We would like to express appreciation to the reviewer for their insights and detailed review that made this paper stronger. We have taken them all into serious consideration. Our responses (in blue) for each comment (in black) and updates to the paper (in *italics*) are provided below.

Authors' response to RC1

Synopsis: This is a pretty straightforward paper comparing passive Aerosol Layer Height (ALH) retreivals generated from TROPOMI, GEMS and EPIC over two Asian domains for signciant dust and smoke events. Comparisons are made to AERONET for AOD, CALIPSO CALIOP products for the vertical centroid, and intercomparring heights between each other. Also included are comparisons of the nature of diurnal retrievals and are two example cases. As the authors note, the oxygen band retrievals are coming into their own, and while they have limited measurement degrees of freedom, they do have coverage that cannot be achieved with lidar systems. Overall, the paper is certainly appropriate to AMT and can have importance to the community. This said, I do think the paper requires major revisions. These revisions are in two prime areas.

First, they authors delicately ignore a number of sampling considerations throughout the paper. Notably, when they compare the passive products to CALIOP, implicit in that comparison is excellent viewing conditions. If there was say thin cirrus, there would not be a CALIOP retrieval to compare. For the intercomarison between retrievals without CALIOP, there clearly is a wider and higher distribution of heights. Notable are little "isolate" retrievals with very high height retrievals. The authors need to examine this data population closely. This may require a lot of hand analysis.

We aimed to capture all dust and smoke events across Asia from 2021 to 2023 during CALIOP overpasses. However, these occurrences were limited, spanning only a handful of days. We recognize the concern regarding the scarcity of data points. Throughout the paper, we have underscored our focus on "golden days" marked by ideal viewing conditions and the absence of cloud contamination.

A second concern is the reported diurnal cycle. Certainly we expect the diurnal cycle to be important to retrievals such as GEMS and EPIC that have widely varying scattering angles for retrieval physics if not reality, and thus can be important to include in a paper like this. Indeed, all of the major AOD retrievals from geostationary have significant diurnal biases. However, the authors gloss through potential artifacts to explain diurnal differences, and are highly suggestive that the diurnal cycle from EPIC (their retrieval mind you) is real. However their explanation of the nature of diurnal aerosol height is flatly wrong-they suggest that the maximum aerosol height should be around solar noon due to PBL mixing. First, mixing will sustain itself through the afternoon and thus we would not expect a solar noon peak. Second, their product uses aerosol index and they are not as sensitive to the PBL anyways. Thus physically their explanation does not make sense. As EPIC stares at the sunny hemisphere of the earth, they may have an unaccounted for diurnal scattering angle issue in their RT code that causes symmetry along solar noon, or they may have a cosine response/resolution issue and perhaps also an associated resolution-based cloud mask bias. Now in full transparency, I am a co-author on a paper from this group that reported a strong diurnal height cycle of dust off of Africa. This said, as part of my contribution I pushed for softer language and examination of biases. As we see the exact same behavior here, I am thinking even more about diurnal bias in their EPIC retrievals. They have to come clean up front, and say they have no current way to evaluate which is correct, noting the possible artifacts, or remove the section all together. I strongly encourage the authors to look at some ground based lidar data in the region to verify their algorithm. There are plenty of Japanese and NASA lidars in this region that they can use.

