Response to reviewers

We thank the reviewers for their comments and efforts towards improving this manuscript. Below, the reviewers' comments are given in blue italic font, and our response follows in black font. Text in small font are excerpts from the new manuscript.

Reviewer #1

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Out of nine models, six models investigated the termination effect, so it would be interesting to see the terminating effect in those models. A similar study which uses sea salt aerosols for MCB reported that termination effect results in an increase in precipitation and extremes (Aswathy et al., 2015). So termination effect, especially on precipitation, cloud cover, and temperature (spatial and zonal averages) could be included in the revised manuscript.

Thank you for this assessment. We had chosen not to emphasize the termination period because we wanted to keep the focus on the effect of performing MCB. We do, however, agree with the reviewer that the climate response to a sudden MCB termination is an important aspect. We have therefore added a new figure and a table in the Supplement, showing temperatures, precipitation, cloud cover and TOA radiation fluxes. We find that the pattern of the changes in temperature, precipitation and cloud cover during the termination period is to a large extent a reversal of the pattern of change resulting from performing MCB in the first place. As already stated in the text, however, the rate of change is higher in the termination period. We have now added the following paragraph at the end of Section 4:

The ability of ecosystems to adapt, and the risk for extinction, dramatically increases under rapid climate change (e.g., Jump and Peñuelas, 2005; Menéndez et al., 2006). One of the concerns regarding climate engineering is the possibility that, due to unforeseen events or government issues, there may be a sudden suspension of the climate engineering efforts, casting Earth's climate into a phase of rapid rewarming. This termination effect has been investigated in several studies (Aswathy et al., 2015; Jones et al., 2013; Matthews and Caldeira, 2007). As mentioned in Section 2.1, six models in the present study simulated the termination effect by turning off the CDNC perturbation and continuing the simulations for 20 years. The effect on global temperatures (relative to the RCP4.5 scenario) in this termination period can be seen in the last 20 years in Fig. 3b. At the end of these 20 years, temperatures are almost back at the RCP4.5 levels. Previous GeoMIP publications investigating stratospheric aerosol injections (see, e.g. Berdahl et al., 2014) have noted a much faster warming in the rebound or termination period than in the RCP4.5 scenario, and this we find also here: for years 2070 to 2090 there is a warming of 0.07 K/decade for RCP4.5 and a warming of 0.40 K/decade for G4cdnc. In a GeoMIP study of stratospheric aerosol injections using three global climate models, Aswathy et al. (2015) find that comparing the mean temperatures of the years 2050-2069 to the years 2020-2079 (where the latter is the termination period), there was a strong Arctic amplification when looking at the RCP4.5 scenario, but a weaker amplification in the climate engineering scenario. Consistently with this, we find that the model median Arctic amplification is 3.6 for the RCP4.5 scenario and 1.7 for G4cdnc, for the same years (see Table S2). The pattern of change in the termination period (Fig. S6) is broadly a reversal of the geographical patterns seen in Fig. 4. However, the spread between the models, as indicated by the hatching in the maps, is much larger for the termination effect precipitation response than for the temperature response, as found also in Jones et al. (2013).

