Pre-print link

Impact of Seasonality on Climate Outcomes for Mid Latitude Marine Cloud Brightening

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Marine Cloud Brightening (MCB): Solar Climate Intervention Strategy

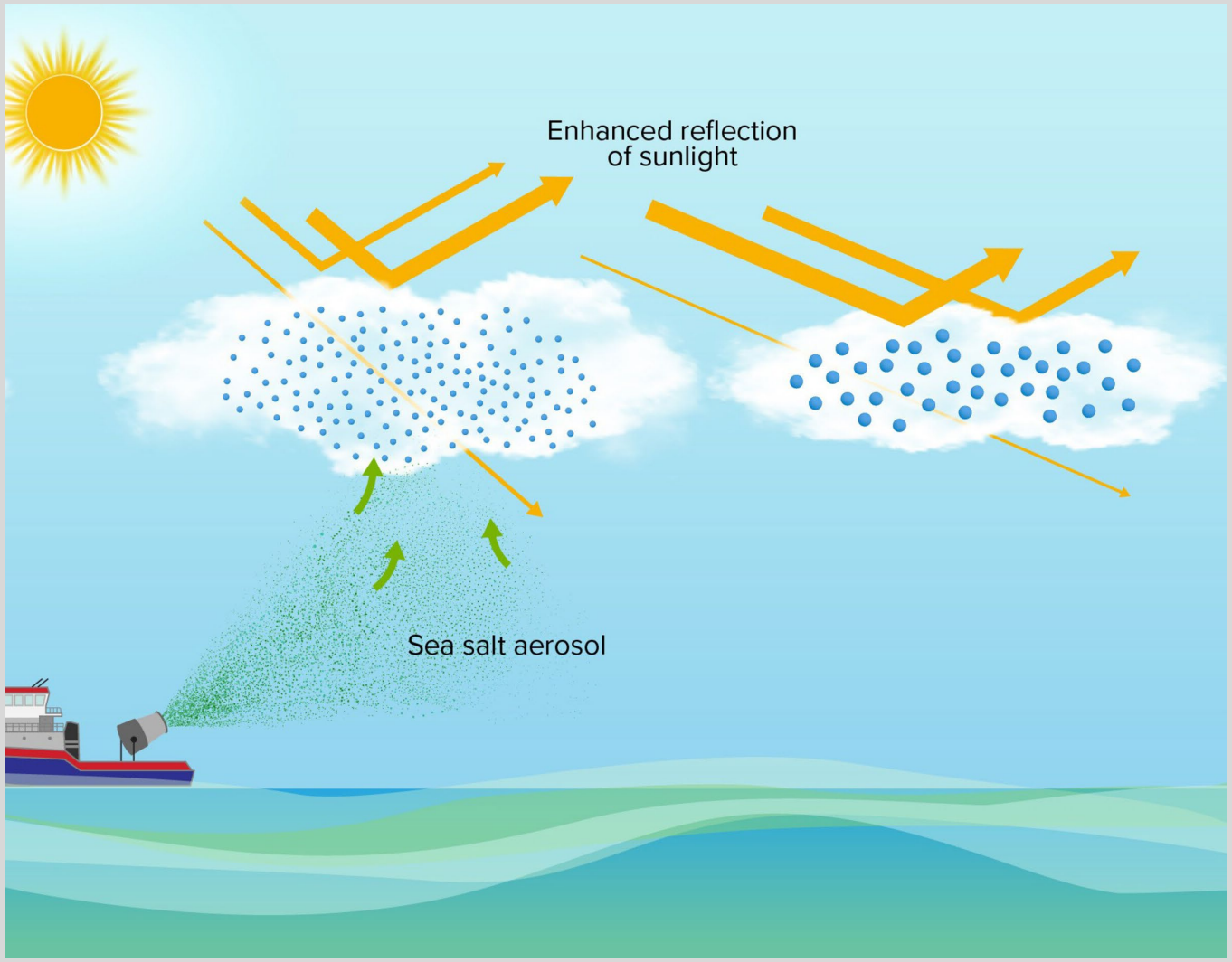
- Aims to modify the albedo of maritime boundary layer clouds through seeding with sea salt aerosols
- Injected sea salt aerosols act as efficient cloud condensation nuclei which can activate as cloud droplets

