Except for the inland parts of India, AEH in high AOD pixels ranged from 1.5 to 3.5 km."

l. 267: Please rephrase the following:
"severe aerosol plumes"
"AEH was stably estimated"

Ans) We removed phrases.

and l. 279.

"larger aerosol heights"

Ans) The sentence is modified in lines 303-305.

"Given the difference in definition for the aerosol height parameters between ALH and AEH, relatively high height values were retrieved from GEMS compared to TROPOMI."

l. 280-281: "In an ideal case, the AEH from GEMS was overestimated by around 0.5 km relative to the ALH from TROPOMI, (..). Why in an ideal case? What is overestimated? Do you mean the altitude was higher?

Ans) To clarify the difference of definition between ALH and AEH, we added the Figure 1 and related explanations. Based on this description, we also modified and added sentences in 305-311 in the revised manuscript as:

"In an ideal case under symmetric gaussian distribution with a width of 1 km, the AEH from GEMS was around 0.5 km higher than the peak height of aerosol layer. The ALH expresses the center (or peak) height, thus, the AEH from GEMS was overestimated by around 0.5 km relative to the ALH from TROPOMI. Although AEH had higher values than ALH from TROPOMI, the GEMS AEH retrievals for the dust transport case study were successfully retrieved and mostly shown the expected uncertainty of 1 km."

l. 278-284. Place in a discussion section and elaborate.

Ans) During the revision and modifying sentences, details of explanation are added for case study. For this reason, we decided that these sentences are not changed to the section.

l. 283-284. "(...) the GEMS AEH retrievals for the dust transport case study were good." Why? What is good? Please, quantify.

Ans) Thank you for your comment. We agreed the reviewer's suggestion, and we removed the sentence in the revised manuscript.

l. 285-286: "Furthermore, the retrieval area covered by GEMS is larger than by TROPOMI, as demonstrated by a comparison of Figures 2 and 3.". The shown area in Figs 2 and 3 are equal, so this is not demonstrated from comparing the figures. Rephrase.

Ans) To clarify the paragraph, we modified sentences in lines 312-318 in the revised manuscript as:

"Furthermore, the AEH retrieved pixels covered by GEMS is larger than by TROPOMI, as demonstrated by a comparison of Figures 3 and 4. In East Asia, AEH from GEMS estimated a continuous dust plume from China to South Korea. In addition, the GEMS retrieval more widely estimated aerosol height information in coastal India compared to TROPOMI. Although high AEH values were retrieved for low AOD regions over low latitude ocean surface, the AEH from GEMS was successfully retrieved over the area of interest for the case study."

l. 289. What does "greater aerosol height information" mean?

Ans) This expression is inadequate. Therefore, we removed the phrase and rephrase sentences in the revised manuscript.

l. 289-291: "Although high height values were retrieved for clear-sky regions, in particular low latitude ocean regions, the AEH from GEMS was successfully retrieved over the area of interest for the case study.". Even after three tries, I fail to understand this sentence. Please, rephrase.

Ans) Due to the weak sensitivity of aerosol height signal at the low AOD pixels, some low AOD pixels shows the unrealistic AEH values. To clarify this phenomenon, we modified the sentence in lines 316-318 in the revised manuscript

"Although high AEH values were retrieved for low AOD regions over low latitude ocean surface, the AEH from GEMS was successfully retrieved over the area of interest for the case study."

l. 311-321. This paragraph discusses Fig 4b., but it starts with the sentence on Fig 4a. Elaborate on Fig 4a, because it is not further described. Then describe Fig 4b in another paragraph.

Ans) In the revised manuscript, we modified and reconstruct the paragraphs to describe Figure 4a and 4b, respectively.

l. 317-319. If surface reflectance is retrieved, why use a LER? Why mention this?

l. 319-321. What is the impact? If you mention this, then you should either explain why a LER is used and quantify the error/uncertainty, or use the surface reflectance.

Answer to above 2 comments) In this study, we have limitation to use the L2SFC product. Instead of using the L2SFC product, we use the surface reflectance information based on the minimum reflectance method. To describe this point, we modified sentences in lines 345-350 in the revised manuscript as:

"Because AEH from GEMS uses only the O2-O2 absorption band, the accuracy of AEH is sensitive to uncertainty in surface reflectance and AOD. Recently, GEMS accurately estimated surface reflectance in near real time in operation. However, this study used the minimum reflectance under the Lambertian assumption to retrieve AOD and AEH to coincide with the use of surface information on L2AERAOD and AEH retrieval."

l. 329. "To correct the inconsistency of definition, (...)". What correction has been applied?

l. 330. "After correction, ". What correction?

