Efficiency of marine cloud brightening solar climate intervention simulated by CESM2

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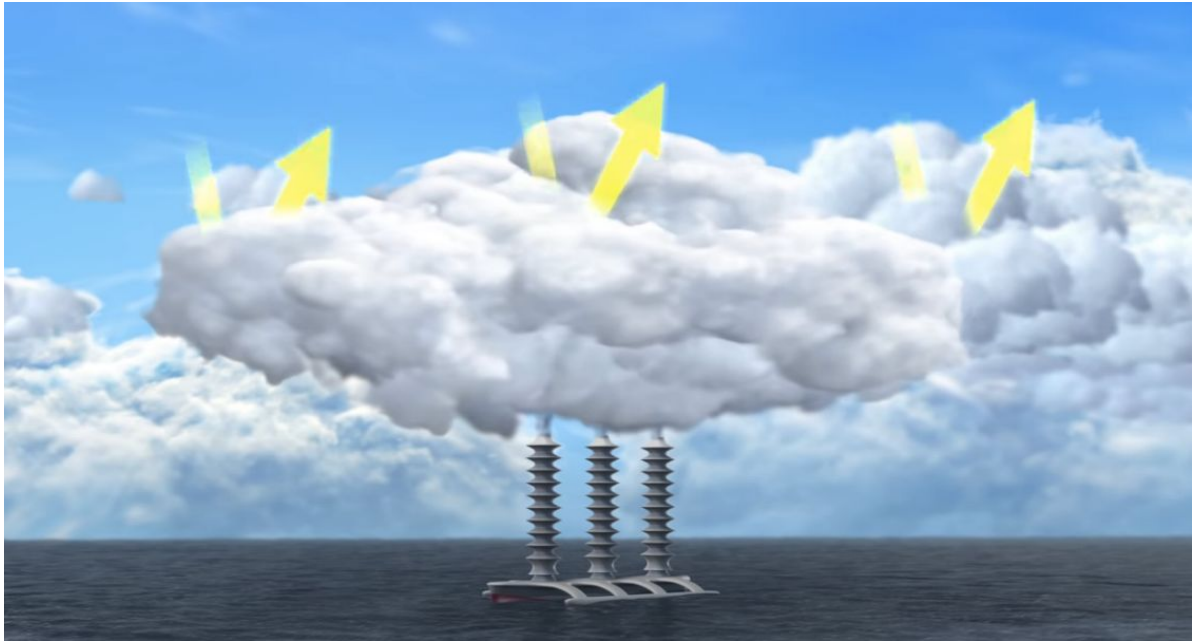
solar climate interventions:

1. stratospheric aerosol injection (SAI)

2. marine cloud brightening (MCB)



indirect effects of cloud seeding due to smaller cloud drops:

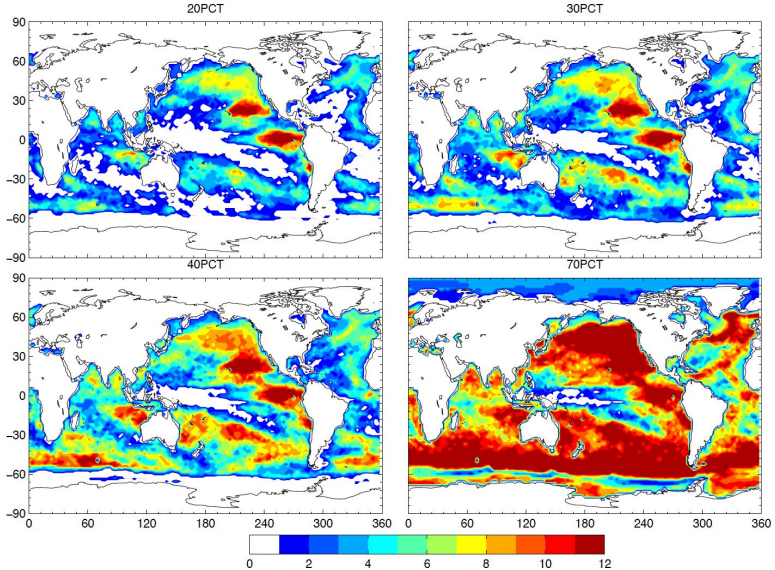
1. Twomey effect: clouds become more reflective of solar radiation

2. Albrecht effect: clouds become more persistent (less precipitation)

constrained approach - following Rasch et al. 2009

1. identify grid points most susceptible to cloud seeding
2. prescribe cloud drop number concentration to 375/1000 #/cm3 within boundary layer
3. compare shortwave cloud forcing (SWCF) against a control simulation
4. grid points with the strongest negative difference in SWCF are most susceptible for cloud seeding to produce cooling effect

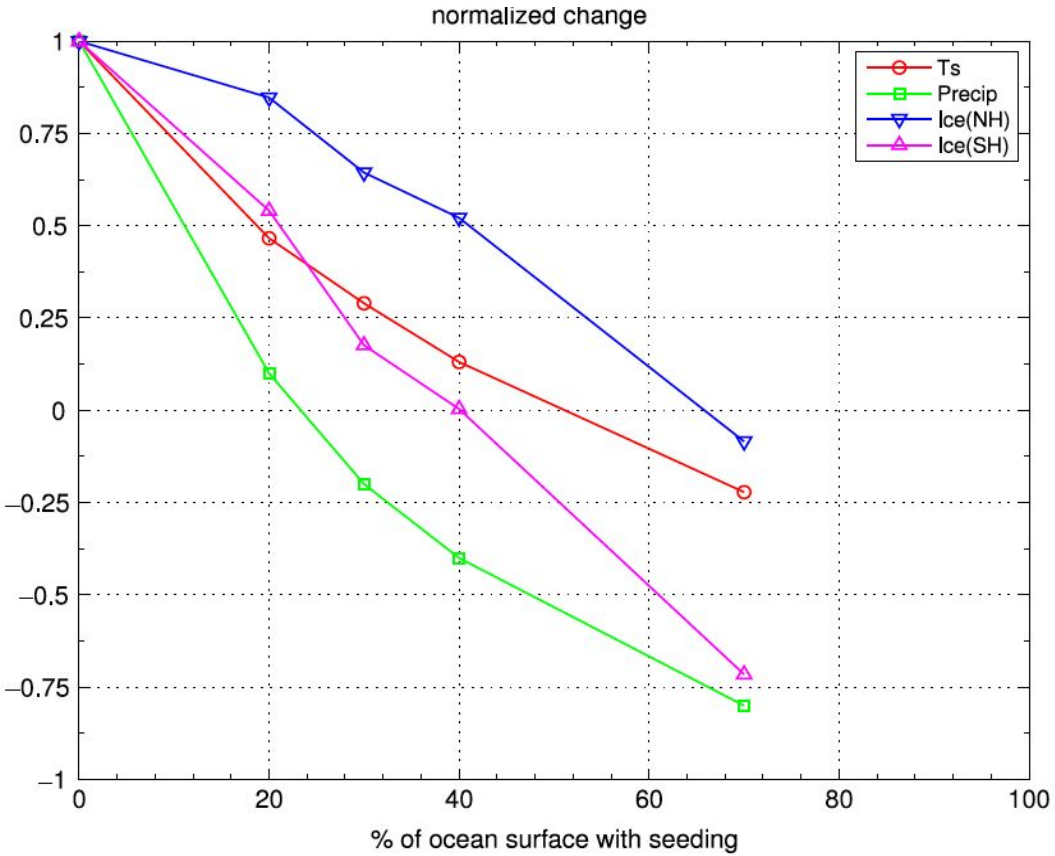
CCSM3 (Rasch et al. 2009) 1000 # per c.c.



