Review on Manuscript No. AMT-2023-267

Using OMPS-LP color ratio to extract stratospheric aerosol particle median radius and concentration with application to two volcanic eruptions by Wang et al.

Wang et al. derive stratospheric aerosol microphysical parameters from OMPS using the color ratio. They discuss various sources of uncertainty and apply their algorithm to measurements from SAGEIII on ISS and validate their method with balloon data and then apply the algorithm to measurements made during two volcanic eruptions.

I personally do not have any problems with this study being published. Although the method itself of using two wavelengths for deriving microphysical parameters seems not to be new, I still think this study is of value for the community since it is applied to a different instrument and under different conditions than the ones used in previous studies. Especially when only measurements at two wavelengths are available such a method is clearly of value. However, I agree that the referencing should be done correctly, that the study should be better motivated and that the implications for the community should be more clearly stated. In addition, before resubmission the manuscript should be carefully checked for language and technical correctness. The present version is full of mistakes and could have definitely be prepared with more care.

Response: Thanks for your comments. The new manuscript has revisions using all three reviewer's comments and some comments from the community reviewers as well. The response details can be found below.

General comments:

For me it did not become clear why you do everything with two wavelengths if there are more wavelengths available and one could do everything more accurately without making so many assumptions? Or are the observations at several wavelengths only available from SAGE III and not from OMPS? If you have only measurements at two wavelengths from OMPS I can totally understand why you develop the method you are presenting here. If there however are measurements of three or more wavelengths available from OMPS I would wonder why you make analyzing the data more complicated than necessary.

Response: The OMPS instrument has six channels with a wavelength range narrower than that of SAGE. The three-channel technique used in SAGE measurements relies on the wider range of wavelengths—specifically, 449 nm, 756 nm, and 1544 nm, as selected by Wrana et al. (2021). By comparison, the OMPS range of available wavelengths is 510-997 nm. Figure A1, added to the manuscript, shows that the shorter wavelength range makes it more difficult to derive the distribution width from two OMPS color ratios. Relevant discussions have been added to Section 2.2.

I think adding subsections describing the OMPS-LP and SAGE III measurements would be quite helpful for the reader. This is definitely missing in the current version of the manuscript. You cannot expect the reader to be an expert on both instruments. Further, I would suggest that you first describe the comparison to the balloon measurements since this is the main comparison (validation) of your method and then present the SAGE III comparison.

Response: We added a paragraph to Section 2.1 to describe the instrument. "As a space-based limb scattering measurement instrument, OMPS-LP on the S-NPP satellite (Flynn et al., 2014; Jaross et al., 2014), launched in October 2011, operates in a sun-synchronous ascending orbit with a 13:30 Equator crossing time. A second instrument was launched aboard the National Oceanic and Atmospheric Administration-21 (NOAA-21) satellite in 2023. Additionally, the OMPS LP is slated to be onboard the next Joint Polar Satellite System satellites, with JPSS-3 scheduled for 2027 and JPSS-4 for 2032. The OMPS-LP sensor utilizes three vertical slits to measure the Earth's limb by pointing aft along the spacecraft's flight path, capturing the sunlit portion of the globe without directly observing the sun. In this study, we selected the central slit. Our algorithm uses the aerosol extinction coefficient (E) from the L2 OMPS-LP products, V2.1 (Taha et al., 2021), which provides E at six wavelengths: 510, 600, 675, 745, 869, and 997 nm. The OMPS-LP aerosol extinction coefficient products have a vertical resolution of 1.6-1.8 km, reported every 1 km, and provides more than 7000 profiles per day."

In the original manuscript, we had a section that uses SAGE data. That section has been dropped. So there is no need to describe the SAGE instrument. In response to the strong opinions expressed in the community comments, we have decided to remove Section 3.1, which compared of OMPS-LP PSD retrievals with SAGE III/ISS. However, we will restore this section if the reviewers disagree.

Why do you apply your method then to SAGE III? Why is it necessary to have a comparison to another satellite? Could you more clearly state what you try to achieve with this comparison? Couldn't you also use more than two wavelengths from SAGE III to also show what the difference to the more accurate way of deriving aerosol microphysical parameters is?