INCREASE
Cloud drop number concentration

DECREASE
Mean droplet size

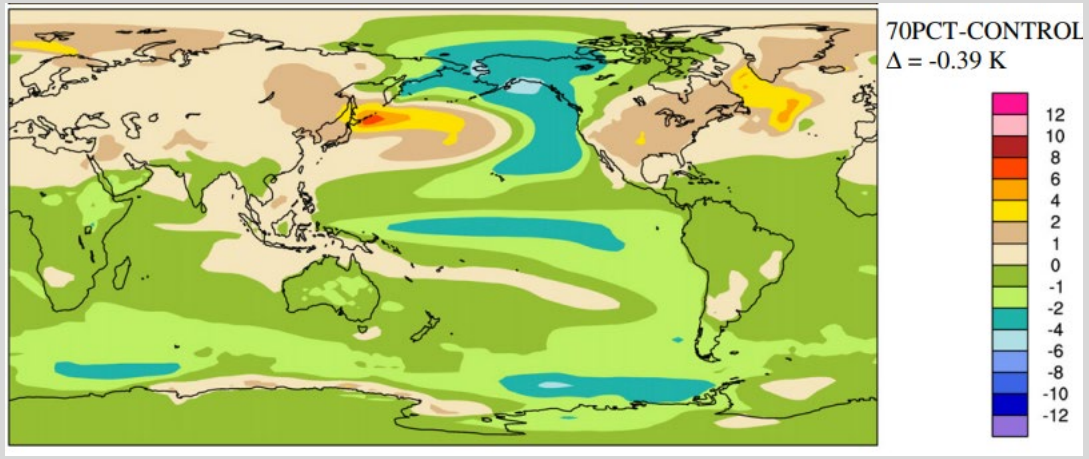
→

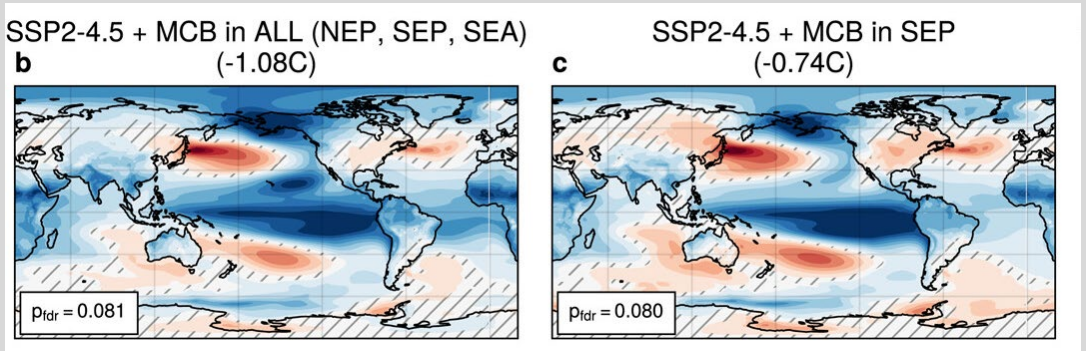
INCREASE
Cloud albedo, lifetime, and areal extent of clouds



(Feingold et al., 2024)

