IGS Global Seminar, 2024.03.07, 02:00 UTC

Reduced mass loss from the Greenland ice sheet under stratospheric aerosol injection*, and some general considerations about pros and cons of geoengineering techniques

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* Based on

Moore, J. C., R. Greve, C. Yue, T. Zwinger, F. Gillet-Chaulet and L. Zhao. 2023. Reduced ice loss from Greenland under stratospheric aerosol injection. JGR Earth Surface 128 (11), e2023JF007112, doi: 10.1029/2023JF007112.

Geoengineering techniques have been proposed to mitigate the impact of global warming

Solar geoengineering

Carbon dioxide removal

Targeted geoengineering

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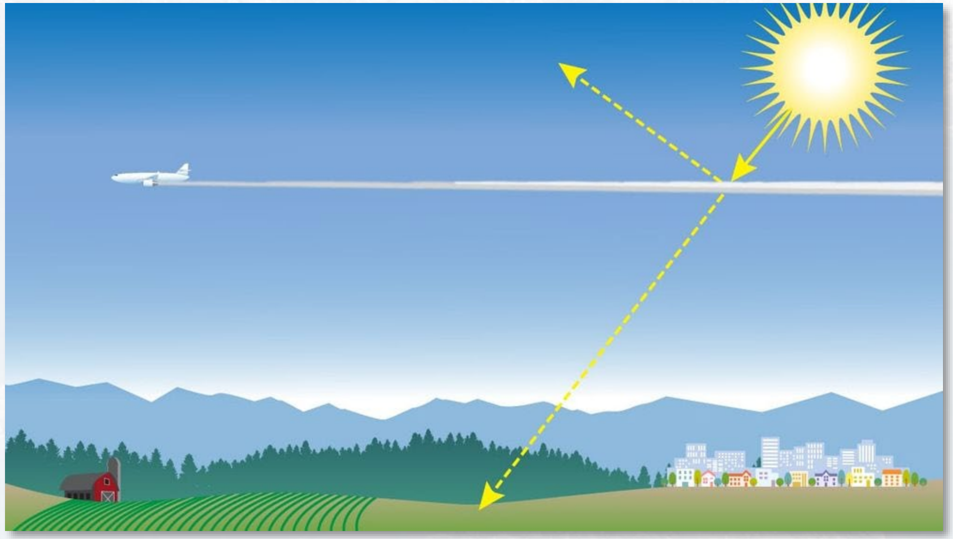
One possibility:
Stratospheric aerosol injection (SAI)

(e.g., Jones+ 2018, MacMartin & Kravitz 2019)



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Study by Moore, Greve et al. (2023, JGR) (see title slide)

Modelling the impact of an SAI scenario ("GeoMIP G4") on the mass loss of the Greenland ice sheet.

(Kravitz+ 2011)

Background:

Hokkaido University Foreign Visiting Professorship of John Moore
(Univ. Lapland, Rovaniemi, Finland),
December 2019 – February 2020.

ISMIP6: Ice Sheet Model Intercomparison Project for CMIP6

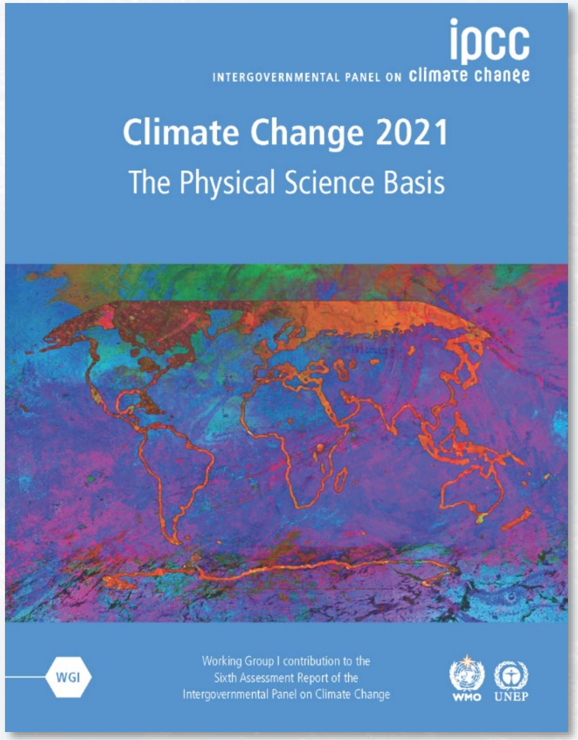
(Nowicki+ 2016, 2020)

(CMIP6: Coupled Model Intercomparison Project Phase 6)

Primary goals of ISMIP6:

- State-of-the-art projections of ice-sheet contribution to future sea-level rise.
- Quantify associated uncertainties.

