Review of: "What is the limit of stratospheric sulfur climate engineering?" by U. Niemeier and C. Timmreck
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General Comments

I find the title somewhat misleading. The paper deals with climate engineering by injection of SO_2 only. Other methods have been explored to inject sulfur (eg. H_2SO_4 by Pierce et al., 2010; and OCS injection) which are not dealt with here, and these could be expected to have different efficiencies and limits. A more appropriate title might be "What is the limit of climate engineering by stratospheric injection of SO_2?"

This paper represents a contribution to the literature on geoengineering by solar radiation management. However, the main conclusion is not new or surprising. That geoeingineering injections become less efficient with increasing emissions has been demonstrated and discussed previously by Heckendorn et al. (2009), Pierce et al. (2010), and English et al. (2012). This paper does look at sensitivity to injection region both longitudinally and meridionally, which has been discussed in much less detail by previous authors. It also attempts to derive an upper limit for TOA radiative forcing that could be achieved by SO_2 injection, though the uncertainty in this number is large and its utility questionable. And it is the first paper to include radiative feedback in the calculation of aerosol distributions as part of the sensitivity calculations.

The authors treat the subject of geoengineering by solar radiation management as if there is only one possible method (injection of SO_2) and if employed, it would be used to halt future global warming. A more thorough discussion would mention other methods, such as injection of H_2SO_4 or solid particles, e.g. soot or TiO_2. It should also be mentioned that amounts of geoengineering which slow, rather than attempt to halt, surface temperature rise, may have a role in an effective climate strategy (see e.g. MacMartin et al., 2014). The fact that the very high levels of geoengineering discussed in this paper would almost certainly present unacceptable risks to ozone gets one brief mention at the end of Section 4. This important point should be included in the introduction as well, and could include an editorial comment that RCP8.5, with continued growth in use of fossil fuels, is extremely undesirable and has no easy fix via geoengineering injection of SO_2.

The paper's methodology is sound and generally well documented, with a few exceptions noted under "specific comments". The language could use some tweaks to improve the English usage, as noted under "technical corrections". In places the discussion could be broadened and I suggest three references to be added. I support publication after the issues detailed here are addressed.

Specific Comments

Page 10941, line 16, and also in Abstract
"These previous studies were performed with SO_2 injections of 1 to 10 $Tg(S)yr^{-1}$" Pierce et al. (2010) show SO_2 injections up to 20 Mt-S/yr.

Page 10943, line 7
"Nucleation was adapted to high SO_2 concentrations…" Do you mean high H_2SO_4 concentrations? SO_2 plays no direct role in nucleation.

Page 10945, lines 24-25
"These data are derived from a double radiation call" Please explain "double radiation call"

Page 10951, line 23
The statement that "the aerosol is coupled to a radiation scheme" in the Pierce et al. (2010) work is misleading. That study and the Heckendorn et al. (2009) study calculated changes in radiation due to aerosols but there was no feedback of radiation into the aerosol distribution. Aerosols were calculated in a 2-D model with fixed circulation off-line from radiative effects.

Page 10953-10954, the paragraph spanning this page transition
Robock (2009) did not perform a serious analysis of delivery systems for geoengineering. The work of McClelland et al. (2012) covers this topic in more depth and would provide a more appropriate citation. Table 1 of that reference gives number of aircraft required to lift 1 Mt-S per year into the stratosphere for several existing aircraft types. From this, the fleet size required to inject 26 or 45 Tg-S/yr can be estimated.

Page 10954, lines 16-17
In the discussion of possible cloud feedback, add reference to Cirisan et al. (2013). The reference indicates that this feedback might go either way. I suggest changing "would" to "might": "the resultant brighter clouds might reflect more sunlight, a positive feedback"

You might consider replacing "R_{TOA}" with "ΔR_{TOA}" to be clear that you are talking about the change in top-of-atmosphere radiative forcing due to geoengineering aerosols, not total radiative forcing.

Suggested additional references:

Cirisan, A., Spichtinger, P., Luo, B. P., Weisenstein, D. K., Wernli, H., Lohmann, U., and Peter, T.: Microphysical and radiative changes in cirrus clouds by geoengineering the stratosphere, J. Geophys. Res., 118, 4533-4548, doi:10.1002/jgrd.50388, 2013.

MacMartin DG, Caldeira K, Keith DW. 2014 Solar geoengineering to limit the rate of temperature change, Phil. Trans. R. Soc. A, 372: 20140134.
http://dx.doi.org/10.1098/rsta.2014.0134

McClellan, J., Keith, D. W., and Apt, J.: Cost analysis of stratospheric albedo modification delivery systems, Environ. Res. Lett., 7, 034019, doi:10.1088/1748-9326/7/3/034019, 2012.

Technical Corrections

Page 10940, Abstract, line 4
Change “the amount injected of sulfur dioxide” to “the injected amount of sulfur dioxide”

Page 10941, line 17-18
“which aim to counteract anthropogenic forcing towards 2020 forcing conditions”
Correct to: “which aim to counteract continuing anthropogenic climate change by maintaining 2020 forcing conditions”

Page 10943 line 21-22
“Model results using this setup show for e.g. particle size and radiation at top of the atmosphere (TOA) a good overall agreement”. Better English would be “Model results using this setup show overall good agreement for particle size and radiation at the top of the atmosphere (TOA).”
Page 10943, lines 25-26
“calculated aerosol concentrations in the tropics were six months after the eruption lower than observed.” Better English is “calculated aerosol concentrations in the tropics six months after the eruption were lower than observed.”