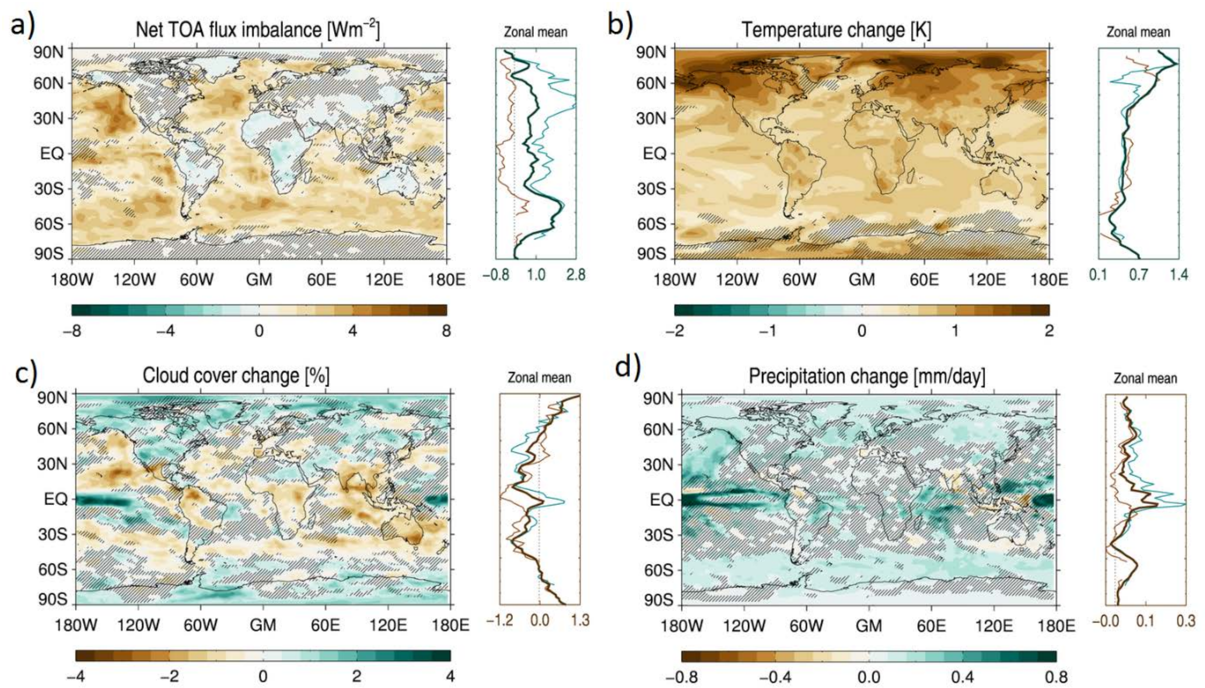


Figure S6: Termination effect. First, the mean change for the G4cdnc years 2050-2069 (the last 20 years of the geoengineering period) is subtracted from the termination period 2070-2089, and the difference for the corresponding years of the RCP4.5 simulations are then subtracted from this number. This gives us an estimate of how much stronger the climate change from abrupt suspension of geoengineering is than the change for the corresponding period for RCP4.5. Panels show ensemble median (taken in each grid cell) differences in a) TOA net radiative flux imbalance (Wm^{-2}), b) near-surface air temperature change (K), c) total cloud cover (%), and d) precipitation (%). Hatched areas are grid cells where less than 75 % of the models agreed on the sign of the change. Zonal averages are given to the right of each panel, where brown and blue lines indicate land-only and ocean-only averages.

Also it would be interesting to see the termination effect on polar amplification. A separate section can be included

We thank the reviewer for this suggestion. We have now included a Table S2, where the Arctic amplification for the temperature difference of (2070-2089) minus (2050-2069) is given for both RCP4.5 and G4cdnc and added a discussion of this in Section 4 (see sentences below, which is an excerpt from the paragraph shown in the previous review point):

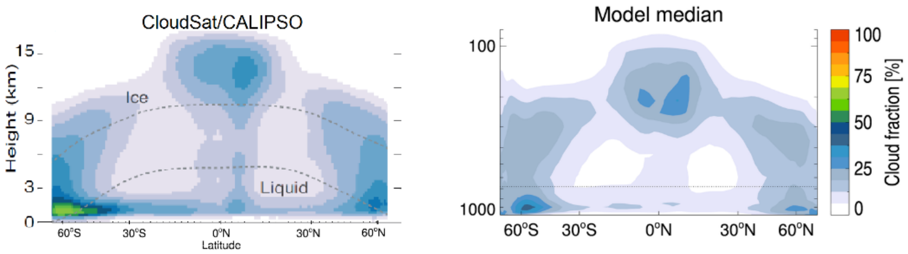
In a GeoMIP study of stratospheric aerosol injections using three global climate models, Aswathy et al. (2015) find that comparing the mean temperatures of the years 2050-2069 to 2070-2089 (where the latter is the termination period), there was a strong Arctic amplification when looking at the RCP4.5 scenario, but a weaker amplification in the climate engineering scenario. Consistently with this, we find that the model median Artic amplification is 3.6 for the RCP4.5 scenario and 1.7 for G4cdnc, for the same years (see Table S2).

	MCB period	Termination period, RCP4.5	Termination period, G4cdnc
BNU-ESM	6.6	6.6	1.7
CanESM2	3.6	3.6	2.0
CSIRO-Mk3L-1-2	3.8	3.8	0.6
GISS-E2-R	2.1	2.1	---
HadGEM2-ES	3.8	3.8	0.9
IPSL-CM5A-LR	1.9	1.9	2.0
MIROC-ESM	1.1	1.1	---
MPI-ESM-LR	---	---	---
NorESM1-M	2.1	2.1	-0.5
Median	3.6	3.6	1.7

Table S2: The first column give the Arctic amplification for the MCB period 2020-2060, calculated as the difference between G4cdnc and RCP4.5. The next column show for RCP4.5 and G4cdnc, respectively: the Arctic amplification in the termination period, estimated as the mean temperature change (average of 2070-2089 minus average of 2050-2069) for the Arctic (defined as all area above 60° N) divided by the globally averaged temperature change. Leftmost column shows numbers for RCP4.5 while rightmost column shows changes for G4cdnc. Models that did not simulate the termination period is marked with '---'.

Page 4. l8: Modeled clod climatologies, is it Section 2.3.?
Thank you for noticing this error – this is actually Section 3! This has now been fixed.

Figure 1. Indicate a reference mark/line for low clouds (at 680 mb).
We agree that this would improve the readability of this figure. Lines at 680 hPa are now added as suggested.