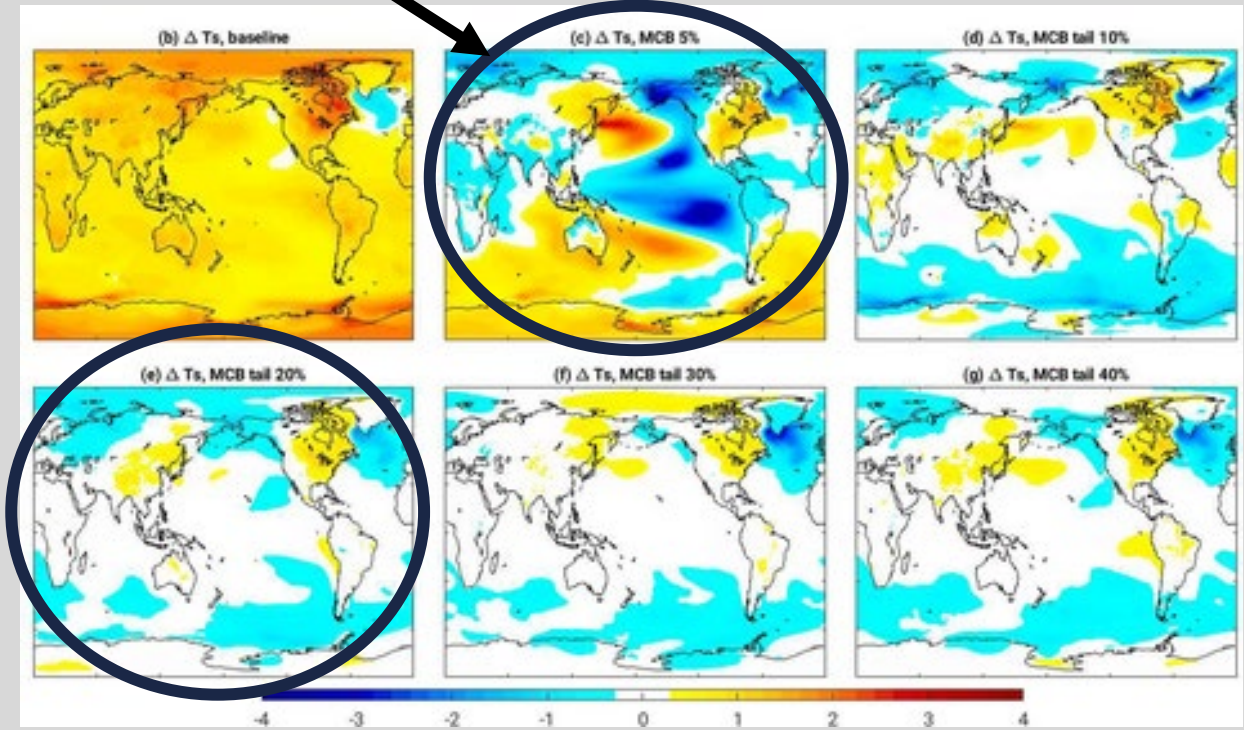
Previous MCB studies commonly show uneven cooling patterns and a perpetual La Niña-like sea surface temperature (SST) response.





Top: (Rasch et al., 2009) Bottom: (Hirasawa et al., 2023)

Targeting less susceptible regions leads to more uniform cooling and avoids triggering La Niña

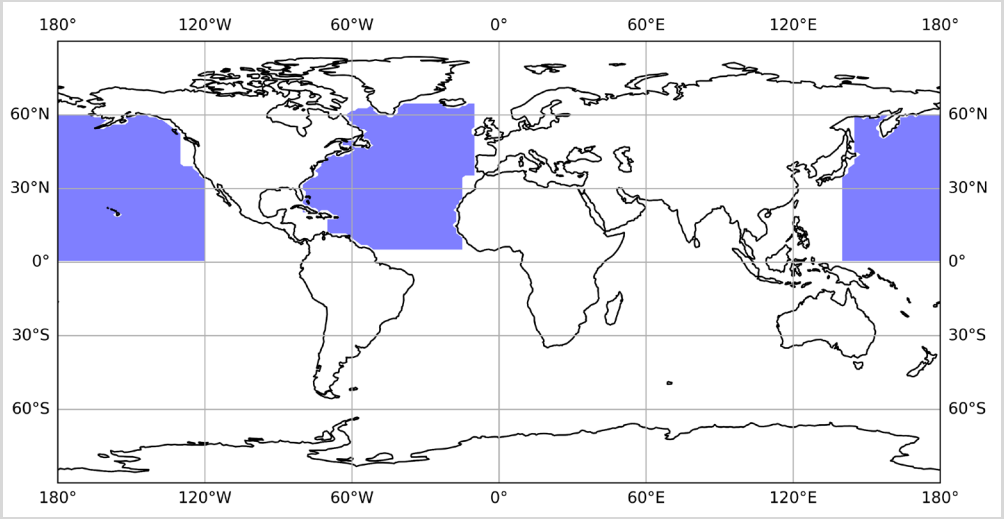


(Chen et al., 2024)