→ **Input for IPCC AR6 WG I (2021).**



(https://theghub.org/groups/ismip6/wiki)

ISMIP6: Ice Sheet Model Intercomparison Project for CMIP6

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(CMIP6: Coupled Model Intercomparison Project Phase 6)

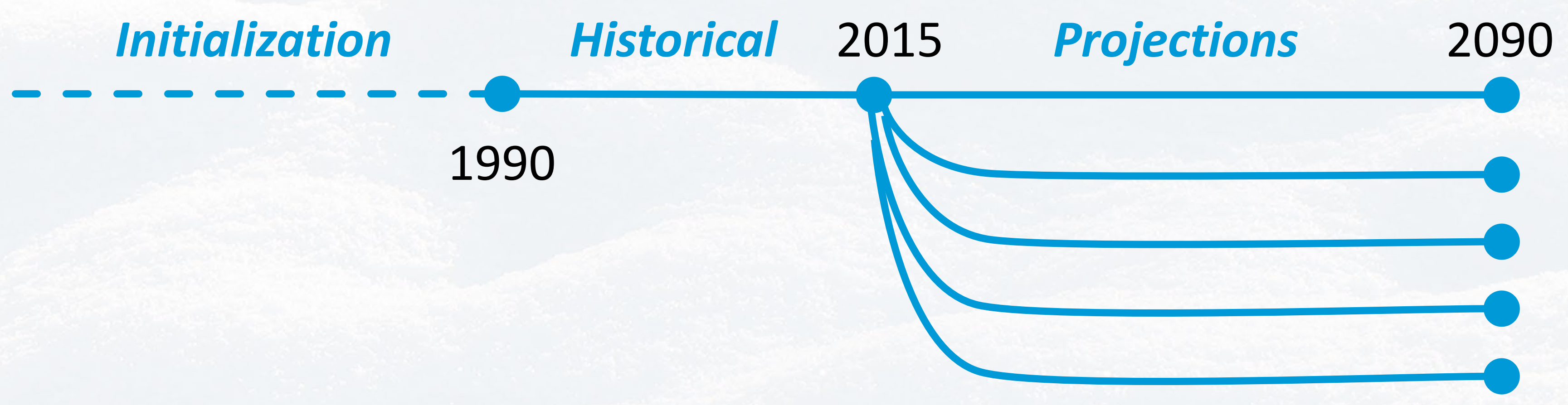
The ISMIP6 team (> 80 members):

IGS Richardson Medal 2022

"for its academic and leadership activities in the design and production of future sea-level projections"

(https://theghub.org/groups/ismip6/wiki)

Our study: ISMIP6-like experiment design (but not ISMIP6-endorsed)



Approach:

Initialization: Modeller's choice. (Not covered here; see Greve+ 2020.)
Historical: Modeller's choice. (Not covered here; see Greve+ 2020.)
Projections: ISMIP6 protocol, climate forcings from selected GCMs.

Climate forcing for projections

Climate model

Ice-sheet model

Model time 2015–2090.

Three scenarios:

RCP8.5 (worst-case scenario),
RCP4.5 (intermediate scenario),
GeoMIP G4 (RCP4.5 + 5 Mt a^{-1} SO_2 injection
[~1/4 of 1991 Mt. Pinatubo eruption]
to the equatorial lower stratosphere, 2020–2070).

Four Earth system models (ESMs):

