

Comment on Zhang et al

Anonymous Referee #1

Referee comment on "How large is the design space for stratospheric aerosol geoengineering?" by Yan Zhang et al., Earth Syst. Dynam. Discuss., <https://doi.org/10.5194/esd-2021-70-RC1>, 2021

The submitted paper discusses the number of independent degrees of freedom in climatic response to stratospheric sulfate injection as a mechanism for geoengineering. The paper considers a superset of existing simulations using CESM, where aerosol injections are varied by latitude and season. The authors identify an approach for assessing the similarity of both the resulting Aerosol Optical Depth (AOD) pattern and the resulting perturbations in regional temperature and precipitation. Independent degrees of freedom are isolated by considering both the optimal/minimal subset of modes to linearly reconstruct the remaining ensemble of forcing patterns, and the resulting detectability of reconstruction errors in the context of internal variability.

The paper is well written and comprehensive, and addresses an interesting and pertinent point with respect to geoengineering strategy design. The mathematical formulation is a little unconventional, and the results are more empirical than might be strictly necessary. The authors should also take care to avoid statements that imply that their design space is an inherent property of the system (rather than a subset of the small number of injection experiments conducted to date). That said, the paper makes some strong and interesting points is quite adequate for publication in ESD with just some minor clarifications.

Minor points

1 - The approach is semi-empirical, and subject to the properties of the parent ensemble. Though the end product is useful, the design space is only a subset of the possible degrees of freedom in the response to injection. Several additional degrees of freedom are unexplored in the parent ensemble - longitudinal variation in injection site, additional injection altitudes, adaptive injection (i.e. responding to synoptic conditions), variation in background scenario - which could potentially increase the design space. This should be highlighted more clearly.

2- The iterative approach of selecting subset members by their ability to represent the remaining ensemble through linear combination is logical - but this may still not reveal the minimum possible number of degrees of freedom, and is again subject to the original ensemble sampling. The patterns maximize independence within the source ensemble, but they are not orthogonal (as is strictly implied by the linear concept of a degree of freedom). An orthogonal set of patterns may be able to describe the ensemble variation of AOD forcing with a smaller number of degrees of freedom than those found in this study.

3- The choice of 20 year mean pattern differences as a metric for signal emergence may mask important aspects of the climate, especially for precipitation. Extreme frequency, drought, variability, seasonality - are all not represented in this mean state metric - and though this limitation is noted in the discussion, but it is potentially answer-changing in terms of the degrees of freedom in response. Precipitation response in particular to may have additional detectable degrees of freedom in the source ensemble if other climatological metrics are taken in to account.

4 - Aspects of the language regarding SAI in policy in the abstract and introduction need revision to highlight the uncertainty in the efficacy and risks associated with SAI. For example, the second line in the abstract should perhaps read: "Adding aerosols to the lower stratosphere has been modeled to produce temporary global cooling." The first sentence of the introduction is overly leading and unjustified. A cessation in GHG emissions today would prevent further warming. Policy may fail to deliver these reductions - but it is not the concept of emissions reductions itself which would be insufficient to prevent escalating climate risks. It should also be noted that SRM does not only have the capacity to reduce risks - it also has the potential to create additional risks relative to a non-SRM conventional mitigation scenario (e.g. rapid climate change in the event of early cessation).

Technical points:

Subfigure 10 should be labeled (a-d)