We thank the reviewer for suggestions and comments. Comments helped to clarify several parts of the text. Our point by point answers to the comments are presented below. Referee comments are in bold and our replies in body text.

Reviewer 2:

The paper provides an extensive analysis of inter-model difference in the global (and regional) precipitation response to Stratospheric Aerosol Injection. On the whole, this is a sound piece of work, carefully analysed and well written, with clear plots.

. On the whole, this is a sound piece of work, carefully analysed and well written, with clear plots.

A not too major criticism is that the paper is rather technical, and readability and possibly usability by a larger set of readers could be improved by adding some clarifications and physical interpretation here and there. I hope my comments can help. In addition, there is a handful of minor improvement points regarding things like figure captions and labels, listed below.

Interpretation and readability

Overall aims: Maybe the overall aim(s) could be stated in a small number of clear research questions at the end of section 1. Currently line 81 states: "We investigate how these impacts depend on the injection rate and the aerosol microphysics model", which is relatively vague and mixes physics questions (how does precipitation change under different SAI intensities) with modelling questions (is there model uncertainty). Unless the main focus is strictly the model uncertainty part, the paper, which is now relatively technical, may profit here and there from a bit more physical interpretation.

Now it reads: *"We investigate how aerosol impact on SW and LW radiation changes the atmospheric absorption and further atmospheric energy budget and hydrological cycle. We also study how precipitation changes under different SAI intensities. Furthermore, we examine how these outcomes vary based on the aerosol microphysics model employed to simulate the aerosol fields, as well as the Earth System Model used to simulate climate responses."*

Structure, especially Section 4: It would help the reader to get a short hint at the beginning of sect 4 what the subsequent pieces of analysis are meant to do and how they relate to each other and the overall aim / research questions of the paper. For example, it helps to know before sect. 4.3 that you first estimate the precip change based on the radiation diagnostics and then will compare the overall change to the actual model results in 4.4.

This was a good suggestion. Now in the beginning of results section it reads:

"In this section, we begin by employing regression analyses on simulations to estimate the temperature changes in simulated SAI scenarios, based on the effective climate sensitivity. We then proceed to quantify the fast precipitation response and the radiative forcings

associated with simulated SAI and CO2 perturbations. These metrics allow us to estimate the extent of CO2 radiative forcing that each simulated SAI scenario could offset. Given the assumption that there should be no change in global mean temperature, the quantified fast precipitation responses can then be utilized to estimate changes in global mean precipitation in scenarios where the radiative forcings of SAI and CO2 are balanced. Lastly, we conduct climate equilibrium simulations for various SAI injection rates and their corresponding CO2 concentrations. These simulations are utilized to examine how estimated precipitation changes, based on the fast precipitation responses, differ from the actual simulated values and to analyze regional responses."

Fast response and absorbed radiation, line 56 ff. The paragraph could be clearer. Line 57 "Further precip change" -> further with respect to what? Line 59: rather than saying "Any change in X translates to a change in Y", it is clearer to say e.g. "Any increase in X translates to a decrease in Y", to immediately give the direction of change. The whole sentence seems unnecessarily long-winded. Most importantly, since some of the readers may not be experts in hydrological cycle but e.g. in SRM or impact modelling, it would be helpful to explain in a bit more detail 1) what fast and slow precip responses are (you mention the fast one but not what the slow one is) and 2), give a few sentences about the physical meaning of the link between absorption of radiation (up to which height?) and the global precip response. I appreciate you give several references, but seeing how central this information is to the whole paper, it increases readability of the piece to spend a few more sentences (and an equation or two).

We rewrote the paragraph about atmospheric energy budget and fast and slow responses in the introduction section so that now it reads:

"Changes in atmospheric radiation have a direct impact on precipitation. Precipitation changes can be explained by the changes in the total column atmospheric energy budget (O'Gorman et al., 2012). The atmosphere possesses a relatively low heat capacity, and following a perturbation, it rapidly reaches a state where the incoming and outgoing energy fluxes to and from the atmosphere balance each other. In other words, the budget of perturbations between two atmospheric states can be expressed as:

$$L\delta P = \delta RSurf - \delta RTOA + \delta SH = -\delta Rabs + \delta SH, \quad (1)$$

where L is the latent heat of condensation, P is precipitation, RTOA and RSurf are the change in the radiative fluxes at the top of the atmosphere and surface, SH is the sensible heat flux change and δRabs is the change in absorbed radiation. Niemeier et al, 2013, showed that changes in global latent heat flux dominate changes in sensible heat flux, establishing a roughly linear relationship between precipitation and the discrepancy between the radiative imbalance at the surface and at the top of the atmosphere. Other studies have also shown that changes in precipitation are proportional to the difference between changes in radiation at the surface and in the atmosphere, i.e absorbed radiation (O'Gorman et al., 2012; Kravitz et al., 2013b; Liepert and Previdi, 2009). The atmospheric energy budget can also be utilized to represent precipitation in a transient climate. Given that radiation (and changes in atmospheric absorption) are known to be relatively linearly correlated with global mean precipitation, as evidenced by climate models (e.g (Zelinka et al., 2020)) and *observations (Koll and Cronin, 2018) precipitation change can be approximated by a simple equation comprising temperature dependent and independent components(s):*

$\delta P = a\delta T + F = Pslow + Pfast$, *(2)*

where δT is the global mean temperature change, a is constant and F are the temperature independent components. Within this equation, aδT accounts for all feedbacks attributable to temperature change, including the variation in surface sensible heat flux. This is often referred to as the slow precipitation response or component, which changes over a multi-year timescale alongside alterations in sea surface temperature. F is referred to as fast precipitation response (or component) or rapid adjustment. It can be considered to include the direct radiative forcing, or precisely direct change in absorbed radiation. Thus, at the global scale, a change in global mean precipitation has been shown to be linearly dependent on the absorption part of the induced radiative forcing (Laakso et al., 2020; Myhre et al., 2017; Samset et al., 2016); therefore, a stronger absorption of radiation is linked to a decrease in global mean precipitation"

And late in the introduction it now reads: *"Niemeier et al. (2013) investigated the impact of different SRM techniques applied at different altitudes. Their findings show that the precipitation changes predicted by Equation 1 aligns closely with the precipitation changes observed in simulations. Changes in sensible heat flux within their simulations were minimal, suggesting that the calculation of precipitation based on atmospheric absorption is not influenced by the altitude at which the absorption change occurs."*

Following up on the fast response and absorbed radiation relationship (see also eq 1 of O'Gorman 2021 which you cite): I am wondering about the direction of causality. Is it really such that changes in absorbed radiation determine precip, and not vice versa? After all, precipitation (and evaporation) changes may be related to changes in water vapour content or clouds, which may feed back on radiation budget. So it would be good to clarify whether the relationship is (largely) a causal one, or whether it should be seen as merely a diagnostic relationship. If the latter is the case, then of course it can still be used for e.g. the analysis in sect. 4.3, but I would then suggest to me more careful with statements such as "precipitation changes as a function of injection rate can be understood based on the absorbed radiation" (line 279), a formulation which to me suggests causality.

This is a valid point. While the aerosol fields represent the external variable being modified, and their influence on both shortwave and longwave absorption is logical, it's not definitive based on our results that the latent heat flux wouldn't impact the atmospheric temperature, thereby affecting the emission of LW radiation which would be then see as a change in the atmospheric absorption. However, the e.g observed differences in atmospheric absorption and precipitation between solar dimming and stratospheric aerosol simulations suggest a direction of causality (Visioni et al., 2021). We have now clarified this in the introduction (see our earlier response).

Visioni, D., MacMartin, D. G., & Kravitz, B. (2021). Is turning down the sun a good proxy for stratospheric sulfate geoengineering? *Journal of Geophysical Research: Atmospheres*, 126, e2020JD033952. https://doi.org/10.1029/2020JD033952

sect 4.2 ff: you focus strongly on the fast precip response. Obviously this is an important quantity, especially in scenarios where GMST changes and hence the slow response are eliminated by SAI. However, since other scenarios are conceivable (e.g., keeping GMST change at 1.5 degrees), it would be quite nice to know how the fast response compares with the slow response. This can be inferred from S6, but is not discussed much. Maybe summarise the results in an equation like "P = a C + b S + c T" where P is the precip change, C the radiative forcing from CO2 (GHG), S the forcing from SAI, and T the GMST change, and a,b,c, are the fit parameters that arise from this study, though admittedly, at least b will suffer from nonlinearities (fig. 4).

