Replies to community comment

Comment: This study is an interesting one, but ultimately its messaging and perhaps methodologies might be misguided.
I agree with Referee 2, that, if the authors find an extreme case to be too limiting, that perhaps a range of injection mass rates should be explored.

Reply: Thank you for the comments. We assume that this refers to reviewer 3, since no comments from reviewer 2 are available for the time being. In agreement and in line with the comments and suggestions made by reviewer 3 on this point, we have added the following:

We added the following to the introduction:
"This injection rate is analysed as a deliberately high, upper-end SAI scenario to probe the zero-transmission problem under conditions where radiative forcing effects are most pronounced. Although it appears to be a comparatively high emission rate, the upper limit in the context of possible SAI applications depends, for instance, on the specific goal, such as specific radiative forcing effects."

We added the following to the discussion:
"The injection rate of $30\,\mathrm{Tg\,S\,yr^{-1}}$ was selected as a deliberately high, upper-end SAI scenario to probe the zero-transmission problem under conditions where radiative forcing effects are most pronounced. This enables an assessment of whether and how zero transmission may emerge in a hypothetical large-scale deployment. While ambitious, injection rates of this magnitude have been discussed in previous SAI modelling studies (e.g., Niemeier and Timmreck, 2015; Laakso et al., 2022). The injection rate lies at the upper end of proposed scenarios, however, potential upper limits in SAI applications depend on the specific objectives, for instance the targeted radiative forcing."

As well as:
"The $10\,\mathrm{Tg\,S\,yr^{-1}}$ injection was selected as a Pinatubo-like reference (the 1991 eruption injected approximately 20 Tg SO_2), while emphasising that volcanic eruptions represent impulsive rather than continuous injections. This lower rate allows examining whether and to what extent the zero-transmission problem occurs at more moderate injection rates and to determine the minimum wavelength required for the latitude range of the injection, since this latitude range is where aerosol loading is highest (for the month analysed here) and the possible zero-transmission effect is most pronounced, making it the region of greatest concern for this problem."

Comment: One of the issues I have here, is that the "solar occultation" retrieval algorithm is a nonlinear inversion technique that requires an a priori under an extreme case and subsequently demonstrates the lack of efficacy of the technique under these circumstances. However, a proper solar occultation retrieval is a well-posed linear problem that does not require an a priori, so it's possible the solution would be better behaved.

Reply: It is correct that our results demonstrate challenges under extreme conditions. However, this is precisely the point of our investigation: to characterise the limitations and performance boundaries of the retrieval under a challenging scenario (high injection rates, ”zero transmission” and wavelength threshold). The retrieval problem is ill-posed due to noise, and the need to constrain the solution in regions with low sensitivity (e.g., at altitudes with poor signal-to-noise ratio or where transmission approaches ≈ zero). Therefore, the use of an a priori and its associated error covariance is not a limitation of the method but an essential part of the regularisation that stabilises the solution while minimising the influence of the prior where the measurement provides sufficient information.

Comment: Additionally, I would like to point out that the ”zero transmission” problem very much depends upon the instrument's capabilities. While it is true that SAGE II could not see through the injected aerosol layer from Mt Pinatubo, ultimately what dictates this is the instrument's signal-to-noise ratio in its measurements and its maximum dynamic range. It is entirely possible, using currently available technology, to achieve meaningful measurements through much higher maximum line-of-sight optical depths than what SAGE II was capable of.

Reply: We agree with this comment. In line with the comments and suggestions of Reviewer 3 we added the following to our manuscript:

We added the following to Sect. 2.2.1:

”Vertical field of view, and sampling assumptions represent a typical satellite solar occultation instrument and the resulting error characteristics are likely transferable to other occultation sensors with comparable vertical resolution and pointing performance, provided that a similar retrieval approach is applied.”

And in line with this comment, we added the following:
”Better detector technologies could potentially cover a wider dynamic range with low noise, which could lead to a reduction of the zero transmission problem.”

Comment: I think the high-level message is clear and unquestionable: Namely that an instrument can make measurements when the signal is not saturated. Since aerosol extinction is naturally lower at longer wavelengths, it is easier to measure under extreme loading conditions than at lower wavelengths. Of course, it is harder to measure under background or slightly elevated conditions. Generally speaking, there is value in aerosol measurements across the visible and IR spectra. I also believe it is worthwhile to discuss the potential limitations of different observation techniques under different atmospheric scenarios. However, ultimately the capability to make measurements depends upon the unique configuration and capability of the individual instrument. One can certainly perform such a study for an already existing instrument with known performance parameters, but one cannot make a blanket statement about a technique in general without testing the range of what is currently and technologically possible.

Reply: Thank you for the comment. We agree that the capability to obtain reliable aerosol measurements ultimately depends on the specific characteristics and performance of a given instrument.

However, our intention was not to make a blanket statement about all potential solar occultation instruments, but rather to provide an assessment within a clearly defined simulation framework. As outlined in the Methodology section, the instrument specifications used for our simulations were not arbitrary but were chosen based on realistic parameters representative of existing typical solar occultation instruments. The results therefore illustrate the expected performance under these assumed conditions, and we explicitly emphasise the assumptions made, when analysing our results.