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Comment on acp-2022-56

Anonymous Referee #4

Referee comment on "Retrieving instantaneous extinction of aerosol undetected by the CALIPSO layer detection algorithm" by Feiyue Mao et al., Atmos. Chem. Phys. Discuss., https://doi.org/10.5194/acp-2022-56-RC4, 2022

The analysis presented in the manuscript demonstrates the ability to detect "faint" aerosol that is unreported in CALIPSO level 2 retrievals because it lies below feature detection thresholds. The manuscript explains the importance of quantifying this under-represented aerosol based on literature. In order to "detect" the missing aerosol, the authors follow a similar procedure as is used to construct the CALIPSO level 3 stratospheric aerosol product (Kar et al., 2019): cloud and aerosol layers detected by CALIOP are removed from the level 1 attenuated backscatter and then a Fernald retrieval is performed using a fixed lidar ratio. The difference is that the CALIPSO level 3 product reports monthly averages of aerosol extinction, whereas this manuscript analyzes extinction retrieved from individual level 2 granules. This is what is meant by the "instantaneous" descriptor. The manuscript shows three examples where the CALIOP level 2 algorithms did not detect aerosol layers, but the extinction retrieved by the authors does indicate aerosol enhancement. It goes on to compare their retrieved aerosol extinction values to co-located SAGE III measurements, finding decent correlation at night and a high-bias in their CALIPSO retrievals during the daytime. The logic here is that because their retrieved aerosol extinction at night matches well with SAGE III measurements, then the retrieved aerosol extinction is a fair representation of what was missed by CALIOP level 2 feature detection.

General comments

There are some areas where greater details are needed to avoid confusing readers. For example, the manuscript discusses "detectable extinction" by CALIOP multiple times. This is inaccurate because the CALIOP level 2 algorithms do not detect extinction. They detect aerosol layers using attenuated scattering ratio and then perform an extinction retrieval. The minimum "detectable" extinction is really just the minimum extinction occurring within detected aerosol layers. This distinction is important and needs to be made clear. Based on this and my specific comment below about the lack of details regarding CALIPSO vertical resolution, I recommend that the authors provide more information about the details of the CALIPSO level 1 product, and the steps involved in how the level 2

algorithms ultimately retrieve extinction. That would provide important context for the reader.

The impact of lidar ratio selection is important and inadequately discussed in the manuscript. Two values are used for this analysis (50 sr stratospheric, 28.75 sr tropospheric). The manuscript justifies the two selections for generalized values. However, the aerosol type is known in at least two of the specific cases evaluated: smoke. Since smoke lidar ratios are around 70 sr, this leads to a sizable bias. The manuscript should add a discussion of the limitations of the lidar ratios used by the method.

The conclusions claim to be able to retrieve aerosol extinction down to 0.0001 /km. At that level, however, it is important to consider uncertainty and biases. It is not discussed how large the relative uncertainties are for such small extinction values for the averaging being used. A greater discussion on uncertainties should be added to specify the value the proposed method yields to capturing undetected aerosol.

Specific comments

Lines 69-70: "The CALIPSO lidar is highly sensitive to cloud/aerosol layers with a lower bound of optical depth…". What is the lidar highly sensitive to? Presumably layer detection is meant, but the sentence does not say.

Line 70: "minimum detected extinction of 0.01 to 0.02 /km." This statement does not accurately represent the order of the level 2 CALIOP algorithms. The level 2 algorithms do not detect extinction. Layers are first detected using attenuated scattering ratios and then extinction is retrieved. Suggest rewording to clarify.

Line 93-94: Rather than just reference the Kar et al., 2019 paper to explain how clouds and aerosols are removed, it is recommended to add a sentence or two summarizing the removal procedure of that paper. Also, Kar et al., 2019 applies additional filters to remove undetected cloud layers beyond just using the VFM to cloud-clear. Does the method for this manuscript do the same?

Line 95: "The TAB is averaged at a vertical resolution of 300 m…" How is it possible to average the TAB to 300 m vertical resolution from 20.2 to 30.1 km when the range bins reported in the level 1 data product are at 180 m vertical resolution for that altitude region? Averaging two bins together in this region would yield 360 m, not 300 m. Furthermore, the TAB is already reported at 300 m vertical resolution from 30.1 – 40 km, so no average is required. Please clarify if the averaging used for this study considers the vertical resolution of the range bins in the level 1 data products.

Line 147. According to this line, the extinction retrieval yields a value of 0.01 /km. However, the text suggests the layer is smoke, so the lidar ratio being used is too low by 50/70. Therefore, this extinction value should be larger.

Figure 3. According to pre-processing step (a), clouds and aerosols detected by CALIPSO are removed, along with the data beneath them. However, the purple boundaries in Fig. 3(c) shows that a smoke layer is detected and there is an extinction coefficient reported there. The text even quotes the extinction value on line 148 and panel (d) shows where these layers are detected. I thought that the backscatter was supposed to be removed where layers are reported. Why are they shown in this figure? They are not shown in Figure 7. This should be made clear somewhere which data is used in the retrieval shown in the extinction figure.

