We thank Anonymous Referee #3 for the helpful suggestions and comments which improved the manuscript. Our point by point answers to the comments are presented below. Referee comments are in bold and our replies in body text

General Comments:

This study aims to investigate how different sulfate injection strategies (from different locations) would affect the changes of radiative forcing, temperature and precipitation using ECHAM-HAMMOZ and MPI-ESM. This type of study is a good fit for ACP GeoMIP special issue. However, more clarifications and analysis are needed. More detailed model description and the experiment design are needed. It is not clear whether the model has chemistry involved, how the experiments are set up, e.g. whether the injection is continuously over the year or just couple individual injections in different seasons? What is the amount for each individual injection?

Based on the referee suggestions, we have clarified our model description and the experiment design. We have also included more analysis on the aerosol microphysical processes in the simulations with ECHAM-HAMMOZ (see also replies to referees #1 and #2).

The injections were done continuously over the year. While this was mentioned in the abstract and conclusions, it was missing from the model description. Section 2.1.1 now reads:

"Eight zonally different sulfur injection strategies were simulated. In all of these scenarios, 5 Tg(S)/yr of gaseous SO2 was injected continuously over the year to the stratosphere at the height of 20 km and to a 20 degree wide latitude band specified below (2 bands in one of the simulated scenarios). "

In section 2.1.2 we added:

"The model contains an explicit description of sulfur dioxide oxidation chemistry (Feichter et al 1996. The hydroxyl radical (OH) and ozone concentrations are accounted for through prescribed monthly mean fields. Thus, the effect of sulfur injections on the ozone layer is not simulated in our model.". "

The set-up of this experiment (separating the aerosol model and the climate circulation model) limits the soundness of the conclusion. The offline calculation of radiative properties of stratospheric aerosol will prohibit the feedback between the stratospheric circulation change (e.g. Brewer Dobson Circulation) and the aerosol transport. There should more discussion on this.

The dynamical feedback of the injected particles to the stratospheric circulation was taken account in our simulations with ECHAM-HAMMOZ. However the changes in the atmospheric circulation due forcings given by RCP45 scenario are not taken account in the aerosol simulations and may affect the transport of aerosol so that they would differ from those simulated by ECHAM-HAMMOZ.

To clarify to reasons to use of two models and possible disadvantages we added following text to section 2.2:
"The two-step approach was selected because the currently available middle atmosphere configuration of MPI-ESM does not include a prognostic calculation of aerosol properties. In addition, modelling aerosol microphysics is computationally heavy. Thus it was feasible to simulate aerosol microphysics only relatively short period (few years) and use the ECHAM-HAMMOZ simulated aerosol fields as prescribed fields in the longer simulations in MPI-ESM. Simulations with ECHAM-HAMMOZ were carried out using a free running setup to include the dynamical feedback resulting from the additional heating due to absorption radiation by the injected aerosols. However, stratospheric circulation could also be altered by changes in atmospheric GHG concentration (in our case following the RCP4.5 scenario) and its impacts on tropospheric climate; however, these impacts were not taken account when the aerosol fields were calculated in ECHAM-HAMMOZ."

More analysis are needed on the aerosol microphysics (e.g. the aerosol size distribution change, how long it takes for SO2 changing to H2SO4?), aerosol chemistry (e.g. OH map in different seasons? whether the model includes ozone chemistry in the stratosphere?), and the trajectory (e.g. stream function of the stratospheric circulation to indicate how sulfate aerosol is transported under different injection strategies? The transport of SO2 and H2SO4?

We added two new figures in the manuscript and the topic is now discussed in a new section 3.1.2. Figure 3 shows the zonal mean effective radius and Figure 6 shows the time dependent zonal mean of AOD for 533nm and stratospheric circulation at the height of the sulfate field. Section 3.1.1 was also amended with couple of clarifying sentences. See replies to Referee #1 and #2 for details. The ozone chemistry is now mentioned in section 2.1.2.

Specific comments:

Page 1:
-Lines 11-12: "In geoengineering studies these injections are ... the solar radiation is highest". This sentence sounds like the only reason of tropical injection is because of the highest solar radiation. But actually, there is another important reason: the strong upwelling in the tropics brings sulfate aerosols polar-ward through Brewer Dobson Circulation.
-Lines 12-13: "However, it may not be the most optimal
::
the meridional temperature gradient". What is 'optimal'? Why do we need to keep the meridional temperature gradient as the same as before geoengineering?

We agree that 'optimal' is a wrong term in the context of our study design, and hence we have reformulated the text accordingly.

These lines pointed out by the referee now read:
"In geoengineering studies, these injections are commonly targeted to the Equator, where the yearly mean intensity of the solar radiation is highest and from where the aerosols disperse globally due to the Brewer Dobson Circulation. However, compensating the

greenhouse gas induced zonal warming by reducing the solar radiation would require a relatively larger radiative forcing to the mid and high latitudes and a lower forcing to the low latitudes than what is achieved by continuous equatorial injections"

-Line 20: should it be "the reduction of shortwave radiative forcing decreased by 27% ..and increased by 15%"? As shown in Figure 3.
-Lines 21-23: "Compared to the continuous...hemispheres respectively". This sentence is confusing. In summer months, radiative forcing increase in both hemispheres when comparing p2 to EQ? But figure 4 shows different results.

