Responses to Community comments

Thank you to Dr. Knepp for these comments. Our responses are listed in blue below.

The authors present a comparison of SAGE, OSIRIS, and MAESTRO extinction products (including derived products like stratospheric aerosol optical depth and Angstrom exponent) and present a method of correcting MAESTRO extinction to better match SAGE III/ISS. They developed a model as a function of wavelength, altitude, and latitude to transform the MAESTRO data to better agree with SAGE III/ISS.

First, the good! I find this paper to be scientifically interesting, and I see potential utility in this method. If this product can be validated (or at least evaluated to determine the quality and consistency of its performance) then it could be a valuable tool in filling the "SAGE gap". I thank the authors for presenting this interesting study.

Thank you!

Second, the concerns. The paper would benefit from a thorough proofreading for the sake of clarity. It's not poorly written, there are just several sentences that do not make sense and several details that are not clear enough to enable the reader to reproduce the methodology. While I have tried to address some of these factors below, I suspect the authors will make several more corrections after a thorough proofreading.

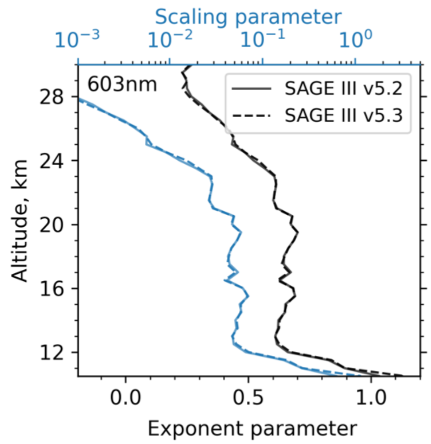
We do believe our edits in response to the reviewer and community comments have improved the readability of the manuscript, and we have proofread the revised manuscript to improve word choice in many instances.

I have 3 major concerns with this paper as written:

1. The authors used v5.2 of the SAGE III/ISS data product while v5.3 is available. This is not a big deal, per se. However, v6.0 is scheduled for release in January 2025 and the changes between v5.3 and v6.0 are aerosol-centric. For example, the so-called seagull effect (i.e., a low bias in the 520, 601, and 676 nm channels) has been nearly completely eradicated. This will undoubtedly impact some of the authors' corrections.

We have performed a quick check to see how using SAGE III v5.3 data would change our analysis. The figure below shows the parameters of a power law fit between MAESTRO and the two versions of the SAGE III data (v5.2 and v5.3). It shows that there is a nearly identical result with either v5.3 or v5.2. We checked other wavelengths and they also show negligible difference between the two SAGE III data versions.

It is interesting to learn that v6.0 data is now available. It will be interesting to include version 6 in future work. That being said, we predict that changes in SAGE III/ISS aerosol retrievals will be relatively small compared to the large biases we have highlighted in the MAESTRO data (up to a factor of two difference compared to SAGE III under perturbed conditions), and we suggest that since the aim of our study is to assess the broad utility of the MAESTRO data, and that changing the version of SAGE III/ISS in our comparison is unlikely to change the main conclusions of our study.



2. The authors tended to focus more on lower altitudes (e.g., 12-18 km, Figs. 8 & 9) where the seagull effect was less prominent. If the authors insist on using v5.2 or v5.3 then it would greatly benefit the reader to see how your correction method performed at altitudes that are more susceptible to the seagull (i.e., 20 - 30 km).

Indeed, as discussed in the manuscript, we did focus on lower altitudes where aerosol extinction has its largest signal, and where MAESTRO inter-wavelength correlations show greatest values. We understand some readers may be interested in the comparisons at higher altitudes, and have updated Fig. 9 (revised manuscript) with the vertical axis extended to 30 km compared to 25 km before.

3. The paper would benefit from a more systematic and thorough presentation of how this method improves the agreement between MAESTRO and the other instruments (including more discussion with the agreement with SAGE II). I think this is a missed opportunity to highlight the impact of your work. Something that shows how the overall statistics (e.g., median percent difference, median absolute deviation, etc.) improved (even breaking the samples into “background” and “elevated” aerosol conditions). I don’t want to dictate how this is done, these are just suggestions; I am happy to discuss possibilities offline if you prefer.

We agree this is useful idea, and we have addressed this comment with two additional figures.

First, Fig. 2 of the revised manuscript shows the results of a more traditional comparison between MAESTRO and SAGE III, based on collocated measurements, for the full overlap period, as well as for a subset representative of "background" aerosol conditions. This plot and the discussion related to it provides evidence of the scatter in the MAESTRO raw measurements, and motivates the use of robust metrics like the median.