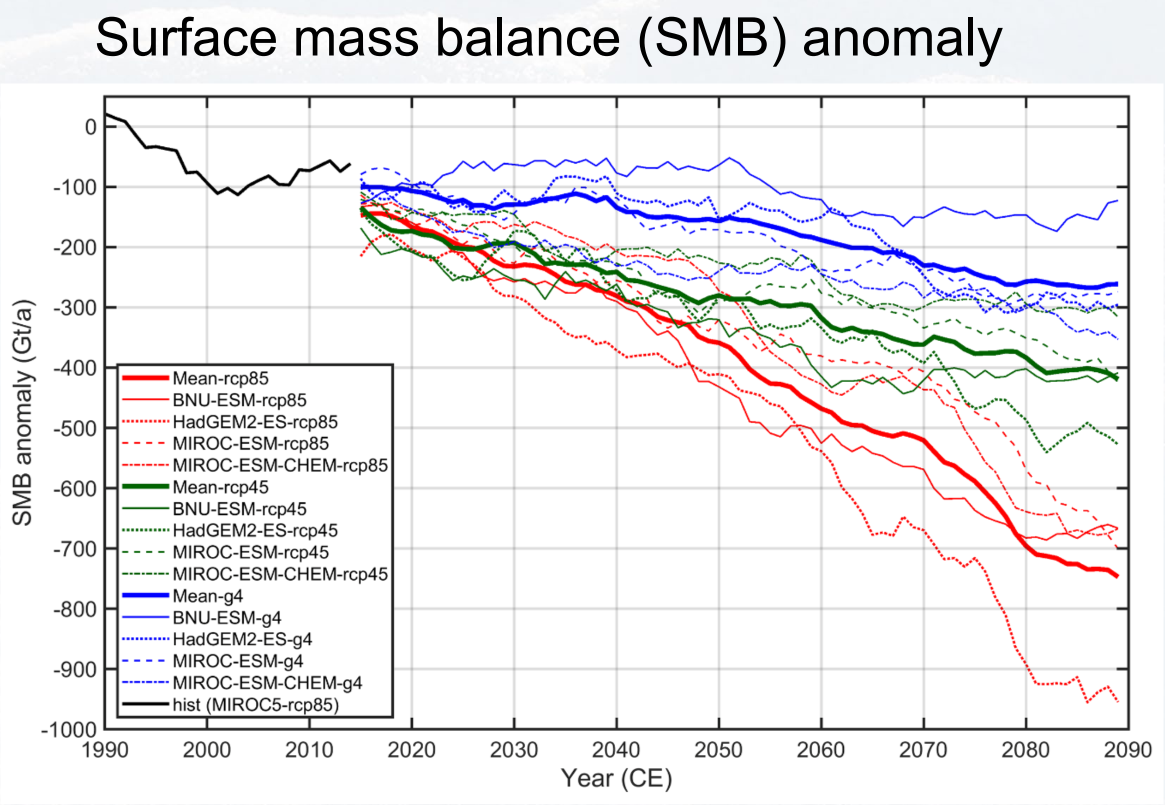
BNU-ESM, HadGEM2-ES, MIROC-ESM, MIROC-ESM-CHEM.

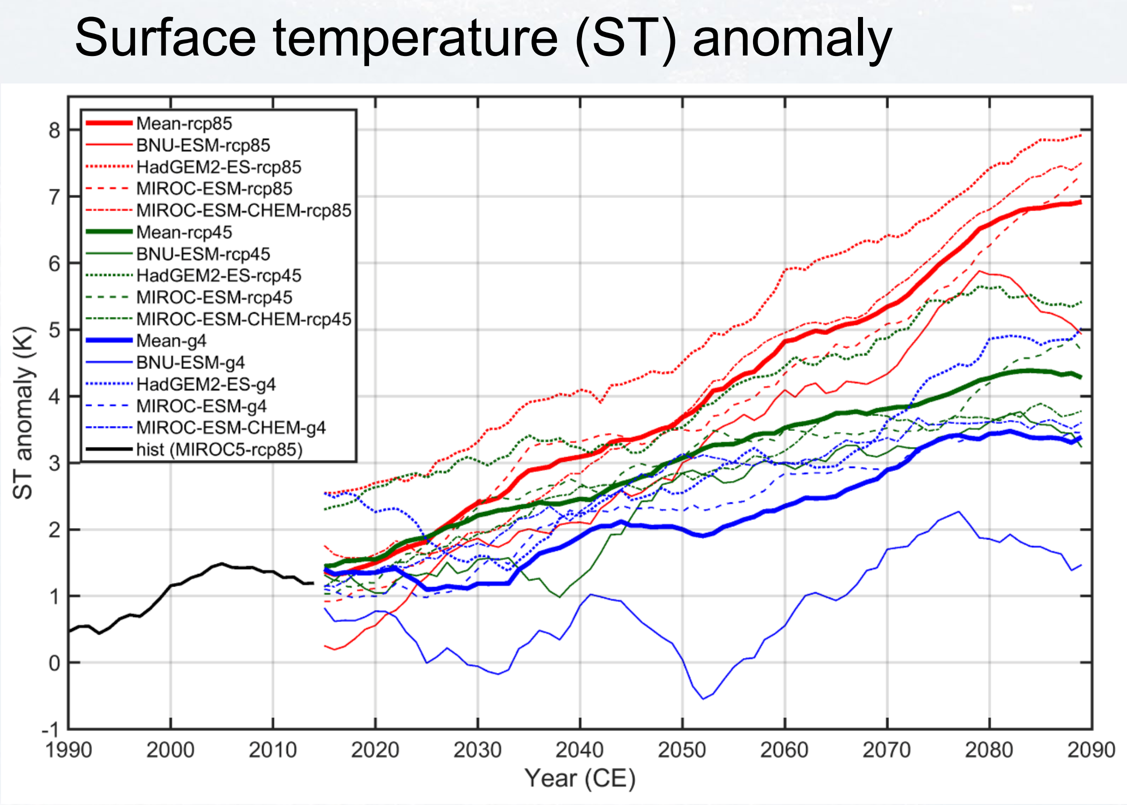
Intermediary model SEMIC (Krapp+ 2017)

Atmospheric forcing (SMB, ST) and oceanic forcing (retreat masks).

