Response to Referee 4

Overview:

This paper investigates the effect of the solar radiation modification on the downwelling solar radiation at the surface over China and hence on the surface temperature. For this purpose, it uses the simulation data from the G4 experiment from 3 climate models of the Geoengineering Model Intercomparison Project (GeoMIP). In G4, SO2 is injected into the stratosphere at a rate of 5 Tg SO2 per year on the RCP4.5 emission scenario. The analysis in this paper focuses on the contribution of key processes involved in the reduction of solar radiation at the surface. Four processes are assessed: AOD changes in the atmosphere due SO2 injections, water vapor changes due to tropospheric cooling, changes in clouds and surface albedo. A simple 1-layer atmosphere model is used to facilitate the understanding. This decomposition of changes in downwelling shortwave radiation at the surface by a simple model is an elegant approach that helps to understand the complex interaction between various physical processes in climate models. The presentation is fine but could be improved in the revision. The paper could be accepted for publication after the main and specific comments listed below are addressed.

Major Comments:

(1) Clear insight into the contribution of water vapor changes and albedo changes should be provided in the revision. A colder atmosphere holds less water vapor –7% decrease in water vapor per deg C decrease in temperature. Reduced water vapor causes reduced absorption of solar radiation that is coming down. In the case of surface albedo, colder temperatures are likely to lead to an increase in snow on the surface which would reflect more sunlight and hence a reduction in net surface shortwave radiation.

Response: In the revision, we have evaluated physical processes responsible for the SAI-induced temperature change based on the surface energy budget equation (Lines 265–300). The decreased tropospheric temperature reduces atmospheric water vapor amount following the Clausius-Clapeyron relationship as you mentioned. On the one hand, the reduced atmosphere water vapor decreases the downward surface clear-sky LW, contributing to the surface cooling primarily. On the other hand, the reduced water also increases the downward surface clear-sky SW by changing the atmospheric absorption. This effect partly offsets the decreased SW caused by aerosols scattering over China. In addition, the seasonal difference in water vapor change leads to a severer surface cooling in winter over China (Lines 265–282).

Under SAI forcing, the negative surface albedo feedback due to the increased snow cover contributes to the surface cooling over China. However, the surface albedo feedback change has large seasonal and spatial variations. The decreased snow cover over the upper reaches of the Yellow River and the middle and upper reaches of the Yangtze River leads to an abnormal winter warming in MIROC-ESM (Lines 290–300).

(2) The authors find that there is decrease in clouds over China in the G4 experiment (Figures 7, S1 and S2). This decrease allows more net solar radiation at the surface. Some insight into the reason for the decrease in cloudiness in G4 should be provided in the revision.

Response: In summer, the SAI-induced decrease in cloudiness mainly occurs over northeastern and southeastern China. In winter, this decrease is coherent over China. The results indicate that the decreased cloud cover is related to the decreased latent heat flux under SAI forcing (Figs. 11c, f, and S1c). However, in summer, the effect of latent heat flux is partly offset by the SAI-induced moisture convergence at the troposphere in most models. The resultant increased cloud cover enhances the surface cooling over northwestern and central China (Fig. 11h). The relevant discussion has been added in the revision (Lines 284–290).

(3) Equations 8-11: How are these equations implemented in this work to estimate the 4 contributions discussed in section 4.3? This should be briefly discussed right after the derivation of these 4 equations. Also, the connection between these 4 equations and discussion in section 4.3 should be discussed in the beginning of section 4.3

Response: Considering the change in research method, this part has been shortened in the revision. Under SAI forcing, both the changes in atmospheric reflection and atmospheric absorption affect the downward clear-sky SW at the surface. We assume that the clear-sky atmospheric reflection change is only affected by atmospheric water vapor amount, and the clear-sky atmospheric absorption change is only affected by the aerosol scattering effect. Therefore, the change in downward surface clear-sky SW can be separated into two parts: the effects of solar radiation scattering (SW_{SRM}) and atmospheric water vapor amount (SW_{WV}). The relevant explanation has been added into Sect. 2.3 and the beginning of Sect. 4.3 (Lines 153–166, 269–271 and 278–282).

(4) Why does this focus on China? Why not the entire global domain? The rationale for the choice of the domain should be discussed in the revision.

Response: We agree that the global temperature response to SAI is of interest. We would like to mention that global-scale studies have been investigated systematically (e.g., Niemeier et al., 2013; Kashimura et al., 2017; Ji et al., 2018). Recently, increasing attention has been given to the climatic response to solar radiation modification on a regional scale (e.g., Pinto et al., 2019; Da-Allada et al., 2020; Xu et al., 2020). As the largest developing country in the world, China plays an important role in combating climate change. China's attitude to geoengineering is crucial to the international geoengineering research community. Considering the combined effect of the Tibetan Plateau and the East Asian monsoon, the climate over China would be strongly influenced by SAI. But the climatic impact has not yet been examined explicitly. For these reasons, we focus on China rather than the entire global in this study. The relevant explanation has been added accordingly (Lines 75–79).

In the revision, we have also changed our research method based on the comments of other reviewers. The diagnosis based on surface energy budget quantifies the effect of downward energy fluxes changes on surface air temperature over China under SAI forcing (Lines 136–153). The physical processes which dominate the temperature change have also been evaluated (Lines 265–300). We believe that this study provides new scientific insights.

Specific comments:

(1) Line 45: delete "simulating"

Response: Text revised (Line 51).

(2) Line 50: change "the decreasing" to "decrease".

Response: Text revised (Line 58).