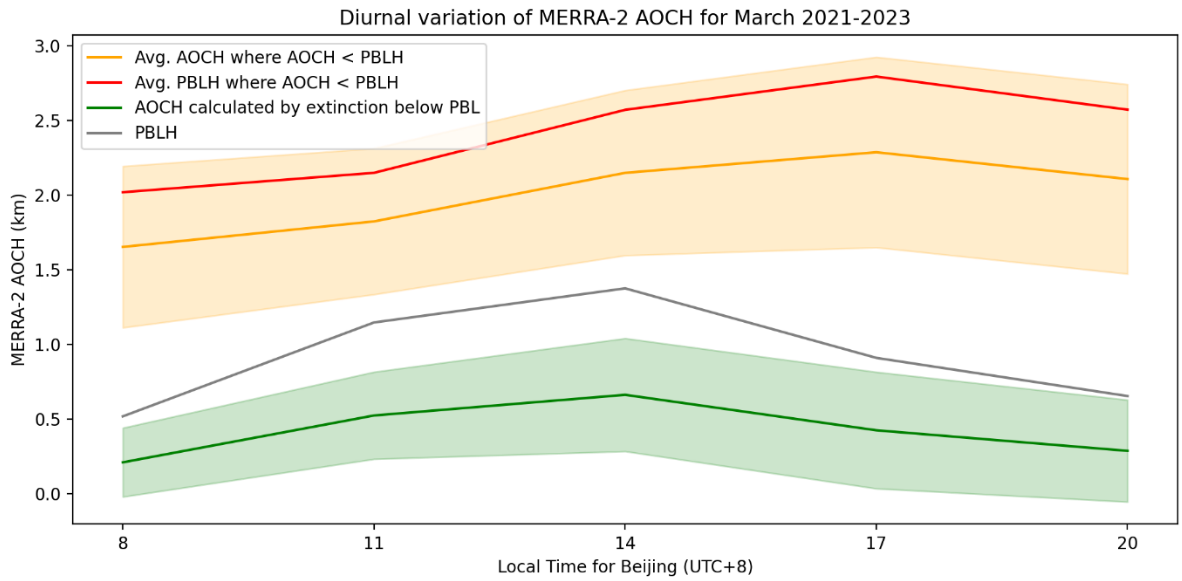
Thank you for your concern. Firstly, it's important to clarify that our paper does not advocate for any specific product. Instead, we position ourselves as impartial users of several aerosol layer height products. While it's true that some of our co-authors contribute to the development of the EPIC product, we also have team members involved with GEMS and TROPOMI aerosol products. We have taken great care to ensure that our analysis remains objective and unbiased towards any particular product.

We acknowledge your valid concern regarding potential artifacts such as scattering angle issues for GEMS, however, EPIC focuses on backscattering with narrow varying scattering angles given its long distance to the Earth. Still, biases in cloud masking, particularly at lower resolutions near the edges, may influence the diurnal cycle of aerosol height. Additionally, the limited data points obtained from selected case study dates could introduce uncertainty when attempting to generalize aerosol height trends.

In this section, our intention was to illustrate the disparity in diurnal patterns between GEMS and EPIC, rather than definitively concluding that aerosol layer height peaks at local noon time. To reflect this, we have revised the language to adopt a more cautious tone, omitting the statement of a peak at local noon time and emphasizing the inherent difficulty in determining the accuracy of either dataset. Nonetheless, we believe this section remains valuable as it underscores the contrasting diurnal patterns observed between GEMS and EPIC, even if these differences may partially be attributed to measurement biases.

Additionally, we examined three years of MERRA-2 data spanning from 2021 to 2023, focusing on March within the East Asia domain. MERRA-2 AOCH is defined same as the CALIOP AOCH in the manuscript, weighted by optical depth at each vertical layer using aerosol extinction vertical profiles. Orange line indicates the average AOCH where AOCH is lower than the PBLH and the red represents the average of those PBLH values. Furthermore, AOCH calculated considering the aerosol extinction only below the PBLH (illustrated by the green line) show similar diurnal pattern with the PBLH. These similar diurnal variation between AOCH and PBLH indicates that when most aerosols locate within the PBL, diurnal variation is affected by the PBL process, which changes the PBLH during daytime.

The diurnal variation of EPIC AOCH from Figure 8 is consistent with the MERRA-2 PBLH (grey line) and AOCH calculated by extinction below the PBL (green line), as ascending throughout the morning and descending after 2 pm local time, although EPIC AOCH values are higher than MERRA-2 AOCH, due to its constrain by PBLH. The diurnal variation of GEMS and MERRA-2 AOCH show similarities for the afternoon decrease. However, GEMS showing an overall decrease throughout the day, does not coincide with the MERRA-2 data, which shows in increase until 14 local time.



To further support our analysis of diurnal variations, we tried exploring data from MPLNET. However, only one MPLNET site falls within our Southeast Asia domain, it does not coincide with any of the dust or smoke plumes on our selected dates. We remain open to exploring additional ground-based lidar datasets for future studies.

