Replies to comments by reviewer 3

Comment: The manuscript addresses one aspect of geoengineering—enhancement of the stratospheric aerosol layer to mitigate climate warming. The authors analyze the detectability of stratospheric aerosols formed as a result of sulphur dioxide (SO_2) injection into the stratosphere. The topic is timely and relevant, and the paper could be suitable for publication after some major issues are addressed.

Reply: We thank the reviewer for his/her constructive and helpful comments. We tried to answer every comment in an appropriate way.

Comment: While the paper is generally well written, further clarification is necessary to ensure the content is accessible to a broader audience beyond specialists in stratospheric aerosols.
The numerical experiment involving SO_2 injection should be clearly described in a dedicated section. Specifically:
How was the injection distributed over time? Was it a single injection of 1–2 Tg, or was the amount spread uniformly over the course of a year? The terms "initial phase" and "quasi steady-state phase" should be explicitly defined in this context.
The key distinctions between the geoengineering experiment and isolated volcanic eruptions should be emphasized more clearly.

Reply: Thank you for the comment. In the process of addressing the comments from reviewer 1, we added the following illustration and further explanations:
We performed a single simulation over several years. The injections for SAI ran for 15 years. For our study, we took three years at the end of these simulations and averaged them over time. This is similar to previous simulations and publications, e.g. Niemeier et al. (2020) and Weisenstein et al. (2022), where three-year averages were also used. Fig. A1 illustrates the time series of the global sulphate burden showing that the steady-state phase is reached after two years. We used the early phase to include sulphate level below the steady-state level to see if we could detect sulphate even earlier. At this point, the goal was not to use a stabilized result. The aim was to find a lower threshold at which detection would be possible.

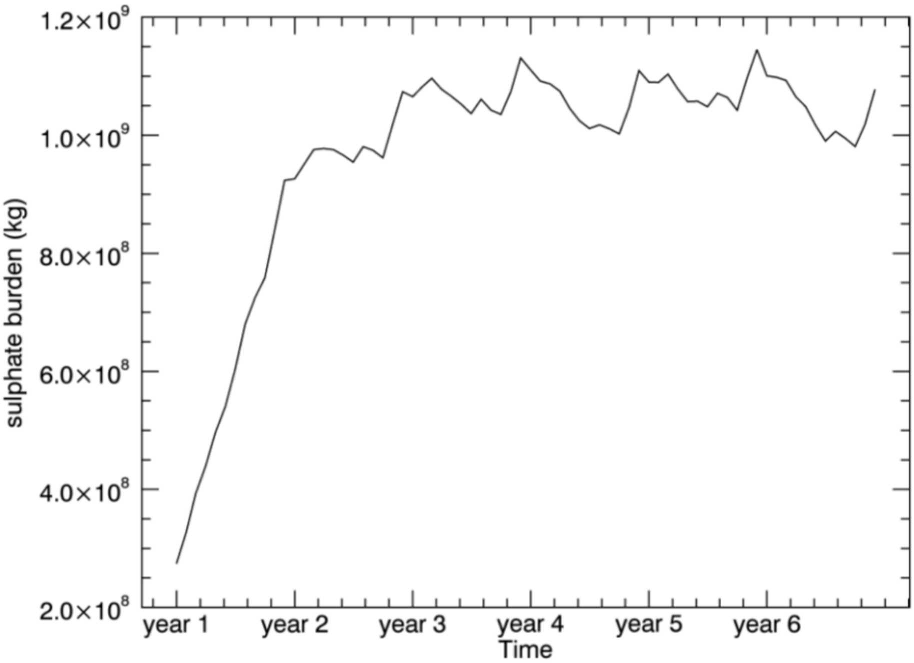

Figure A1. Monthly mean sulphate burden in kg over time (2005 – 2010) for 1 Tg S/y, showing the differences between the two-year initial phase and the quasi steady-state phase.

As described in the ECHAM section of the preprint, these are continuous injections at an altitude of 60 hPa.

Comment: The authors argue that the injection of 1–2 Tg/y of SO_2 is relatively small, and therefore, if such an amount is detectable, larger quantities should also be detectable. However, they should clarify what they consider to be the upper limit of SO_2 injection. Additionally, they should discuss how detectability changes with increased injection amounts, particularly in light of the potential zero transmittance in occultation geometry, as observed shortly after the Pinatubo eruption.

Reply: The upper limit of the injection amount depends on the specific goal. Depending on the model, 8 to 16 Tg SO2 per year would be required to cool the Earth's surface by 1 degree on a global average (Niemeier, 2023).
We assume that with larger injection rates the detectability increases, the aerosol extinction signal becomes larger and the total errors smaller (compare 0 Tg S/y $\rightarrow$ 1 Tg S/y $\rightarrow$ 2 Tg S/y) up to a certain amount, possibly about 20 Tg (as in the case of the Pinatubo eruption, although a volcanic eruption does not represent continuous injections). We cannot prove it at this point, and it is outside the scope of this study, but we agree that 'zero transmittance' is a potential problem.
However, we note that the zero transmittance problem does not mean that solar occultation measurements are entirely useless. They cannot provide aerosol extinction below a certain altitude, but at slightly higher altitudes they will still work and provide information on enhanced aerosols levels. In the case of Pinatubo, SAGE II measurements were always available at altitudes above about 24 km.
We added this points to the discussions.
Referring to: Niemeier, Ulrike. (2023). Eine künstliche stratosphärische Schwefelschicht: Der ein-

fache Ausweg aus dem Klimaproblem? (Version 1. Aufl.). In WARNSIGNAL-KLIMA: Hilft Technik gegen die Erderwärmung ? Climate Engineering in der Diskussion (pp. 243–249). Hamburg, Germany: Wissenschaftliche Auswertungen in Kooperation mit GEO Magazin-Hamburg. http://doi.org/10.25592/uhhfdm.12856

Comment: It would also be beneficial to model the particle size distribution and its temporal evolution. This would allow for the calculation of transmittance at wavelengths longer than 550 nm and help overcome the issue of transmittance saturation.

