Response to Reviewer#1

The manuscript has been revised considerably, which is appreciated. The results from GEMS are scientifically very interesting, because they add valuable temporal information of aerosol vertical distrubution which is not currently available from other instruments, and therefore the results are important. However, the manuscript should be edited for English, because many paragraphs are still difficult to read, even after the suggestions of the two reviewers in the first round. Also, suggestions have not been followed throughout, e.g. it was made clear that an satellite passes THE equator, not TO the equator. Yet, this was corrected for S5P only, not for CALIPSO. Similarly, suggestions to remove and quantify vague statements like "significantly" have been made at some places but many remain. The figures with 21 panels are unchanged, etc. I feel some more effort is needed to improve the readability.

Ans) Thank you for the review and comments for improving the manuscript. We revised the manuscript based on reviewers' suggestions. In addition, we also considered the readability of manuscript, such as English correction and changing the figure design. Detailed of the revised points are listed as below.

The main criticism is that it is still not clear what physical quantities are compared. AEH is defined for GEMS, but the manuscript states that "representative" AEH and ALH parameters from CALIOP were estimated, it is not mentioned how. ALH can be defined as SUM(ext * z) / SUM(z) or aerosol layer (bottom+top)/2, both available from CALIOP. The first has a direct relationship with AEH, but for the latter the relationship can be quite obscure for multiple layers and distinct non-Gaussian profiles. TROPOMI AER_LH is defined in similar terms, aerosol layer (top+bottom)/2, and the authors state that the comparison between AEH and ALH was "corrected" to minimum the bias. The correction is not given and there is not a bias but a comparison of different quantities. The ALH should be compared to ALH and AEH to AEh for all comparisons. It should be clear which definitions are used at all times.

Ans) Many thanks to the physical quantities of the aerosol vertical parameters. Because the GEMS retrieves the AEH amount, definition of aerosol vertical parameter is different as compared to the TROPOMI product. To clarify the difference of definitions between AEH and ALH, we added the Figure 1 in the revised manuscript and also added the related paragraph to explain the AEH and ALH definitions. We know that the ALH and AEH (which are retrieved from passive sensors) have limitation to consider the various aerosol vertical structure, such as multiple layer or non-Gaussian profile shapes. However, the AEH and ALH have assumption of aerosol vertical distribution to simplify and identify the simulated radiance (or simulated slant column density of O2-O2) for the retrieval. So, the correction from AEH to ALH is not exact. However, for the comparison between AEH and ALH, we have to consider the difference of definitions. For the GEMS AEH retrieval, the simulation assumed to the theoretical aerosol vertical distribution as the Gaussian distribution with 1.0 km of FWHM. Based on this assumption, the AEH and ALH difference is around 0.5 km. For this reason, we adopted this correction value during the intercomparison. However, in real, the height difference between AEH and ALH will be varied as changing to the aerosol vertical distribution. We mentioned the lines 400-403 in the revised manuscript.

More suggestions are given below:

L55 The manuscript still states that that cloud signals are detected using the UVAI. This is not true and certainly not in one of the mentioned references. In the response to reviewer 2 it is first stated that this

would be changed, but it is mentioned still.

Ans) As the reviewer knows, the UVAI is used as the absorbing aerosol detection. However, some previous studies investigated the scattering radiative index to detect the scattering dominant materials (such as scattering dominant aerosols and cloud). To include the various previous studies for the scattering material detection based on the environmental satellite sensors, we mentioned both UVAI and scattering radiative index in the Introduction section. To clarify the paragraph, we revised in lines 59-72 in the revised manuscript as

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

For the quantitative estimation, measurements of aerosol optical depth (AOD) and radiative cloud fraction have also been retrieved from pixel-based radiance data in UV-visible wavelength range. Recently, various aerosol retrieval algorithms have been developed in order to be applied in passive satellite sensors. These algorithms focus on improved trace gas retrieval as well as direct monitoring of aerosol properties, such as AOD and single scattering albedo (SSA) (e.g., Ahn et al., 2014; Kim et al., 2020; Torres et al., 2020)."

Figure 2. A description of the flowchart was requested. However, the manuscript was extended with the paraghraph 158-179 according to the response, but there is no mention of Figure 2 anywhere in the manuscript. The flowchart is still unreadable. Why?

Ans) Thank you for your comment. We re-checked and re-described the Figure 2. In addition, the description of Figure 2 is added in the revised manuscript.

Table 2 and the description of the fitting are still unclear for me. It may be common for DOAS retrievals, but I can't judge whether the description makes any sense.

Ans) Thank you for your comment. For the DOAS retrieval, detailed DOAS setting is important. For this reason, the manuscript showed the Table 1 for the detailed setting of DOAS fitting. In addition, the fitting of O2-O2 is relatively broadband structure as compared to other gas absorption structure. Therefore, the performance of O2-O2 SCD fitting by changing the polynomial setting for the assumption of spectrally broadband extinction structure is also important. To describe the appropriate setting for this study, we included the Table 2. Detailed explanation of Table 2 shows in lines 309-318 in the revised manuscript.

281-283. "Although the AOD and SSA for these plumes are differed significantly, the retrieved AEH results from these different plumes show similar ranges."

(1)The improper English is in this part: "are differed significantly", please rephrase, and remove significantly also in this case

(2) I still don't understand why a correlation is assumed here.