Response: After considering the suggestions from the community reviewer, we have decided to remove the entire section comparing our OMPS retrievals to the retrievals from SAGE III from this manuscript. While we don't necessarily agree with the community reviewer opinions on the utility of comparing SAGE and OMPS profiles, the confusion about whether SAGE provides independent validation detracted from the overall focus of the paper.

Specific comments:

P1, L15: "....assuming...... width of 1.6". You are not only assuming this with value. You also derive the best result/agreement with this value, thus I think you could/should clearly state this.

Response: Rephrased the sentence to "Our results compare favorably to balloon borne particle size measurements and concentrations under ambient condition and 2019 Raikoke volcanic eruption assuming a log-normal particle size distribution width of 1.6, which also shows the best agreement with this value under these conditions."

P1, L22: Instead of citing the text book from Seinfeld and Pandis (2016) I would suggest to cite Brock et al. (1995) and/or Kremser et al. (2016). Note, stratospheric (sulfuric acid) aerosols form mainly in the tropical upper troposphere (see Brock et al., 1995). Please rephrase/correct the sentence.

Response: We have updated our references to cite more recent measurements by ballon and lidar soundings of stratospheric aerosols. Brock et al., (1995) is included.

P1, L28: What is meant with "black" and "brown" aerosols? Please explain this to the reader. To my knowledge these terms are only used for tropospheric aerosol (e.g soot containing aerosols).

Response: Basically, non-sulfate aerosols provide condensation centers for sulfate. Thus the aerosols are not transparent liquids but are also absorbing.

P1, L28: What is meant with "self loft"? Without explanations this sentence is useless. I would suggest to omit this sentence.

Response: Omitted.

P2, L34: What about SAGE and SAGE II? I think a sentence about this two instruments should be added.

Response: We have slightly expanded our discussion of SAGE I, II.

P2, L37-38: Is the stellar occultation technique also used to measure aerosols? Without any further explanations this sentence is useless and could be omitted.

Response: Deleted it.

P2, L51: Are there currently or in the future other missions measuring aerosols in the stratosphere? Or will OMPS be the only one irrespective of the measurement technique? When was OMPS launched and how long are the measurements expected to continue? Please add here some more information.

Response: Currently, there are two OMPS-LP instruments, one onboard S-NPP, and NOAA-21, with further two to be launched in 2027 and 2032. We added this to section 2.1.

P2, L63-P3, L64: Without any further explanation this sentence is useless. What is the difference between your algorithm and the one from Thomason and Vernier (2013)? What are the differences between the algorithms? What has been changed?

Response: The basic idea behind the algorithm is the same, but we are applying the technique to limb scattering measurements. The sentence has been modified to make that clear.

P3, L69: Add here a section or sections describing the instruments/data used in this study (SAGE, OMPS, balloon)

Response: We added a paragraph to Section 2.1 about the OMPS dataset.

P3, L77: What are N, r_0 and s are. This has not been explained.

Response: We added the explanation to the eq (1a).

P3, L81: Why in this study? How is the color ration defined in other studies? Isn't the color ratio always defined the same way?

Response: Yes, the color ratio can be any two wavelengths divided by each other. Writing it this way is intended to be more clear.

P3, L83: There is no Ångström exponent in Equation 1b.

Response: We have added a discussion of the relation of CR to the Ångström exponent .

P3, L8: Which wavelengths combinations are available and which ones have been used?

Response: Any two wavelengths can be used to calculate the color ratio. In this study, we selected the ratio of 510 nm to 869 nm. The relevant information has been added following Equation (2). The 997nm can also be used, but it does not extend over the whole OMPS measurement period.

P4, L116: How "large"? Please give some numbers.

Response: The large aerosol particles are > 0.4 µm. We added it to there.

P4, L121: Why? Why this value? Do you derive this value from Fig. 1? Provide figure or reference for this value.

Response: The color ratio of clouds is around of 1. Based on Figure 1 and Figure 9 (similar as Figure 3 in Schoeberl et al., 2021), we select color ratio of 1.1 as the threshold.

P5, L134: Using a log-normal distribution is quite common for stratospheric aerosols and thus here you should instead of a specific paper rather cite a textbook as e.g. Seinfeld and Pandis (2016).

Response: Since log-normal is so common, citing a text book seems appropriate to us.

P6, L176: If the error is large for small radii wouldn't this then cause difficulties when plume events are considered where many small particles are produced?

