

Earth Syst. Dynam. Discuss., author comment AC2
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Reply on RC2

Yan Zhang et al.

Author comment on "How large is the design space for stratospheric aerosol
geoengineering?" by Yan Zhang et al., Earth Syst. Dynam. Discuss.,
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Original referee comments are in italics

Author responses are in plain text

The manuscript provides and demonstrates a mathematical method to quantify the degree of freedom of stratospheric aerosol injection (SAI) geoengineering. The authors transform the simulated AOD pattern and temperature and precipitation responses to the vectors in multi-dimensional spaces and explore their relationship, then use it to search the meaningfully-independent injection choices. As there are lots of possible injection choices in SAI geoengineering research, the manuscript will be useful to guide future SAI studies, although the sample space used in this study is limited due to available SAI simulations and all samples are based on a single earth system model. In general, the manuscript is well written and fits the scope of the ESD. However, the manuscript uses some specific mathematical tools, it is necessary to make the manuscript more readable for a wider geoscience community.

We thank the referee for their comments on our paper, and respond individually to each of their comments below.

Minor points:

1. As similar AOD patterns yield similar climate responses but different AOD patterns do not guarantee different climate responses, how does this might affect searching the meaningfully-independent injection choices?

We thank the referee for this question. This means that one might explore too many options and the effective number of DOF might be smaller than what we found in our study (which is better than the converse problem of possibly ignoring important DOF). In L281, we have added explanations to make this point more clear.

2. The AOD patterns are constrained by the stratospheric circulation and lifetime of the aerosol. Is it feasible to explore more possible AOD patterns by using widely available non-geoengineering CMIP simulations? With more AOD patterns, the sample space can be well expanded.

We thank the referee for this suggestion. Using the non-geoengineering CMIP simulations

would be a potentially valuable complement to our analysis. Available simulations include, for example, the response to volcanic eruptions at different latitudes, altitudes, and times of year. However, this dataset of opportunity may not fully span the design space. Compared to using non-geoengineering data, our approach has two advantages: (1) Our sample set has good resolution of injection latitudes and seasons. The AOD patterns obtained from available non-geoengineering data depend on the location of active volcanoes and the time of volcanic eruptions, which may not have a better spatiotemporal resolution. (2) Our sample set allows a direct connection back to the injection choices that span the design space. Using the AOD from simulations of volcanic eruptions does not clearly reveal a direct relationship between a certain injection choice and the AOD pattern arising from a volcanic eruption.

Technical points:

L34-35: Please clarify why the number of independent injection choices is equivalent to the number of independent climate goals.

We assess meaningfully-independent injection choices based on whether different choices yield sufficiently distinct patterns of AOD that they can be expected to yield meaningfully different climate responses. Thus, the number of independent injection choices is equal to the number of meaningfully different climate responses. Assuming that the climate response can reasonably be approximated as linear, the ability to independently combine n patterns of climate response allows n independent goals to be managed, provided that they do not conflict.

We have modified the text to make this point clear.

L136-139: Please clarify the definitions of the length of vector and the angle between the vectors.

Thank you. We have modified those sentences to clarify the definition of the length of vector and the angle between the vectors.

L261: Do the vectors of T and P responses adopt similar definition for the vectors of AOD pattern? If yes, it is better to explain them together.

They adopt different definitions. The vectors of T and P include annual mean surface responses at different longitudes and different latitudes, while the vector of AOD includes monthly zonal mean AOD values.

L263: Define the abbreviation "EQ" at its first appearance.

Thank you. We have defined "EQ" in Table 1.

L429: Extreme events can be part of future consideration due to their profound impacts on social and economic activities.

We agree with the referee that extreme weather events should be considered in future research, although they are not likely to add further degrees of freedom for the range of cooling considered in this paper. We have noted this in the "Conclusions" section, as noted in our response to the other reviewer.

Figure 9, 10 and 11: Please explain their x & y axes.

We have added explanations in the figure captions, that "both x- and y-axis are distances

in number of standard deviations".