Ans) Thank you for your comment. These sentences are confusing. To clarify the explanation of this case, we revised these sentences in lines 377-379 in the revised manuscript as:

“Retrieved AEH results from these different plumes show similar ranges. For both detected plumes, the AEH shows similar pattern ranging between 1.0 to 2.0 km in this case.”

l 90. "other satellite for passive sensors" -> Do you mean: "other passive satellite sensors"?

Ans) We revised to the reviewer’s suggestion.

l93-94 "It means that the number of information for aerosol vertical distribution have a limitation." -> "It means that the number of information for aerosol vertical distribution has a limitation for OMI". What about other instruments?
Ans) We added the sentences in lines 99-102 in the revised manuscript. These sentences include the number of information for aerosol vertical distribution about other instrument

“In addition, the number of degrees of freedom is not exceeded to 3 from the shortwave satellite measurements (e.g., Rao et al., 2019; Choi et al., 2021). It means that the amount of information for aerosol vertical distribution has a limitation for satellite sensor.”

l 106 remove either "in addition" or "additionally"

Ans) We revised it.

L 126. "AEH is a layer height parameter that considers the penetration of photons into the aerosol layer." I would think the AEH considers the penetration of photons into the atmosphere. But to be honest, the definition of AEH is strange to me and this statement may actually be right. However, it must be understood that the ALH considers the penetration height of photons in the atmosphere, so then the relationship between AEH and ALH becomes obscure for any vertical aerosol distribution that is non-Gaussian and not integrated from the surface to the top of the atmosphere.
Ans) Thank you for your comment. We know that both ALH and AEH consider the penetration of photon into the aerosol layer. However, due to the definition difference between ALH and AEH, the difference of height value between ALH and AEH has sensitivity by aerosol vertical distribution. For the clarify the difference between ALH and AEH, we added the Figure 1 and definitions of aerosol vertical parameters are revised in lines 252-269. In Figure 1, the idealized Gaussian profile have constant difference between ALH and AEH. However, as widening the aerosol layer, the AEH and ALH difference increases. Similarly, aerosol vertical distribution shape is also affected to the uncertainty of aerosol vertical parameters, including difference of ALH and AEH.

L150 Remove "For this reason"
Ans) We revised it.

L. 166 "Main error sources for AEH retrieval can be obtained from the L2AERAOD results." This would be very useful, but I don't think you can get the error sources for the AEH from the AOD results. Do the authors mean that they can calculate AEH errors using the AOD product as input?

Ans) The sentence is confused to read. We intend that the AEH retrieval is largely influenced by the AOD and SSA. So, we adopted these values from the L2AERAOD result. To clarify the meaning of sentence, we revised to lines 151-154 in the revised manuscript.

“The main variables causing errors for AEH retrieval can be obtained from the L2AERAOD results. Therefore, the L2AERAOD results for AOD at 550 nm and SSA at 443 nm were adopted as input data for aerosol properties.”

L 224 - 226. Aerosols are still called "dominant" here, please rephrase.As a minimum, change "absorbing dominant aerosol" to 'absorbing-dominant aerosol", but I would prefer to simply write "absorbing aerosols" since you also simple refer to scattering aerosols as "non-absorbing aerosols". Please, also rephrase "is more efficiently absorbed the radiance."
Ans) We revised it.

L 253: Resolution of TROPOMI AER_LH is 3.5x5.5 km^2
Ans) We revised it.

L 261 It was suggested to change "crossing to equator" into "crossing the equator". This also holds for the second time this term was used improperly. Please, rephrase this wrong sentence: "crosses to the equator".
Ans) We revised it.

L 263-264: Please rephrase: "..the pixel data can retrieve with extremely high horizontal and vertical resolutions .."
Ans) We revised it.

Figures 3 and 6 still cannot be read. As mentioned before, a figure with 21 panels will just not do. Why not add them in the supplement or make a movie out of them in the supplement, and show here two times that align with the TROPOMI and CALIOP overpasses?
Ans) We revised the figures. The Figures 3 and 6 are revised to show the hourly AEH distribution only. Remained figures (hourly plots of AOD and SSA) are moved to supplement figures (Figures S1 and S2) in the revised manuscript.

L 310 "the GEMS AEH were (...) mostly shown the the expected uncertainty of 1 km". How was this shown then?

Ans) As reviewer’s suggestion, the expected uncertainty is not clarified. For this reason, we revised the sentences in lines 400-405 in the revised manuscript.

“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.”

L. 316-318. "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." Please, rephrase this sentence, it is completely unclear.

Ans) During the revision, we updated to the TROPOMI ALH V2.04 result for the intercomparison. The TROPOMI ALH V2.04 is improved to the retrieved area. For this reason, we deleted this sentence and

this paragraph in the revised manuscript.

L. 361. " To correct the inconsistency of definition between ALH and AEH, the difference between two retrieval results decreased to 0.5 km bias. " What is the correction? I think apples and pears are compared here. The proper comparison is AEH and AEH or ALH and ALH. Please, compare the same physical quantities and change your analysis accordingly.

Ans) We agreed the reviewer's comment. The AEH and ALH is not exactly same definition and it is not able to direct comparison. To supplement this consideration, we revised in lines 431-436 in the revised manuscript.