Page 10944, lines 6-7
“As a result the simulated particle number distributions compares better to those described by a sectional aerosol model” Minor correction: “As a result, the simulated particle number distributions compare better with those calculated by a sectional aerosol model”

Page 10944, lines 21-22
“To study the dependence of the particle size distribution on the amount of injected SO2, a series of numerical experiments were performed” Add comma after “SO2”.

Page10945, lines 23
“Figure 1 (left) shows the simulated global radiative fluxes at the top of the atmosphere”
Change go: “Figure 1 (left) shows the simulated change in global radiative fluxes at the top of the atmosphere”

Page 10946, line 9
Correct typo: “negativ forcing” to “negative forcing”

Page 10948, line 3-4
“3. Due to advection are larger particles in accumulation and coarse mode globally dispersed.” Correct to
“3. Due to advection, there are globally dispersed larger particles in accumulation and coarse mode.”

Page 10948, line 8-9
"As a consequence of the continuous emission flux under sulfur SRM are large and fine particle sizes always available." Better English is "As a consequence of the continuous emission flux under sulfur SRM, large and fine particle sizes are always available."

Page 10948, lines 24-27
"The distribution of nucleation and Aitken mode particles is determined by microphysical processes only, while accumulation and coarse mode particle distributions depend on microphysical processes such as coagulation and transport." Change wording a bit to clarify: "The distribution of nucleation and Aitken mode particles is determined mainly by microphysical processes, while accumulation and coarse mode particle distributions depend on both microphysical processes such as coagulation and on transport."

Page 10949, line 10
"In Geo10-lon injections occure along the Equator." Typo, change "occure" to "occur".
Page 10949, lines 19-20
"a more even distribution of particle and an overall quite regular availability of small particle." Change "particle" to "particles" two times in this sentence.

Page 10949, line 22
Change "in meridional direction" to "in the meridional direction"

Page 10949, line 23
Add 's' to 'simulation' - "in simulations Geo10-5 and Geo10-30"

Page 10950, line 17
Typo: change "injectiona" to "injection" "The zonally larger injection area"

Page 10952, line 12-13
"These findings are different to those" Change "to" to "from"

Page 10952, line 24
Change "an" to "a" in "show an more even distribution"

Page 10953, lines 10-11
Change "of" to "off" in "less vertical transport in the tropics when switching off the coupling of aerosols to radiative processes."

Page 10953, line 26
Change "an" to '"a" in "an TOA forcing reduction"

Page 10954, line 5-6
Suggest not to start new paragraph here but at line 12.

Page 10954, line 12-14
The meaning of this sentence is unclear: "The estimated numbers are certainly based on

the ECHAM-HAM calculations including all model uncertainties discussed above." Probably the word "certainly" can be removed. What is the range of injection amounts suggested by ECHAM-HAM to counteract RCP8.5? Is it 26-45 Mt/yr?

Page 10954, lines 16-17
English improvement: "Additional nuclei for cloud condensation may get into the upper troposphere via sedimentation of sulfate aerosols"

Page 10954, lines 19-20
Add "the" in sentence: "side-effects of sulfur SRM on society and the environment"

Page 10954, lines 25-26
Removed the comma after "strength": "TOA forcing to injection strength, with increasing SO_2 injection"
Page 10955, line 5
Add "s" to "contribute" and change "on" to "of": "This study contributes to the discussion of"

Page 10955, line 12-13
Change "even" to "evenly": "particles are less evenly distributed."

Page 10955, line 19
Change "inject to "injecting: "and injecting outside of the tropical transport barrier"

Page 10955, line 29
Change "with" to "from": "different in details from other models."

Page 10956, line 13-14
Change "founding" to "funding": "C. Timmreck acknowledges funding from the BMBF project"

References: Is it common practice to include manuscript page numbers where the citation is referenced in the reference list?

Figure 1: Year is abbreviated "y" in the right panel y-axis label, but "yr" in caption and manuscript text.

Figure 2 y-axis label needs superscript on "cm-3". Legend labels should be changed to "Tg(S)yr−1"

Figure 2 Caption
Change "radiative" to "radiatively" and reword for better English: "Only particles in accumulation and coarse modes are radiatively active."

Figure 3 y-axis labels should be changed to "mg m-2" Or should it be "mg m-3" ?

Figure 3 Caption
"Burden of (left) SO2 and (right) sulfate coarse mode particles"

Figure 4 y-axis label needs superscript on "cm-3".

Figure 5 y-axis label needs superscript on "cm-3".

Figure 5 Caption
Remove "different", as injection rates are all 10 Mt/yr: "~~different~~ injection rates of $10Tg(S)yr^{-1}$"

Change "extend" to "extent": "varying extent of the injection area"

Figure 7: Year is abbreviated "y" in the left panel x-axis label, but "yr" in manuscript text.

Figure 7 Caption
"results from Pierce et al. (2010), labeled P10, and English et al. (2012), labeled E12"