Studying geoengineering with a climate model

Antti-Ilari Partanen[1]*, Anton Laakso[1], Harri Kokkola[1], Sami Romakkaniemi[2], Anja Schmidt[3] Tuomas Kuokkanen[4],Veli-Matti Kerminen[5], Tommi Bergman[1], Antti Arola[1],Joni-Pekka Pietikäinen[6], Lauri Laakso[6] Kari E. J. Lehtinen[1,2], Ari Laaksonen[6,2] and Hannele Korhonen[1],

[1]Kuopio Unit, Finnish Meteorological Institute, Kuopio, Finland , [2]Department of Applied Physics, University of Eastern Finland, Kuopio campus, Kuopio, Finland,[3]School of Earth and Environment, University of Leeds, Leeds, United Kingdom, [4]Department of Law, University of Eastern Finland, Joensuu Campus, Joensuu, Finland,[5]Department of Physics, University of Helsinki, Helsinki, Finland, [6]Climate change, Finnish Meteorological Institute, Helsinki, Finland

*Presenting author, **antti-ilari.partanen@fmi.fi**

Introduction

- Aerosols are in the main role in several solar radiation management (SRM) proposals such as:
  - Stratospheric sulfate injections
  - Marine cloud whitening with sea spray
- There are several significant risks involved with SRM
- Our studies have concentrated on the effects on the Earth's radiative balance
- We used global aerosol-climate model ECHAM5-HAM [1]
  - Aerosol emissions, microphysics and removal processes
  - Interaction of aerosols and clouds

Conclusions

- Controlled aerosol emissions have potential to significantly cool the climate
- Uncertainties in modeling the effects of SRM are large
- SRM cannot substitute urgent emission reductions

Sea spray injections

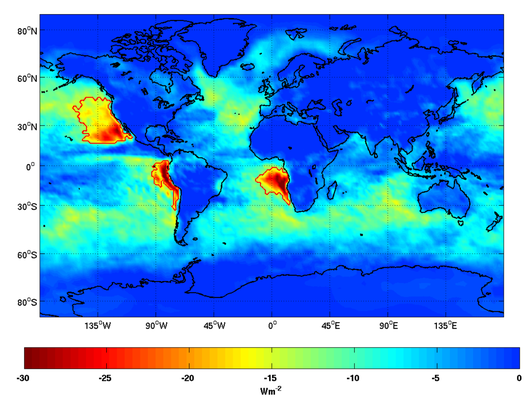

Figure 1. Change in the top-of-the-atmosphere net total radiation due to sea salt injections over all ocean area. [2]

- Injecting sea salt particles into marine clouds cools the climate in two ways:
  1. Affect microphisical properties of clouds and make the clouds, on average, brighter (aerosol indirect effect)
  2. Scatter solar radiation (aerosol direct effect)
- Especially the aerosol indirect effect is sensitive to several factors such as
  - Injected particle size
  - Updraft velocities in clouds

Stratospheric sulfate injections with commercial aircraft

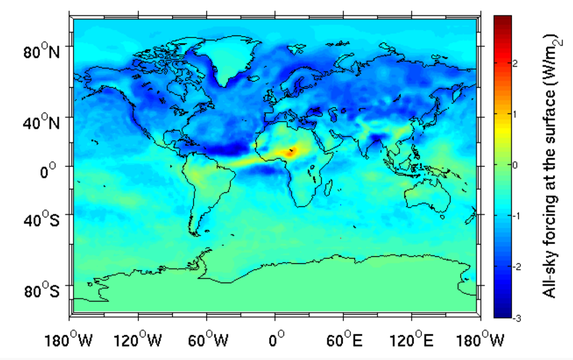

Figure 2. . Global mean of all-sky aerosol forcing at the surface when intercontinental flight routes are in the lower stratosphere and the sulfur content of the fuel is 50 times the current level. [3]

- Commercial aircraft could be used to deliever sulfate into stratosphere by increasing fuel sulfur content and the flight altitude of inter-continental flights
- The sulfur content of the fuel should be increased to about 50 times the current level to have a significant cooling effect
- The cooling effect would be confined to the Northern Hemisphere

Manipulating shipping emissions

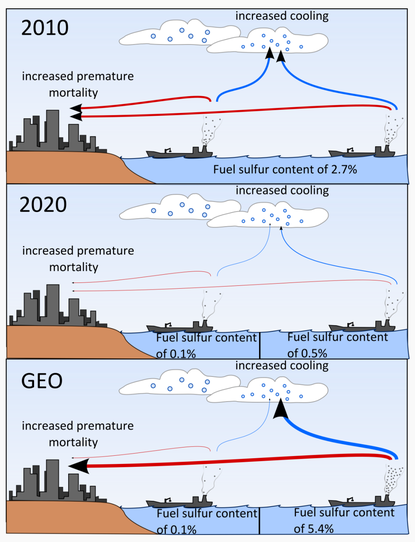

Figure 3. Schematic representation of the main shipping emission scenarios.