"Based on the assumption of aerosol vertical distribution for AEH retrieval, the difference between AEH and center height of aerosol extinction profile is around 0.5 km. To consider the inconsistency of definition between ALH and AEH, the difference between two retrieval results decreased to 0.5 km bias. After consideration of definition inconsistency, the proportion of pixels within the expected error ranges of 1.0 km are enhanced to 76.4% and 36.7% over ocean and land, respectively."

L. 411-413 "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."
This sentence has no meaning ("significant" again) to a reader who cannot cite Go et al (2020) by heart. Please, state what the UVAI algorithm has to say about discrepancies between AOD and SSA from GEMS and ground-based measurement and why this is relevant here.

Ans) Thank you for your comment. To explain the details of AERAOD algorithm uncertainty, we revised in lines 500-502 in the revised manuscript.

"Go et al. (2020) reported that the root-mean square error (RMSE) of AOD between MODIS and OMI UV aerosol algorithm is 0.276~0.341."

L 421-428 is actaully interesting and useful information!

L. "For dust plumes over East Asia, AEH indicated significant aerosol vertical information and insignificant diurnal variation in regions with severe dust plumes. "
Significant and insignificant are complete meaningless. And you compare technical information ("good enough" height retrieval) with geophysical information (static dust plume). Please, rephrase.

Ans) Thank you for your comment. We carefully checked and revised the meaningless words for expressing comparison results in the revised manuscript.

L. 484-485. ". In addition, the difference in the definition of ALH from TROPOMI and AEH from GEMS impacted the comparison. " So, why did you not convert AEH to ALH?

L 556-558 "In addition, AEH from GEMS was overestimated compared to the TROPOMI ALH results

due to different definitions of ALH from TROPOMI and AEH from GEMS." Again, simply compare the same physical parameters and remove this statement.

Ans) We agreed reviewer's comment. However, the standard parameter of aerosol vertical information in GEMS is AEH. The AEH is upper than the peak height of aerosol layer. During the simulation test, the AEH has advantage of the stability for aerosol vertical distribution variation based on the radiative transfer model study. To supplement the definition discrepancy, we also included the AEH comparison between GEMS and CALIOP. To clarify the meaning of sentence, we revised the sentence in lines 645-648 in the revised manuscript.

"In addition, AEH from GEMS was overestimated compared to the TROPOMI ALH results. The overestimation is partially caused by different definitions of ALH from TROPOMI and AEH from GEMS."

Response to Reviewer#2

Most of my comments have been well addressed, but there are still some unclear parts of the manuscript requiring revision. The structures and presentation quality of the Introduction, Algorithm and Data and Method parts still need to be improved. The details are as follows:

Ans) Thank you for your comments. We tried to improve the structure and presentation quality of the manuscript during the revision.

1. Previous Comment 7: It is still unclear that what the principle and process of DOAS fitting are. Do the authors mean fit the O2-O2 SCD with GEMS observed radiance in the fitting window using polynomial function? What is the SCD error? What do none offset and 0th offset mean in Table 2?

Ans) Thank you for your comment. To clarify the principle and process of DOAS fitting, we revised the Section 3 in the revised manuscript. During the revision, we include the reference and brief theoretical basis of DOAS fitting. In addition, we added the previous studies of aerosol height retrieval by using the Oxygen-related gases from satellite remote sensing. Finally, we also added the importance and meaning of polynomial and SCD error in this study in the revised manuscript.

2. Line 204: It is mentioned that ”L2AERAOD results for AOD and SSA at 550 nm were adopted as input data for aerosol properties”, but in Table 3, the refractive index at 440 nm is used in the LUT. How do the authors convert the wavelength dependent refractive index or SSA and AOD?

Ans) Sorry for confusing the sentence. We modified the sentence in lines 152-154 in the revised manuscript.

“Therefore, the L2AERAOD results for AOD at 550 nm and SSA at 443 nm were adopted as input data for aerosol properties.”

3. I suggest to move the descriptions about how to collocate GEMS and CALIOP or TROPOMI data into an independent subsection in Section 3.

Ans) Thank you for your comment. For the reviewer’s suggestion, We reconstructed the manuscript.

Section 2 is the data section independently including the details of GEMS, TROPOMI and CALIOP, and data selection for the intercomparison. Section 3 is the explanation of details of AEH algorithm.

4. Previous Comment 13: I don’t think this comment is well addressed. 1) I don’t un- derstand why some collocated pixels are overlapped. Do the authors mean GEMS or CALIOP pixels? I think the normal way to collocate GEMS and CALIOP pixels is to use the averaged value of GEMS within pre-defined distance (such as 50 km used in this manuscript) or 10% closest pixels with the standard deviation as the error bar. Refer Chen et al., 2021. 2) Even though ”retrieval around the 2 km AEH from CALIOP is not from single plume regions”, why do the retrievals from GEMS differ so a lot?

Ans) Thank you for your comment. 1) For the intercomparison, some cases are overlapped during the collocation because the horizontal distance of adjoined pixels in CALIOP is very close. To avoid the overlap, we considered and used the average value of GEMS within 50 km or 10% closes pixels.

However, sometimes it still appears that. 2) Also, we rechecked the collocated intercomparison result in this case. During the AEH estimation from CALIOP, the vertical pixels are discrete (60 m resolution) and it retrieved same values in different plume regions. In addition, most of the collocated CALIOP pixels are small AOD values. In these pixels, the CALIOP retrieval results are horizontally and vertically smoothed. Although the AEH from GEMS has uncertainty, retrieved AEH from CALIOP around the 2 km is not located in specific region.