In terms of quantifying the impact of the correction procedure, we include Fig. 10 in the updated manuscript, also reproduced below. This figure shows the result of using a "coincident" data comparison of MAESTRO with SAGE III, and shows the median percent difference before and after application of the correction scheme. The correction works best for the 603 and 675 nm wavelengths, reducing the percent bias down to less than about 25% below 24 km. While at longer wavelengths the correction works less well, it generally decreases the median bias at all altitudes and generally reduces the median bias to less than approximately 30%. Further work may well improve upon our methods, but we believe this is a useful proof of concept for the MAESTRO data correction we have introduced here.

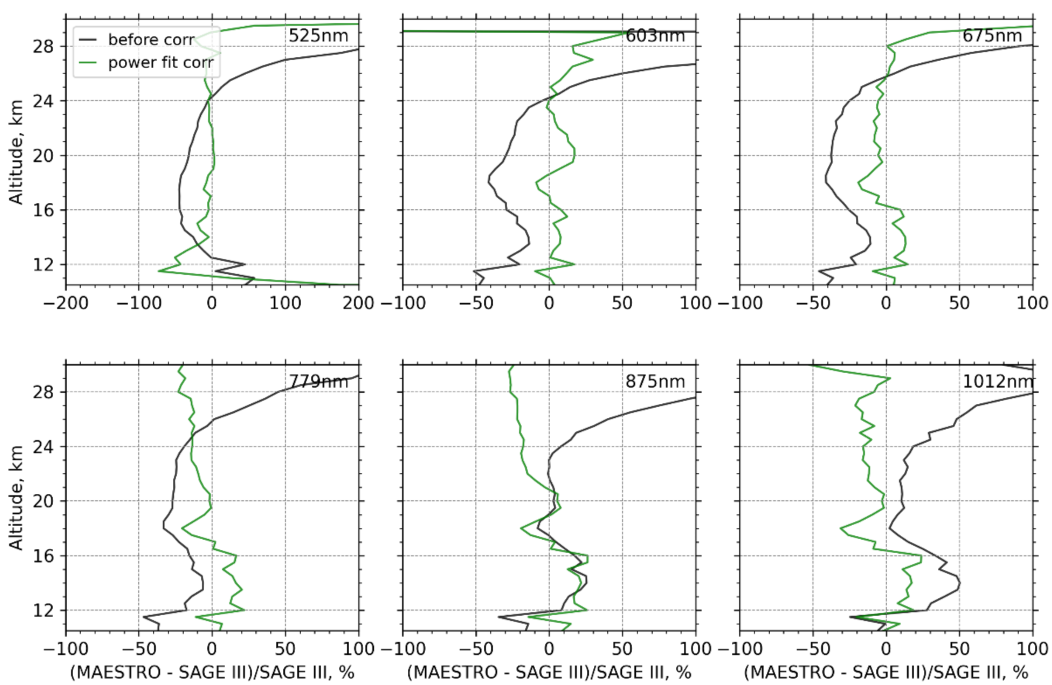


Figure 10: Coincident comparison of MAESTRO aerosol extinction measurements with SAGE III. Lines show the median of differences computed as (MAESTRO – SAGE III)/SAGE III. Black lines show the median of differences for the raw data, while green lines show the same for the data after the correction of Sec. 4.1 is applied to the MAESTRO data

General Conclusion

This is an interesting paper and I believe it should be published after the authors have had an opportunity to make some modifications. While I listed several concerns with the paper above, and more detailed concerns/corrections below, I do not believe any of these would preclude publication. If I could insist on 1 change to this paper it would be the improvement suggested in the 3rd bullet above. Why? Because this will provide the greatest benefit to the reader for understanding the value of the authors' work. That said, I accept that these changes will be made at the authors' and editor's discretion.

Specific Comments

Line 52 you state that particle size distribution information is available within multi-wavelength occultation measurements. This is true, but this is generally overly simplified in the literature and too often important details are neglected. We addressed many of these challenges, and the impact of various assumptions, within a recently-published paper that you may find interesting and useful (https://amt.copernicus.org/articles/17/2025/2024/).

Thank you for pointing us to this study which does very nicely spell out the challenges involved in retrieving particle size information from spectral measurements. We have modified the text here to acknowledge the challenges involved with reference to the suggested paper.

Line 136: Why not use v5.3? It probably makes minimal difference for the aerosol product, but if you have a reason for 5.2 over 5.3 it would be interesting to hear. As an aside, v6.0 will soon be released (January 2025), which has noticeable changes to the aerosol product (e.g., the "seagull" effect has been largely corrected) and you may wish to re-evaluate your correction factors after that release.