(Goelzer+ 2020, Nowicki+ 2020)

Climate forcing





As expected, RCP8.5 > RCP4.5 > G4.

Two ice-sheet models

SICOPOLIS (www.sicopolis.net)

Finite difference method.

Shallow-ice–shelfy-stream hybrid dynamics.

Enthalpy method for ice thermodynamics.

Regular grid, 5 km resolution.

elmer ICE (elmerice.elmerfem.org)

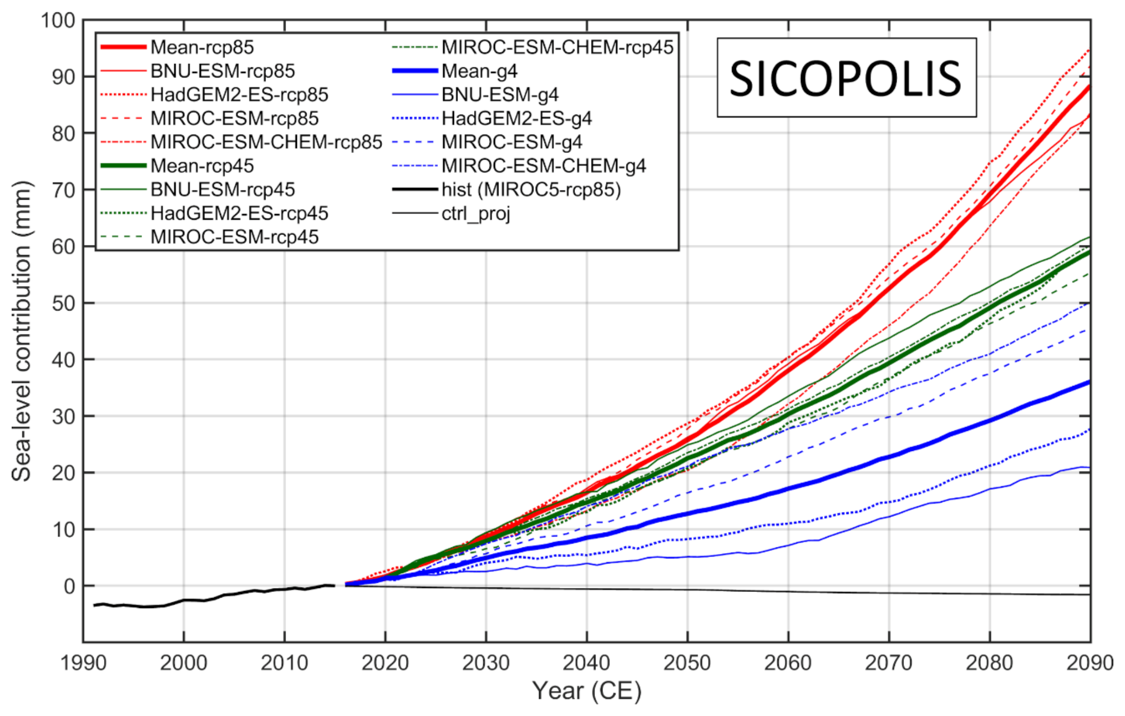
Finite element method.