Response to Reviewer#3

General comments:

The reviewed paper entitled by "Retrieval Algorithm for Aerosol Effective Height from the Geostationary Environment Monitoring Spectrometer (GEMS) (Park et al., 2023)" introduces the newly developed GEMS aerosol effective height product and shows the initial results of aerosol vertical structure information. This is an interesting new product with a little heritage. Introduces and adds an important value in the community regarding the aerosol height retrieval from passive satellite sensors. This type of products are scarce and satellite instruments that monitor aerosol height are needed to constrain models. I suggest that the paper deserves to be published, but there are many unclear descriptions in the manuscript and the presentation quality, especially the English grammar and writing style needs to be improved. I leave this task to the co-authors and to the copy-editing service of AMT. I would appreciate the authors to address the comments below, before the final publication, as I believe they will help the readers.

Ans) Thank you for your comments. We added and revised based on the reviewers' comments in the manuscript during the revision process. Details of revision is listed below.

Abstract section. The bias value for CALIOP and GEMS comparison is not provided in the abstract, only the STD. Please add the statistic metric.

Ans) We added the statistical value including mean and standard deviation value in the abstract session.

Introduction section. A general message is missing in the introduction part to highlight the importance of having a product for the height of the aerosol layer. (e.g. "Height information for aerosols in the free troposphere is particularly important for aviation safety. Scientific applications include radiative forcing studies, long-range transport modelling and studies of cloud formation processes. Etc etc")

Ans) Thank you for your comment. In Introduction section, we added the importance of aerosol layer and aerosol products. We revised in lines 53-65 in the revised manuscript as:

'In addition, aerosol vertical information is also important information for the application. For example, aerosol height information in the free troposphere is particularly important for aviation safety by affecting the visibility. Also, scientific applications including radiative forcing studies, long-range transport modelling and studies of cloud formation processes have been used aerosol vertical information as an input parameter.

Environmental satellite sensors, in particular those that measure UV-visible wavelength range, have been used the UV aerosol index (UVAI) for aerosol detection (e.g., Buchard et al., 2015; Herman et al., 1997; Torres et al., 1998, 2002; Prospero et al., 2000; de Graaf et al., 2005). Furthermore, scattering radiative index values were investigated for the possibility of the cloud signal detection (Penning de Vries et al., 2009, 2015; Kooreman et al., 2020; Kim et al., 2018). However, these indices only have qualitative characteristics and limitations to identify aerosol amounts.'

Comments/ suggestions for TROPOMI/S5P section. Although the aerosol layer information by the environment satellite missions is limited, several previous studies were investigated including sensitivity results and methodologies. Provide findings of these works adding the relevant references.

Ans) Thank you for your comment. We include and remake the paragraph in lines 83-92 in the revised manuscript to explain the previous study of aerosol layer height retrieval.

Some specifics comments:

- What height does the TROPOMI ALH algorithm refer to? above ground (a.g.l) or above sea level (a.s.l)? Please clarify.

Ans) The ALH from TROPOMI is based on the height plume above sea level. We added the reference of TROPOMI ALH information in lines 178-179 in the revised manuscript as:
'The definition of ALH from TROPOMI is the optical centroid layer height of the plume above sea level.'

- Another point that has to be mentioned is the challenge of S5P to detect ALH over land due to surface albedo issues. I suggest providing a relevant reference about that.

Ans) We added the issues of TROPOMI ALH retrieval in lines 193-196 in the revised manuscript.
'From Michailidis et al. (2023), a mean bias of -0.51±0.77 and -2.27±1.17 km is estimated over ocean and land, respectively. In addition, the TROPOMI ALH product has strong dependence of the surface albedo, especial to the bright surfaces (Sanders et al., 2015).'

- Is there any limitation regarding the upper and lower limit (for pressure or height) of TROPOMI algorithm to retrieve the ALH product?

Ans) Thank you for your comment. From the reviewer's suggested reference of Michailidis et al. (2023), retrieval range of upper and lower limit of TROPOMI ALH is listed. We added this information in the revised manuscript in lines 196-199.
'Furthermore, experimental retrieval range of ALH from TROPOMI is 0.27~6.5 km and 0.06~2.15 km over ocean and land, respectively. It has strong retrieval dependence of surface types (Michailidis et al., 2023).'
In addition, We checked and revised the sentence of retrieval range of TROPOMI ALH in lines 186-188 in the revised manuscript
'Furthermore, the ALH retrieval has limitation to the aerosol plume with higher than 12 km, because the ALH neural network method is currently adopted to the plume pressure range of 75~1000 hPa (Michailidis et al., 2023).'

The reader should have some knowledge about the product limitations, used in the study. The S5P AER_LH product limitations is not clear. I suggest adding some details and relevant references highlighting that. In the description of the ALH product, it should be stated that ALH retrievals have been validated using the multi-year EARLINET aerosol record (Michailidis et al., 2023), and, similarly, the ALH parameter have been evaluated with CALIOP retrievals onboard CALIPSO (Nanda et al., 2020). More specifically, the paper of Michailidis et al. 2023 provides several sensitivity analyses that detail the importance of the aerosol height under different conditions (multilayered structure, surface type, aerosol type).

