Viability and Desirability of Proposed Radiation Management Methods

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Stratospheric aerosol injection (SAI) = Brightening Earth by injecting sulfur (or other aerosols) into the stratosphere

Marine Cloud Brightening (MCB) = Brightening marine clouds by seeding them with sea-spray or other soluble aerosols

Cirrus Cloud Thinning (CCT) = Decreasing Earth's greenhouse effect by reducing cirrus clouds

Precipitation anomalies, 4xCO_2 vs. geoengineering

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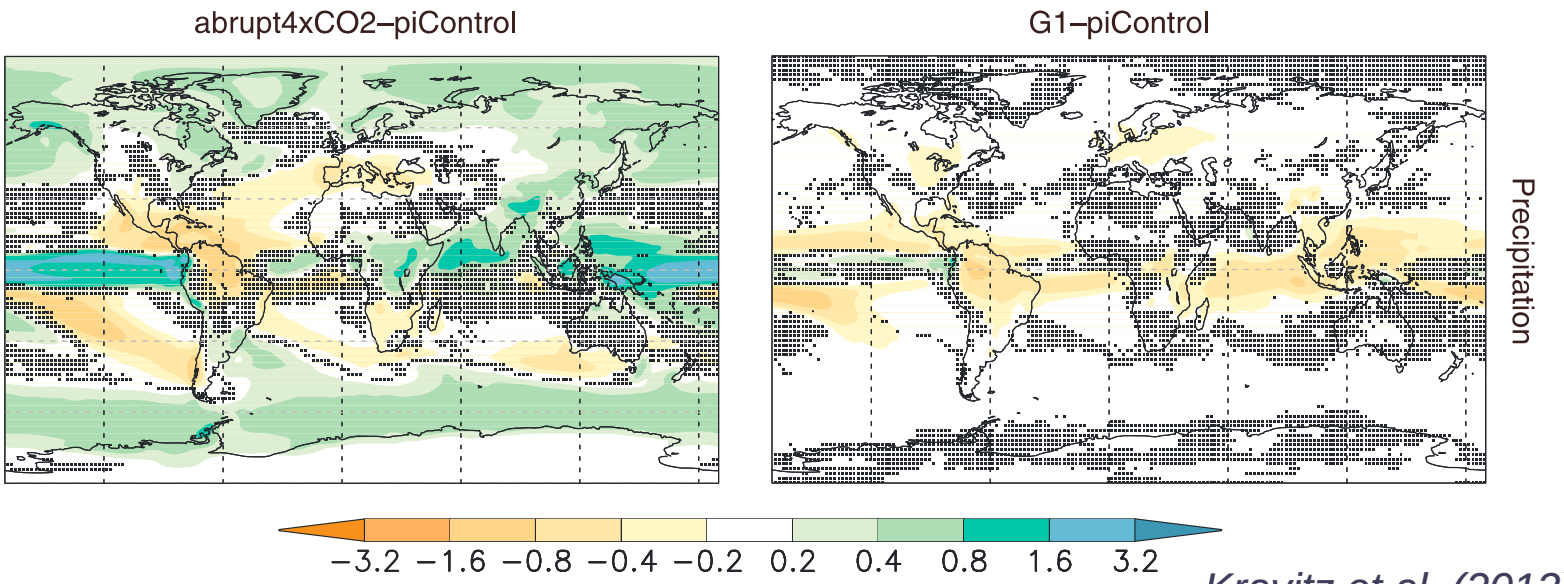

Kravitz et al. (2013)

NOTE: There is broad climate model agreement that precipitation anomalies (relative to the pre-industrial climate) are much larger in a world with strong CO_2 warming compared to one where CO_2 warming has been neutralized with SRM.

