

## **Review of “Assessing Responses and Impacts of Solar climate intervention on the Earth system with stratospheric aerosol injection” (ARISE-SAI) by Richter *et al.***

In this paper, Richter et al. introduce a new stratospheric aerosol injection (SAI) simulation protocol that can readily be adopted in climate models. Specifically, the protocol (ARISE-SAI-1.5) involves maintaining global warming at the Paris target of 1.5°C against the backdrop of a middle of the road emissions scenario (SSP2-4.5) using SAI and an advanced feedback controller. The difference between ARISE-SAI-1.5 and previous SAI model intercomparison projects is that in ARISE-SAI-1.5 the emissions scenario is more consistent with projections than in, e.g., GLENS, and that ARISE-SAI-1.5 uses an advanced feedback controller to reduce residual climate changes, unlike in GeoMIP. Richter et al. then perform simulations with the CESM2(WACCM6) climate model using the SSP2-4.5 and ARISE-SAI-1.5 protocol and 10 ensemble members and provide a preliminary analysis of climate impacts in those simulations.

The ARISE-SAI-1.5 simulation protocol certainly represents a marked improvement over GLENS and GeoMIP such that it is more realistic, and therefore will provide more policy-relevant answers than those previous projects. While the paper contains much detail of interest and is generally well written, I found the structure of the paper to be rather confusing which obscures its overall purpose. To be clear, I think that the paper is very interesting and scientifically valid but needs a simple restructuring, as I outline in the General Comments below, before it is ready to be published.

### **General comments**

The paper singularly concentrates on the “ARISE-SAI-1.5” simulation, which should be reflected in the title rather than the umbrella term “ARISE-SAI” as I assume that in future other simulations will be added to the ARISE-SAI project. The title is also rather uninformative and should reflect that the paper both describes a protocol (i.e., ARISE-SAI-1.5) and further includes preliminary analyses – maybe “Protocol and preliminary results from the policy-driven “Assessing Responses and Impacts of Solar climate intervention on the Earth system with Stratospheric Aerosol Injection” (ARISE-SAI) project”? At present, it is unclear what the scope of the paper is from either the title, the abstract, or the introduction.

The abstract is not particularly comprehensive. For instance, it is missing the overall justification for the ARISE-SAI project, something like “previous SAI simulation protocols have been overly simplistic and not particularly policy relevant, instead concentrating on identifying structural differences between climate models” or something to that effect. Additionally, the model used to perform these preliminary analyses (CESM2(WACCM6)) should be mentioned in the abstract, as it is unclear how many models have contributed to this paper.

The end of the introduction is rather weak, and I was left unclear as to what the structure or content of the paper was going to be. Additionally, the overall structure of the paper is rather confusing. Instead, I think the paper should be structure as follows

1. Introduction and justification for new geoengineering project
2. ARISE-SAI project overview and ARISE-SAI-1.5 protocol
3. Model (CESM2(WACCM6)) configuration (including location of output)

4. Preliminary climate analyses
5. Conclusions

Currently, the ARISE-SAI-1.5 protocol is buried in section 2, after the model description and so it makes it seem that the CESM2(WACCM6) simulations are the emphasis of the paper, rather than the simulation protocol itself. This may be the reason that Richard Rosen left a comment lamenting the lack of seasonal climate impacts analysis in the paper. To be clear, I think more emphasis should be on the novelty of the new protocol and ARISE project, and that the preliminary climate analyses (including the description of CESM2(WACCM6)) should be of secondary importance in the paper.

Related to this, I was disappointed at the lack of discussion over the wider ARISE project, seeing as this is the first paper on something that seems to be a rather comprehensive multinational project. What other simulations are planned for this project? Which other groups are currently contributing to the project and which other climate models? What is the scope or mantra of the project, and will other temperature or climate targets be considered (ARISE-SAI-2.0)? What is the length of the project and are there any time constraints for potential contributors (e.g., initial simulations should be submitted by MM/YY)? Greater clarity here would be very beneficial. Also, more emphasis on the novelty of the project would be helpful to the paper.

Just to be clear, I do not support the previous comment by Richard Rosen saying that the paper should investigate seasonal impacts of SAI on precipitation and temperature, or air quality, etc. That is clearly outside the scope of this paper which I feel should emphasize that the preliminary climate results are of secondary importance to the description of the ARISE-SAI-1.5 protocol. I do not think that the authors need to add anything extra in terms of new climate analyses as that is clearly outside not conducive to the goals of the paper (and there are many precedents for this), but maybe an extra line in the conclusions listing further analyses that could be performed would be beneficial.