Ans) Thank you for the valuable comment. We agree the reviewer's points. Ideally, reference data for aerosol layer height intercomparison is CALIOP. However, it is hard to get sufficient number of colocated data by solely using the CALIOP. For this reason, we also used the TROPOMI ALH for

intercomparison. So, we checked and referred the Michailidis et al. (2023) and Nanda et al. (2020) during the revision. Finally, we added the TROPOMI ALH product information in the introduction, TROPOMI data sections in the revised manuscript. Unfortunately, we have limitation to the severe aerosol loading cases of colocated CALIOP dataset in our analysis period. For this reason, we are limited to show the detailed analysis of different aerosol height conditions.

Conclusions section. A final message is missing. Please if is feasible, provide a concluded comment on the future satellite missions that will be use Aerosol Height products. What is missing from the presented comparison results which would be beneficial in the satellite community? I also suggest adding some comments highlighting important areas of potential improvement in the current GEMS AEH product.
Ans) Thank you for the reviewer's comment. We added the studies applied to the aerosol height product. In addition, we also listed to the next working of improvement for AEH product in the conclusion section in the revised manuscript.

A section for "Data availability" at the end of the paper is missing. Please provide the satellite dataset sources for CALIPSO, TROPOMI and GEMS satellite platforms used in the study following the appropriate DOIs for each satellite product.
Ans) Thank you for your comment. We added the 'Data Availability' at the end of the paper.

Specific comments & Technical corrections
-In several places within the text, the authors use the word "significant" without providing any statistical information. (e.g. significant dependence, significant uncertainty, significant discrepancies, etc.). Please check this, must be clear for the reader.
Line 60: "scattering material amounts". Please rephrase.
Ans) We deleted this phrase and rewrite the sentence in lines 66-68 in the revised manuscript as:
'For the quantitative estimation, measurements of aerosol optical depth (AOD) and radiative cloud fraction have also been retrieved from pixel-based radiance data in UV-visible wavelength range.'

Line 63: "…for use with satellite sensors" to "…in order to be applied in passive satellite sensors."
Ans) We revised it.

Line 90: change "… for passive sensors …" to "… hosting passive sensors…"
Line 90: Reference "Omar et al., 2009" is missing.
Ans) We revised it and added the reference of Omar et al. (2009).

Line 91: Reference "Veihelmann et al. (2007)" is missing.
Ans) We added the reference of Veihelmann et al. (2007).

Line 156: Rephrase "aerosol amounts" to "aerosol load".
Ans) We revised it.

Lines 192: "…absorption materials..." .Is not sounds good. Please rephrase to: "..absorbing species.." or "...atmospheric components…"
Ans) We revised to the reviewer's suggestion.

Line 237: Add the relevant reference (Veefkind et al., 2012) for the TROPOMI/S5p mission.
Ans) We revised it (in lines 172-174).

Line 237-239. I suggest the following rephrase: "TROPOMI is a nadir-viewing spec- trometer, the only payload of the Sentinel-5 Precursor (S5P), measuring radiance in the ultraviolet, visible, near-infrared, and the shortwave infrared. The Sentinel-5P crosses the equator at 13:30 local time in a polar orbit with ascending node providing near-global daily coverage."
Ans) We revised it.

Line 251-253: Please specify the TROPOMI AER_LH L2 dataset version used in the study. For example v.02.00 is a generic statement. Currently four versions are existed:
02.02.00 - 02.05.00. Which one is used in the study? Also provide the reference DOI for the version according to Data Citation Guidelines V2:" Copernicus Sentinel-5P (processed by ESA), 2021, TROPOMI Level 2 Aerosol Layer Height products. Version
02. European Space Agency. https://doi.org/10.5270/S5P-7g4iapn"

Ans) Thank you for your comment. In past revision process, we checked the version of TROPOMI AER_LH and we found that the algorithm version is version 2. However, during this revision, we re-checked and the analysis before the revision is used the product version 1. For this reason, we revised and re-analyzed all the comparison and validation using TROPMI Version 2.04. In this study, we added the sentence to clarify the version of TROPOMI data in lines 199-201 in the revised manuscript.
'In this study, we use version 02.04.00 of the TROPOMI offline level 2 AER_LH product (European Space Agency, 2021) with the spatial resolution is 3.5 km × 5.5 km at nadir viewing geometry.'

Line 253: Please check the spatial resolution: 3.5 x 7.0 km (across x along track), at beginning of mission and 3.5 x 5.5 km (across x along track) since 6 August 2019.
Ans) We revised it.

Line 260-262: Please add the info about the footprint of the CALIOP and the Repeat Cycle time of CALIPSO.
Line 263-264: "...the spatial resolution coverage is narrow". How narrow? Add the footprint of CALIOP.

Ans) We revised the CALIPSO information in Section 2.3 in the revised manuscript.
Line 266-268: How the AEH from CALIPSO is estimated? Be more specific about the methodology or/and add some references from previous studies.
Ans) We modified the sentence in lines 215-219 in the revised manuscript as:
'The AOD from CALIOP is vertically integrated aerosol extinction coefficient from surface to top of atmosphere, and representative layer height parameters (ALH and AEH) are directly estimated by using the vertical profile of aerosol extinction coefficient at 532 nm to minimize the spectral discrepancy of aerosol extinction.'