Figure 3 caption. "…additional mean filtering (3x3 window) to highlight the faint aerosol area." The premise of the paper is that averaging to 20 km x 300 m resolution is enough to highlight the faint aerosol. Why is additional averaging needed? Can these features still be discerned without this additional filtering? If not, then should the 3x3 window filtering be included as part of the methodology?

Line 173: "…indicating a low bias in the CALIPSO retrieval." Some clarification should be added here because there could be two interpretations of this statement. (1) Because the CALIPSO level 2 layer detection did not capture these extinction values, there is a low bias in what CALIPSO reports. Or, (2) the retrieval of extinction from the CALIPSO products performed in this study has a low bias. Please clarify which condition this statement is addressing.

Line 176: "…we can see that the retrieved aerosol extinction is much less than the detection limit (0.01 km-1) of the CALIPSO Level 2 product". More precise language is requested here. The CALIPSO level 2 algorithms do not detect extinction, they detect layers and then retrieve extinction. This study addresses the extinction from aerosol layers below the layer detection limit of the level 2 feature finder.

Lines 198 – 200: "Young et al. (2013) noted that the CALIPSO retrievals with SNR≤1 usually contain a positive bias. The SNR during daytime above 20 km is usually less than 1 for TAB at 20 km horizontal scale (Figure 6b), which leads to a significantly positive bias in the retrieval" It is not immediately clear how an SNR < 1 yields a positive bias. SNR speaks toward the (inverse of the) variability with respect to the average value, but not necessarily a bias. I would assume that a bias is more governed by calibration rather than noise. Or is it that the noise is not Gaussian? Please add information as to why a "significantly positive bias" is expected in the retrieval when SNR < 1.

Line 210: It would be helpful to explain why the white areas of missing data occur between ± 15° in the level 3 panels of Figure 7 (because of the tropopause height).

Section 3.3. Possible smoke from Siberian wildfires is not the only explanation for aerosol enhancement in the stratosphere during this time period. The June 2019 Raikoke volcano eruption also emitted a substantial amount of sulfate at northern latitudes. This should be discussed as part of the explanation and interpretation for aerosol enhancement in August 2019.

Line 225: "These faint aerosols propagate from 60N to near 10N…" The word "propagate" might be inaccurate for this discussion.

Lines 243 – 244: "The retrievable aerosol extinction greatly extends to 0.0001 km-1…" What is the relative error on these very low extinction values?

Lines 244 – 246: "The comparison is unavailable at low altitudes, but the retrieval should be more reliable (i.e., in the troposphere) because the SNR is higher." The improvement in SNR is only part of the story. A far more substantial factor that will cause larger errors in the troposphere is the choice of lidar ratio, which can range from 20 – 70 sr. This can cause the biases up to a factor of three when the wrong lidar ratio is used. It is important to include a discussion on how the choice of lidar ratios for this analysis impacts comparisons with SAGE retrievals.

Lines 247 – 248. Same question as before, how does low SNR yield a positive bias? More should be added here to summarize why this is true.

Lines 249 – 252. A couple of points about conclusion item (3).

First, the stratospheric aerosol enhancement for this time period includes contributions from the Raikoke volcanic plume in addition to (possible) smoke from Siberian wildfires. This should be included with the discussion of sources for this example. There is some discussion in the literature about the contribution of these aerosol types in August 2019.

Second, this sentence can easily be interpreted as an over-generalization, "our retrieval shows that these faint aerosols even propagate to near 10°N, which is much beyond the detecting range of the CALIPSO L2 products (50° N and 60° N)." I believe this sentence is a summary of the single level 2 granule evaluated in Figure 7 where the level 2 algorithms did not detect a large extent of the stratospheric aerosol enhancement from 10N to 50N, Fig 7(d). For this specific case, the aerosol was not detected by CALIOP level 2. However, the sentence is written as though this is a general result: faint aerosols following the 2019 Siberian fires (and Raikoke eruption) are not detected as far south as 10N by CALIOP level 2 retrievals. This cannot be concluded based on the one granule examined. To make the possibility of misinterpretation more probable, Figure 7(b) shows nothing reported in the CALIOP level 3 stratospheric aerosol product from about 15 N/S. This is merely because the tropopause is above 15.2 km at those latitudes, but a reader could easily read this

sentence and look at Figure 7(b) and conclude that CALIOP level 2 missed detecting all of that aerosol during August 2019. It is unlikely that CALIOP level 2 did not detect all of this aerosol, and even if so, it was not proven in the manuscript. I recommend rephrasing conclusion item (3) to be more specific on the evidence for the conclusion being made.