In addition to these two science concerns, the paper has many minor copy editing typos, language irregularities, verb tense, dropping articles etc., Just an example, starting a paragraph on line 84 "The light travels longer path when aerosols locate at lower altitude than those at higher altitude, leading to more absorption from more O2 molecules in longer path (Ding et al., 2016; Xu et al., 2019)." The paper has sentences like this in almost every paragraph, and frequently drops articles (the/a/an). I suggest the authors utilize university copy editing programs before the paper can proceed.

We have addressed grammatical errors and improved sentence structures. Your feedback is appreciated. Thank you.

Specific notes

Abstract Line 15 (And Intro lineS 72-76). I think from the beginning the authors should be a little more modest about what an aerosol layer height retrieval means. It does indeed provide information, but it is only a single degree of freedom in what can be a complex aerosol vertical structure. From the beginning, Aerosol Layer Height (ALH throughout) can be a bit misleading, and largely based on a false presupposition-that there is one layer. I am ok with language like "scale height", or "aerosol centroid", but honestly ALH has always bugged me as a labeled variable. Indeed, as noted in line 23 they have to make adjustments in definitions from the different product lines. I only ask they authors be mindful of this throughout the paper.

We appreciate this comment regarding the terminology of aerosol layer height. Given the diverse definitions and names of aerosol height products across platforms, we used the term "aerosol layer height" (ALH) to encompass all such products, including aerosol optical centroid height (AOCH), or aerosol effective height (AEH). Acknowledging the limitation of ALH in multiple aerosol layer structure, we revised some parts in the manuscript.

(Abstract) Aerosol vertical distribution is crucial for assessing surface air quality and the impact of aerosols on climate. Although aerosol vertical structures can be complex, assuming a shape of the aerosol vertical profile enables the retrieval of a single parameter, aerosol layer height (ALH), from passive remote sensing measurements.

(Introduction) Hence, many algorithms have been developed to extract a single piece of information regarding aerosol vertical distribution, with a primary emphasis on aerosol layer height, which approximates the altitude of aerosols from a presumed aerosol vertical profile shape.

Abstract line 24-25, you may want to mention how the products cross correlate.

We included the cross correlation of the products.

When comparing GEMS ALH to TROPOMI and EPIC, GEMS shows a narrower range and correlation coefficients are both below 0.4 ($R < 0.4$).

Abstract line 30 "EPIC and TROPOMI tend to overestimate AOD by 0.33 km and 0.23 km, respectively, in dust cases" I am not sure where the km fits into this, as AOD is unitless.

Thank you for pointing this out. This was a mistake. We removed 'km', since AOD is unitless.

Introduction. Line 52 "Cloud-Aerosol Lidar with Orthogonal Polarization (CALIOP) on board with the Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation (CALIPSO) platform detects aerosol backscattering extinction profile with fine vertical resolution (Winker et al., 2013)." This is a bit of unusual language. What CALIOP measures is attenuated backscatter. It retrieves aerosol extinction profiles, but these are retrievals and can have uncertainties of their own.

We revised the sentence.

Cloud-Aerosol Lidar with Orthogonal Polarization (CALIOP), on board with the Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation (CALIPSO) platform, detects *backscatter signal from different altitudes and retrieves aerosol extinction profiles with high vertical resolution (Winker et al., 2013)*

Introduction. Line 55. "With the retirement of CALIPSO in August 2023, passive remote sensing will become the only routine technique from space for filling the data gap of measuring aerosol vertical distribution before next lidar dedicated to measure aerosols are launched into space." Technically this is not true, as the Chinese have an HSRL in space. But they don't release the data. We will see if they ever do.

Thanks for the information. We modified the sentence.

With the retirement of CALIPSO in August 2023, passive remote sensing will become the only routine technique accessible for the public at present, from space for filling the data gap of measuring aerosol vertical distribution before next lidar dedicated to measure aerosols are launched into space.

Methods, Section 2.3. I think throughout the paper, it needs to be emphasized that "golden days" are being used in this evaluation. I have no objection to this per say, as long as they make it clear in the abstract and introduction that these results are for ideal viewing conditions, and indeed day to day "mileage may vary considerably" Indeed, the very use of the CALIPSO as a verification dataset implies that they don't have to worry so much about things like cirrus or other cloud contamination.