Line 267: Are there any specific reasons to use 532nm instead of 1064nm? Please specify the thresholds used to filter out CALIPSO aerosol height data (for clouds?). Please add some relevant references.
Ans) Although the 1064 nm information has significant signal for aerosol information, but the AOD has spectral sensitivity as the aerosol type changes. Because of minimizing the spectral discrepancy between CALIPSO and GEMS aerosol products, we used to 532 nm data instead of 1064 nm. The aerosol profile product of CALIPSO is only shown to the aerosol dominant signals by distinguishing

cloud signals in advance.

Line 274: "... thin AOD pixels". Rephrase. Maybe you mean "pixels with low AOD values".
Ans) We revised it.

Line 277: "Yellow" change to "yellow". (Also, in lines 327 and 374)
Ans) We revised it.

Line 283: «For both plumes, AEH shows around 1.0~2.0 km in this case» I suggest rephrasing to: «For both detected plumes, the AEH shows similar pattern ranging between 1.0 to 2.0 km"
Ans) We revised it.

Lines 356-357: "To ensure the accuracy of ALH from TROPOMI, only pixels with quality assurance (QA) values greater than 0.5 were used." According to the ATBD, the ALH is very sensitive to cloud contamination. However, aerosols and clouds can be difficult to distinguish. Using this criterion for QA, are cloudy pixels excluded in the selected scenes? What about the presence of cirrus clouds? Is this type of clouds are also taken into account or additional flags need to be considered? Some details about the cloud masking procedure for TROPOMI is necessary to be added somewhere in the text.
Ans) During the revision, we changed the version of TROPOMI ALH to version 2.04. After version up of TROPOMI data, we adopted various types of quality variables. To consider the cloud contamination and quality of ALH data, we adopted the QA values of TROPOMI ALH. In addition, we also used to the cloud mask indices from VIIRS and TROPOMI. To clarify the quality of ALH data, we revised the section 2.4 in the revised manuscript.

Line 387: Based on what the limit of 50km for the AEH was chosen?
Ans) To clarify the spatial colocation, we explained the criteria of spatial range and its reference in lines 218-223 in the revised manuscirpt.
'For spatial colocation, we selected pixels for which distance between GEMS and CALIOP (or TROPOMI) observations was less than 50 km. From Park et al. (2020), the spatial scales for AOD validation are 30~40 km. To secure the number of observation pixels, we mitigate the spatial scale condition for the colocation. In addition, only the closest 10% of pixels were used. Given the different orbital characteristics of CALIOP (or TROPOMI) and GEMS, temporal colocation was also considered.'
Park et al. (2020)
Park, S. S., Kim, S. -W., Song, C. -K., Park, J. -U., and Bae, K. -H.: Spatio-temporal variability of aerosol optical depth, total ozone, and NO2 over East Asia: Strategy for the validation to the GEMS Scientific Products, Remote Sens., 12, 2256, 2020.

Line 388: Remove the word "As".
Ans) During the revision, we removed the related sentence.

Lines 459-460: "As TROPOMI retrieved only ALH data with high QA values over pixels containing strong aerosol plumes…". Please specify what you mean with "high QA". Also, what the "strong" is meaning? Thick plumes regarding the AOD or UVAI? Please specify.
Ans) After updating the version 2 of TROPOMI ALH, the colocated number of pixels are increasing. For this reason, we deleted to this sentence in the revised manuscript.

Line 423: Change “Aerosol height information...” to “The aerosol height parameter...”
Ans) We revised it.

Line 426-428: “Even if the uncertainty due to aerosol properties is fixed, the variability of AEH is affected by the sensitivity of AEH error to aerosol absorptivity.” Please clari- fy this sentence.
Ans) To clarify this sentence, we revised in lines 513-517 in the revised manuscript.
‘The aerosol height parameter is more sensitive to absorbing-dominant aerosols than scattering-dominant aerosols (e.g., Park et al., 2016; Nanda et al., 2020). For this reason, the variability of AEH is smaller in absorbing-dominant aerosols than scattering-dominant aerosols, if the uncertainty of other aerosol parameters (AOD, SSA, and TYPE) is the same conditions.’

Line 463: “… was insufficient”. How many? Add the number of pixels.
Ans) After updating the version 2 of TROPOMI ALH, the colocated number of pixels are increasing. For this reason, we deleted to this sentence in the revised manuscript.

Line 463-465: Rephrase the sentence “the operational algorithm of TROPOMI is only retrieved the ALH over absorbing dominant aerosol pixels” to “the TROPOMI opera- tional algorithm is able to provide ALH pixel retrievals only for scenes dominated by absorbing aerosol particles”.
Ans) We revised it.

Line 465-467: “pixels with small positive UVAI (weak absorbing cases) pixels are identi- fied with small QA values in the offline product of ALH.” The message of this state- ment is not clear and confuse the reader. Please rephrase and clarify what small QA means (e.g. QA<0.5?).
Ans) We revised it.

Line 504-505: Also add the STD values (mean±std)
Ans) We revised it.

Line 746-749: Update the Reference. The link is not available.
Ans) We revised it.

Figure 1.: I suggest changing the caption to: “A schematic illustration of AEH and ALH definitions in an idealized aerosol vertical distribution.” What “idealized vertical distribution” means?
Ans) We modified to ‘idealized Gaussian shape’ in the revised manuscript.