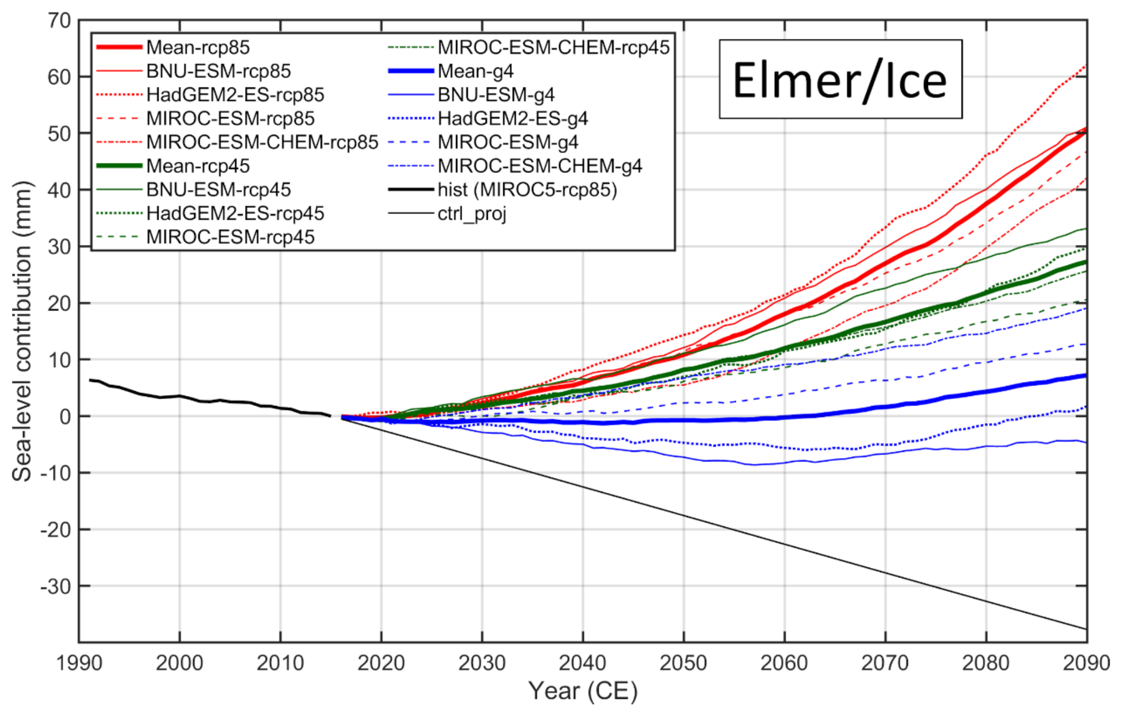
“Elmer/Ice-sheet” set-up with shelfy-stream dynamics.

No thermodynamics.

Unstructured mesh, 195k nodes forming 372k triangular elements.

Simulated sea-level contribution



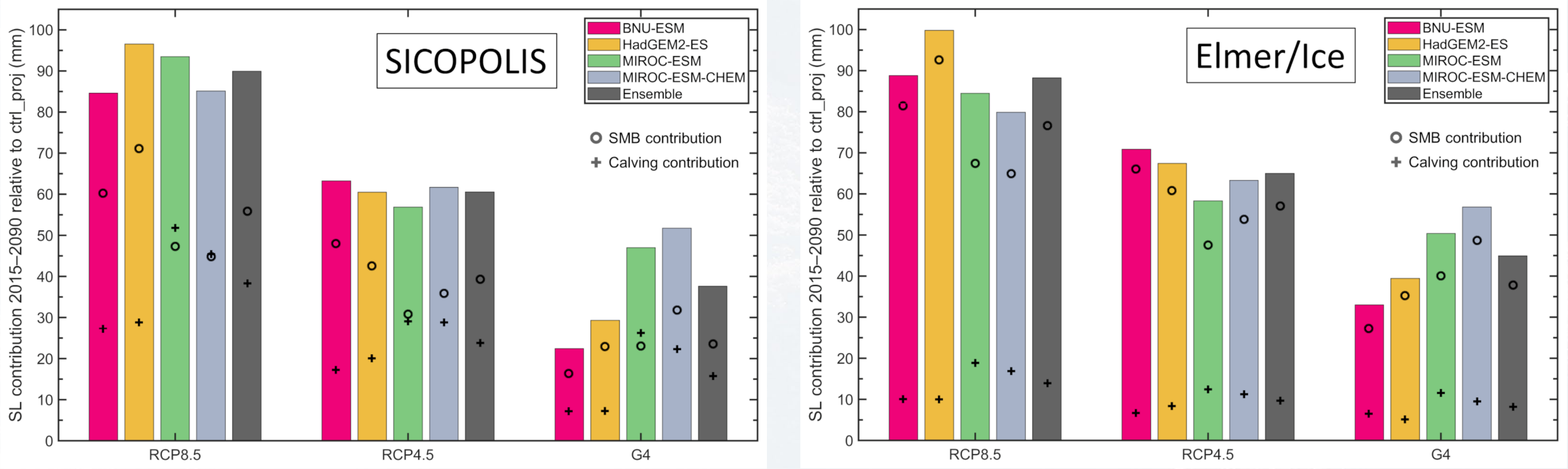


Elmer/Ice produces more drift than SICOPOLIS in the control run.

Reason: “off-the-shelf” set-up for Elmer/Ice vs. tuning by “implied SMB” for SICOPOLIS.

Relative to control, the results from the two ice-sheet models are similar.