The side effects of albedo modification

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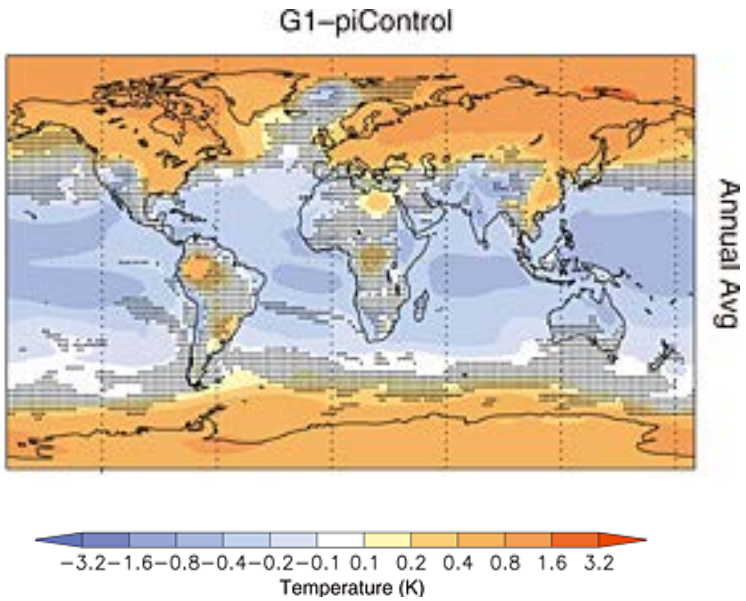
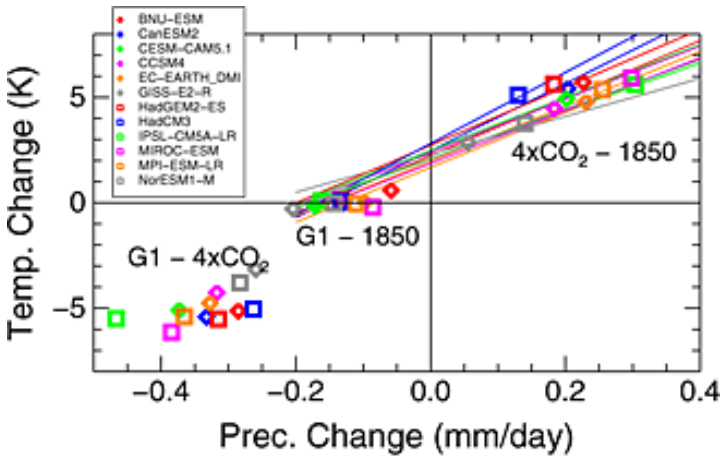
Too much cooling in the tropics, not enough at the poles



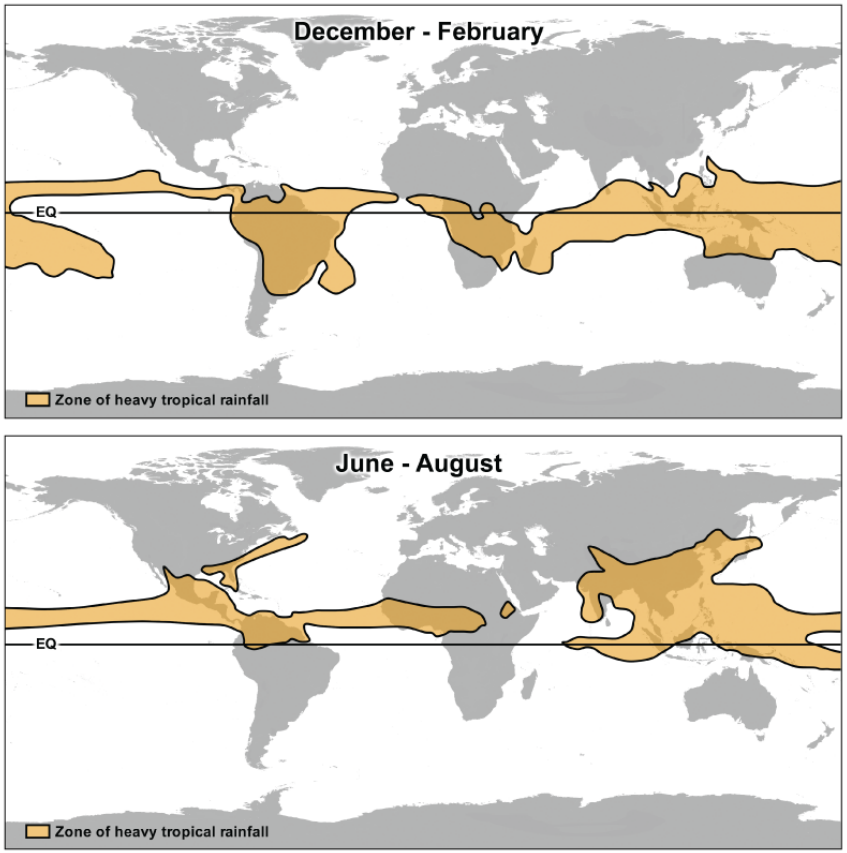
Kravitz et al. (2013), based on GeoMIP simulations.

