Response to Referee 1 Comments on "The G4Foam Experiment: Global Impacts of Regional Ocean Albedo Modification," by C. J. Gabriel et al.

Referee comments are in black. Responses are in blue.

1) In the case of termination of G4Foam, why not study a gradual termination instead of an abrupt termination? It would be interesting to see the recovering phase of G4Foam in a gradual termination process.

It would be interesting to study a slower return to reference simulation conditions probably not only in G4Foam, but in other GeoMIP experiments as well. However, all GeoMIP experiments to date that have included termination, including G4SSA, have imposed abrupt termination. We keep to this convention to facilitate comparison with RCP6.0 and G4SSA. If one has simulated a large step response, it is straightforward to scale the results to a more gradual response. The abrupt change has the advantage of a large signal-to-noise ratio, so the response is easily identified.

2) Paper claims the G4Foam experiment would cool the NH tropics and hence reduce the heat related mortality (Line no : 127, 377). However, heat related mortality is caused by extreme temperatures not the mean values, please justify.

We have eliminated the assertion that G4Foam would reduce heat-related mortality, as we have found that this may not be true. The following text has been added to the manuscript. Please see lines 100-115 in the revised manuscript.

"The asymmetric cooling would force changes in the Hadley Cell, enhancing cross-equatorial flow, which would cool the surface in the NH tropics, especially during JJA, when heat mortality and morbidity is highest. However, despite a reduction in the JJA mean temperature in the tropics, extreme events are responsible for most heat-related mortality and morbidity, and the reduction in the mean temperature does not necessarily mean that there will be a reduction in the type of extreme heat events that cause human tragedy. While Kharin et al. (2007) showed that, in general, temperature extremes track with the mean temperature, this is not always the case. The changes in extreme events may, for example, be greater at high latitudes and the variability of temperatures over land may increase in a warmer climate.

"Specific to geoengineering, Aswathy et al. (2015) showed that different climate engineering methods produce spatially heterogeneous changes in extreme precipitation and temperature events. They showed that one SRM scheme may be more effective than another in reducing different types of extreme events despite relatively similar global and regional mean responses. In particular, a marine cloud brightening scheme that brightens ocean areas between 30°N and 30°S is shown to be less effective in reducing extreme precipitation and temperature events over land than the G3 experiment is."

Aswathy et al. (2015) used output from three different earth system models, each with multiple ensemble members, and performed detailed analysis of five variables related to extreme events. In the event more modeling groups run G4Foam, or we run

other similar test bed experiments, that type of analysis would be valuable. Our goal in this testbed experiment is to describe the G4Foam experiment and describe some of the mechanisms that bring about the mean climate response.

3) Line no 382-386 : Please provide the values in comparison with RCP6.0?

We now also provide the values relative to RCP6.0.

4) From Table1 (also from Figure 6) it is clear that the G4Foam experiment increases the tropical land precipitation by 1.4% annually and 2.02% during JJA relative to RCP6.0. How does this affect the extreme precipitation and frequent flooding events occurring in tropical land regions during monsoon time? Similar to reduction in precipitation, excess precipitation also affects the society right? So does this cause more adverse affects than benefits?

This is an important point and we have removed references to the desirability or benefits of any of the respective hydrological regimes under G4SSA, G4Foam and RCP6.0 in the manuscript. G4Foam was designed to cool Earth and increase precipitation, particularly in the tropics, relative to G4SSA. The fact that G4Foam produces this excess precipitation response relative to RCP6.0 is one of the reasons why we mention in 4.4 Future Research that we may combine stratospheric SRM with surface albedo modification to more effectively cool the planet without increasing precipitation to a level above that under RCP6.0 in already wet tropical areas. The manuscript has been adjusted. We are endeavoring to portray a balanced picture of the climate effects of G4Foam. We remain agnostic as to whether those climate effects are good or bad. In particular, section 3.2 Hydrological Impacts now offers a balanced description of the results of G4Foam, as does 4.3 Caveats. Future work that considers extreme events and natural resource economics may address whether the climate impacts brought about G4Foam ultimately can be rigorously characterized as more adverse or more beneficial both regionally and globally.