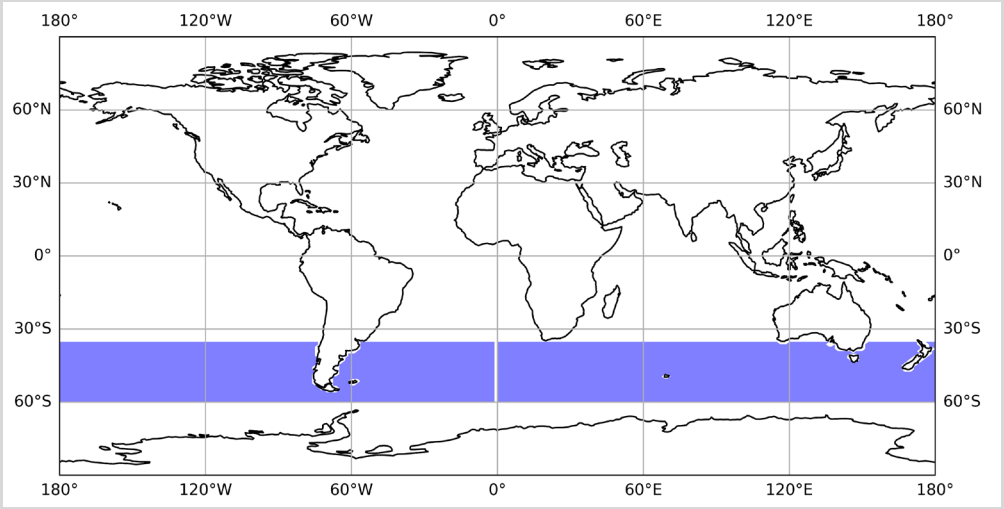
MCB Experiments with CESM2 (fully coupled)

- We adapt the 20% cloud seeding scheme from Chen et al. (2024) to more uniform midlatitude regions in a single hemisphere.
- MCB is simulated within the **purple regions** by artificially increasing the cloud droplet number concentration of clouds within the boundary layer (<850 hPa) to 375 cm^{-3}.
- MCB experiments are initiated in 2035, when they branch off the **control** (spun-up first member of the 16-member ensemble of simulations from 2015 to 2100 following the moderate Shared Socioeconomic Pathway scenario **SSP2-4.5**).

Target: restore ***present-day*** (control 2020-2039) temperature and precipitation conditions



20% least susceptible (**purple**) and 5% most susceptible (**red**) ocean surface to cloud seeding (Chen et al., 2024)