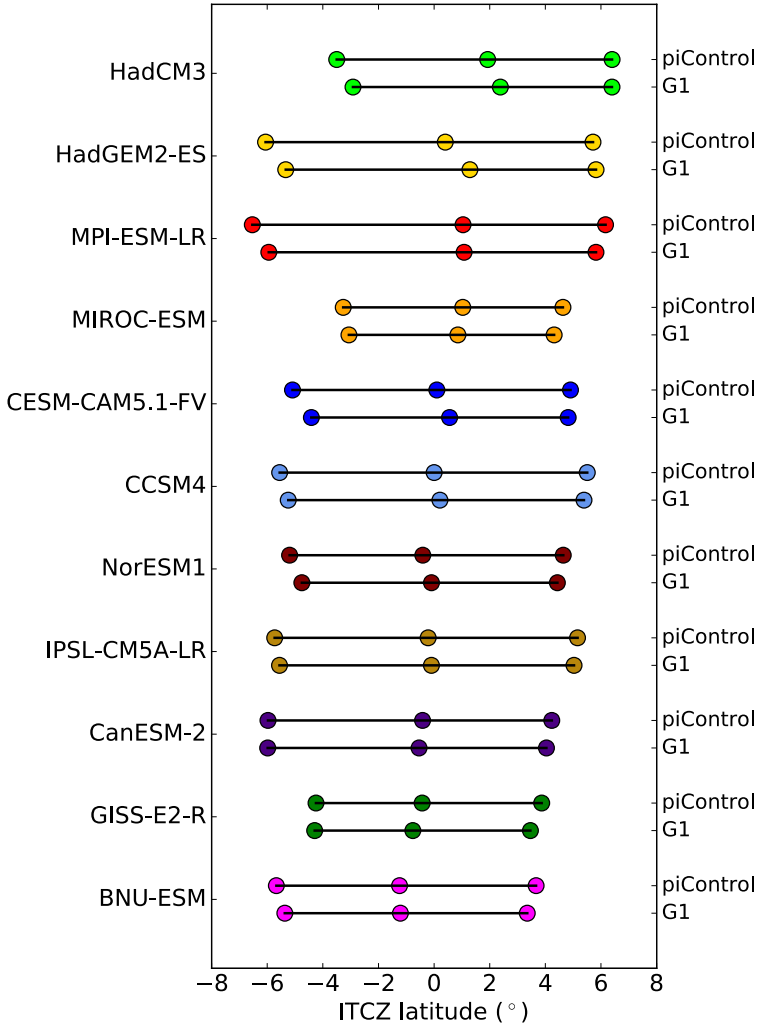
Overcompensation for CO_2 warming in the hydrological cycle



Tilmes et al. (2013), based on GeoMIP simulations.