We have emphasized this in the abstract and introduction.

(Abstract) All analyses are conducted for selected "golden days", which represent ideal viewing conditions for typical dust and smoke cases.

(Introduction) Considering that the spatial coverage of CALIOP is limited, we carefully selected "golden" cases where dust and smoke events favor the retrievals from all three sensors. This selection can maximize the signal to noise ratio for ALH retrieval, and hence, the evaluation can shed light on the future improvement to bring the closure of various types of retrievals. Note that these conditions may differ from those observed on non-selected days.

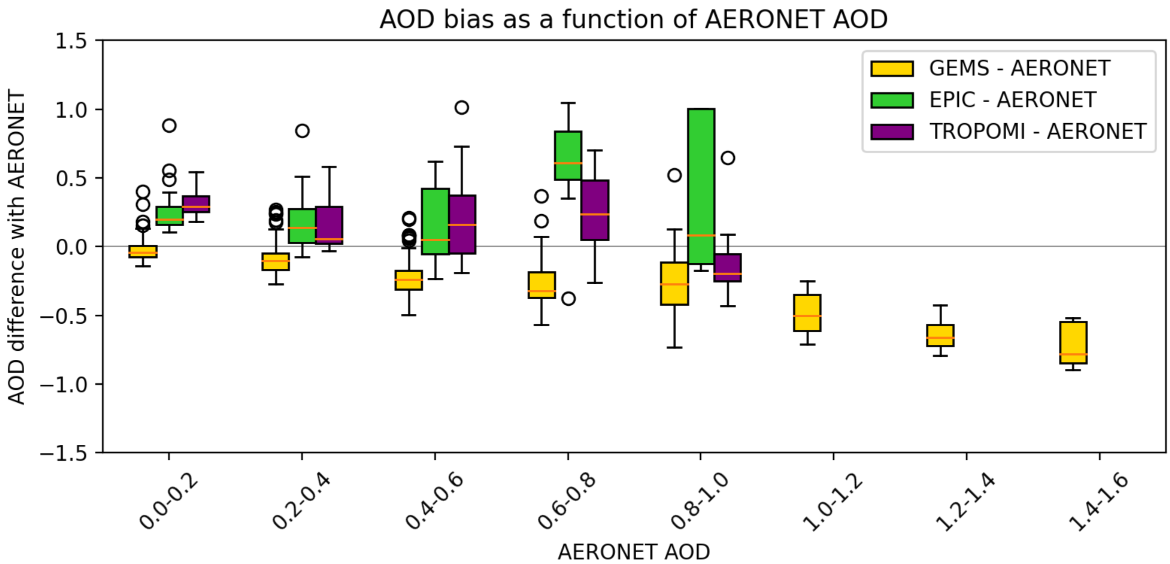
(2.3 Comparison Approach) Given the availability of EPIC/TROPOMI retrievals for absorbing aerosols, we focus our comparison on a selection of "golden days" characterized by ideal viewing conditions for dust and smoke cases, excluding cloud-covered areas, as observed within GEMS field of regard from 2021 to 2023.

Results

Line 295: I am not entirely sure how meaningful the stats are here "For dust cases, both TROPOMI and EPIC AOD exhibit a positive bias compared to AERONET AOD, with values of 0.23 and 0.33 for TROPOMI and EPIC, respectively." As these are for a distribution of AODs with different densities across AOD values. You can calculate bias as a function of AOD, or if it is linear enough a slope bias.

Thank you for your feedback. We assessed the difference in AOD between passive sensors with