Response: Based on Figure 4, the affected aerosols have a radius smaller than 0.03 µm, which is smaller than typical aerosols even under ambient conditions.

P6, L185-186: In both sentences you cite Chen et al. (2018). One of these citations could be skipped and the grammar of the second sentence should be corrected.

Response: We rephrase to "This approach is similar to that used by Chen et al. (2018). OMPS-LP aerosol retrieval algorithm assumes a gamma aerosol size distribution with fitted parameters of $\alpha = 1.8$ and $\beta = 20.5$, resulting in effective radius r_{eff} of 0.185µm."

P7, L21-202: Not necessarily. You will have both small and large particles. If you make such a statement you should give a reason and/or provide a reference.

Response: The initial eruption will include large particles, but as SO2 oxidizes and sulphate aerosols form, the size distribution shifts to small particles that slowly grow. This evolution is shown in ballon measurements and 2-color ratio retrievals in Wrana et al. (2023). PyroCBs show a more complex size distribution as shown by Fromm et al, (2008).

P7, 208ff: I would suggest to change the order and to first describe the validation with the balloon data and then the verification with SAGE. If you want to keep the current order you should provide a motivation or reasoning why this order is more logical.

P8, L227: Which wavelength pair has been chosen and why? How would the result differ if a different wavelength pair would be used?

P8, L231: Be more precise. Cleary state above which altitudes.

P8, L235: "matched at all altitudes". This is not correct. You do not have a match at all altitudes. Give the altitude range. Further, I see here a better agreement for particle size than for number density.

Response: Regarding to the comments from the community reviewers, we have decided to remove the entire section comparing our OMPS retrievals to the retrievals from SAGE III from this manuscript

P9, L279: If this method does not give you information on bimodal distributions, isn't than that a significant drawback for investigating volcanic plumes? Especially shortly after the eruption the distribution will be bimodal for a certain time. Could you give an estimate in percent how large the deviation for the derived microphysical parameters are?

Response: Yes it is a drawback as implied in our discussion. The percent estimate is highly dependent on the actual distribution e.g. the two modal radii and the width of each mode.

P9, L281: "....... Because the extinction is mostly due to fewer large particles.....". Sentence not clear. Please rephrase.

Response: Revised.

P10, L296: What is meant with "concentration"? A high number of measurements with extinction coefficients 4x10-4 km-1?

Response: Yes. We rephrased that sentence.

P10, L298: Which sizes? Give some numbers.

Response: Added 1.e-4

P10, L300: Also here. Give a number. How small?

Response: Deleted.

P10, L309-310: This is not clear. What has the self-lofting of the plume to do with the composition?

Response: The composition describes the plume in the previous sentence, and the sentence about self-lofting is meant to clarify that the plume may extend above 18 km in height. We rephrased the sentence to avoid any misunderstanding.

P10, L313: Give a number.

Response: Sentence revised to "The aerosol particle radius and concentration plot (Fig. 11d) shows a shift toward larger particles, with sizes above 0.1 μm and with a concentrations > 50 particles/cm3 compared to background."

P11, L316: Is the eruption equal to day 0? If yes, I would write or state this more clearly, e.g. eruption = day 0.

Response: Thanks. We take your suggestion and revised the sentence.

P11, L319: at a later time -> add when exactly

Response: We revised to "The eruption cloud is initially at 50° N, and as it moves southward the aerosols are detected at more southerly latitudes approximately a month later (Gorkavyi et al., 2021; Boone et al. 2022)."

P11, L323: at higher altitudes -> at which altitudes. Add a number.

Response: Added. Revised to "At all latitudes after day 80, the particle radius at higher altitudes (i.e., above 15 km) decreases consistent with gravitational settling (e.g English et al., 2013)."

P11, L323-324: the settling or sedimentation process is several times mentioned, but never explained.

Response: Gravitational settling is a well known process by which aerosols are removed from the stratosphere. Reference added.

P11, L326-327: Why referring here to other studies? Why don't you include a figure showing the same from SAGE?

Response: Our goal of this study focus on OMPS-LP measurements, so we refer to other studies. In addition, in this revision, we deleted the materials that using SAGE measurement in this manuscript.