Figure 4.: Add the label “[km]” in the colorbar legend (similar to Figure 3, in first column).
Ans) We revised it.

Figure 7.: Add a title similar as this in Figure 5. If is possible add the label “[km]” in the colorbar legend (similar to Figure 6, first column).
Ans) We revised it.

Cited References:

Michailidis, K., Koukouli, M.-E., Balis, D., Veefkind, J. P., de Graaf, M., Mona, L., Papagianopoulos, N., Pappalardo, G., Tsikoudi, I., Amiridis, V., Marinou, E., Gialitaki, A., Mamouri, R.-E., Nisantzi, A., Bortoli, D., João Costa, M., Salgueiro, V., Papayannis, A., Mylonaki, M., Alados-Arboledas, L., Romano, S., Perrone, M. R., and Baars, H.: Validation of the TROPOMI/S5P aerosol layer height using EARLINET lidars, Atmos. Chem. Phys., 23, 1919–1940, https://doi.org/10.5194/acp-23-1919-2023, 2023.

Veefkind, J. P., Aben, I., McMullan, K., Förster, H., de Vries, J., Otter, G., Claas, J., Eskes, H. J., de Haan, J. F., Kleipool, Q., van Weele, M., Hasekamp, O., Hoogeveen, R., Landgraf, J., Snel, R., Tol, P., Ingmann, P., Voors, R., Kruizinga, B., Vink, R., Visser, H., and Levelt, P. F.: TROPOMI on the ESASentinel-5 Precursor: A GMES mission for global observations of the atmospheric composition for climate, air quality and ozone layer applications, Remote Sens. Environ., 120, 70–83, https://doi.org/10.1016/j.rse.2011.09.027 , 2012.

Ans) Thank you for the references. We referred reviewer's suggested references and we added these information in the revised manuscript.

Response to Reviewer#4

Review of Park et al., Retrieval Algorithm for Aerosol Effective Height from the Geostationary Environment Monitoring Spectrometer (GEMS), submitted to AMT

This paper presents preliminary results of GEMS AEH retrievals and shows the validation results. The performance of the algorithm is highlighted in the form of comparisons to correlative measurements from other sensors such as CALIOP and TROPOMI. The performance metrics are stratified in different ways to demonstrate what input parameters affected the retrievals and so forth. I must admit I had great difficulty reading this paper. The content of the paper is rather simple and easy because the analysis is straightforward. However, the writing style and leaps of faith in the retrievals boggled my mind. The whole Introduction section is so bizarre; the authors could not explain in clear terms why retrieving AEH is important and what work has been done so far by other researchers –basically a literature survey. In its current form, the manuscript cannot be published. Work can be improved and will be useful. So, a rejection with resubmission with better scientific discussion of findings and succinct writing is recommended. Specific issues:

Ans) Thank you for your comments. During the revision process, we modified and revised the whole structure of manuscript. In addition, we also tried to revise the manuscript for readability. Please check and see the revised manuscript and several revision points as shown below.

(1) These retrievals are all new and I encourage the authors to show some look-up-table information. Without that information, it is hard to believe the conclusions. For example, AEH retrieval is sensitive to AOD and SSA. How strong is the sensitivity? Without this information, how are we supposed to believe that uncertainty in AEH stems from uncertainties in AOD or SSA or both? I can understand SSA uncertainties could be large but we can retrieve AOD reasonably accurately.

Ans) Thank you for your comment. We referred the Park et al. (2016) and several previous studies for the possibility of AEH retrieval including error budget studies. We mentioned the details of retrieval method in Section 3 and also we added the references.

(2) In the algorithm description section, the authors mention that they use surface reflectance climatology but it looks like retrieved surface reflectance is used? Because they attribute part of the AEH uncertainty to surface reflectance uncertainty.

Ans) Thank you for your comment. In operation, we used the retrieved surface reflectance from GEMS L2SFC product. However, the L2SFC is recently beginning to make operational results. For this reason, we used to the minimum climatological LER value to estimate the surface reflectance. This surface reflectance is only used to this study, and operationally version 2.0 of AEH product uses the L2SFC. To explain the input parameters of surface reflectance, we clarify the surface reflectance information in Section 2.1 (in lines 155-169) and Section 3 (in lines 361-363). In addition, we revised the figure 2 in the revised manuscript to clarify the surface information.

(3) GEMS vs. CALIOP AEH differences are quite remarkable. Sure, the mean bias is small or within a kilometer or so but the scatter plots indicate no correlation whatsoever. By presenting just mean bias metrics and not discussing root mean square error (rmse) and correlation coefficient, the authors are sending the wrong message. All analysis should use rmse or precision (standard deviation of the bias) to fully understand the performance of the algorithm. Standard deviations are shown in some cases but those are too large. Does GEMS have a specification for AEH retrieval? If yes, do these biases, precisions, and uncertainties (rmse) meet those specifications?

Ans) Thank you for your comment. Sure. The statistical performance of GEMS AEH was only shown by mean and standard deviation value. Because the individual pixel results have large variation (~1.4 km of standard deviation), correlation coefficient is not mentioned in the manuscript. Instead, the manuscript mentioned the correlation between TROPOMI ALH and GEMS AEH in case studies. From Park et al. (2016), the AEH retrieval based on O2-O2 band have total error budget of 0.74~1.28 km (described in lines 357-361 in the revised manuscript). During the revision, we added and make up the statistical results related to the correlation coefficients, mean bias and standard deviation in Section 4 in the revised manuscript.