regions most favorable for seeding is time dependent due to solar inclination

seeding mask: 1 means applying seeding in one month, and 12 means applying seeding in all 12 months

results from Rasch et al. 2009 (CCSM3)



To counteract the effects of 2XCO2:

surface temperature:
seeding needs to take place over **50%** of the ocean surface (very high!)

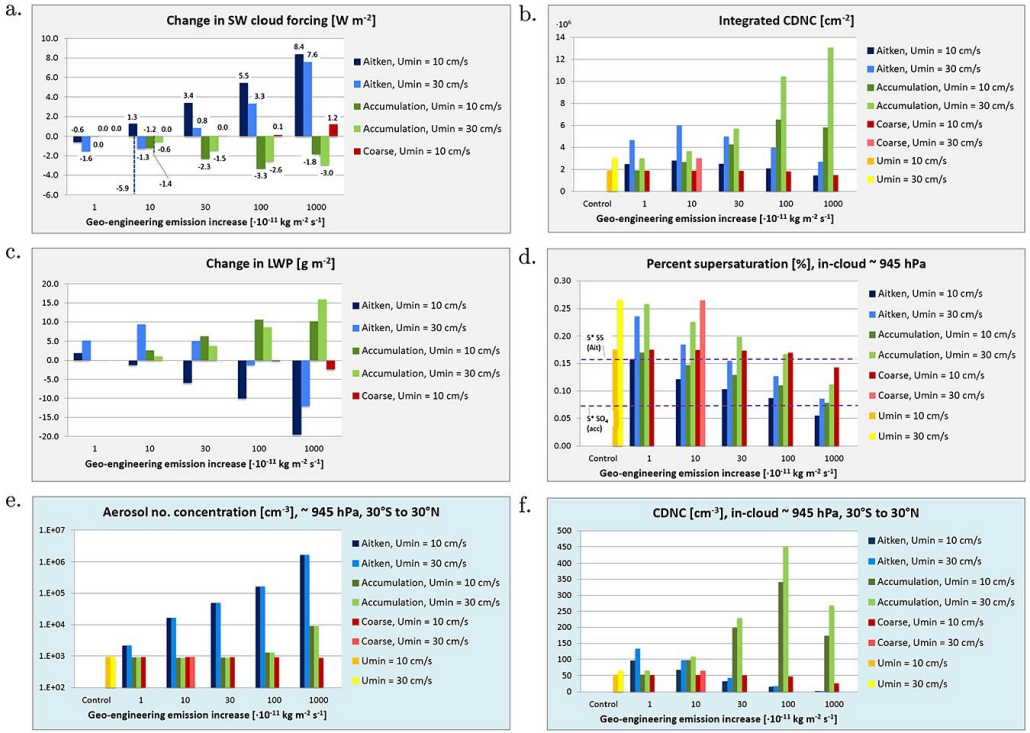
precipitation:
seeding over **25%** of the ocean surface

sea ice (NH):
seeding needs to take place over **70%** of the ocean surface (extremely high)

see ice (SH):
seeding needs to take place over **40%** of ocean surface.

unconstrained approach

1. sea salt particles are injected through the aerosol model
2. the model simulates aerosol-cloud interaction
3. sensitivity of injected particle sizes needs to be examined