P11, L328-329: This result is for this study not important and thus, the sentence does not make any sense here.

Response: Deleted.

P11, L333-334: Why is the impact of the distribution width limited? The evolution of the width could be simulated with a box model. I assume that the small particles will quickly disappear (within a few days). You could check the literature for modelling studies of volcanic eruptions. I guess you could find there some numbers how quickly the distribution is back to the background distribution.

Response: This paper (English et al., 2013) shows the small particles spend a couple of months to settle.

P12, L352: Sentence not clear. Check and rephrase. Further, I could not find your statement in Wrana et al. (2023). How did you derive this width? From the figures?

Response: We corrected the reference. Here is the revision. "Based on the in situ measurements from Baron et al., (2023), we assume a log-normal particle size distribution width of 1.2 for this eruption event, which is also consistent with SAGE III/ISS measurements (Duchamp et al., 2023)."

P12, L365: Don't just write larger. Give numbers.

Response: The settling rate increases with particle diameter according to the Stokes parameters. Since our retrievals are sensitive to particles < 0.5 µm larger means at the large end of the retrieval.

P12, L366: Which settling rate? You mean the sedimentation rate of the particles. Do you mean that particles < 0.5 µm sediment out?

Response: It means the aerosol plume setting rate is equivalent to the downward gravitational settling of aerosols with diameters of 0.5 µm. We revised that sentence to "Both Legras et al. (2022) and Schoeberl et al. (2022) argue that the aerosol distribution settling rate is characteristic of 0.5 µm or larger particles when assuming downward gravitational settling.".

P12, L374-375: Sentence not correct. Please check and correct.

Response: Revised to "The scattering angle variation range of 85o - 130° during the analyzed time period (Figure A6) indicates a less than 15% uncertainty for a 40% phase function error."

P13, L378-382: This paragraph is giving a motivation for the study and thus this paragraph should rather appear in the introduction than in the summary and conclusion section.

Response: Sentence moved to introduction.

P13, L387: Clearly state here that you refer here to log-normal distributions with one mode.

Response: Added.

P13, L390-391: The two sentences should be rephrased and maybe combined. Add also why a CR of 1 is problematic.

Response: Revised to "The algorithm cannot distinguish radii greater than ~0.4 µm because their color ratio (E510/E879) approaches one. Such particles are usually identified as large aerosols or aerosols mixed with clouds (Schoeberl et al., 2021)."

P13, L403-405: I think before you stated the opposite. Further, the second sentence starting with "We examined……." is incomplete.

Response: Revised to "We examined how variations in retrieved aerosol radius change with different assumptions about distribution width by comparing to balloon measurement."

P13, L406-408: Add more details. Under which conditions does this happen?

Response: We added details as follows "The size range can vary from 0.05 to 0.25 µm by adjusting the distribution width from 1.2 to 1.8, assuming a particle size of 0.1 µm with a distribution width of 1.6."

P14, L420: What are the future implications? For what can the method be applied? The future OMPS measurements? Nevertheless, during volcanic eruptions you have large uncertainties and you need to rely on other studies to derive your input values?

Response: As discussed in the introduction, this study focuses on testing whether OMPS-LP measurements can be used to retrieve particle size and number density. The results are reasonable for background conditions and the 2019 Raikoke volcano. However, for the 2022 Hunga-Tonga eruptions, the distribution width needs to be updated based on additional inputs.

Reference list: Check the style. Some journal names are written out. others not. Same with the author names. In some cases the entire first name is written, in most other cases the first initial.

Response: Thanks. Updated.

Check the ACP guidelines and prepare your reference list accordingly. Further, there are some references misplaced as e.g. Kremser and Yue and Deepak. The Box and Deepak paper is listed in the reference list, but not cited throughout the manuscript.

Response: Updated.

Figure 9 and 10: Add a legend to the figure. Is there no uncertainty range for the CPC data given or are these so low that these are not visible? What are the black zigzag lines on the right and left corners of the figure?

Response: We explained the two colored lines in the caption. The uncertainty range for the CPC data is too low to be visible. The black zigzag lines represent one of the bi-modal distributions.

Figure 11: Wouldn't it make much more sense to compare the background at 30° -60°N with the distribution during Raikoke at 30°-60°N and the background at 30°S-15°N to the 30°S-15°N distribution during Hunga-Tonga? I really think the same regions should be compared.