Simulated sea-level contribution by 2090

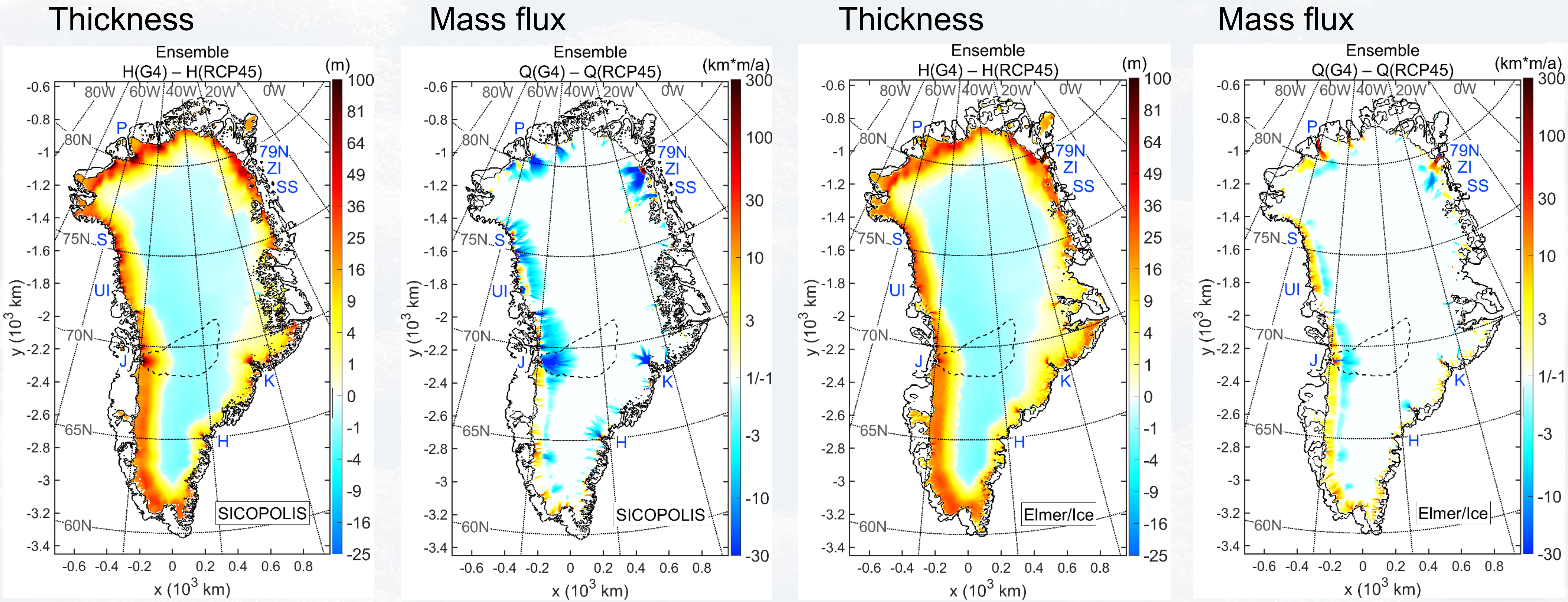


Mean mass loss for 2015–2090 under G4 31–38% smaller than under RCP4.5.

Larger calving contribution for SICOPOLIS, larger SMB contribution for Elmer/Ice.

Simulated thickness and mass flux changes by 2090

(ESM ensemble, G4 relative to RCP4.5)



Less thinning under G4, impact on dynamics (flow) more pronounced for SICOPOLIS.

Findings in a nutshell

Mass loss of the Greenland ice sheet

under RCP4.5 36%–48% smaller than under RCP8.5,

under G4 (RCP4.5 + SAI) 31%–38% smaller than under RCP4.5.

Partitioning between SMB and calving differs between the two ice-sheet models

(more calving for SICOPOLIS, more SMB for Elmer/Ice).

This study is not meant to be a plea for SAI testing or implementation.

The wider scope…

Geoengineering techniques have been proposed to mitigate the impact of global warming