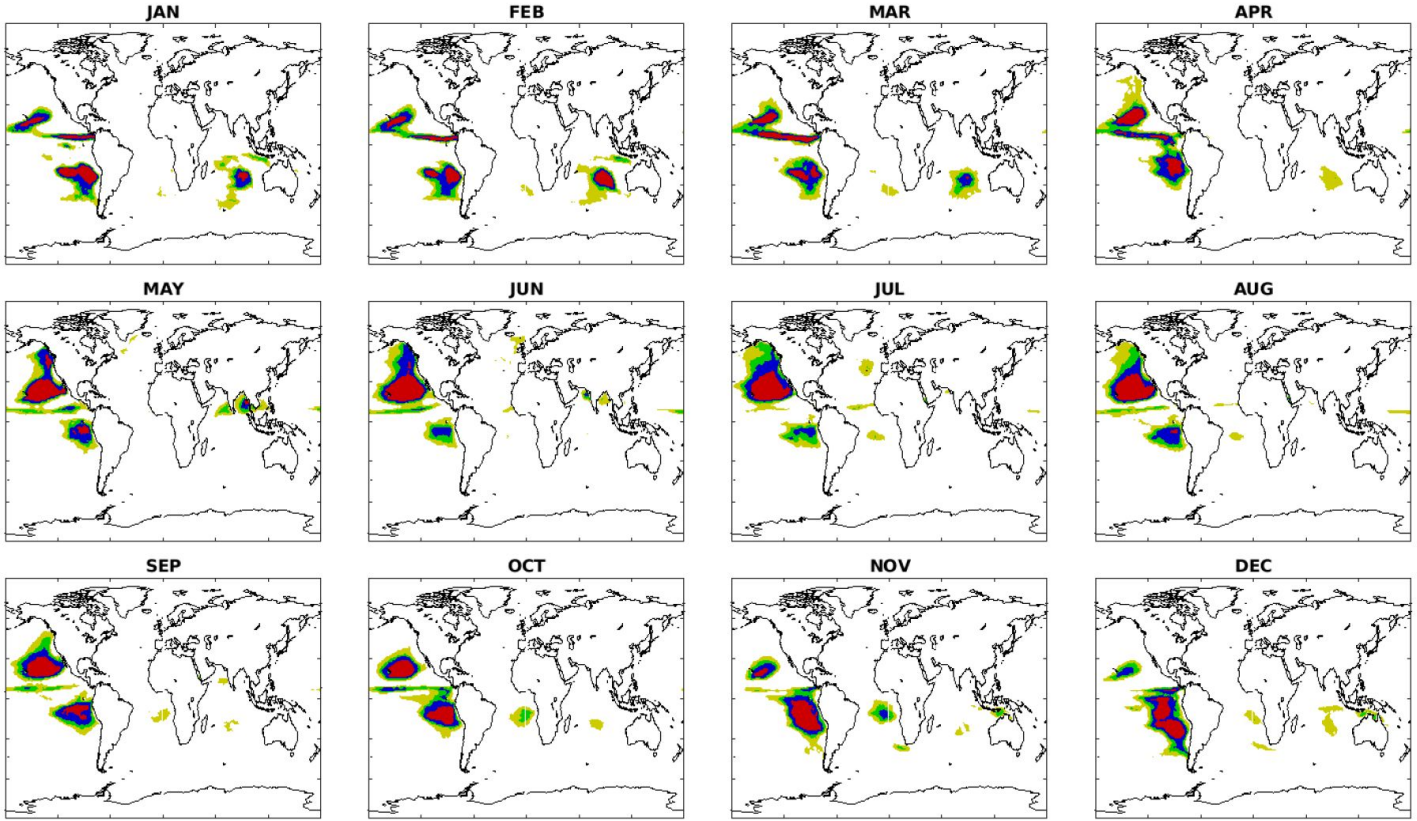
Alterskjær et al., 2013

injection in Aitken mode could lead to a **warming effect**

injection in accumulation mode produces cooling

cloud drop number concentration could increase to ~**450** #/cm3

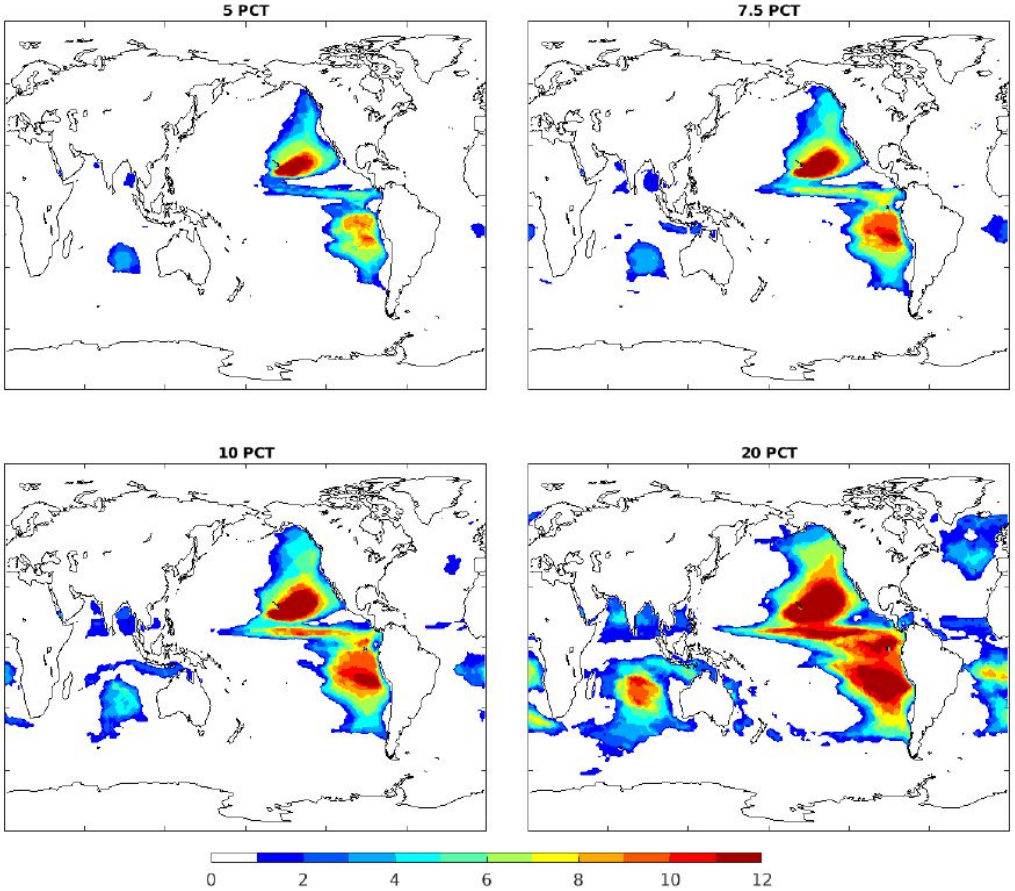
Monthly seeding masks - 2.5%, 5%, 7.5%, 12.5% based on SSP2-4.5 2015-2034 (20 year avg, 375 per c.c.)



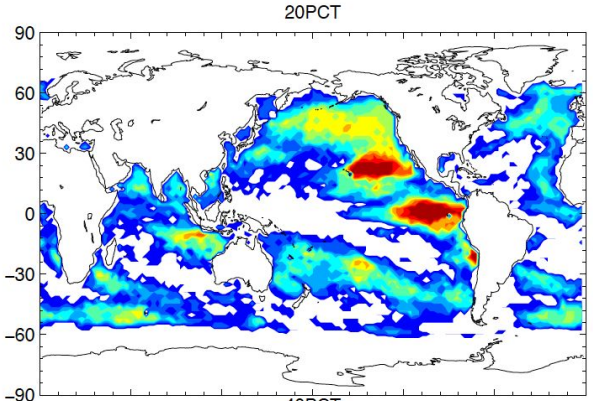
2.5% red
5% blue
7.5% green
12.5% yellow

factors in regulating seeding masks:
1. solar inclination
2. low cloud distribution