As written above, we have checked and see that the change in version 5.2 to 5.3 does not affect our comparison. While the changes included in version 6 may quantitatively affect the comparisons, we are confident that such changes will not change our main qualitative conclusions, which are that while there are substantial challenges with the MAESTRO data, that there is useful information therein. We hope that future work will be able extend our work by including new data versions.

Did you make any corrections to the SAGE III/ISS 520 nm channel? Ray Wang showed an offset in that channel as well as 601 and 676 nm (Fig. 3 in https://doi.org/10.1029/2020JD032430) and we discussed our correction method using a simple power-law correction (Eq. 2 in https://doi.org/10.5194/amt-15-5235-2022). I am not saying these papers must be cited; I provide them for your reference.

We have not applied any correction to the SAGE III data. We have added text in Sec. 2.1.4 to make this clear in the manuscript.

Line 159: The 603 and 675 nm channels (520 to a lesser extent) for SAGE III are significantly impacted by ozone and should be used cautiously. Maybe this does not impact your analysis, but it's worth noting. This should all be resolved in v6.0.

These biases in SAGE III are now included in Sec. 2.1.4 and discussed again in the conclusions.

Starting on line 159: "During background stratospheric conditions…" I do not understand what the author's are trying to communicate here. Please consider rewording?

We have reorganized these sentences to more clearly communicate the issue here. The text now reads "The small differences in wavelength values between the two instruments is not expected to produce significant differences in the extinction values: during background stratospheric conditions (relatively undisturbed by volcanic eruptions or wildfires), the difference in extinction is expected to be less than 6% for the pair having the largest separation in wavelengths (779 nm and 756 nm) and less than 3% for all other wavelength pairs."

Line 173: "…525 nm is excluded, details in Sect. 3.1…" It is unclear why the 525 nm channel is excluded and Sect. 3.1 does not shed light on this either (at least it is not clear to me). This channel looks no worse than any other; why exclude it? Can you please clarify in the paper?

The MAESTRO bias compared to SAGE III varies non-monotonically with height compared to the other wavelengths—also the correlation between the two instruments is rather weaker at 525 nm compared to the other wavelengths. We have edited the text here as well as in Sec. 3.1 to make these points and the motivation for excluding 525 nm from the AE calculation more clear.

Fig. 3: First off, the authors highlighted the differences at low altitudes (e.g., around 12 km, or so). I am not so concerned about this; did you filter for clouds? If not, then I suspect cloud contamination. Mahesh Kovilakam has a cloud-filter algorithm for SAGE III/ISS (https://amt.copernicus.org/articles/16/2709/2023/) that should be part of the v6.0 release in January (it is currently available in a separate repository cited in his paper) and could be used in your current analysis.

Cloud screening is not part of the MAESTRO data processing chain, nor is screening explicitly applied to the MAESTRO aerosol retrievals used in this work. This point is included in our description of the MAESTRO aerosol data (Sec. 2.1.1), and whether or not cloud screening is used for comparison data sets is listed in the respective descriptions. Nonetheless, since many of our comparisons rely on median values within latitude and month bins, it is likely that many of the retrievals strongly affected by clouds are excluded from our analysis. This point is mentioned in Sec 2.3.

If MAESTRO data were to be used in future scientific studies, application of a cloud screening procedure, for example similar to that described by Kovilakam et al. (2024) should be investigated to better understand their impact.

Fig. 3, continued: My main concern with this figure is the similar behavior between the 525/603/779 channels. The SAGE 602 channel was significantly impacted by ozone in v5.2 and v5.3 (biased low by 10-40% depending on latitude/altitude), so I would expect the percent difference in your plot to favor MAESTRO (i.e., MAESTRO should be greater than SAGE…or at least less negative), but it looks like the percent difference becomes more negative. Further, the offset changes sign for 1021 nm throughout much of the atmosphere. Overall, this makes it difficult to interpret and I wonder how well behaved the MAESTRO extinction spectra are (sorry, but I know almost nothing about MAESTRO). Can the authors please comment on this? Should we expect the aerosol spectrum to be better behaved?

This work is really the first to do any systematic comparison of MAESTRO aerosol extinction with other data sets. Due to some challenges with the instrument and data analysis—which we now mention explicitly in the manuscript—we are not terribly surprised by the fact there is significant scatter in the MAESTRO data and biases with respect to other instruments. We hope that this work will motivate future work to look more carefully at the sources of bias and improve the MAESTRO retrieval or post-processing.

Fig. 3, final comment: The color scales are difficult to read (this applies to all contour/meshgrid plots in the paper). The authors claimed that the coefficient of correlation was 0.6, but I cannot infer this from the figures. Have you evaluated different color maps and/or limits? As is, I cannot interpret these plots because I cannot distinguish between the various shades. I realize creating these types of figures is quite challenging, so I am sorry to complain about this, but I have a very hard time reading these. Just a suggestion.