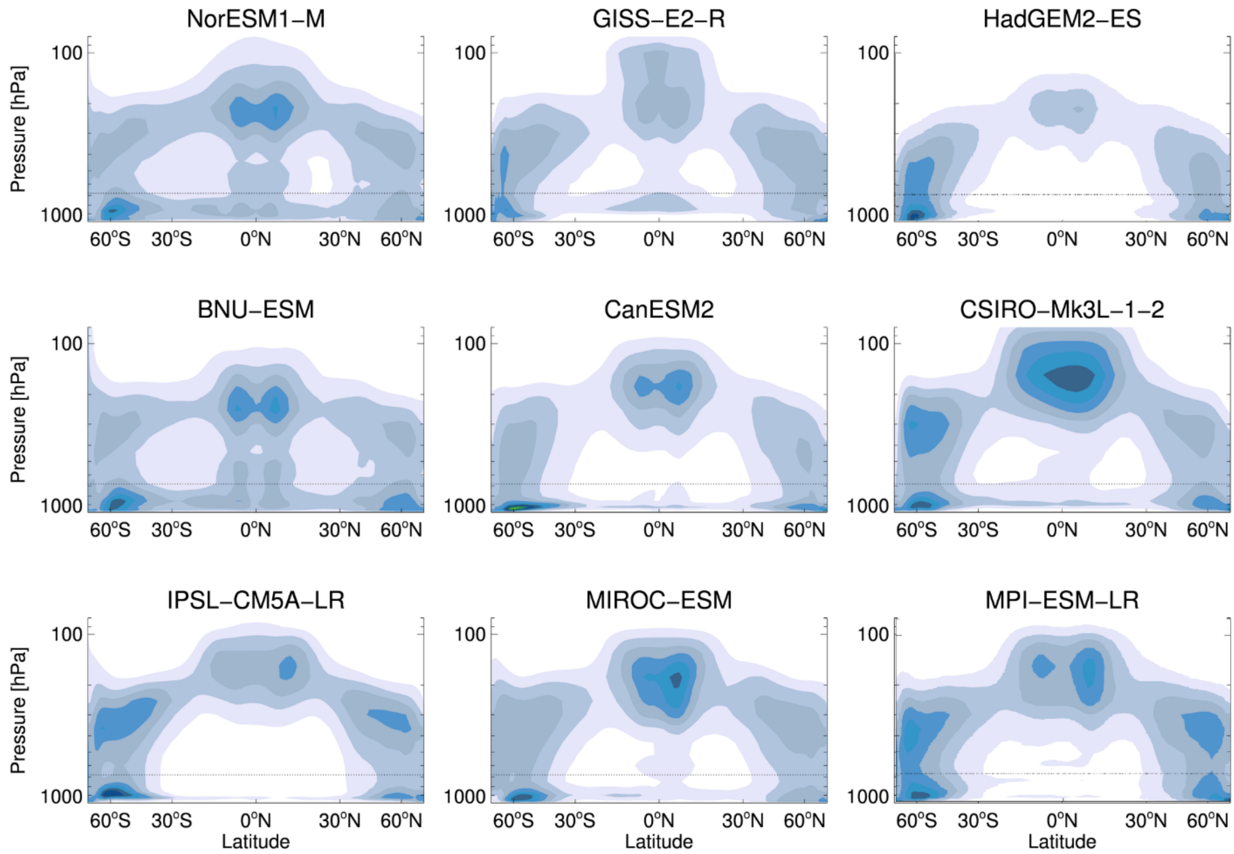


Figure 1: Upper left panel shows cloud fraction [%] from CloudSat/CALIPSO (upper left panel), adapted with permission from Fig. 7.5 (c) from Boucher et al. (2013). Upper right panel shows the GeoMIP model median for the first 20 years of the RCP4.5 scenario (upper right panel), and remaining panels show individual RCP4.5 GeoMIP model results for the same years. Note different vertical axes for the AR5 and GeoMIP plots. Dashed lines mark the 680 hPa level.

Figure 2. Please consider, including observation.

We appreciate the reviewer's suggestion, and we agree that it would be informative to be able to compare these panels to observations, as in Figure 1. However, the low cloud fraction as used in this work is approximated using a random overlap assumption based on monthly mean data. While this provides insight into the geographical distribution of low clouds, as well as how these amounts and distributions vary between models, we do not believe that this quantity will be directly comparable to observations. We have therefore chosen not to provide any observation-based map in Figure 2. However, we have added a reference to Cesana and Waliser (2016, GRL), who show a map of annual mean observationally based low clouds;

Although the low cloud amounts in this study are an approximation as explained in Section 2.2, a comparison between Fig. 2 and the satellite-based observations of low clouds in Fig. 1 of Cesana and Waliser (2016) clearly demonstrates this.