This was a valuable suggestion, and the proposed equation could indeed be informative. However, we opted for an even simpler approach. We have now included the following line in the sections discussing the range of fast precipitation responses for the simulated SAI scenarios:

"Overall quantified fast precipitation response due to the SAI varied between 0.69% increase in global mean precipitation to -3.19% reduction in precipitation depending on injection rate and ESM-aerosol model combination. Based on the average hydrological sensitivity in our simulations (Supplement Fig. S6), which were 2.46 %K−1 (σ=0.28 %K−1) the range between the maximum and minimum fast precipitation responses corresponds to a global mean precipitation change associated with a temperature variation of 1.6 K"

Fig 4a: you state in the main text that the slope differs little among models. However, could you comment also on whether the slope is the (approximately) same for SAI and CO2? at least for MPI-ESM and SALSA, this seems not certain to me from the plot.

We included a new paragraph at the end of the section 4.3:

"However, as indicated by Supplement Figure S6, employing a simplistic approach using fast and slow responses to estimate precipitation changes may not be straightforward. Supplement Figure S6 reveals variations in the hydrological responses among the three Earth System Models (ESMs), particularly in the variation of the hydrological sensitivity (i.e., the slope in the figure) across various simulated forcing agents. Simulations using CESM and MPI-ESM suggest that the hydrological sensitivity increases with larger injections. But the range of this increase differs significantly from the sensitivity observed in simulations where CO2 concentration was perturbed. Conversely, in EC-EARTH simulations, hydrological sensitivity ranged from 2.39 to 2.48 %K-1 in scenarios with CO2 perturbations, while in SAI scenarios, the total range was 2.79 - 3.22 %K-1. This discrepancy is a crucial factor to consider, especially in cases where the forcing induced by CO2 and SAI does not fully offset each other but might also have an impact when those are expected to compensate each other."

line 373: is there any clear physical reason why GMST increases in two models despite radiative balance being closed?

There are some indicators for possible physical reasons which can be made based on regional responses in the next section (i.e arctic warming and melting sea ice, different responses of stratocumulus clouds on SW and LW radiative forcing). These topics were discussed in greater depth in the next section. Initially, this was mentioned at the end of the paragraph where line 373 is found, with the statement, *'We will discuss more about this in section 4.6.'* However, to enhance clarity, it has now been revised to read, *'We will discuss possible physical reasons for the residual global mean warming in CESM and EC-Earth simulations in section 4.2.3."*

line 395, fig 6d: You suggest that in EC-earth, the correction hydrological sensitivity (i.e. effect of residual GMST change) "slightly overadjusts" precip estimates. This seems rather optimistic. In fact, the error hardly shrinks, of even becomes worse, in some scenarios in EC-earth, even if the correction works nicely in CESM. So it seems to me that in EC-earth there is stuff going on that is not easily captured by your method… could you comment?

This is a valid point. "slightly overadjust" was quite optimistically said. Now it reads: *"For EC-Earth, this adjustment corrects precipitation values to the direction of estimated ones, but it over-adjusts them for most of the simulated scenarios."*

We also added to the same paragraph the following text: *"It remains unclear why this temperature adjustment leads to an overestimation in the results for EC-Earth simulations. However, this could be related to the larger hydrological sensitivities for SAI compared to CO2 perturbations, as discussed in section 4.1.3. Although there are discrepancies between the actual simulated values and the estimated ones, this analysis shows that estimating the total precipitation change based…"*

line 428: why is there the local radiative forcing peak at ≈50ºN and S? if I understand correctly, then the reference, Laasko 2020 sect. 3.1.2 explains nicely why the forcing effect is lower at the poles, but not why there is a local maximum between the subtropics and the poles.

Now it reads: *"Furthermore, concerning stratospheric aerosols, the impact on radiative forcing is more pronounced at the Equator and latitudes around 50 degrees north and south where aerosol concentration is large due to the atmospheric circulation (Laakso et al. 2017). Thus radiative forcing is larger compared to the latitudes in between these regions"*

Fig 7-10: how linear are the responses (within each model combination) at the local level? Is it possible, like you did on the global level, to understand the local response as approximately the sum of the slow response, fast GHG response and fast SAI response?