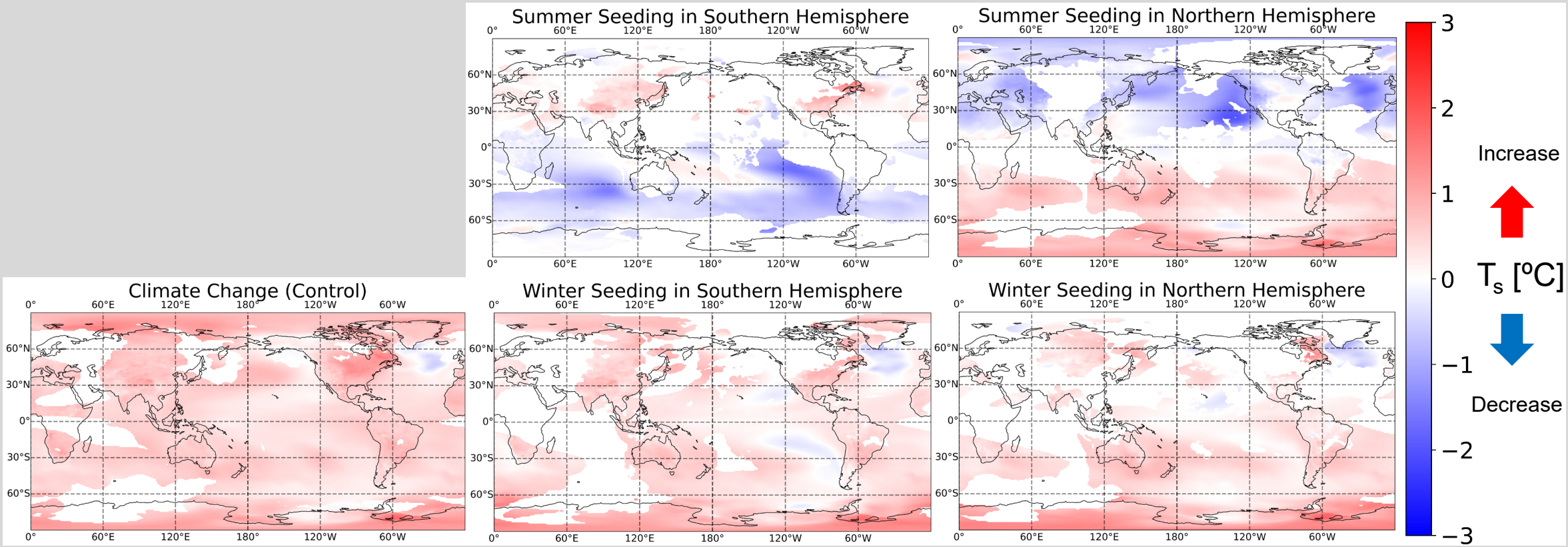


Sensitivity Experiments: Local Winter vs. Summer Single-Hemisphere MCB Deployment

20-year (2035-2055) MCB Sensitivity Experiment Scenarios		
Local summer cloud seeding	MCB deployed in local summer for 3 months each year (**maximum** incoming solar radiation)	Southern Hemisphere: *December, November, January*
		Northern Hemisphere: *June, July, August*
Local winter cloud seeding	MCB deployed in local winter for 3 months each year (**minimum** incoming solar radiation)	Southern Hemisphere: *June, July, August*
		Northern Hemisphere: *December, January, February*