annual seeding masks established 2015-2034 CESM2 SSP2-4.5

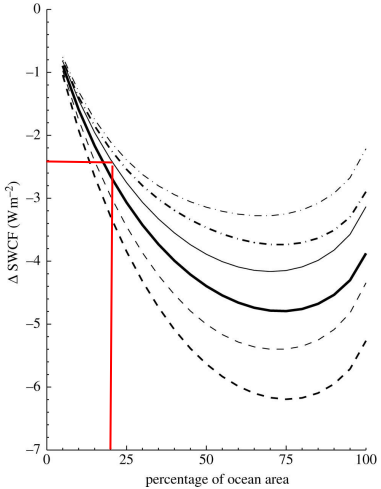


CCSM3

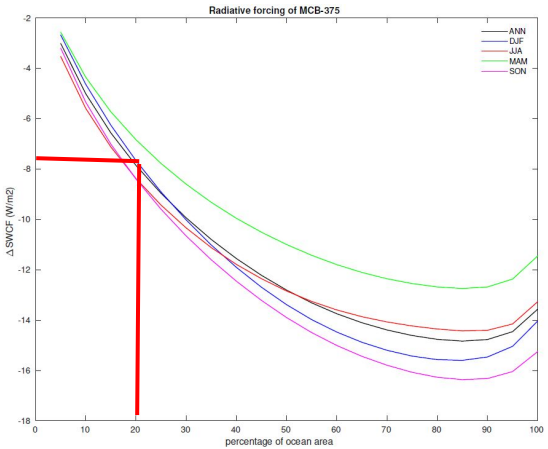


shortwave radiative forcing associated with seeding masks

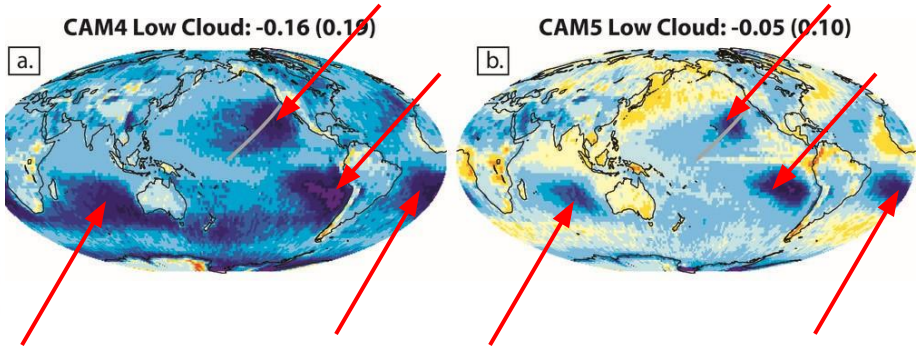
CCSM3, Latham et al., 2008



CESM2



Kay et al. 2012



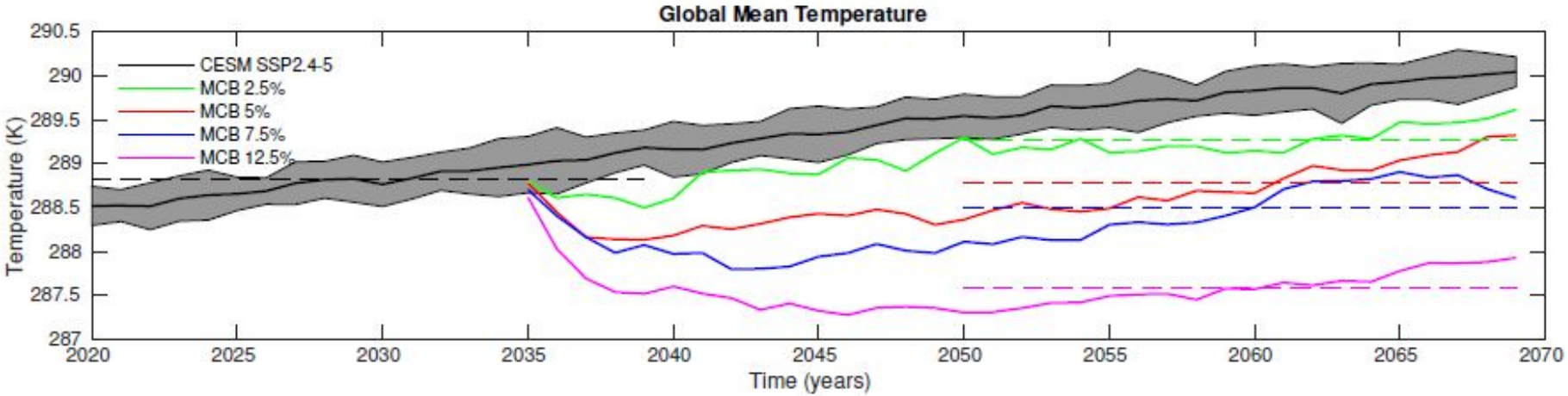
strong low cloud biases in CAM4 vs CAM5 over maritime stratocumulus regions!

seeding over 20% of ocean surface (375 per c.c.):
CCSM3: ~2.5 W/m2
CESM2: ~7.5 W/m2

MCB simulation configuration

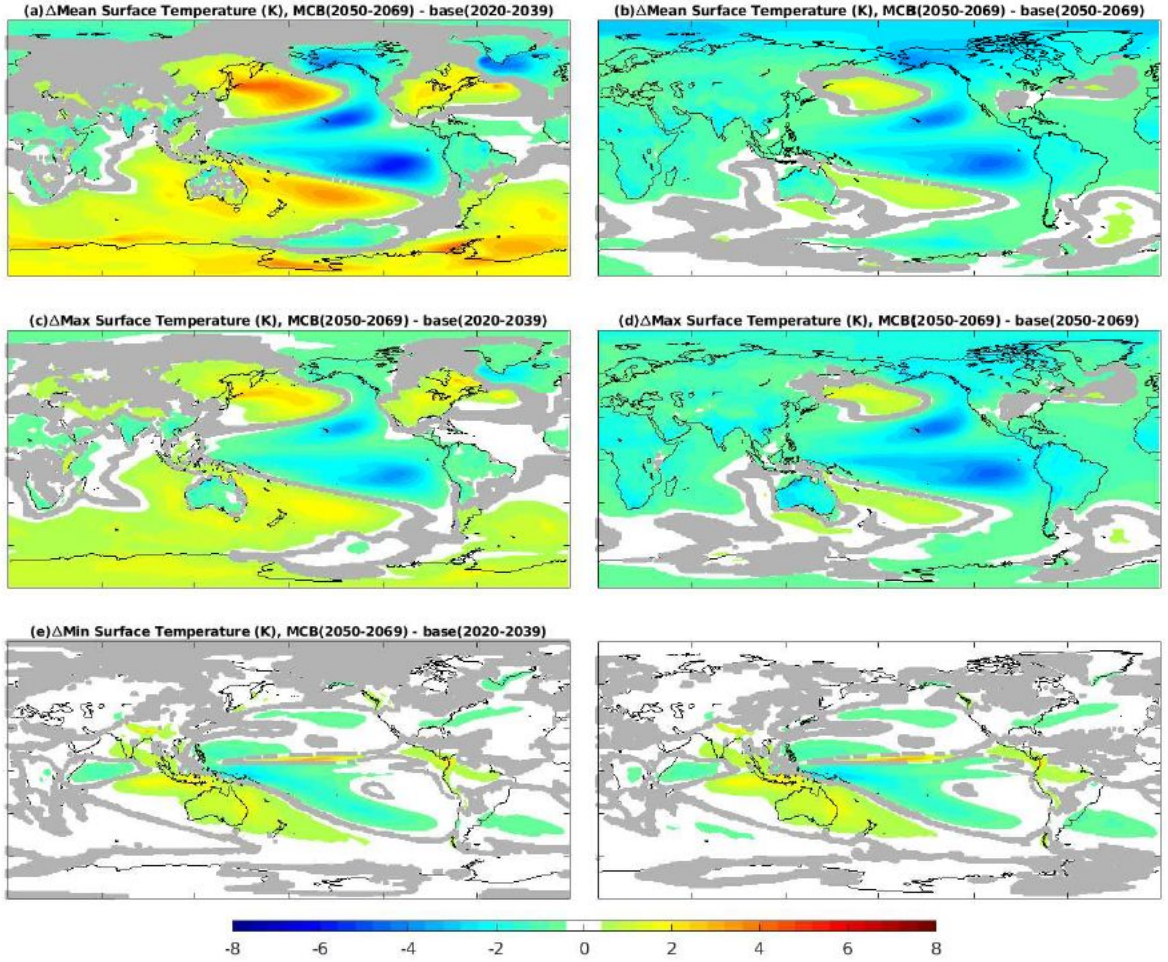
- CESM2, 1 degree resolution
- four seeding schemes: 2.5%, 5%, 7.5%, 12.5% of the ocean surface
- SSP2.4-5 scenario
- start in 2035 (to 2069)
- target: global surface temperature 2020-2039 (~ 1.5 C) between 2050-2069