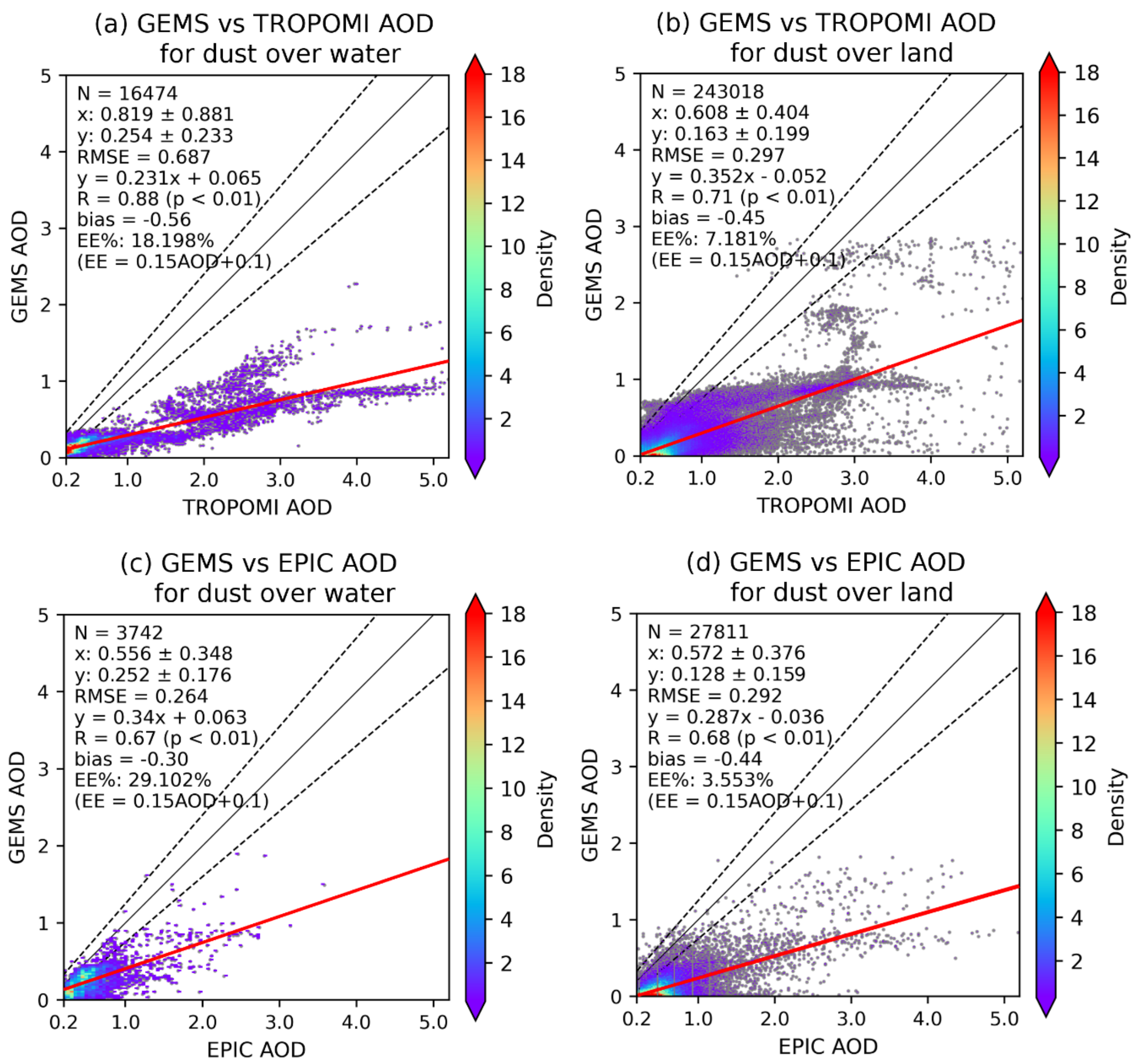
AERONET AOD as a function of different AOD bins. GEMS AOD consistently underestimate AERONET AOD, with the disparity increasing as AOD levels rise. EPIC and TROPOMI show positive bias, which is consistent with Fig. 3, but no significant trend in the difference is observed across different AOD bins. We included this figure below in the Supplementary (Fig. S1).



Line 320-323: The authors should probably use more direct language, that based on Figure 3, the TROPOMI and EPIC dust AOD products were quite high biased (presumably as stated line 323 due to surface reflectance), and GEMS was low perhaps due to the optical model. Thus, when you cross compare, of course there is a massive bias between them. But can you also check this by looking only at data over water?