- Aerosol emissions from shipping both cool the climate and cause adverse health effects
- Internationally agreed emission limits will reduce both effects
- We studied whether present-day cooling effect can be retained with simultaneous improvements in air quality if shipping emission are decreased only in the coastal zones and increased elsewhere (Fig. 3) [4]

Volcanic eruption and geoengineering

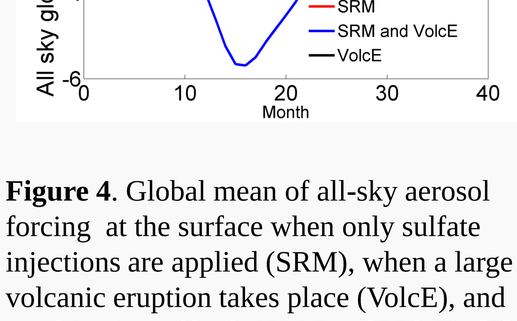

Figure 4. Global mean of all-sky aerosol forcing at the surface when only sulfate injections are applied (SRM), when a large volcanic eruption takes place (VolcE), and combination of both (SRM and VolcE). [5]

- Combination of stratospheric sulfate injections and volcanic eruption creates a strong cooling pulse
- The life-time of stratospheric sulfate is shorter in the combined case compared to either only SRM or volcanic eruption

References

1. Zhang, K.; O'Donnell, D.; Kazil, J.; Stier, P.; Kinne, S.; Lohmann, U.; Ferrachat, S.; Croft, B.; Quaas, J.; Wan, H.; Rast, S.; Feichter, J. The global aerosol-climate model ECHAM-HAM, version 2: sensitivity to improvements in process representations. *Atmos. Chem. Phys.* 2012, *12*, 8911-8949.
2. Partanen, A.-I., H. Kokkola, S. Romakkaniemi, V.-M. Kerminen, K. E. J. Lehtinen, T. Bergman, A. Arola, and H. Korhonen (2012), Direct and indirect effects of sea spray geoengineering and the role of injected particle size, *J. Geophys. Res.*, 117, D02203, doi:10.1029/2011JD016428.
3.Laakso, A., A.-I. Partanen, H. Kokkola, A. Laaksonen, K.E.J. Lehtinen, H. Korhonen (2012). Stratospheric passenger flights are likely an inefficient geoengineering strategy. *Environ. Res. Lett.* *7*, 034021, doi:10.1088/1748-9326/7/3/034021
4. Partanen, A.-I., Laakso, A., Schmidt, A., Kokkola, H., Kuokkanen, T., Pietikäinen, J.-P., Kerminen, V.-M., Lehtinen, K.E.J., Laakso, L., and Korhonen, H. (2013). Climate and air quality trade-offs in altering ship fuel sulfur content , *submitted*.
5. Laakso, A. et al. Effects of concurrent stratospheric sulfur geoengineering and a large volcanic eruption. *In preparation*.

Acknowledgements

We thank Dr. Ulrike Niemeier, Dr. Sylvaine Ferrachat and Prof. Ulrike Lohmann for technical assistance with the ECHAM model; Dr. Karsten Peters for kindly providing us with the model modifications to improve the treatment of ships aerosol emissions and for giving detailed instruction how to implement them; Dr. Thomas Kühn for interpolating the ACCMIP emissions for ECHAM; and Tommi Ekholm and NASA for providing the gridded data set of the world's countries. This work was supported by Maj and Tor Nessling foundation under grants 2011072 and 2012116, the Academy of Finland's Research Program on Climate Change (FICCA) (project 140867), Academy of Finland's project 123466. and an Academy Research Fellow position (decision 250348). The ECHAM-HAMMOZ model is developed by a consortium composed of ETH Zurich, Max Planck Institut für Meteorologie, Forschungszentrum Jülich, University of Oxford, and the Finnish Meteorological Institute and managed by the Center for Climate Systems Modeling (C2SM) at ETH Zurich.