Solar geoengineering

Carbon dioxide removal

Targeted geoengineering

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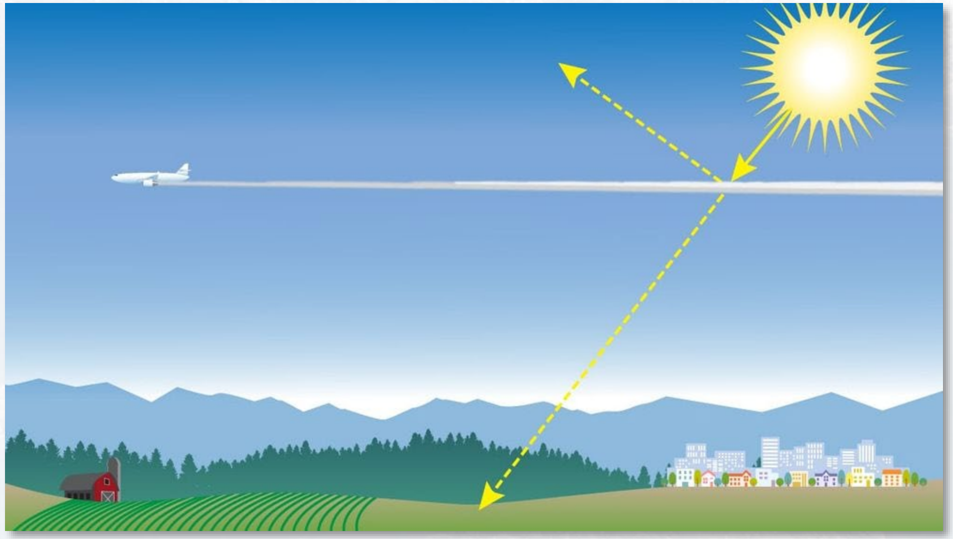

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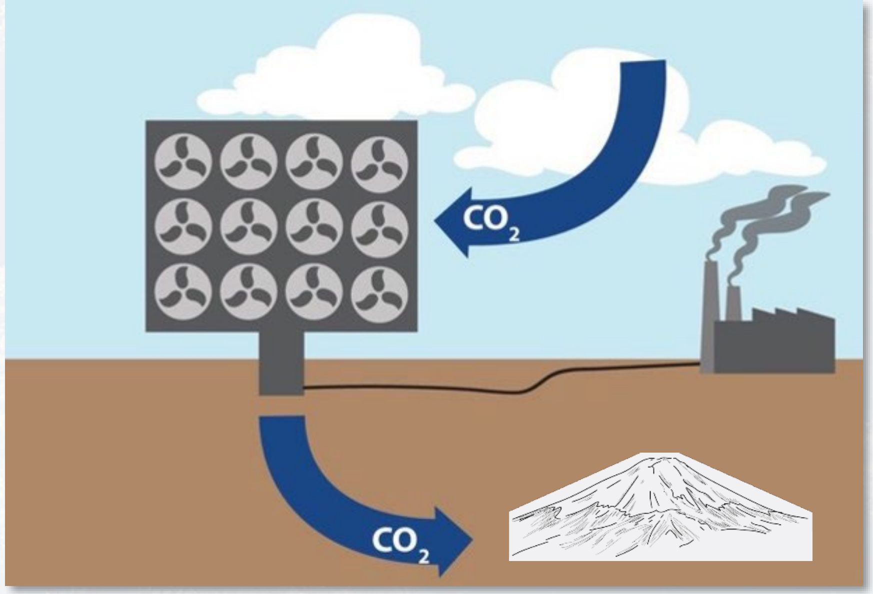

https://docs.climateinteractive.org/projects/en-roads/en/latest/guide/tech_removal.html

Consider global emissions:

~ 40 Gt a^{-1} CO_2
~ 35 km^3 a^{-1} liquid CO_2
~ 1 Mount Fuji (400 km^3) every 11.5 years!

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Targeted geoengineering

Targeted glacial geoengineering (focusing on the PIG/Thwaites system of the Antarctic ice sheet)

- Extracting or freezing water at the glacier base, reducing sliding.
- Artificial island to resist ice-shelf flow, buttressing the upstream glacier.
- Artificial sea-bed sill or curtain, blocking warm water from melting the ice-shelf base.

(Moore+ 2018)

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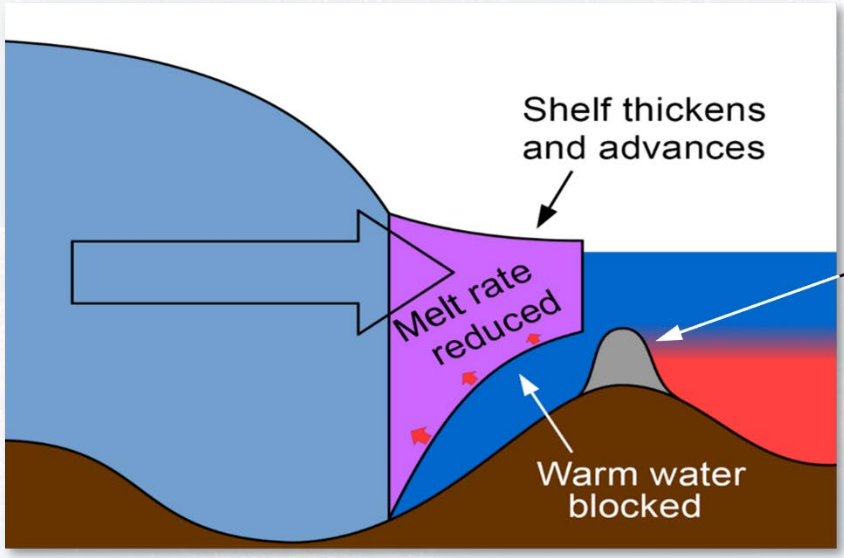

Artificial sill
(or sea-bed curtain)

(Moore+ 2018,
Wolovick and Moore 2018,
You 2024)

Geoengineering is a highly contentious topic

(e.g., AGU 2023; Moon 2018, 2023)

Pros

May be a tool to mitigate some of the worst aspects of global warming.