Statistically Significant Surface Temperature (T_s) Response

Multi-Year Mean T_s Difference: MCB experiment (2035-2055) – Present-day

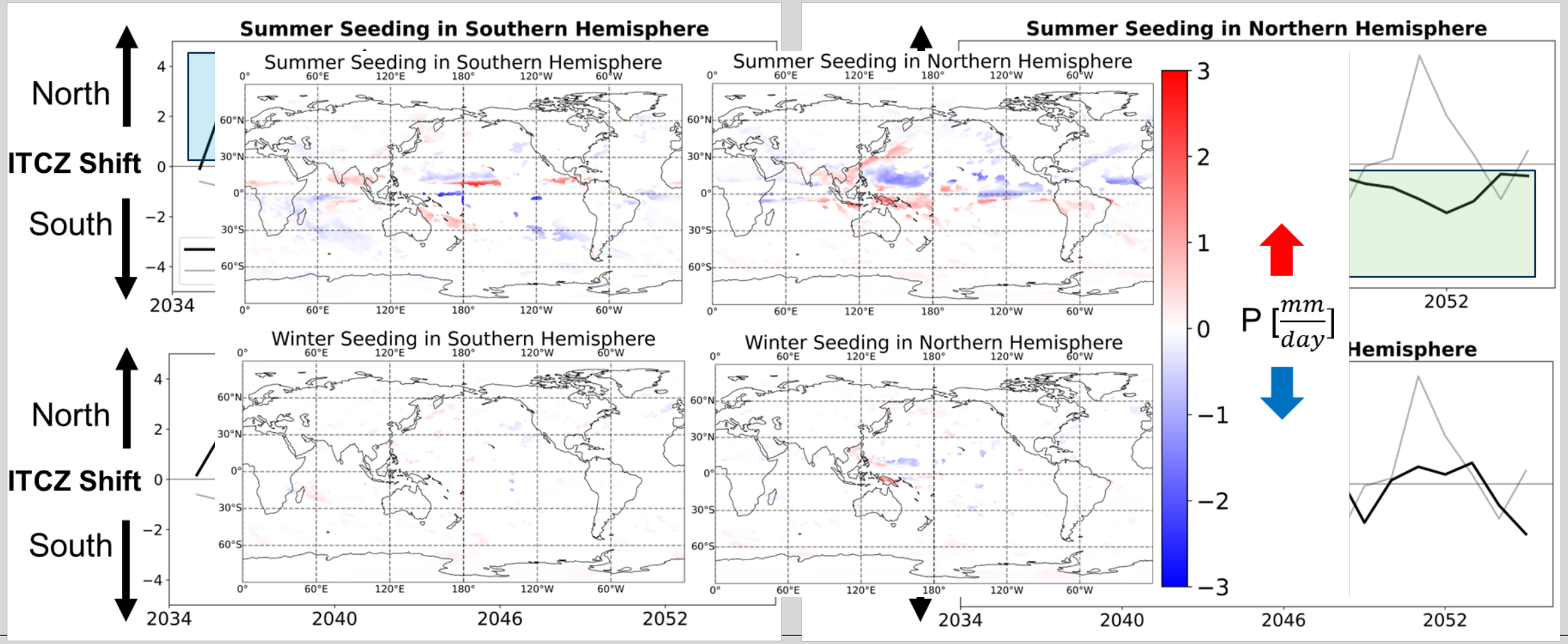


Summer Seeding Shifts the ITCZ.

Shift in Intertropical Convergence Zone (ITCZ): *Change in latitude of location of maximum precipitation (MCB experiment (annual mean) – Present-day)*

Statistically Significant Precipitation Rate (P) Response

Multi-Year Mean P Difference: MCB experiment (2050-2069) – Present day

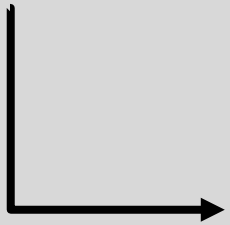


Local summer seeding leads to

- Uneven cooling patterns
- A shift of the ITCZ

Local winter seeding

- More uniformly impacts temperature
- Does not produce strong enough cooling

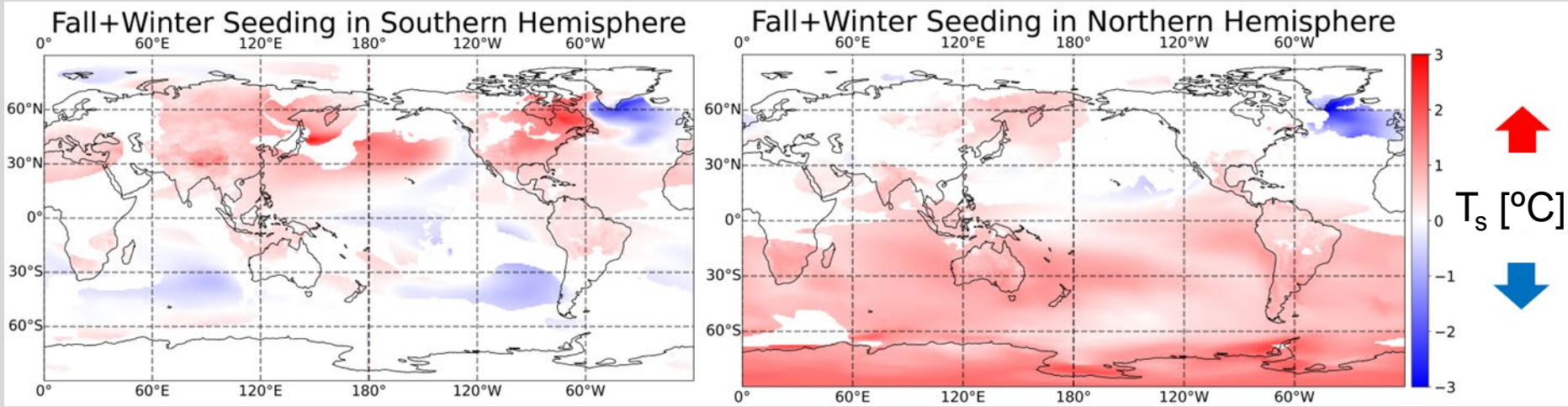


35-year (2035-2069) MCB Experiments		
Local fall+winter cloud seeding	MCB deployed in local fall and winter for 6 months each year for 35 years.	Southern Hemisphere: *March, April, May, June, July, August*
		Northern Hemisphere: *September, October, November, December, January, February*

