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The Cryosphere Discussions

Interactive comment on "Brief communication: Understanding solar geoengineering's potential to limit sea level rise requires attention from cryosphere experts" *by* Peter J. Irvine et al.

Peter J. Irvine et al.

p.j.irvine@gmail.com

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A combined response to reviewers generated in word is attached. A - Author responses, R - reviewer comments.

A - We submitted this article to The Cryosphere as a brief communication after communicating to the editors that our article that was someway between a commentary and a technical review of the sea-level rise response to solar geoengineering. In such articles novelty is not the central goal. However, in responding to the reviewer comments we have added some novel analysis of the surface mass balance response to solar geoengineering. With the revisions recommended by the reviewers we believe

this article makes a useful contribution to the discussion on the sea-level rise response to solar geoengineering.

R - This article reviews the links between solar radiation management (SRM) and the dynamic and surface mass balance (SMB) of ice sheets. However, there is no effort to understand or even reduce the uncertainty on the ice sheet component under SRM, except to provide an action plan to do this. The focus of climate modelers is on making future scenario based projections of sea level rise with new coupled ice sheet components. There is a long way to go before we can attempt to understand paleo-simulations much less SRM. Since the influence of SRM on ice sheet dynamics is unexplored, I would suggest the paper focus on SMB and should ideally include an analysis, however brief, of the GeoMIP model simulations. The article is bloated in comparison to what can be concluded from the small number of relevant simulations. In addition I find some of the assertions at odds with the references omitted from this review, and these are commented on below.

A - We thank the reviewer for their suggestions and have made several major changes to address the concerns raised and to improve the manuscript: - We've added a quantitative analysis of the factors driving surface mass balance changes for the GeoMIP climate model ensemble. - We've restructured the main section of the paper. Sections 3 and 4 from the original paper are now sub-sections of a broader section which frames the issues we address more clearly and also briefly addresses thermosteric sea-level rise. - We've removed the "sea level rise engineering" section - We've rewritten the recommendations for research.

R - P1:L28. You are referencing 'Expert Judgements' here, which do not really quantify projection uncertainty. The uncertainty should be expressed from model projections as described in AR5 (Ch 13). This is relevant since the next sentence refers to two such projections.

A - Bayesian statistics is widely applied in the Earth sciences and in sea-level rise pro-

jections and provides a framework in which expert judgements can be used alongside other inputs to estimate uncertainty in projections. We believe that it is appropriate to refer to studies which draw on expert judgements of projection uncertainty in this case due to the fact all models miss certain processes which are known to be critical to the future contribution of ice-sheets to sea-level rise. To rely on the spread in model projections alone would be to severely under-estimate uncertainty in ice-sheet contributions to sea-level rise. As our point in this paragraph is to highlight the large uncertainty in sea-level rise contributions from Antarctica we believe it is appropriate to cite studies that illustrate this point using a range of approaches including expert judgement.

R - P1:L29. Remove 'both of which were published in Nature'. This is a judgement statement implying quality of the referenced research (although this is not the use here, the commonality in source of the papers is irrelevant)!

A - We've rephrased this as follows:

A - "For example, two recent high-profile publications made conflicting estimates of Antarctica's contribution to sea-level rise by 2100 with a best-guess of 10cm (Ritz et al., 2015), and of around 1m (DeConto and Pollard, 2016)."

R - P1:L29-30. State the period at which these estimates of sea level equivalent apply. 2100?

A - See last response

R - P1:L32-35. Evidence required. AR5 (Ch 12 & 13) provides this as does Bouttes (2013) below. Bouttes, N., J.M. Gregory, and J.A. Lowe, 2013: The Reversibility of Sea Level Rise. J. Climate, 26, 2502–2513, https://doi.org/10.1175/JCLI-D-12-00285.1 P2:L1. Carbon removal (e.g. Jones CD et al, 2016, Environ. Res. Lett. 11, 095012).

A - We thank the reviewer for this useful suggestion which we cite elsewhere, though in this case we have cited Clark et al. (2016) which points out the millennial sea-level rise implications of fossil-fuel emissions (without CDR or solar geoengineering).

R - P2:L29. RF and GHG not previously defined

A - We have removed RF as this was the only usage and defined GHG here.

R - P4:L2-3. This is not self evident. Kravitz et al (2013) suggest that a polar warming might occur with over-cooling in the tropics, when compared against the reference state (Preindustrial). Kravitz, B., et al. (2013), Climate model response from the Geoengineering Model Intercomparison Project (GeoMIP), J. Geophys. Res. Atmos., 118, 8320–8332, doi:10.1002/jgrd.50646.

A - We have made it clearer in the text that we are referring to the effects of solar geoengineering alone, which cools everywhere, not the combined effect of elevated CO2 and solar geoengineering. The relevant comparison in that Kravitz study is the abrupt4xCO2 experiment, not the pre-industrial.

A - "As solar geoengineering would reduce temperatures across the world, offsetting some of the warming from elevated GHG concentrations, it is clear that to first order it would reduce both the thermal expansion of the oceans and the melting of land ice."