Reply: Thank you for the idea. We agree that this is of course a potential problem, but as explained above, it is not relevant for the present study. For the analysis of a 'Pinatubo scenario' we agree it would be a problem, but that is not the case here. We will investigate the effects of S-injections on the particle size distribution of sulphate aerosols - and the effects on detectability - in another study.

Comment: Throughout the manuscript, different names are used for the circulation model—ECHAM, EHAM5-HAM, MAECHAM5, and MAECHAM5-HAM. If these refer to the same model, a consistent name should be used. If they are different, the distinctions should be explained.

Reply: We adapted this. It is now called MAECHAM-HAM at the first mention (and in the abstract and in the introduction) and thereafter ECHAM.

Comment: Table 3: Please justify the use of a 2% value for error estimation.

Reply: In the process of addressing the comments of reviewer 1, we added the relevant literature to Table 3. For the temperature and pressure uncertainties: e.g.: Nowlan et al. (2007) and Langland et al. (2008). For the total ozone column: e.g.: Garane et al. (2019) and the pointing error: e.g.: Bramstedt et al. (2012).

Nowlan, C., McElroy, C., and Drummond, J.: Measurements of the O2 A-and B-bands for determining temperature and pressure profiles from ACE–MAESTRO: Forward model and retrieval algorithm, Journal of Quantitative Spectroscopy and Radiative Transfer, 108, 371–388, 2007.

Langland, R. H., Maue, R. N., and Bishop, C. H.: Uncertainty in atmospheric temperature analyses, Tellus A: Dynamic Meteorology and Oceanography, 60, 598–603, 2008.

Garane, K., Koukouli, M.-E., Verhoelst, T., Lerot, C., Heue, K.-P., Fioletov, V., Balis, D., Bais, A., Bazureau, A., Dehn, A., Goutail, F., Granville, J., Griffin, D., Hubert, D., Keppens, A., Lambert, J.-C., Loyola, D., McLinden, C., Pazmino, A., Pommereau, J.-P., Redondas, A., Romahn, F., Valks, P., Van Roozendael, M., Xu, J., Zehner, C., Zerefos, C., and Zimmer, W.: TROPOMI/S5P total ozone column data: global ground-based validation and consistency with other satellite missions, Atmos. Meas. Tech., 12, 5263–5287, https://doi.org/10.5194/amt-12-5263-2019, 2019.

Bramstedt, K., Noël, S., Bovensmann, H., Gottwald, M., and Burrows, J. P.: Precise pointing knowledge for SCIAMACHY solar occultation measurements, Atmos. Meas. Tech., 5, 2867–2880, https://doi.org/10.5194/amt-5-2867-2012, 2012.

Comment: Equations:
Is the sigma (σ) in Equation 7 the same as r in Equation 6? If so, use consistent notation.

Reply: Thank you for the comment. Eq. 7 is a standard expression for determining the total error based on the parameter errors. We understand that the equation can be misinterpreted at first glance and without context, so the text below (line 153) explains: 'The individual errors (relative differences) (compare Eq. 6) of a certain height were added up quadratically.'.

Comment: Compare your aerosol extinction error estimates with those from SAGE III aerosol extinction retrievals.

Reply: Thank you for this idea. It is difficult to make a comparison, as the present study considers different phases (quasi steady-state phase and initial phase) and different injection rates (1 Tg S/y, 2 Tg S/y and background), which means that only a comparison of the order of magnitude is possible. Wrana et al, 2021 (Tab. 1) shows the extinction measurement uncertainties at 520 nm averaged from June 2017 to December 2019 at an altitude of 20 km (SAGE III/ISS level 2 solar aerosol product) with a value of 5.66 %. The total errors for 1 and 2 Tg S/y at 20 km are of approximately the same order of magnitude for the northern and southern mid-latitudes.

We added this facts to the preprint.

Wrana, F., von Savigny, C., Zalach, J., and Thomason, L. W.: Retrieval of stratospheric aerosol size distribution parameters using satellite solar occultation measurements at three wavelengths, Atmos. Meas. Tech., 14, 2345–2357, https://doi.org/10.5194/amt-14-2345-2021, 2021.

Comment: Figures:
A logarithmic scale should be used for figures displaying extinction profiles and optical depths.

Reply: We changed that and use now log scales for the extinction profiles (except for Fig. 2). For the figures representing the SAOD, we decided against it, as the clarity of the individual graphs within the figure would be reduced.

Comment: Cases with 1 Tg and 2 Tg/year should be shown on the same figure for easier comparison.

Reply: Thank you for the suggestion. We tested this, but merging the figures would reduce the clarity of the illustration, reduce the visual selectivity of the individual results and thus impair the interpretation of the central statements at first glance. Nevertheless, we understand the idea and the potential benefits and tested it but decided against it.

Comment: In Figure 1, part (a) should represent the initial phase, and part (b) the steady-state phase, to reflect chronological order. Different colors should be used to indicate high and low extinction values for better visual clarity.

Reply: We have changed the order of the subplots (a) and (b) of Figure 1 and adapted the corresponding text. Following the guidelines for illustration in ACP and the specifications for colour blindness friendliness, we have decided to use this colour scale. For the sake of readability of all subplots and due to the different value ranges, it is unfortunately not possible to display all subplots with the same colourbar.