“We won’t make it without it” (buys some time, unavoidable GHG emissions, already ongoing or committed West Antarctic MISI?).

Cons

May serve as an excuse to delay tackling the root course of the problem (reducing GHG emissions) even further.

Adverse side effects will likely hit people who have not demanded it.

Resource-consuming: work time, money, energy, logistics.

My personal stance…

Technology brought us to the brink of climate catastrophe.

Now even more technology is supposed to fix it?

I'm sceptical…

> We cannot solve our problems with the same thinking we used when we created them.
>
> — ALBERT EINSTEIN —

However, I'm not against doing further research into the matter.

The ideas are out anyway, so let's rather try to understand the potential implications (and not leave that to the corporate world).

Thank you!

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JSPS KAKENHI Grant Nos. JP16H02224 and JP17H06104;
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References

AGU. 2023. Position statement on climate intervention. https://www.agu.org/share-and-advocate/share/policymakers/position-statements/climate-intervention-requirements

Goelzer, H. and 41 others. 2020. The future sea-level contribution of the Greenland ice sheet: a multi-model ensemble study of ISMIP6. *Cryosphere*, 14 (9), 3071-3096, doi: 10.5194/tc-14-3071-2020.

Greve, R., C. Chambers and R. Calov. 2020. ISMIP6 future projections for the Greenland ice sheet with the model SICOPOLIS. Technical report, Zenodo, doi: 10.5281/zenodo.3971251.

Jones, A. C., M. K. Hawcroft, J. M. Haywood, A. Jones, X. Guo and J. C. Moore. 2018. Regional climate impacts of stabilizing global warming at 1.5 K using solar geoengineering. *Earth's Future*, 6 (2), 230-251, doi: 10.1002/2017EF000720.

Krapp, M., A. Robinson and A. Ganopolski. 2017. An efficient surface energy and mass balance model applied to the Greenland ice sheet. *Cryosphere*, 11 (4), 1519-1535, doi: 10.5194/tc-11-1519-2017.

Kravitz, B., A. Robock, O. Boucher, H. Schmidt, K. E. Taylor, G. Stenchikov and M. Schulz. 2011. The geoengineering model intercomparison project (GeoMIP). *Atmos. Sci. Lett.*, 12(2), 162-167, doi: 10.1002/asl.316.

MacMartin, D. G. and B. Kravitz. 2019. Mission-driven research for stratospheric aerosol geoengineering. *Proc. Natl. Acad. Sci. U.S.A.*, 116 (4), 1089-1094, doi: 10.1073/pnas.1811022116.

Moon, T. 2018. Geoengineering might speed glacier melt. *Nature*, 556, 436, doi: 10.1038/d41586-018-04897-5.

Moon, T. 2023. Glacial geoengineering statement, Dec 2023. *YouTube*. https://www.youtube.com/watch?v=rLnQe3ostoQ

Moore, J. C., R. Gladstone, T. Zwinger and M. Wolovick. 2018. Geoengineer polar glaciers to slow sea-level rise. *Nature*, 555, 303-305, doi: 10.1038/d41586-018-03036-4.

Nowicki, S. and 8 others. 2016. Ice Sheet Model Intercomparison Project (ISMIP6) contribution to CMIP6. *Geosci. Model Dev.*, 9 (12), 4521-4545, doi: 10.5194/gmd-9-4521-2016.

Nowicki, S. and 29 others. 2020. Experimental protocol for sea level projections from ISMIP6 stand-alone ice sheet models. *Cryosphere*, 14 (7), 2331-2368, doi: 10.5194/tc-14-2331-2020.

Wolovick, M. J. and J. C. Moore. 2018. Stopping the flood: could we use targeted geoengineering to mitigate sea level rise? *Cryosphere*, 12 (9), 2955-2967, doi: 10.5194/tc-12-2955-2018.

You, X. 2024. Could giant underwater curtains slow ice-sheet melting? *Nature* (News article), doi: 10.1038/d41586-024-00119-3.