surface temperature response

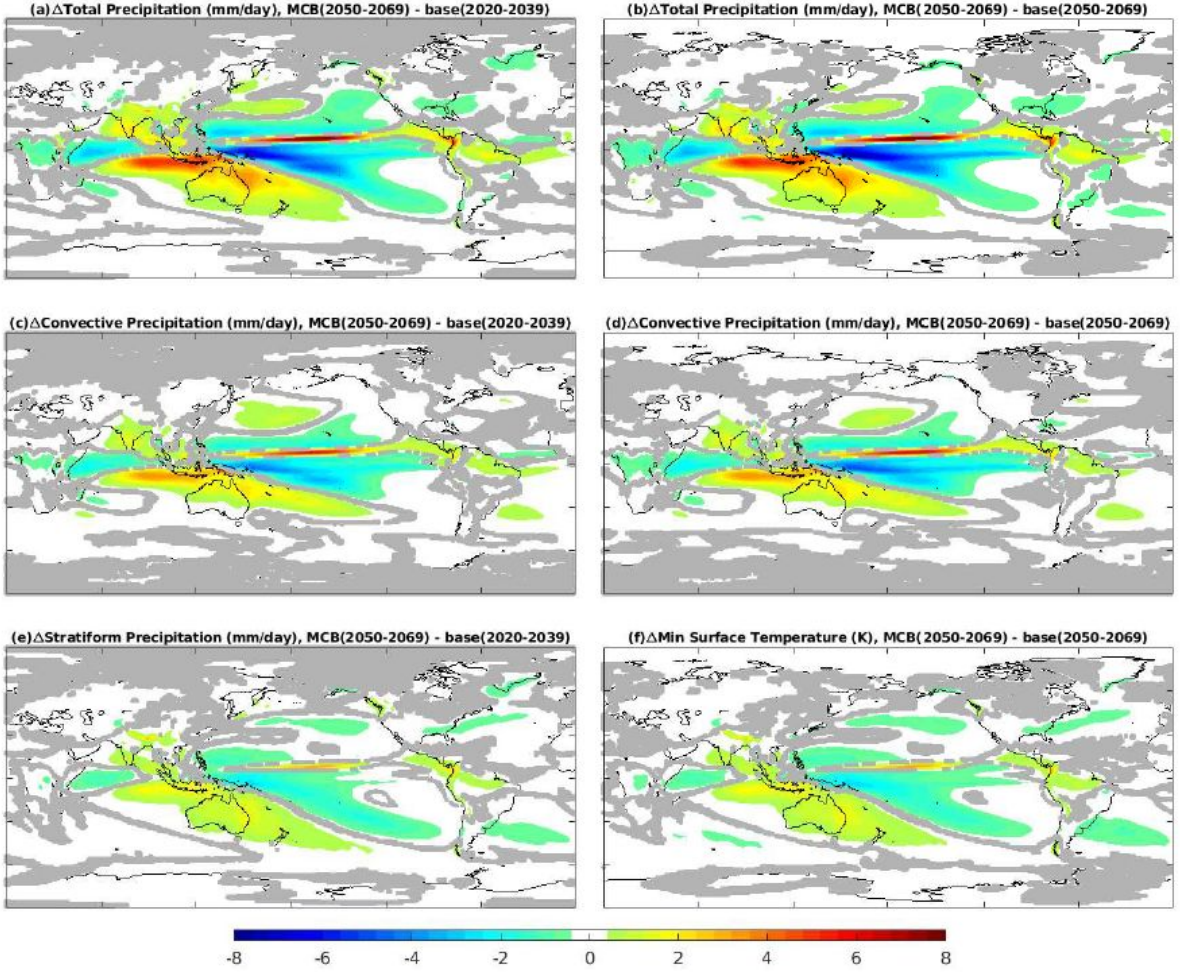


seeding over **5%** of the ocean surface maintains the global surface temperature at the 2020-2039 level.

