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Interactive comment on "Reaching 1.5 °C and 2.0 °C global surface temperature targets using stratospheric aerosol geoengineering" *by* Simone Tilmes et al.

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We thank the Referee 2 for sending very helpful comments and suggestions to the manuscript.

The general comments of referee 2 are in line with the comments by referee 1. Therefore, we want to point to the general response we have provided to the first referee: "Based on the two referees comments we realized that the framing of the paper, on the one hand, proposing a test-bed simulation for GeoMIP and on the other hand, discussing novel findings, did not adequately convey the contributions of the paper – in particular, that the impacts of stratospheric aerosol geoengineering strongly depends

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Discussion paper

on various different aspects of the experiment, the considered baseline scenarios and therefore the CO2 concentrations, the amount of SO2 injection, and the chosen temperature targets. To better emphasize the contributions, in revising the paper we will focus on the novel findings, and use those, along with the potential for model-dependent outcomes, as motivation for the suggestion that these could be new test-bed simulations for GeoMIP. The referee is correct that main novelty of the experiments lies in the fact that we have combined the feedback controller with the overshoot scenario. Other novelties, that we have failed to point out more clearly and plan to mention in the revised manuscript, include that for the first time these types of simulations use the CMIP6 future pathways, which are unique since they are based on socio-economic considerations. Furthermore, we are using an updated Earth-System model, that includes more impact relevant coupling, including interactive crop models, land-ice model, and ocean-bio-chemistry. This paper also serves as an overview paper that describes the general setup of the experiments, while additional papers that are in preparation that will refer to this paper. We also agree with the referee, that the results are highly model dependent. While some of the results are aligned with earlier findings, the focus of the paper is not on repeating what has been done before, but describing potential impact relevant outcomes and for other modeling groups to repeat these experiments in order to produce multi-model comparisons to help determine uncertainties of outcomes. One example is already provided in this paper, comparing the Atlantic Meridional Circulation changes with earlier model results. Further, we have been improving the figures to be added the revised version of the manuscript as suggested by the referee."

Addressing Major Comment 1) It is not completely clear to me, what the actual proposed testbed (and the related protocol) is. From the abstract it appears (to me) that two simulations limiting global warming to 1.5C or 2.0C (with reducing side effects) based on an overshoot baseline scenario are the central experiments. However, it seems (e.g. discussions and conclusions) that also the comparison with the high greenhouse emission baseline is part of the protocol. This needs clarification. Furthermore, if the latter is true both the 1.5C and the 2.0C case need to be included in this

study.

We agree with the referee that the testbed scenarios were not sufficiently explained. We will clarify that the testbed experiment is only based on the overshoot baseline experiment and the additional SSP5-85 cases were performed to be able to compare to earlier studies using a different model version. As described above, we decided to shift the focus of the paper from defining the test bed simulations to describing and discussing the new numerical simulations. We have now finalized a second ensemble member for each of the experiments. We are still planning to recommend that it would be beneficial if the experiments based on the overshoot scenario are performed by other modeling groups to identify the range of outcomes of impact relevant diagnostics.

Addressing Major Comment 2) The feedback controller appears to me a major factor defining the results, as it determines the sulfur dioxide forcing. It is not clear to me whether the forcing computed by the controller is unique in terms of reaching the given targets and limiting the side effects. A clear defined forcing is, in my view, a major point in defining testbed experiments. In the present case, it seems even more important as some results strongly depend on the particular sulfur injection. Thus, some more words on the forcing (and controller, see minor 3) are needed, in particular: how unique is the forcing obtained from the controller given the set of target temperatures?

We agree with the referee to add more information to the controller algorithm and to explain the purpose of the use of this controller: In detail, the controller algorithm is designed to check annual temperatures each year, in order to determine how much SO2 injections are required for each of the four predefined injection locations to reach the 3 temperature targets. Since models will respond differently, it is expected that the amount of SO2 injections will differ for each model version. This has been shown if comparing WACCM6 results with the GLENS results. Therefore, the forcing of SO4 in the stratosphere will differ in each model version, some will require more injections than others, some will require a different amount in different hemisphere. Instead of running a feedback algorithm, the required SO2 injection rates could be estimated through

trial-and-error, but this would be very time-consuming to “learn” the right injection rates to use at multiple latitudes, and as a function of time, to achieve the 3 temperature targets in any given model. We therefore recommend that use of a feedback algorithm, while not an essential component of the testbed specification, is a more efficient way of achieving the desired targets. More details on the feedback controller as described above will be provided in the revised version of the manuscript. We are planning to add an appendix or separate section to the manuscript, including the description on how we implemented the feed forward and how this can be done by other modeling groups. The idea of the proposed GeoMIP testbed experiment is to compare the behavior of different models while the injection rates are chosen to meet the same 3 temperature goals. We are not proposing to compare model results that use the same injection rate but result in the same temperature outcomes. Thus, one question would be to explore how different the forcings will be to reach the same temperature targets. Also, if the same temperature targets have been reached, we can ask the question whether the outcomes on impact relevant measures be different or similar? This approach will help to identify the ranges of outcomes in order to help quantify the ranges of uncertainties. We will also add more details along these line in the revised version of the manuscript.

Addressing Major Comment 3) So far, only one simulation for every scenario has been performed. This strongly hampers the assessment of uncertainties. For example, it is not clear how much of the pronounced North Atlantic warming hole is related to internal variability or the models sensitivity to the particular forcing. This makes the interpretation of the presented results difficult, and complicates the comparison with simulations performed by other models following the proposed protocol. Thus, without having an (at least very small) ensemble, or any other convincing assessment of the uncertainties, the presented results may not include enough robust information.

We have now finalized a second ensemble member for each of the presented experiments and therefore increased the significance of the results. We will show in the revised version of the manuscript that the conclusions drawn from the two ensemble

members have not changed compared to just using the one ensemble member. This is because the variability of the different impact measures between the different ensemble members is to the most part smaller than the difference between the different model experiments.

Addressing Minor & technical: 1) It would be valuable to have a more comprehensive motivation for such a testbed. What information may we get from it, except the sensitivity of particular models to a specific forcing scenario which may 'not be policy relevant' (L422)?

We agree with the referee and add more information to the motivation of these experiments, as discussed in the response to Major comment 2.

2) Independent of my major points above, I think that a protocol as precise as possible would help to establish such a testbed.

We agree with the referee and will describe a precise protocol to allow other modeling groups to perform the same experiments. We will focus only on the cases using the overshoot scenario and clarify this.

3) As the feedback controller appears central for the scenarios and results (see Major 2). Thus, a thorough description would be helpful.

In the revised version of the manuscript, we are planning to provide detailed information to allow modeling groups to implement the feedback algorithm.

4) Table 1: It may be noted that the RCP-85 simulations are run with a different model version (as far as I understand).

As suggested by referee 1, we will add an additional column to clarify the model versions used for the different experiments.

5) L300: citep[]Kravitz2013 -> (Kravitz et al., 2013) 6) L415: SSP5-34_OS 1.5 -> SSP5-34_OS 2.0 7) Figure 3, caption: See text more more -> See text for more

We will correct the 3 items above.

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