Answer to above 2 comments) We removed this sentences in the revised manuscript. Instead, we added the detailed definition difference between ALH and AEH in the revised manuscript (Figure 1 and related sentences).

Figure 5. Same as Fig2: decrease the number of panels and device a cleverer way of presenting the results, 21 panels are not readable.

Ans) Same as Figure 2, We added the original figure files by the supplements.

l. 351. "(...) the GEMS (..) AEH can be used in several application studies.". What studies? How? Please, remove a vague commentary and be explicit in what you mean.

Ans) We removed it.

l. 378-397. should go into a discussion section and be removed from the results section.

Ans) We agreed reviewer's suggestion. However, these paragraphs explain and analyze the Figure 9. For this reason, we modified the paragraph in lines 408-420 in the revised manuscript as:

"Because of uncertainty in GEMS operational products, AEH from GEMS exhibits large variability. Although L2AERAOD from GEMS retrieved the AOD, SSA, and aerosol types, the retrieved results from L2AERAOD include significant uncertainty. Go et al. (2020) noted that the UV aerosol retrieval algorithm, which is the basic method to the L2AERAOD algorithm, has significant discrepancies for both AOD and SSA compared to ground-based data. In addition, significant fitting error perturbs the fitting signals and tends to result in the underestimation of SCD. Although the fitting error of O2-O2 SCD from GEMS radiance was minimized, the fitting error is still remained around 6%, as indicated in Table 2. The discrepancy in fitting condition between the simulated and observed radiance biased the SCD estimation, which in turn led to bias and variation in the AEH retrieval. Combined with the high sensitivity of AEH errors to aerosol optical properties, uncertainty arising from L2AERAOD causes significant variability in AEH."

In addition, parts of sentences are moved to discussion section in lines 581-585.

"Although several fields of study may apply the AEH retrieval results, retrieval uncertainty in AEH remains due to the uncertainty of retrieved AOD and SSA. In addition, the uncertainty in surface reflectance and the discrepancy in O2-O2 SCD values between the simulation results and observations can be affected to the potential error sources of AEH from GEMS."

l. 381-382. "Although L2AERAOD accurately retrieved the optical and physical properties of aerosols (...)". Improper English, please rephrase.

Ans) We rephrase the sentence in lines 409-411 in the revised manuscript.

"Although L2AERAOD from GEMS retrieved the AOD, SSA, and aerosol types, the retrieved results from L2AERAOD include significant uncertainty."

l. 385. "has significant root mean square errors ". What does that mean? Please, rephrase.

Ans) We rephrase the sentence in lines 411-413 in the revised manuscript.

"Go et al. (2020) noted that the UV aerosol retrieval algorithm, which is the basic method to the L2AERAOD algorithm, has significant discrepancies for both AOD and SSA compared to ground-based data."

l. 388. Quantify "significantly".

Ans) We removed it.

Figure 9. Caption is not complete. Specify the boxes, line and bars.

Ans) We modified the caption.
"Figure 10. AEH difference between CALIOP and GEMS with respect to ranges of (a) AOD and (b) AI obtained from GEMS from January 1 to June 30, 2021 (line and error bar is the mean and standard deviation of AEH difference, and the box is number of data)."

l. 439. "TROPOMI is limited to retrieving the ALH over scattering-dominant aerosols". This is difficult to understand and I think it is untrue (although I'm not sure what it mneans). The ALH v1 that was used in Nanda et al (2020) was retrieved only in cloud-free scenes with UVAI>1, so for absorbing aerosol only.

Ans) Thank you for your comment. We modified the description more directly in lines 463-465 in the revised manuscript as:

"Nanda et al. (2020) showed that the operational algorithm of TROPOMI is only retrieved the ALH over absorbing dominant aerosol pixels."

l. 440-441. "Griffin et al. (2020) reported that the small absorbing AI pixels are identified with small QA values in the offline product of ALH.". Please rephrase. There are no small pixels. You probably mean something like: "pixels with low UVAI values are identified by a QA value lower than .. (O.5?)". But this is not true, because low UVAI values are identified by low UVAi values. Please, explain what you actually mean.

Ans) Thank you for your comment. We change the description of Griffin et al. (2020) in lines 465-467 in the revised manuscript as:

"In addition, Griffin et al. (2020) reported that the pixels with small positive UVAI (weak absorbing cases) pixels are identified with small QA values in the offline product of ALH."

l. 452-454. If this is true, then the reason for passive sensors to have a smaller variability needs to be explained, because I don't see it.