(4) Instead of doing gross statistics for land vs. ocean, why not plot bias, precision, uncertainty (rmse) as a function of surface reflectance? Land vs. ocean statistics are fine but show the dependence plot for surface reflectance as well.

Ans) Thank you for the reviewer's comment. We agreed that AEH retrieval dependence according to the surface reflectance has to be shown in the manuscript. The AEH retrieval results are affected by both aerosol and surface optical properties as shown in Park et al. (2016). For the accurate estimation of error analysis according to the surface reflectance, we thought that the AOD and aerosol optical properties have to be controlled before estimating the AEH difference. However, the number of collocated pixels between CALIOP and GEMS is hard to define the correction by changing the aerosol optical properties. For this reason, we are only classified and shown to the AEH difference analysis according to the land/ocean surface change.

(5) What are the reported uncertainties in GEMS AOD and SSA retrievals? Over different surface types and different view conditions (scattering angle or time of the day). How do they relate to AEH retrievals?

Ans) We don't have official report of uncertainty in GEMS AOD and SSA retrieval results. However, in Park et al. (2016), the AEH error sensitivity was shown to the assumed uncertainty of AOD and SSA, respectively. To clarify the dependence of AEH retrieval uncertainty, brief explanations are shown in lines 319-323 in the revised manuscript.

"In AEH estimation, other aerosol characteristics, including aerosol load and optical properties, affect retrieval accuracy. From Park et al. (2016), uncertainty of AEH retrieval result is largest by the SSA uncertainty. In addition, the AEH retrieval uncertainty by the aerosol optical properties and surface albedo has dependence of observation geometries."

(6) Again, not knowing how sensitive AEH is to SSA (show LUTs for us to visually see the dependence), it is hard to tell how the performance of the algorithm would be for dust only, smoke only, smoke mixed with urban pollution etc.

Ans) We agreed the reviewer's comment. On previous answer, we mentioned that the AEH retrieval uncertainty based on the previous reference study. In addition, we showed the example of LUT in Figure 3 in revised manuscript.

(7) There is a positive bias for dust and negative bias for absorbing aerosol and scattering aerosol. This is not explained well. What constitutes scattering aerosol? Sea salt or sulfates and organics?

Ans) It is hard to define constituents of scattering aerosols. Because the scattering aerosol is defined by the optical property, we can't clarify the chemical composition of aerosols. In the UV aerosol algorithm, the scattering aerosol is defined as fine mode with highly scattering particles, such as anthropogenic sulfates or nitrates. However, we can't determine the chemical compositions. We added the aerosol type classification in lines 330-335 in the revised manuscript.

"The aerosol type is considered by the radiative absorptivity and size information, which is based on the method from Lee et al. (2010). Based on the Lee et al. (2010), the aerosol type is classified to absorbing, dust, and non-absorbing aerosol. Absorbing and non-absorbing aerosol types are assumed to the fine-mode dominant particles."

Reference:

Lee, J., Kim, J., Song, C. H., Kim, S. B., Chun, Y., Sohn, B. J., and Holben, B. N.: Characteristics of aerosol types from AERONET sunphotometer measurements. Atmos. Env., 44, 3110-3117, 2010.

(8) How different is the GEMS SSA for dust cases, absorbing aerosol cases, and non- absorbing cases? Can some information be provided?

Ans) It is hard to mention the tendency of GEMS SSA for dust, absorbing, and non-absorbing cases in individual cases. Because the aerosol type is classified using the UV and VIS aerosol indices from L2AERAOD of GEMS. In addition, the aerosol optical absorptivity has variation of SSA, although the aerosol type is categorized in same. In this study, we used that the SSA variation of aerosols in the LUT calculation.

(9) For some of the data points in the scatter plots between GEMS and CALIOP, it would be nice to show the vertical extinction profiles to see if aerosol layers are continuous or stratified? Maybe, the issue is not with GEMS AEH but with how CALIOP ALH is being derived?

Ans) We agreed the reviewer's comment. If we will get the sensitivity of difference between AEH and ALH according to the aerosol vertical distribution shapes, we can consider the additional information of aerosol vertical distribution shapes. To express the application of aerosol height product, we mentioned in the Section 6.

(10) Colors in figures are not consistent. For example, in Figure 9b, red color is used for scattering aerosols (SSA > 0.95) and in Figure 9c, red color is used for dust. Very confusing to interpret the figures when colors are mixed and not consistent

Ans) Thank you for the comment. To solve this confusing, we revised the Figs. 10 and 12 in the revised manuscript to coincide the color of line. In addition, we also revised Figure 13 in the revised manuscript.

In summary, this paper is not qualified to be published as it is neither written well nor the scientific results good. Nothing wrong with a poor performance of an algorithm/product; but the results are not presented that way. The results are presented as if the retrievals are good, which is not the case. Again, I know this is not an easy product to retrieve. I wish the authors said so at the outset and presented the results as is. The authors also leave out what they plan to do to improve the product performance. There is a lot of work yet to be done for this paper to be published.

Ans) Thank you for the comment. During the revision process, we revised and clarified the details of algorithm and related results as much as possible.