Global temperature response -MCB 5% 10-member ensemble



Precipitation response - MCB 5% 10-member ensemble

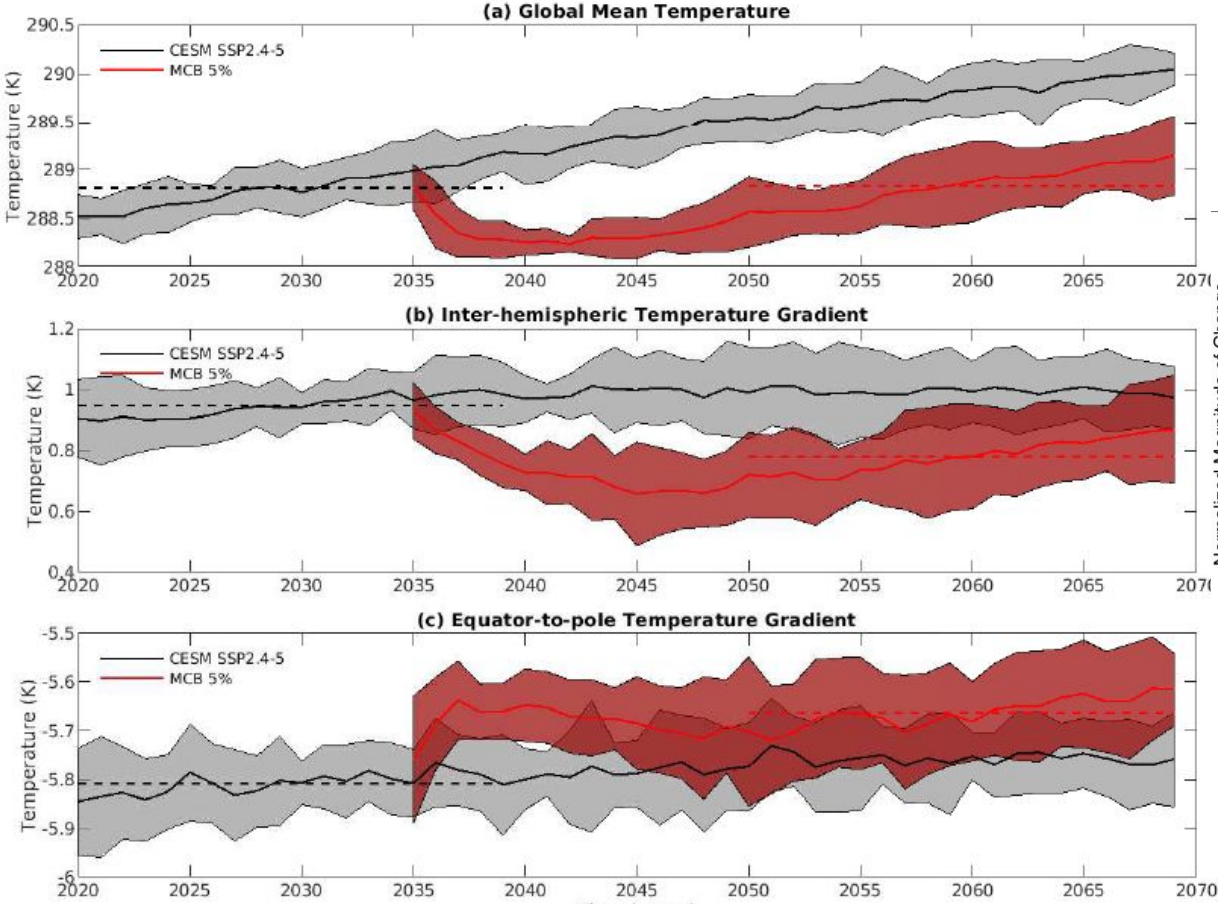


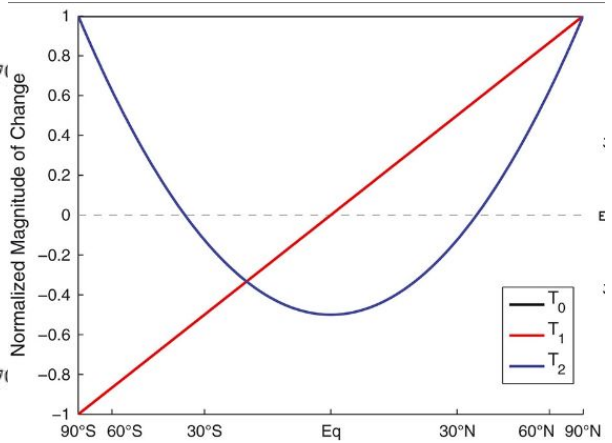
Summary and next step

1. Seeding over 5% of the ocean surface restores the global mean surface temperature between 2050-2069 at the 2020-2039 level.
2. MCB induces the largest precipitation response in the tropics.
3. Precipitation is reduced over ocean but is increased over land (mainly over Australia).

4. build a controller for MCB as ARISE-SAI
5. move to unconstrained approach

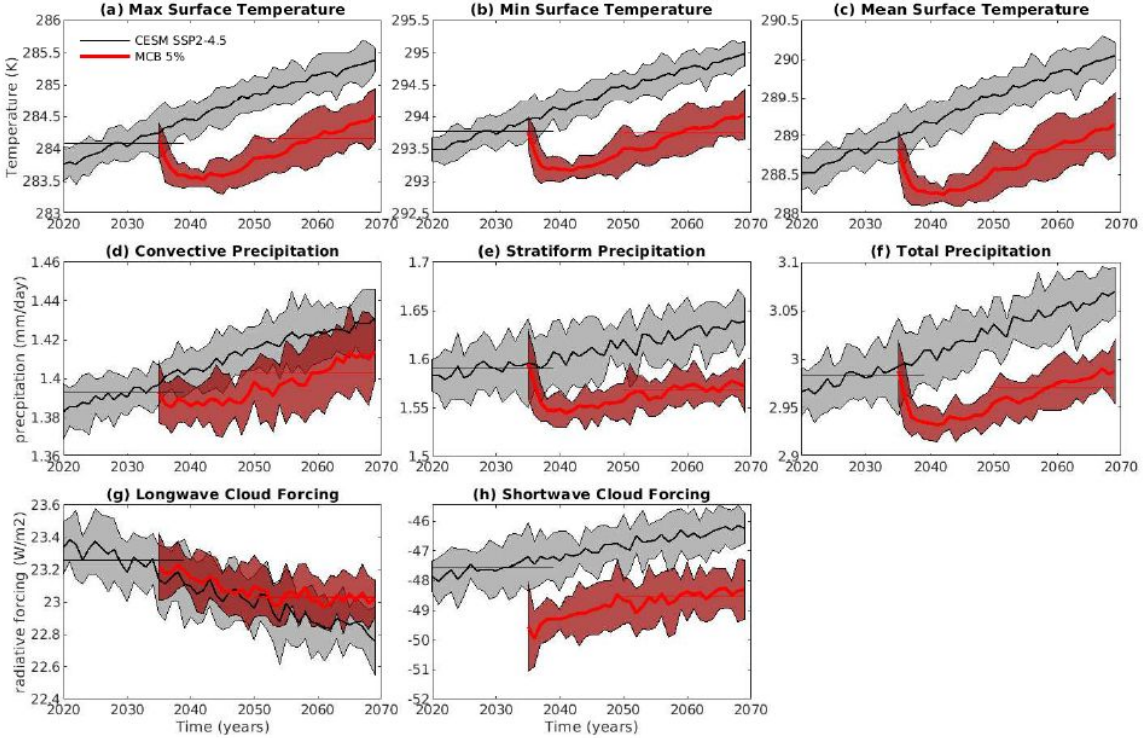
MCB 5% 10-member ensemble - T0, T1, T2





Kravitz et al., 2017

MCB impact globally
10 ensemble members, seeding over 5% ocean surface



spread = 2 standard deviation

MCB 2050-2069 ensemble mean vs Control 2020-2039 ensemble mean

surface temperature is restored to 2020-2039 level by this seeding scheme!

minimum surface temperature slightly higher under MCB.