Ans) This sentence means that the standard deviation from the intercomaprison of (GEMS-TROPOMI, ~0.8 km) is smaller than that from the intercomparison of (GEMS-CALIOP, ~1.4 km), and the reason is due to including the assumption of aerosol vertical distribution both in GEMS and TROPOMI. To clarify this point, we modified the sentence in lines 478-479 in the revised manuscript.

"It is because both TROPOMI and GEMS are passive sensors that use similar retrieval methods for oxygen absorption bands."

l. 557. "driving large deviations in some pixels". What does that mean?

Ans) we removed this phrase.

Minor comments:

l. 74. Oxygen-related absorption bands-> oxygen absoprtion bands

Ans) We modified it.

l. 78. add a reference to Xi et al, 2021, who combined O2-A and O2-B for the retrieval of ALH from TROPOMI.

Ans) We modified the sentence in lines 76-81 in the revised manuscript as:

"Similarly, the aerosol vertical distribution can be estimated using the oxygen absorption bands, such as the O2-O2 (Park et al., 2016; Chimot et al., 2017; Choi et al., 2019, 2020), O2-A (Dubisson et al., 2009; Geddes and Boesch, 2015; Sanders et al., 2015; Zeng et al., 2020), and O2-B (Ding et al., 2016) bands, as well as combinations of these bands (Sanghavi et al., 2012; Chen et al., 2021)."

In addition, Xi et al. (2021) is same reference as mentioned by Chen et al. (2021). We considered the reference by referring Chen et al. (2021) in the revised manuscript.

l. 79-80. as the optical properties of aerosols in the atmosphere differ among aerosol types -> because of varying aerosol properties.

Ans) We removed this sentence during the revision.

l. 87-90. ... and implemented the algorithm operationally.

Ans) We modified it.

l. 95-96. What is 'the standard product of aerosol'? Please, rephrase.

Ans) We removed this sentence during the revision.

l. 153: "To consider the various retrieval products, the L2SFC retrieves .." Please, rephrase. L2FSC does not do something in consideration of products.

Ans) We removed this sentence during the revision.

l. 158-159: "However, L2SFC accurately retrieved surface optical properties with high spatial resolution." Please, rephrase this vague statement. What is "high"? What is "accurate"?

Ans) We removed this sentence during the revision.

l. 172-174. Remove this unnecessary sentence.

Ans) We modified it.

l. 213. The TROPOMI is spectrometer -> TROPOMI is a spectrometer

Ans) We modified it.

l. 215. crossing to equator -> crossing the equator

Ans) We modified it.

l. 230. lidar sensor -> lidar

Ans) We modified it.

l. 234-236. "This sensor is Sun synchronous orbit constellated to the A-train, and also cross to equator at 13:30 local time by ascending node." Improper English. Please, rephrase.

Ans) We modified to the sentence in lines 260-262 in the revised manuscript as:

"The orbit for CALIPSO is Sun synchronous orbit constellated to the A-train with ascending node, and also crosses to the equator at 13:30 local time."

l. 240. "Because the aerosol profile product exists the vertical distribution of aerosol extinction coefficient, ... " Improper English. Please, rephrase.

Ans) We modified to the sentence in lines 266-268 in the revised manuscript as:

"Representative layer height parameters (ALH and AEH) are directly estimated by using the vertical profile of aerosol extinction coefficient at 532 nm."

Figure 3: What is the unit of the colorbar?

Ans) We added the unit of the colorbar in the caption in Figures 4 and 7 in the revised manuscript.

l. 276-277. Place this under the TROPOMI data section.

Ans) We modified it.

l. 360. ". most" -> ", most"

Ans) We modified it.

l. 362. "the AI value for UV" -> UVAI

Ans) We modified it.

l. 437. " scattering dominant aerosols". There is not such a thing as a dominant aerosol. The authors define "Scattering-dominant" as non-absorbing, but I suggest not to introduce these kind a strange wording. Just stick to absorbing or non-absorbing and better yet give the SSA as done here and leave it at that.

Ans) We agreed the reviewer's suggestion. We modified from "scattering dominant" to "non-absorbing" in the revised manuscript.

References

Xi Chen, et al., First retrieval of absorbing aerosol height over dark target using TROPOMI Oxygen B band: algorithm development and application for surface particulate matter estimates , Remote Sens. Env., doi: 10.1016/j.rse.2021.112674 2021.

Ans) We checked and this reference existed in the original manuscript.