In theory it is possible if column-integrated divergence of dry static energy is taken into account (see e.g. Zhang, S., Stier, P., and Watson-Parris, D.: On the contribution of fast and slow responses to precipitation changes caused by aerosol perturbations, Atmos. Chem. Phys., 21, 10179–10197, https://doi.org/10.5194/acp-21-10179-2021, 2021.). We conducted preliminary analyses on fast and slow responses at a regional level. However, as anticipated, the analysis encountered certain nonlinear complexities, making it less straightforward than a global-scale analysis. Consequently, local responses have been omitted from this study, but they may be explored in future research.

≈ line 440, fig 8, CESM-SALSA, SRM20 and (in supplement S8) CESM-M7 SRM50: is there an AMOC response in the north Atlantic?

This is now commented in the text: *"CESM simulations with larger CO2 concentration and large SAI injection rate (e.g SRM20-SALSA and SRM50-M7 (supplement Fig S8.)) are showing cooling in the North Atlantic which is associated to the weakening of the Atlantic Meridional Overturning Circulation seen also in simulations with global warming (Meehl et al., 2020; Fasullo and Richter, 2023)"*

Regarding precip changes (fig 10): For impact modellers, maybe Precip-Evaporation would also be meaningful. Not sure if this is inside the scope of the paper. However, often SAI scenarios reduce not just precip but also evaporation, so that the overall effect on water availability is much less than precip changes suggest.

We considered including the proposed figure in the supplement of the paper. However, as expected by the reviewer, it is a bit outside the scope of the paper and it is not easy to attach to the other analysis. Also, the study already has quite a lot of figures in the manuscript and it's supplement, so after consideration we decided to leave it out. However, it was a good suggestion for a possible future analysis and study.

Last paragraph: Quantify "significant uncertainties". Is the inter-model discrepancy for the most relevant quantities (e.g., global precip change) of the order of 10% of the signal, or 50%, or is there even disagreement of the sign?

Now it reads: *"The overall results of this study indicate that there are significant uncertainties regarding the estimated impacts of the possible deployment of SAI (e.g the coefficient of variation of the fast precipitation response was below injection rate 50 Tg(S)yr-1 were above 1.5)"*

Minor Clarifications

fig. 4: Legend: the dash in "-SALSA" and "-M7" look like a minus, which is a little misleading. maybe write "for SALSA" or "(SALSA)" ? Also, please make more clear in the figure caption that in plots b-d, the symbols and the solid lines are independent, i.e., the solid line is the sum of the other lines (not: "total") whereas the symbols are the actual total (modelled) impacts. It becomes clear from the main text, but the figure itself is not as clear as it could be due to the shortness of the caption.

Figure modified as suggested and in caption it now reads: *"The dashed line is precipitation change caused by SW absorption, the dash-dotted line is based on LW absorption and the solid line is the sum of these SW and LW components whereas markers are modelled fast precipitation responses from regression simulations."*

Supplement figs S1, S2, S3, S5, maybe other equivalent ones: Please add unit to the y-axis label of plot a.

Units added

Fig. 6b: add “estimated” to the y-axis label (equiv to “modelled” in plot d). Clarify in caption that “hydrological sensitivity” (which is a quite general-sounding word with a much more specific meaning), refers to the effect of residual GMST change on precip.

“Predicted” added to y-axis label and “estimated" changed to “predicted” in 6d. *“adjusted by hydrological sensitivity”* changed to **“***slow (temperature) response removed”*

Section 5: you write a rather substantial summary of your findings. This could be further supported by adding references back to the corresponding sections and figures so that one can quickly (re)check the corresponding results in detail.

References back to corresponding sections and figures are added.

Following typos and grammar are corrected as suggested:

Typos, grammar etc

- **line 56: Changes … has -> have**
- **line 60: change translate -> translates**
- **line 254: sentence structure is a bit awkward**

Now it reads: *“The aforementioned observations emphasize that climate sensitivity is an idealized metric contingent on the timeframe considered”*

- **line 274-275: check sentence structure (missing “FOR larger injection…”?)**
- **line 291ff: Awkward sentence. Comma missing after “figure shows”?**
- **line 316: In case -> In this case?**
- **line 490: issensitive -> is sensitive**