SAI impact on ITCZ migration

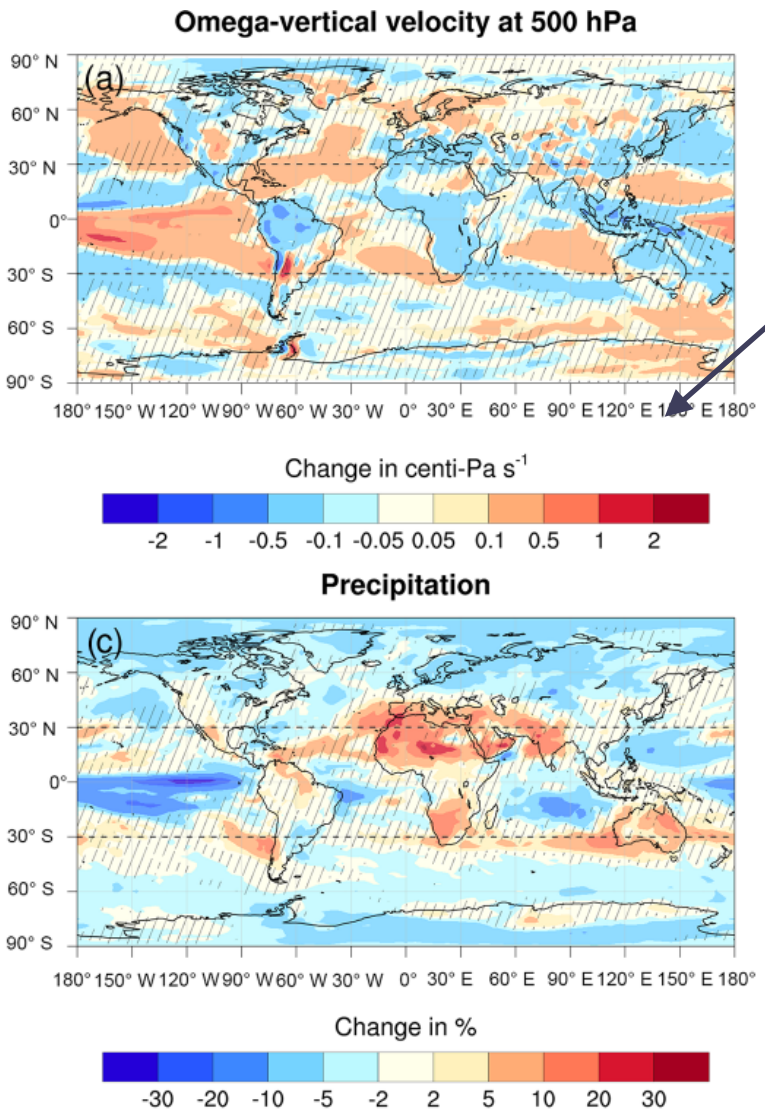




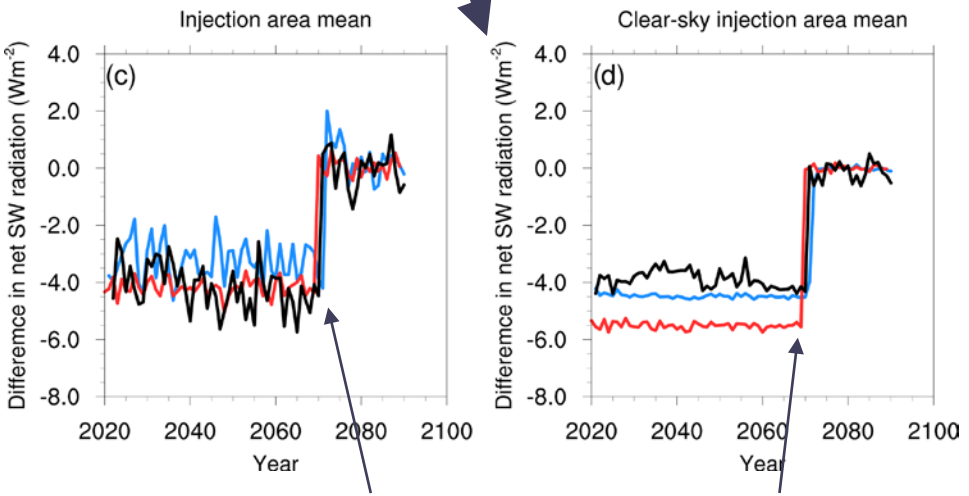
A robust finding across climate models is that the ITCZ seasonal migration contracts under SAI.