Lastly, on a minor note, it would help readability for me if the paragraphs all used “justified” alignment, rather than the mixture of justified and left aligned. This is of course a minor quibble.

### Specific comments

- [L14] “reduce *some of* the consequences of climate change.” – ‘some of’ is rather colloquial. Ideally climate intervention would reduce all of the consequences of climate change, or at least those seen to be detrimental. Consider rephrasing.
- [L16] Line beginning “We present here a new modelling protocol and a 10-member...” – this sentence is long and confusing. I recommend that it is broken up and reworded
- [L23] “We present here the detailed set-up, aerosol injection strategy, and mean surface climate changes in these simulations so they can be reproduced in other global models.”. One thing that is missing from the abstract is justification for running ARISE-SAI-1.5 – i.e., the fact that it is more policy relevant than GLENS and represents an improvement over those simulations. Additionally, the fact that only temperature and precipitation are analysed in this paper should be mentioned here. Lastly, add the name of the model into the abstract. I also recommend mentioning that a feedback algorithm is part of the protocol.
- [L30] “Stratospheric aerosol injection (SAI) has been shown to be a promising method of global climate intervention in terms of restoring climate to present day conditions” – but only in

climate models and on top of this only in certain climate models and under specific SRM implementations. You could also mention the volcanic analogue here

- [L50] “The Geoengineering Large Ensemble (GLENS, Tilmes et al. 2018)” - I recommend introducing a paragraph break here
- [L69] “Here we describe a new set-up of an ensemble of simulations with CESM2(WACCM6) designed to simulate a more plausible implementation scenario of SCI using SAI that can be replicated by other modelling centres, and present preliminary diagnostics to begin enabling community assessment of responses of the Earth system to such an intervention.” – the end confuses the purpose of the paper. Firstly, the ARISE-SAI-1.5 protocol should be differentiated from the CESM2(WACCM6) ensemble of simulations, which is a single realisation of the protocol (albeit the first). The following, I think, reads better.
- “Here we propose a new SAI simulation protocol (ARISE-SAI-1.5) which can be readily implemented in climate models, and we describe realisations of ARISE-SAI-1.5 in the CESM2(WACCM6) climate model. The paper is structured as follows: ...”
- [L76] “Model description” – I think the ARISE-SAI-1.5 description should come before the model description (see General Comments)
- [L96] “CESM2(WACCM6) includes prognostic aerosols which are represented using the Modal Aerosol Model version 4 (MAM4) as described in Liu et al. (2016).” - The aerosol scheme is fundamental to the paper and should be afforded more description, i.e., how many modes, what species, how detailed is the sulphur cycle, etc.
- [L131] “We carried out an additional 5-member ensemble of these simulations from years 2015 – 2069 with augmented high-frequency output for high-impact event analysis, as well as additional output for the land model to match the SCI simulations” – is this part of the ARISE-SAI-1.5 simulation protocol? Do you expect other models to perform the high-frequency simulations? What subset of variables are needed as output from other participating climate models? Please be specific about the ARISE-SAI-1.5 protocol.
- [L143] “we denote the entire planned set of simulations as “Assessing Responses and Impacts of Solar climate intervention on the Earth system,” or “ARISE,” with simulations of SAI denoted “ARISE-SAI”. – this would be a good place to suggest what other climate interventions could or will be considered. MAC, CCT, CDR etc? Also, are other SAI simulations being planned?
- [L148] I recommend moving “possibly” as 1.5°C is seen as a critical threshold
- [L154] “These four injection locations are sufficient to independently control the targets that we are trying to achieve” – this is certainly true in CESM1 but has not been verified in other climate models or indeed in the earth system itself. Please add a caveat.
- [L204] “GLENS also required more at 30oN/30oS to maintain T2” – more “SO2 injection”
- [L306] “The largest exception to that is the North Atlantic warming hole” - Why does AMOC weaken even further under SAI? Or is it that it weakens the same but is not compensated by global warming?
- [L323] Consider combining Figs 5 and 6
- [L349] “Consistent with prior studies, global mean precipitation in ARISE-SAI-1.5 is smaller than during the reference period.” – how significant is this difference? It looks pretty small