Response: Under background conditions, the aerosol retrievals are not significantly different, so we selected the globe to display the results.

Figure 14: I think it would be better to use black instead of red lines. Also omitting some lines would be helpful, e.g is the 26 km line really necessary? I think this one could be omitted. Why is here the eruption on day 15 and not on day 0 as before?

Response: Any color choice is going to have a downside. Black lines would disappear at the top the figure, for example. We think the lines are visible enough. The day number is the day number of the year in the Hunga case.

Technical corrections we have also made:

P1, L20: Introduce the abbreviation "Cb".

P1, L20: Reference of Kremser et al. (2016) is missing in the reference list.

P2, L42: Full stop before reference of Taha et al. (2021) obsolete.

P2, L57: PyroCB -> pyroCb. Use a consistent writing.

P3, L65: In the next section, we detail -> In the next section we describe in detail

P3, L79: scattering measurements -> scattering measurement

P3, L80: is the same as Wrana et al. (2021) Eq. 2 -> is the same as Eq. 2 in Wrana et al. (2021)

P4, L97: Add "the" -> we simulate the scattering....

P4, L103: show the how CR -> show how the CR

P4, L118: Add "a" -> We found that selecting a CR

P4, L119-120: Check sentence and correct sentence.

P5, L137-138: Either use singular or plural.

P6, L171: PyroCB -> pyroCb

P6, L186: Comma obsolete (reference of Chen et al.)

P6, L188: Comma obsolete.

P7, L197: "CR (510/869)" here you write it without adding nm. In other occasions nm is added. This should be done more consistently throughout the manuscript.

P7, L210: using the same algorithm -> the above described algorithm

P8, L246: comparation -> comparison

P8, L246: Add "as shown" -> during Raikoke volcano eruption as shown in Fig. 8

P8, L248: Add "the" -> the bias

P8, L249: Add "the" -> "the comparisons" and move references at the end of the sentence.

P9, L275: settle out -> sediment

P10, L283: Use comma instead of writing twice "and" -> Background Aerosol Radius, Concentration and Volcanic Perturbations.

P10, L285: Add "conditions" so that it reads "background conditions"

P10, L288: Thompson -> Thomason

P10, L287: Move "Figure 11" before "(a, c, e)" so that it reads "The extinction coefficient vs CR is shown In Fig. 11 (a, c, e) and radius vs concentration distributions for these three situations in Fig. 11(b, d, f).

P10, L291: Put a, c, e in parenthesis -> (a, c, e)

P10, L296: One "shows" obsolete. Write "background aerosols" instead of just "background".

P10, L301: aerosols -> aerosol and density -> densities

P10, L302: Section 3 -> Sect. 3

P10, L 306: Comma before reference of Gorkavyi obsolete.

P11, L318: screen -> screening

P11, L320: add "altitude" after 10-15 km

P11, L327: add "is" and particles should read particle -> Our result is also consistent with the larger particle radius......

P11, L332: After the comma "The" should be "the".

P12, L350: Feb.-March -> February to March

P12, L353: Add "is"-> which is consistent

P12, L355: Delete "is" before represents.

P12, L372: Add "the"-> the radius

P12, L373: Add "the"-> the aerosol radius

P12, L372: Add "altitude"-> the altitude range

P12, L374: Add "of"-> conversion of SO2

P13, L390: radius -> radii

P14, L416: Delete "the" before "median radius".

Figure 2 caption: Add "nm" after 501/869. Use a consistent writing style throughout the manuscript.

Figure 5 caption: plot -> Plot and add space before and after "="

Figure 6 caption: Add space before and after "="

References:

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Kremser, S., et al. (2016), Stratospheric aerosol—Observations, processes, and impact on climate, Rev. Geophys., 54, 278–335, doi:10.1002/2015RG000511.

Response: added these references

Response: Thank you so much for your careful review. We have corrected the text as suggested.

References:

Chen, Z., Bhartia, P. K., Loughman, R., Colarco, P., and DeLand, M.: Improvement of stratospheric aerosol extinction retrieval from OMPS/LP using a new aerosol model, Atmos. Meas. Tech., 11, 6495–6509, https://doi.org/10.5194/amt-11-6495-2018, 2018.

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