Smyth, Russotto & Storelvmo (2017)

Sea salt injection in marine boundary layer (MBL)



- Injecting sea salt into the MBL induces sinking motion & drying over ocean, and ascent & increased precipitation over land.
- Intriguingly, the direct (clear-sky) cooling effect dominated the overall cooling effect (!)



Sea salt injection was simulated to end abruptly in 2070

Ahlm et al. (2017), based on GeoMIP experiment conducted by 3 models

Cirrus Cloud Thinning (CCT)

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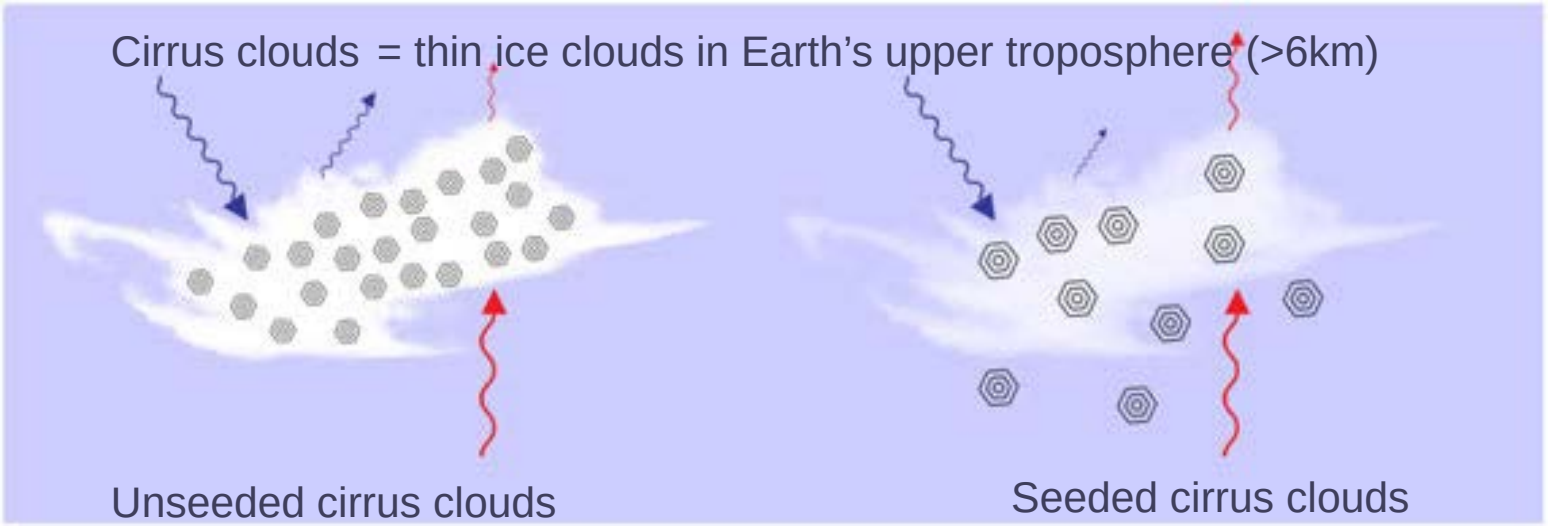

Mitchell & Finnegan (2009): Cirrus cloud cover could be artificially reduced, by seeding cirrus with efficient ice nuclei (BiI_3 was the proposed material).

Cirrus cloud seeding has potential to cool climate

T. Storelvmo,[1] J. E. Kristjansson,[2] H. Muri,[2] M. Pfeffer,[2] D. Barahona,[3] and A. Nenes[4]

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Can cirrus cloud seeding be used for geoengineering?