5) Line no : 461-463, (Similar to the above point) How can it be an important benefit without analyzing the effects of increased precipitation especially during monsoon season. Extreme precipitation may lead to more floods adversely affecting the societies. Could you please justify this point with further analysis.

We now emphasize that a precipitation increase in G4Foam relative to RCP6.0 is not the goal of G4Foam. We have also withdrawn the claims about beneficial changes in water supply and instead only discuss changes in P-E. More broadly, we have removed normative language about “benefits” and desirability” of the precipitation response, and instead just report the scientific results. This manuscript is designed to describe the results of the experiment and to describe the mean response and describe the relevant mechanisms. To justify our points about G4Foam being beneficial to water supply, it would be necessary to study both extreme events and the economic, policy and resource allocation factors that determine the availability of water in a particular area.

6) Line no : 472-474 Could you please give more explanation to the hypothesis.

Lines 472-474 have been removed. This was an oversimplification with little physical meaning. The key here is the northward migration of the ITCZ and the global scale changes in the Hadley Cell.

7) Discussion part seems to be extremely positive about the precipitation response of G4Foam. Increase in precipitation does not always mean without negative impacts. Please rephrase the discussion with inclusion of the negative impacts of excess water supply and precipitation.

We have revised the manuscript to portray a more balanced picture of the climate effects of G4Foam. We remain agnostic as to whether those effects are good or bad. Specifically, we have added discussion to section 3.2 Hydrological Response to give more weight to both the negative effects of excessive rainfall in the tropics and the potential for adverse impacts due to reduced rainfall in the SH. Section 4.3 Caveats also discusses potential problems with G4Foam. Finally, the paper ends with section 4.4 Future Work. While the climate response in G4Foam is robust in that it cools important regions and changes the spatial distribution of rainfall in a way that may be favorable for some, G4Foam has obvious deficiencies. For example, NH land areas are not cooled very much, precipitation increases too much in already wet tropical regions, and parts of the SH receive a very large decrease in precipitation. Additionally, since we do not aim to describe changes in the distribution of extreme events, we eliminate discussion of "water supply" and instead discuss precipitation minus evaporation. A higher or lower amount of extreme precipitation events could increase or decrease runoff, which would then impact water supply independent of precipitation minus evaporation.

Technical corrections

Line no : 91 Please provide expansion of SSI.

Stratospheric sulfate injection (SSI) is now defined.

Line no : 188 Could you please rephrase the sentence for better understanding.

You are correct to point out that this sentence was confusing. The purpose here was to describe the mechanism underlying the southward migration of the ITCZ. We have clarified the sentence, which now reads "The forced cooling over the NH was enhanced by a positive dynamical feedback in the North Atlantic Ocean (Broccoli et al. 2006; Kang et al. 2008), and the ITCZ and associated tropical rainbelts migrated south." There is no need to bring up the energy-flux-equator here.

Line no : 335 This is for JJA season right? please specify it.

Yes. During JJA added.

Line no : 343 Is it G4Foam or G4SSA?

We meant G4SSA and have changed G4Foam to G4SSA in that sentence.

Line no : 396 Please check the value with the one given in Table1.

The values in the table were correct. We changed the text to reflect those values.

Line no : 398 Shouldn't it be RCP6.0 instead of G4SSA?

Yes. We changed it to RCP6.0

Line no : 406 Please check the values with Table1, values seems to be interchanged.

We checked the values and there were a couple mistakes in the text. We fixed those mistakes and the values in the text now match the values in Table 1.

Line no : 856 Typo in Figure caption.

Typo fixed.

We have also shortened the abstract by one sentence. Line 646-647 added to acknowledgements to thank you for your valuable comments.

References

Aswathy, V. N., Boucher, O., Quaas, M., Niemeier, U., Muri, H., Mülmenstädt, J., and Quaas, J.: Climate extremes in multi-model simulations of stratospheric aerosol and marine cloud brightening climate engineering, Atmos. Chem. Phys., 15, 9593-9610, doi:10.5194/acp-15-9593-2015, 2015.

Kharin, V. V., Zwiers, F. W., Zhang, X., and Hegerl, G. C.: Changes in temperature and precipitation extremes in the IPCC ensemble of Global Coupled Model Simulations, J. Climate, 20, 1419– 1444, doi:10.1175/JCLI4066.1, 2007.