R - P4:L9-15. Simple models do not show Greenland ice sheet decline for the strong climate mitigation scenario RCP2.6 either.

A - We've clarified that we are referring to high-CO2 scenarios here.

R - P5:L3. Precipitation is decreased except for over the ice sheets (see fig 7 in Kavitz et al., 2013).

A - We pick this issue up in the revised section on surface mass balance.

R - P5:17-10. This is definitely not true. Nearly all modern Earth System Models now have a dynamic Greenland ice sheet and a few have mountain glaciers, and they are always, of course, driven by the ESM coupled fluxes (e.g. Lipsomb et al., 2013) . ISMIP6 is NOT using PPD for its offline models. Lipscomb, W.H., J.G. Fyke, M. Vizcaíno, W.J. Sacks, J. Wolfe, M. Vertenstein, A. Craig, E. Kluzek, and D.M.

Lawrence, 2013: Implementation and Initial Evaluation of the Glimmer Community Ice Sheet Model in the Community Earth System Model. J. Climate, 26, 7352–7371, https://doi.org/10.1175/JCLI-D-12-00557.1

A - We thank the reviewer for the correction, our view on this was shaped by our analysis of CMIP5-era models which, as IPCC AR5 WG1 Ch13 p1169, makes clear did not include coupled ice sheets: “Goelzer et al. (2013) and Gillet-Chaulet et al. (2012) suggested that SMB and ice dynamics cannot be assessed separately because of the strong interaction between ice loss and climate due to, for instance, calving and SMB. The current assessment has by necessity separated these effects because the type of coupled ice sheet-climate models needed to make a full assessment do not yet exist.”

A - We have reworded the paragraph as follows:

A - “Many ice-sheet and glacier models use a simple parameterization of surface mass balance, using a positive degree-day factor to estimate the amount of melt per degree above freezing at the glacier surface (Ohmura, 2001). Degree day factors are determined empirically and vary due to surface albedo, meaning that a weathered ice surface such as the Greenland ice margin are rather dark and have high degree-day factors, while pristine snow cover has a low factor. This degree-day approach has been used in all studies of solar geoengineering’s effect on surface mass balance to date, but it has some important limitations.”

R - P6:L34. Actually, the hydrological cycle under SRM is increased over ice sheets (Kravitz et al., 2013).

A - We have rewritten this section and include results that support the reviewer’s assessment.

R - P7:L13. Need to briefly state what “marine ice sheet instability” actually is. E.g. Grounding-line retreat leads to larger ice mass flux through the grounding-line gener-

ating further retreat.

A - This section has been completely rewritten (now section 3.3) and we include a brief description of marine ice sheet instability.

R - P7:L17 More precision, perhaps “They suggest that the atmospheric warming that led to the break-up of some Antarctic Peninsula ice shelves would, if the warming continued, destabilize the larger southern ice shelves in the future (Liu et al., 2015). The process is through the hydrostatic head of melt-water filled crevasses which results in “hydrofracture” and the rapid disintegration of the ice shelf.” Though actually it is the Ice Cliff Instability (ICI) that is the killer in DeConto and Pollard but the ice shelves need to go first and in any case SRM will never stop ICI. Stick to the key point from this paper is that air temperatures are perhaps important for ice sheet collapse and these can easily be reversed. You are spending too much time on in DeConto and Pollard given the uncertainty they themselves express in the paper. You can be much briefer here.

A - We have revised this section considerably, reducing the amount of material on the DeConto and Pollard paper and focusing on the potential significance of surface air temperature on ice-shelf stability. We have adopted the phrasing suggested by the reviewer for those sentences.

R - P8:L3-9. This whole discussion belongs back at the first paragraph of this section. Putting it here leads to a disjointed argument and repetition. Getting circumpolar water up on to the shelves depends on the Ekman pumping which is a function of the circumpolar winds. If the winds shift because of SRM or associated ozone depletion then the basal melt will be different. I have not seen any study of changes in the southern ocean winds under SRM. Intermediate waters are not going to cool significantly on the timescale SRM might be deployed.

A - We thank the reviewer for this useful suggestion. We have restructured and rewritten this section, brining this point up nearer to the beginning of this section.

R - P9:L25. Bouttes et al., 2013 is relevant to this discussion.

A - We thank the reviewer for this suggestion and cite Bouttes et al. (2013) on the reversibility of thermosteric sea-level rise in the new sub-section (3.1) devoted to this issue.

R - P10:L15-30. A few coupled global climate models are now including an interactive Antarctic and Greenland ice sheet components. Such models would enable a more complete understanding of the impact of SRM on ice sheets, than the doggy offline components.

A - We thank the reviewer for this suggestion and in the fully revised research recommendations sections, this is our first recommendation.

Please also note the supplement to this comment:
https://www.the-cryosphere-discuss.net/tc-2017-279/tc-2017-279-AC2-supplement.pdf

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