We acknowledge that it is challenging to discuss changes in negative forcings in a way that is both easy for the reader to follow and mathematically accurate. While the referee's suggestion is the latter, we feel it would not necessary be the former.

In a hope of clarifying this issue, we have added to the manuscript the following explanation:
"In this section we investigate the radiative forcing resulting from the aerosol microphysical simulations of different injection scenarios. When talking about the changes in the aerosol short-wave (SW) radiative forcings (which are typically negative), we have applied a commonly used and intuitively clear convention: decrease in the forcing refers to the numerical value of the forcing getting closer to zero (i.e. in strictly mathematical sense increasing); similarly, an increase in forcing refers to the numerical value getting more negative."

Line 23: How to qualify "significant changes in temperatures"?
This line now reads: *"However, these forcings do not translate into as large changes in temperatures"*

-Lines 23-25: Please rewrite "Based on ESM scenarios studies here." It is not clear which scenarios are compared here
Sentence was rewritten:
" However, these changes in forcing would lead only to 0.05 K warmer winters and 0.05 K cooler summers in the Northern Hemisphere which is roughly 3 % of the cooling resulting from solar radiation management scenarios studied here"

Page 3:
-Lines 7-16: Are injections in EQ, NH, NHSH once a year? If so, when?
First line was rewritten:
"In three of the studied injection scenarios, the area of continuous sulfur injections remained fixed throughout the year. "

-Lines 18-24: Are injections in p0, p2, p4, p6 and p2w continuous? If so, what is the flux? If not, what is the amount for one injection? The location is changing in what time step? Monthly or seasonally? Figure 2 shows very smooth change of the locations.

Section 2.1 now explains that the injections were continuous in all of the studied scenarios. The location was changed monthly and this is now mentioned in second line of section 2.1.2 *"In four of these scenarios, the 20-degree wide sulfur injection area changed monthly between the latitudes from 30° S to 30° N in different phases."*

Page 5:

-Line 8: Add citation for HAM. And add couple sentence to evaluate

Lines in section 2.1.1 now read:

"The radiative properties of aerosol fields resulting from the 5 Tg(S)/yr stratospheric sulfur injections were defined by using the global aerosol-climate model MAECHAM6.1-HAM2.2-SALSA (Zhang et al., 2012, The European Centre Hamburg Model coupled with Hamburg Aerosol Model including a Sectional Aerosol module for Large Scale Applications). The model has been shown to simulate the stratospheric aerosol loads and radiative properties consistently compared to the observations of Mt Pinatubo eruption as well as other models (Laakso et al., 2016)." *(Laakso et al., 2016)."*

-Lines 15-19: Does MPI-ESM include atmospheric chemistry, such as ozone chemistry? Does the land model and the ocean model (as well as the ocean biochemistry model) fully coupled or just data model?

Ozone is included as prescribed.

Text "*The hydroxyl radical (OH) and ozone concentrations are accounted for through prescribed monthly mean fields. Thus, the effect of sulfur injections on the ozone layer is not simulated in our model "*was added to section 2.2.1

We now added that echam is *"fully"* coupled and mention that JSBACH and HAMOCC are *"active"* in the simulations.:

"The model consists of the atmospheric component ECHAM6.1 (Stevens et al., 2013) which is fully coupled to the Max Planck Institute Ocean Model (MPIOM) (Junglaus et al., 2012). MPI-ESM also includes land model JSBACH (Reich et al., 2013) and the ocean biochemistry model HAMOCC (Ilyina et al., 2013) as active components. Atmospheric GHG concentrations follow the RCP 4.5 scenario (Moss et al., 2010; van Vuuren et al., 2011))"

Page 6:

-Line 17: not just because "in these two scenarios sulfur is injected to an area where solar intensity is on average weaker', but also the transport of sulfate aerosol in NH and NHSH is not as efficient as in EQ. It would be very helpful to look at how the aerosol transport evolves in difference scenarios.

This line is rewritten as:

*"…*since in these *two scenarios sulfur is injected to an area where the solar intensity is on the average weaker and from where the Brewer Dobson Circulation transports sulfur mainly towards higher latitudes (Robock et al., 2008). "*

We added monthly zonal mean figures of AOD at 533nm and new section 3.1.2 to discuss in more detail the transportation of the aerosol in the studied scenarios as well as the optical properties of aerosols at different time and location.

-Line 25: It would be helpful to look at the size distribution in different scenarios.

In addition to AOD figure and section 3.1.2, we added a figure 3 for zonal mean effective radius during summer and winter seasons. See also replies to referees #1 and #2.

Page 7:

-Line 12: Is OH specified in the model, or there is interaction with the UV and water vapor change?

OH was prescribed in the model as monthly means.