Thank you for the feedback. The figure below illustrates AOD comparisons distinguished over land and water. Comparison with AERONET data reveals that TROPOMI and EPIC AOD estimations for dust cases tend to overestimate. Specifically, in Figures (b) and (d), which compare GEMS to TROPOMI and EPIC AOD over land, we observe a similarity with AERONET comparisons: for GEMS AOD values close to zero, TROPOMI and EPIC AOD values are higher compared to GEMS. However, this trend is not seen over water (Figures (a) and (c)). The discrepancy stem from differences in surface reflectance estimation in retrieval algorithms; GEMS employs the OMI surface reflectance climatology data product OMLER v003, whereas TROPOMI and EPIC utilize climatology MODIS surface products. This suggests that surface reflectance estimates from TROPOMI and EPIC over land may require refinement for more accurate retrievals. We have included this figure in the supplementary document.

Specifically, surface reflectance estimates for land surfaces from TROPOMI and EPIC may need refinement, as GEMS AOD values close to zero tend to be higher in TROPOMI and EPIC over land. However, this trend is not observed over water.



Line 345-352: AI can be a can of worms. There are a host of other issues than those noted, including pressure assumption differences, not just land reflectance but altitude models, resolution differences resulting in different cloud effects, etc. probably you need to calculate it yourself consistently.

We acknowledge the multitude of parameters that can impact UVAI, including those you mentioned. Given the variability in UVAI across different products, we adopted a criterion for classification in our paper based on setting UVAI thresholds to achieve similar spatial coverage. To achieve this, we used TROPOMI UVAI as a reference and set the UVAI threshold accordingly, rather than directly calculating UVAI ourselves. This approach ensures consistency in spatial coverage across the datasets under comparison. We have stated this in the manuscript.

Line 354-Figure 5. Why is there no TROPOMI vs EPIC plot? I think it would be good to cross characterize everything.

A figure comparing TROPOMI versus EPIC UVAI has been included in the Supplementary (Fig. S4).

Line 383-Figure 6. Why do the axis go much further than where there is data? Maybe set to lesser spread and put the results in a table? Also, why not do all of the passive sensors for the different AI ranges?

We reduced the axis size and put the results in two tables. We analysis AOCH for different UVAI ranges only for GEMS since TROPOMI and EPIC AOCH products are already filtered with UVAI values larger than 1 and 3, respectively, to focus on the retrieval of absorbing aerosols.

Line 408-Figure 7. It would be good to verify what is going on with AI cases bigger than 4, and what role clouds may have in increasing these values. There are no CALIPSO verification cases with AOCH values over 4-5 km. I think it will be necessary to show that these cases where the retrieved AOCH are above such values are real, and not due to some artifact, such as thin cirrus above or unmasked low clouds below. In their case study (e.g, Figure 9) spot retrievals of very high AOCH are visible. The authors should look in detail as to what is going on there.

We have examined the areas with high AOCH and found that the issue is a combination of inaccurate cloud detection and inherent sensitivity in the retrieval process. While some areas are influenced by cloud contamination, most of the high AOCH areas tend to have low AOD and not being influenced by clouds. Since AOCH is more sensitive to higher AOD (Xu et al., 2017), there is greater uncertainty in AOCH retrievals in regions with lower AOD. Furthermore, these high AOCH areas do not show high UVAI values greater than 4; instead, they exhibit values around 1-2, using GEMS UVAI as a reference. Therefore, both cloud detection inaccuracies and the low sensitivity of AOCH retrieval to low AOD contribute to the observed high AOCH in these areas, with the latter being more dominant in our selected cases.

Line 430-Figure 8 discussion. The diurnal version of EPIC looks pretty symmetrical around noon. We have talked about this before, that this may be indicative of a retrieval bias. I don't think you can quickly dismiss this as being part of the PBL cycle, especially since the focus is on absorbing aerosol layers above the PBL. Regardless, the effect of the PBL should maintain its height through the afternoon. The authors really need to incorporate a ground based lidar into these diurnal analyses. In fact, they might consider dropping this section until that can be done.

We answered in one of the general comments above.

Line 485-Figure 11. Please add a local solar time to the x-axis.

We added local time for Beijing (UTC + 8) to the x-axis.

Line 518-Figure 13(b). The crosses for GEMS, TROPOMI and EPIC are very hard to read. The authors may want to change the color scheme and line thickness here and back on Figure 10 to make it consistent.

We changed the color scheme and line thickness. Thank you.