(3) Lines 53-55: the overcooling of the tropics and undercooling of the polar regions would happen only if SRM is designed to offset the entire global mean surface temperature change. This important point should be included in the discussion here.

Response: This part has been deleted when we revise the manuscript.

(4) Lines 55-59: SRM does not address the ocean acidification problem caused by increasing levels of CO2 in the atmosphere. This deficiency of SRM should be also mentioned here.

Response: This deficiency has been added as you suggested (Lines 62–63).

(5) Line 70: Why do the author assess only surface temperature change? Why not the other important climate variables such as precipitation?

Response: SAI geoengineering aims to counteract anthropogenic global warming. Surface air temperature is thus a first-order variable that should be focused on. Therefore, this manuscript evaluates the impact of SAI on the surface air temperature over China and the underlying physical processes. As you mentioned, the effects of SAI on other climate variables, such as precipitation and monsoon, are also important. But they are not the objectives in this study.

(6) Line 79: change "the simulations in the G4 experiment" to "the G4 experiment".

Response: Text revised (Line 96).

(7) Line 79: provide a reference for the first phase of GeoMIP.

Response: Added accordingly (Line 96).

(8) Lines 108-118: What is the rationale for using the 1-layer atmosphere model in this study? What are its advantages and disadvantages? This should be briefly discussed.

Response: The single-layer model can help us separate the effects of atmospheric reflection fraction change and atmospheric absorption fraction change on SW. The former corresponds to the solar radiation scattering, and the latter corresponds to the atmospheric water vapor amount. This method has an inherent error due to the non-linear nature of equations. But this error is small and acceptable. This method is effective when analyzing the surface SW change under SAI forcing (Kashimura et al., 2017). The brief discussion has been added accordingly (Lines 163–166).

(9) Line 122: For clarity, change "R is the fraction of reflection" to "R is the fraction of solar radiation reflected by the atmosphere"

Response: Text revised (Lines 161–162). The *R* has been changed into *F* to avoid confusion.

(10) Line 155: "All the SCC are significant at the 99% level" How is this assessment made? Taylor diagram does not provide an assessment of the significance level of the correlation efficient. The method used for the statistical assessment should be briefly discussed.

Response: The significance of the spatial correlation coefficients is determined from the two-tailed Student's *t*-test. This expression has been added to the caption of Fig. 2 (Lines 539–540).

(11) Line 180: the lack of differences in trends between G4 and RCP4.5 is expected because the magnitude of the radiative forcing is the same in the experiment except in the

beginning when aerosols are suddenly injected in the G4 experiment.

Response: We agree with your point. That sentence has been revised accordingly (Lines 206–208).

(12) Line 205-208: The sign convention of LW is not clear in this paper. Is upward or downward LW is considered positive? This should be clarified in the revision.

Response: All the fluxes are defined as downward positive in the original manuscript. In the revision, we only consider the changes in downward surface radiative fluxes according to the surface energy budget equation. Those unclear expressions have been deleted accordingly.

(13) Lines 211-212: The figures show a decrease in clouds, but the text says clouds increase. The authors should carefully check their analysis.

Response: In summer, the regionally averaged changes in the cloud cover fraction over China show a consistent increase, although the decreased cloud cover occurs in some regions. In the revision, we have mainly discussed the robust change for individual regions (e.g., Lines 243–248). The regionally averaged change has been removed.

(14) Lines 215-216: The link between the deficit of downward LH and flux and increase in cloud cover is not clear. Either delete this discussion or provide clarity.

Response: This discussion has been deleted accordingly. In the revision, we consider that the increase in summer cloud cover is mainly related to the SAI-induced moisture convergence at the troposphere over northwestern and central China (Lines 287–290).

(15) Line 220-223: The discussion is unclear. Revise the text.

Response: In the revision, we only consider downward surface LW changes according to the surface energy budget equation. This part has been deleted accordingly.

(16) Lines 251-253: The message from this sentence is not clear. Revise the text for clarity.

Response: This sentence has been rewritten for clarity (Lines 274–276).

(17) Line 303: The Tilmes et al. 2018 paper discusses injection at multiple locations and not regional injections.

Response: The "regional injection" has been changed into "injection at multiple locations" accordingly (Lines 331–332).

(18) Figure 1: I believe cs and cl are interchanged in the illustration. Should be corrected.

Response: As you suggested, the "cs" and "cl" are interchanged in the original Fig. 1. In the revision, this illustration has been removed due to the change in research method.

(19) Figure 2: The last line of the caption: The oblique dotted line cannot be seen in the figure. Revise the figure or the caption.

Response: The statement of "the oblique dotted line" has been changed into "the dotted straight line" in the revision (Line 539).

Reference:

Da-Allada, C. Y., Baloïtcha, E., Alamou, E. A., Awo, F. M., Bonou, F., Pomalegni, Y., Biao, E. I., Obada, E., Zandagba, S., Tilmes, S., and Irvine, P. J.: Changes in west African summer monsoon precipitation under stratospheric aerosol geoengineering, Earths Future, 8, e2020EF001595, https://doi.org/10.1029/2020EF001595, 2020.

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Kashimura, H., Abe, M., Watanabe, S., Sekiya, T., Ji, D., Moore, J. C., Cole, J. N., and Kravitz, B.: Shortwave radiative forcing, rapid adjustment, and feedback to the surface by sulfate geoengineering: Analysis of the Geoengineering Model Intercomparison Project G4 scenario, Atmos. Chem. Phys., 17, 3339–3356, https://doi.org/10.5194/acp-17-3339-2017, 2017.

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