Joyce E. Penner[1], Cheng Zhou[1], and Xiaohong Liu[2]

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[2]Department of Atmospheric Sciences, University of Wyoming, Laramie, Wyoming, USA

Latest update on CCT

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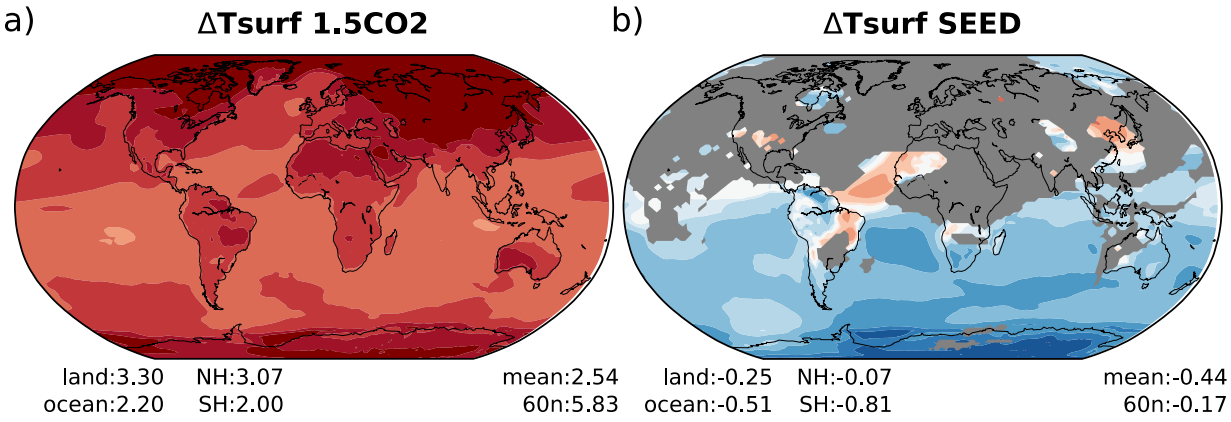
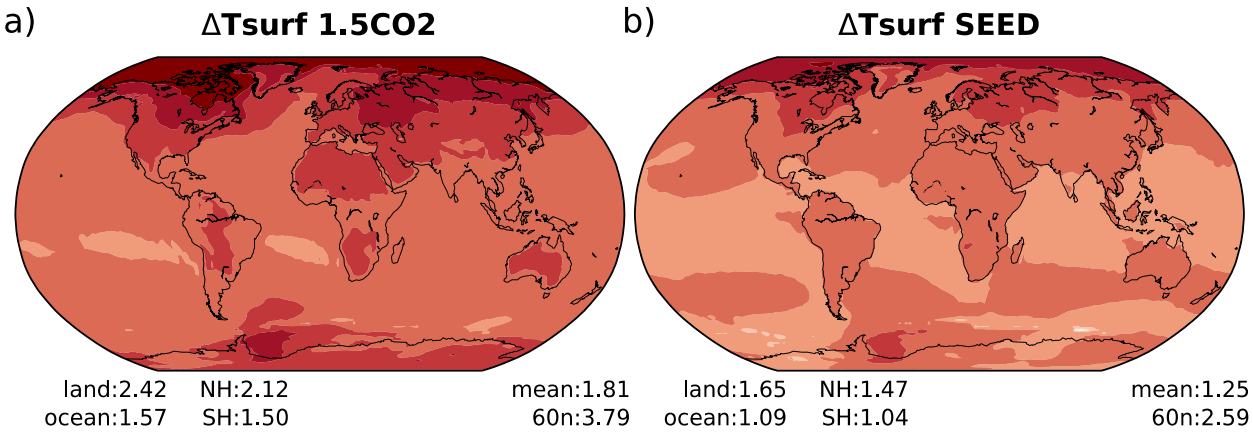
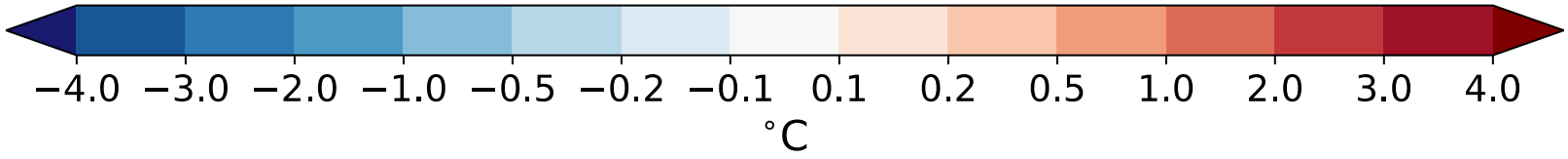


CESM: CCT yields a cooling of almost 3 K, overcompensating for 1.5xCO_2 in the SH.