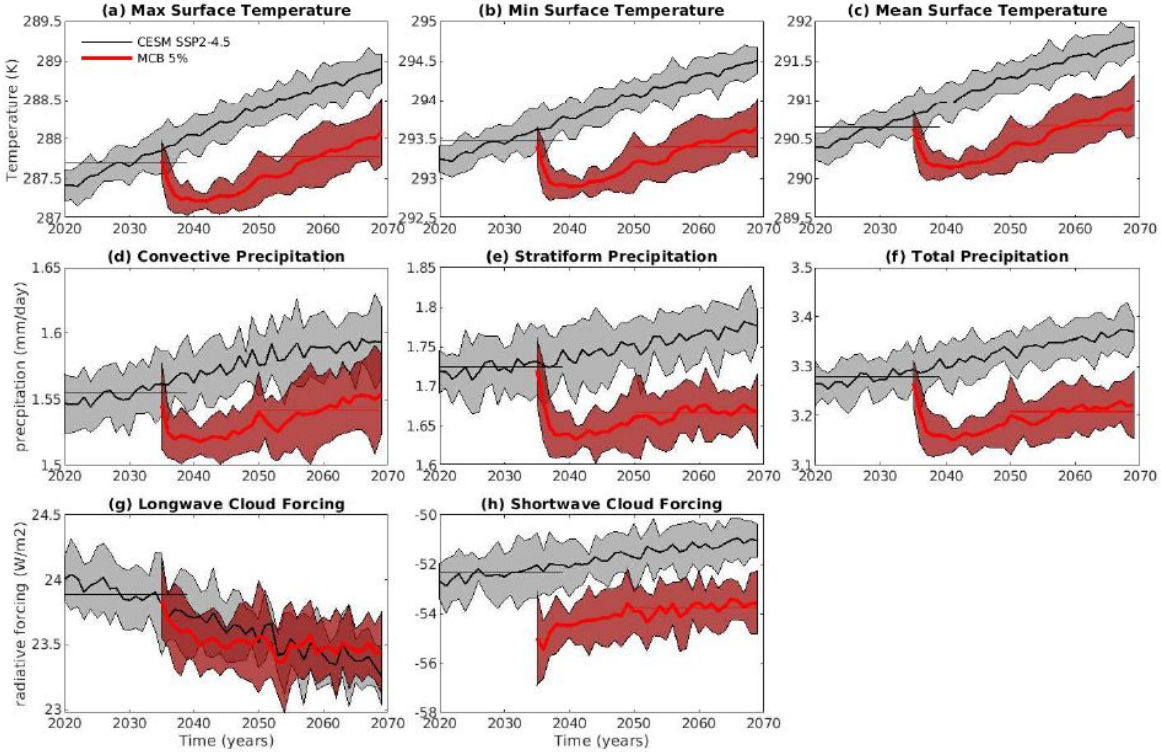
maximum surface temperature slightly lower under MCB.

convective precipitation slightly higher under MCB.

stratiform precipitation lower under MCB.

total precipitation lower under MCB.

MCB impact over ocean
6 ensemble members, seeding over 5% ocean surface



spread = 2 standard deviation

MCB 2050-2069 ensemble mean vs Control 2020-2039 ensemble mean

surface temperature is restored to 2020-2039 level by this seeding scheme!

minimum surface temperature slightly higher under MCB.

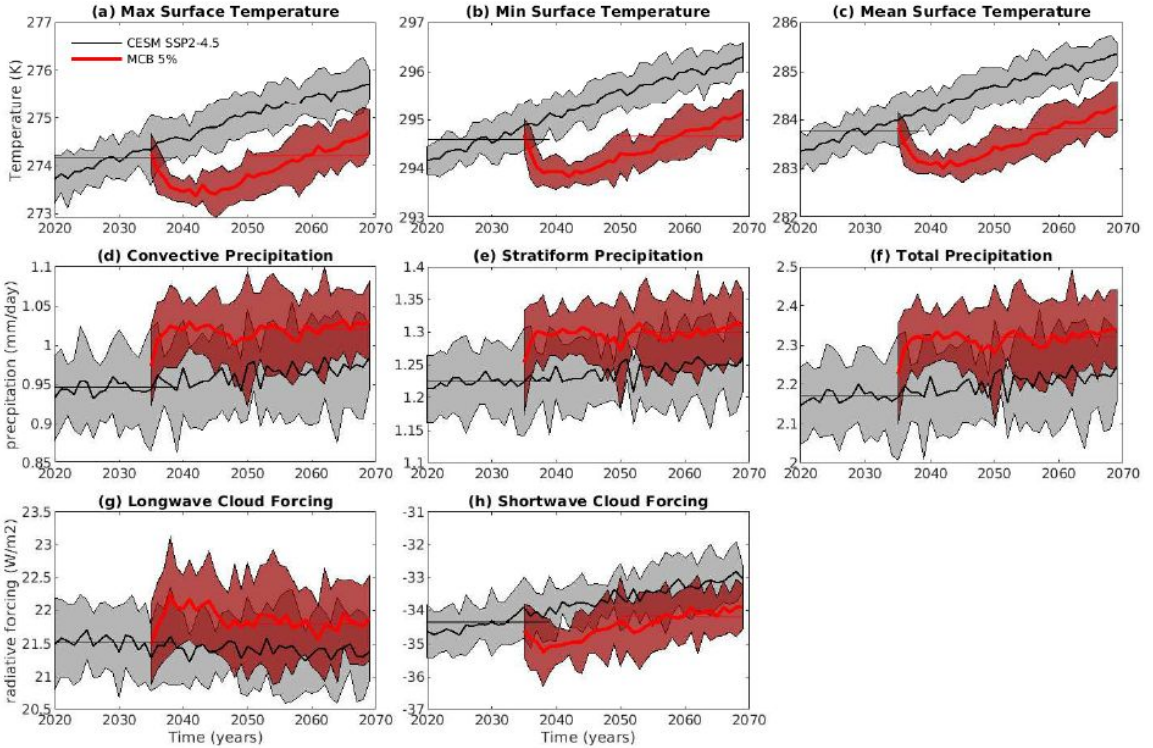
maximum surface temperature lower under MCB.

convective precipitation *lower* under MCB.

stratiform precipitation lower under MCB.

total precipitation lower under MCB.

MCB impact over land
10 ensemble members, seeding over 5% ocean surface



spread = 2 standard deviation

MCB 2050-2069 ensemble mean vs Control 2020-2039 ensemble mean

surface temperature is restored to 2020-2039 level by this seeding scheme!

minimum surface temperature slightly higher under MCB.

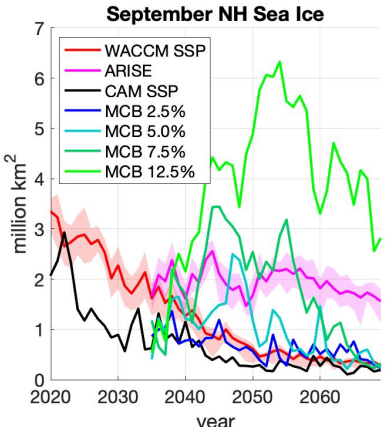
maximum surface temperature slightly *higher* under MCB.