The colorbars in Figure 4 (revised manuscript) have been adjusted to make it easier to read the magnitudes of the anomalies plotted.

Line 257ff: “As aerosol content of the stratosphere varies…” This sentence reads as if composition plays no role. We demonstrated the impact of composition (smoke and sulfuric acid content) in our paper (https://amt.copernicus.org/articles/17/2025/2024/) and Chris Boone demonstrated variability in the sulfuric acid content (https://doi.org/10.1016/j.jqsrt.2023.108815). Because your analysis involves background, volcanically perturbed, and major wildfire events, this sensitivity should be acknowledged.

We have edited the beginning of this section to acknowledge that indeed aerosol composition (especially wildfire smoke content) will affect the AE in addition to size distribution. This section mostly discusses the AE itself, without interpretation of it as a reflection of the size distribution. Only in the final two sentences of the section do we link our AE calculations with prior studies who have interpreted spectral changes with size distributions.

Fig. 6 It is unclear how the AE was calculated. I understand this was discussed in Eq. 1 in Section 2.3, but I did not find that section to be helpful in understanding what you did. Could the authors please clarify how the AE was calculated (was it multi-spectral?) and what wavelengths were used?

We have edited the text after Eq. 1 to clarify our method:

Extinction measurements at five wavelengths (e.g., 603, 675, 779, 875 and 1012 nm for MAESTRO) are used to calculate AE for MAESTRO and SAGE III respectively at each altitude of each profile, by performing an ordinary least squares regression of $\ln(\beta)$ on $\ln(\lambda)$: the slope of this regression is the Ångström exponent.

Line 396: “We note that the bias reported here in MAESTRO measurements is specific to the version 3.13 dataset and would likely be different with updated processing in the forthcoming data versions.” This raises several questions:

• When is the next version scheduled for release?

• Do you have any estimate on how much this may change?

• Why not delay publication until you have the next MAESTRO version and v6.0 of SAGE III/ISS?

MAESTRO version 4 is now available. However, while ozone and a total optical depth product are available, aerosol extinction is not. A data description document mentions this is because of noted biases in the extinction data. Therefore, the version 3.13 aerosol extinction data described in our manuscript is the most up-to-date publicly available MAESTRO aerosol product. We do not know when or if there will be a subsequent aerosol product released. We hope that our study will encourage the investment of further resources into MAESTRO-related work.

Line 405: “Information about stratospheric aerosol particle sizes in the lower stratosphere can be obtained from the MAESTRO AE values…” This will be challenging because of MAESTRO’s limited spectral range. Our group inferred PSD values from SAGE II using 2 channels (525/1020; https://amt.copernicus.org/articles/17/2025/2024/) and it does not appear unreasonable, but the certainty definitely goes down. You may be able to use MAESTRO’s 755 nm channel to tease out some more information, but this would require a lot of caution. I am just urging caution with your current statement. However, if you only intend to make general statements (e.g., the particles got “bigger” or “smaller” after an eruption), then what you have is a generally safe statement. Would you please clarify?

We have modified the start of this final paragraph to be more clear: we mean only that the AE calculated from MAESTRO shows some physically plausible variations after eruptions and wildfires, indicating there may be some value to the multispectral MAESTRO extinction data. Actual retrieval of size distribution parameters and the associated uncertainties in those parameters is certainly still a potential task for future work.

References:

Knepp, T. N., Thomason, L., Kovilakam, M., Tackett, J., Kar, J., Damadeo, R., and Flittner, D.: Identification of smoke and sulfuric acid aerosol in SAGE III/ISS extinction spectra, Atmos. Meas. Tech., 15, 5235–5260, https://doi.org/10.5194/amt-15-5235-2022, 2022.

Kovilakam, M., Thomason, L., and Knepp, T.: SAGE III/ISS aerosol/cloud categorization and its impact on GloSSAC, Atmos. Meas. Tech., 16, 2709–2731, https://doi.org/10.5194/amt-16-2709-2023, 2023.

Wang, H. J. R., Damadeo, R., Flittner, D., Kramarova, N., Taha, G., Davis, S., Thompson, A. M., Strahan, S., Wang, Y., Froidevaux, L., Degenstein, D., Bourassa, A., Steinbrecht, W., Walker, K. A., Querel, R., Leblanc, T., Godin-Beekmann, S., Hurst, D., and Hall, E.: Validation of SAGE III/ISS Solar Occultation Ozone Products With Correlative Satellite and Ground-Based Measurements, J. Geophys. Res. Atmos., 125, e2020JD032430, https://doi.org/10.1029/2020JD032430;PAGE:STRING:ARTICLE/CHAPTER, 2020.