ECHAM: CCT yields a cooling of ~0.6K, leaving residual warming from 1.5xCO_2 (more in NH).



Gasparini & Storelvmo (in prep.)

Simultaneous stabilization of global temperature and precipitation through cocktail geoengineering

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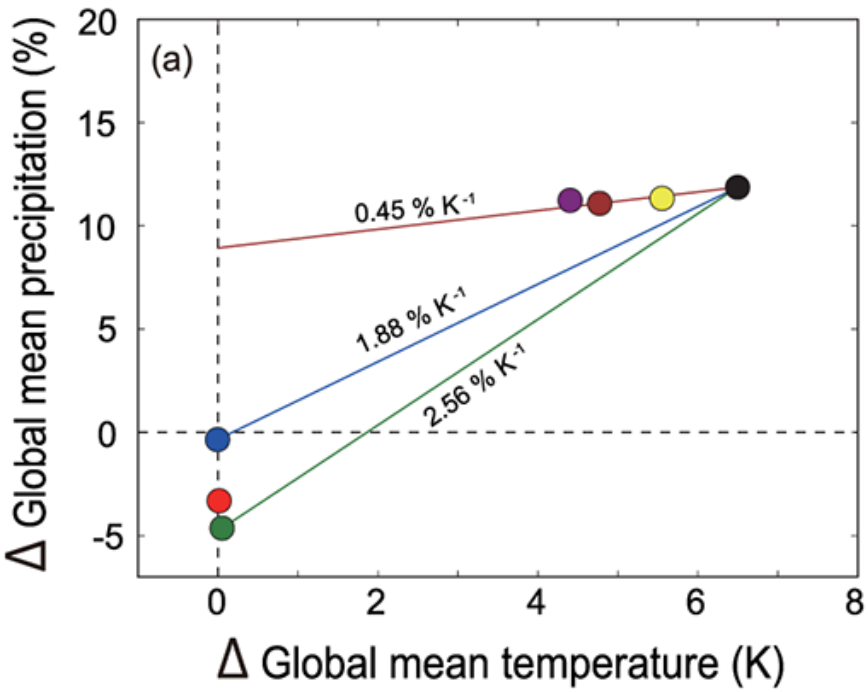

A combination of cirrus cloud thinning and stratospheric aerosol injection appears to be a promising way to simultaneously stabilize global mean temperature and precipitation.

abrupt 4×CO_2 SAI44 2×CCT 4×CCT 8×CCT SAI29+4×CCT SAI38+1.5×CCT

Geophysical Research Letters

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http://onlinelibrary.wiley.com/doi/10.1002/2017GL074281/full#grl56166-fig-0001

Zao et al. (2017)

Viability vs. desirability

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Viability

- **SAI:** Cooling is virtually certain.
- **MCB:** Efficacy of cooling via cloud brightening uncertain. Clear-sky cooling as effective?
- **CCT:** Cooling effect uncertain (contingent on poorly understood ice microphysics).

Desirability

- **SAI:** shifts in ITCZ and contraction of its seasonal migration. Could SAI be designed to mitigate this (MacMartin et al., 2017)?
- **MCB:** Increased precipitation over land, less over ocean (is that good or bad?)
- **CCT:** Cooling w/out much precipitation reduction (again, good or bad?)

Open questions

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- **On viability: Are we currently addressing the key unknowns of SAI, MCB and CCT?** If not, what studies are missing, and what can realistically be done at the current funding level? And have we reached the limit for how much we can learn from modeling?
- **On desirability: Is a large deviation from pre-industrial (or present-day) climate bad, *a priori*?** Some regions could potentially benefit from some residual warming, and likewise many regions would benefit from additional precipitation.