Text *"The hydroxyl radical (OH) and ozone concentrations are accounted for through prescribed monthly mean fields."*

was added to section 2.2.1.

Page 8:

-Lines 5-14: There should be sentences discussing this sulfur distribution doesn't include the changes in stratospheric dynamics induced by the sulfate injection geoengineering.

Part of the dynamical feedback is accounted for in our simulations, as stated in 2.2.1 (now moved to 2.2); however, circulation changes induced by GHG and following energy flux changes between the surface and the atmosphere were not simulated when defining the sulfur fields with ECHAM-HAMMOZ. This is discussed more explicitly in 2.2.

"Simulations with ECHAM-HAMMOZ were carried out using a free running setup to include the dynamical feedback resulting from the additional heating due to absorption radiation by the injected aerosols. However, stratospheric circulation could also be altered by changes in the atmospheric GHG concentration (in our case following the RCP4.5 scenario) and resulting the tropospheric climate; however, these impacts were not taken into account when the aerosol fields were calculated in ECHAM-HAMMOZ"

Page 9 - 10:

-Lines 29 (p9)-5(p10): Does this model include water vapor radiation? In sulfate injection scenarios, temperature reduction would reduce the water vapor content in the atmosphere, which reduces water vapor greenhouse effect as well.

The model includes the effect of water vapor on the radiation. The impact correlates linearly with the temperature and thus does not explain what caused the different warming rates. However, it might amplify the difference in warming rates.

-Line 16-19: Please reorganize this sentence "climate was clearly over cooled before SRM was suspended compared to years before SRM when G4 tempters has been kept Same"

These lines are now rewritten:

"However here, in scenarios which were based on the G4 scenario with 5 Tg(S)/yr injections, climate was clearly overcooled after year 2020 and in most of the scenarios the climate was still cooler before SRM was suspended compared to years 2010-2020. In contrast, in G2, simulated by Jones et al. (2013), the global mean temperature was kept at the same level, or slightly warmer after SRM was started in year 2020 and suspended in year 2070."

Page 12:

-Line 2-17: Since the goal of the experiment design is to reduce the tropic-polar tem-

perature gradient change due to sulfate aerosol injection, it would be better to plot Figure 7 in a different way. Instead of using EQ as the base line, it might be better to use RCP4.5. In that way, we could see how EQ changes the temperature gradient as well as other scenarios. Also it might be better to calculate the tropic-polar temperature gradient and plot the time series change under different scenarios.

The choice of using EQ as the base line scenario instead of RCP4.5 (years 2010-2020 or 2060-2070) was done because we wanted to show results which would be easy to adapt for different background conditions. As seen in figure 6 (fig 8 in revised version) b (and partly a), the arctic cooling was caused mainly by temperatures in year 2010-2020, and thus our results depend on the chosen reference years. If years 2060-2070 from RCP45 scenario were chosen as baseline, the regional temperature/precipitation patterns would be dependent on our choice for the amount of injections. For example Kravitz et al 2016 (fig 1) showed that different solar reductions (amount of injected sulfur) would lead to clearly different zonal mean temperature changes. Thus as was said by Kravitz et al "many of the climate effects of geoengineering are design choices".

Page 13:

Summary and conclusion: This part has too many repeating from the method and results sections. It would be better to add more discussion on the uncertainty of this work

As the referee suggested, we removed some repetition from the results section and included more discussions about injections strategies studied here.

These lines are added or modified in the conclusion section:

"However, the scenarios studied here are only the first step towards more optimal injection scenarios. A full optimization would require a more detailed analysis of incoming and reflected solar radiation, atmospheric circulation and how it is affected by sulfur fields as well as aerosol microphysics and chemistry. Overall, however, results of this study already show the potential of time-varying injection scenarios. "

"Even though seasonally varying injection areas could allow for more control over the geographic pattern of the radiative forcing compared to equatorial injections, this might not lead to large differences in regional climate impacts. This is because the heat transport via the oceans and the atmosphere greatly smooths out the impacts from spatially inhomogeneous aerosol forcing. In addition, due to the atmospheric transport, it is impossible to concentrate the radiative forcing from sulfur injections to any limited area. Thus, stratospheric sulfur injections are not an effective method with which to aim for certain regional temperature or precipitation impacts. Despite this, our results indicate that seasonally changing injection areas could resolve some of the spatial inhomogeneities resulting from more commonly studied equatorial injections. "

These lines were removed from conclusions:

"Compared to RCP45 the warming rate between years 2030-2070 was reduced from 1.95 K / 100 yr to 1.25 K / 100 yr in SRM scenarios due to the ocean cooling caused by aerosol radiative effect. This highlights the role of feedbacks and ocean temperature which reacts slowly to the radiation changes in the atmosphere."

“However modelling precipitation changes is very uncertain and making valid conclusions about regional precipitation by using global model is challenging.”

“Results of this study also indicate that the melting of arctic sea ice is more efficiently prevented by tropical injections than injection only to northern hemisphere (30° N - 10° N, scenario NH), in which case the cooling effect at boreal winter is relatively weak. “