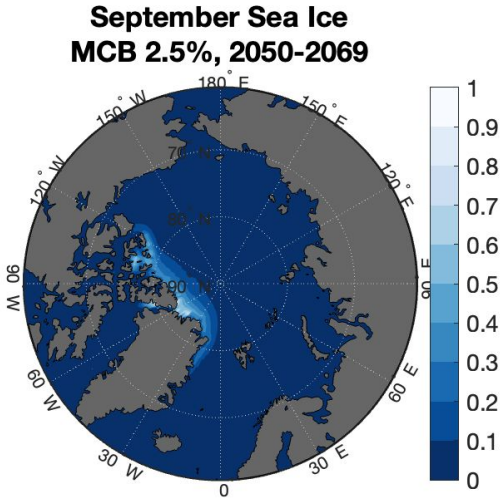
convective precipitation much *higher* under MCB.

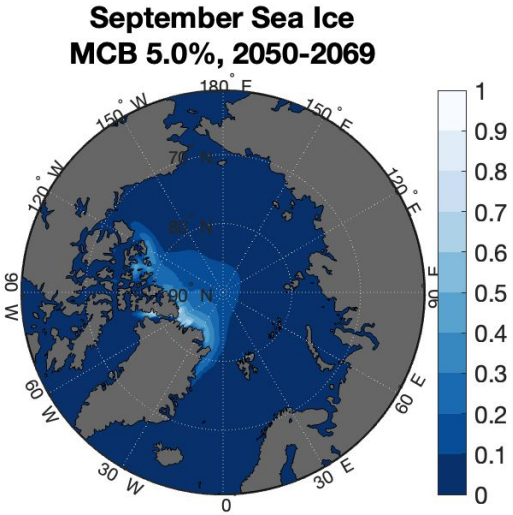
stratiform precipitation *higher* under MCB.

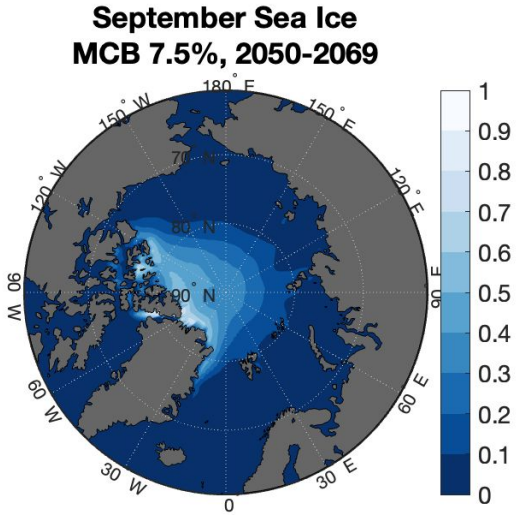
total precipitation *higher* under MCB.

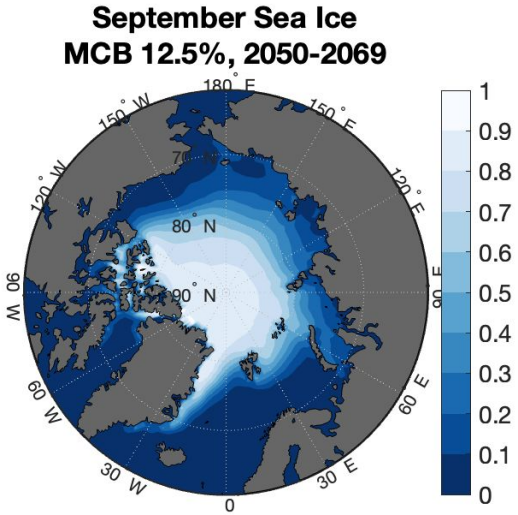
Sea ice response



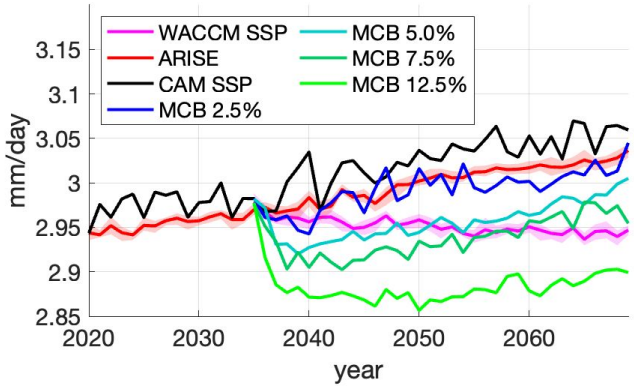


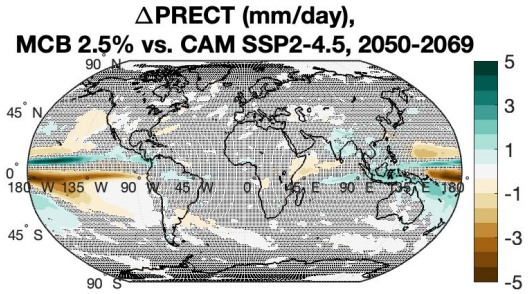


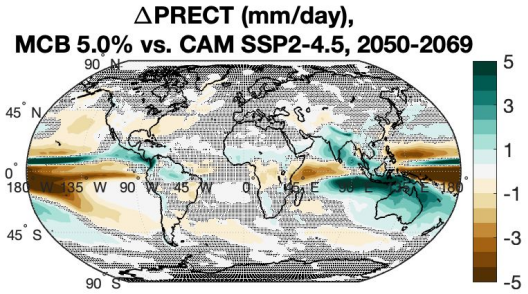


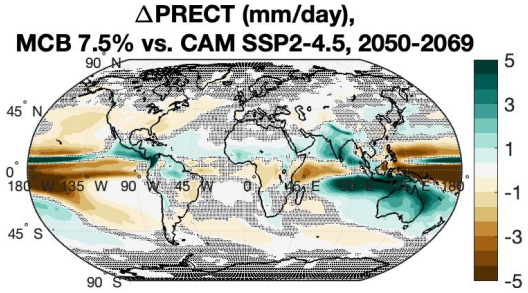


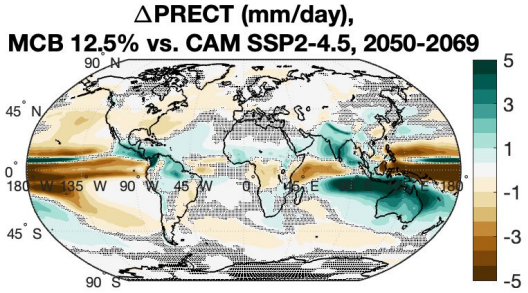
Precipitation response











seeding masks using CESM2 (constrained approach)

assuming 375 #/cm3

2015-2035 SSP2-4.5