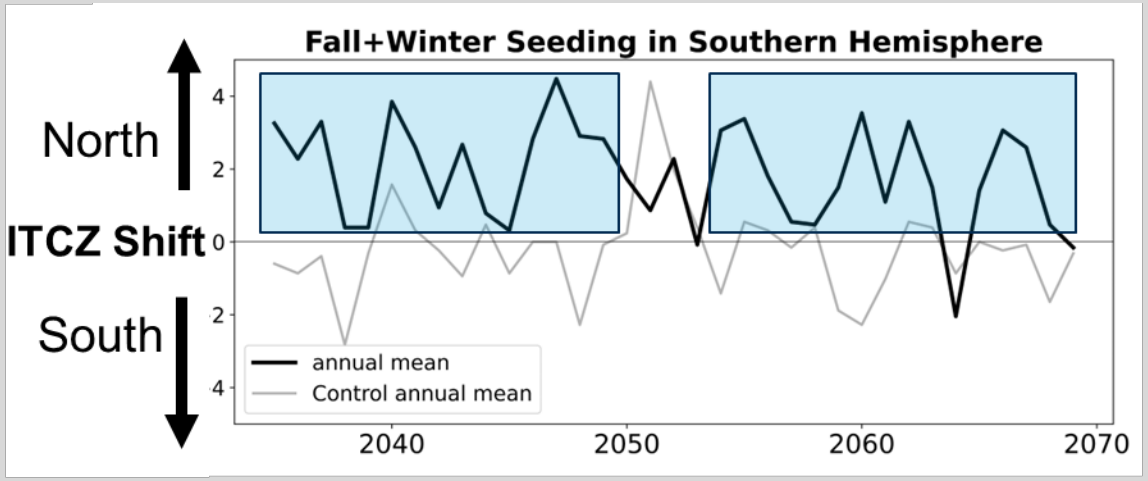
Fall+Winter Seeding in a single hemisphere leads to non-uniform cooling patterns.

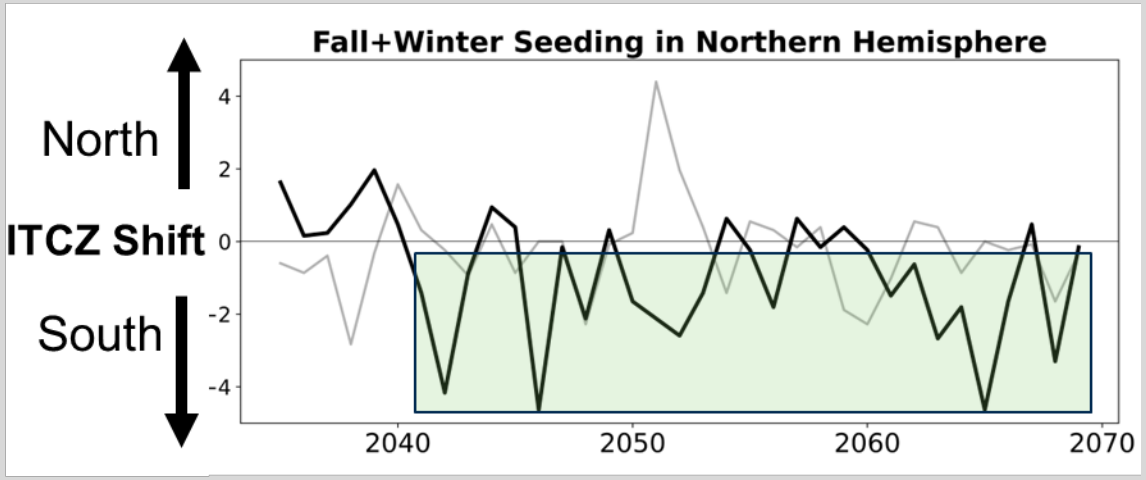
Statistically Significant T_s Response

Multi-Year Mean T_s Difference: MCB experiment (2050-2069) – Present day



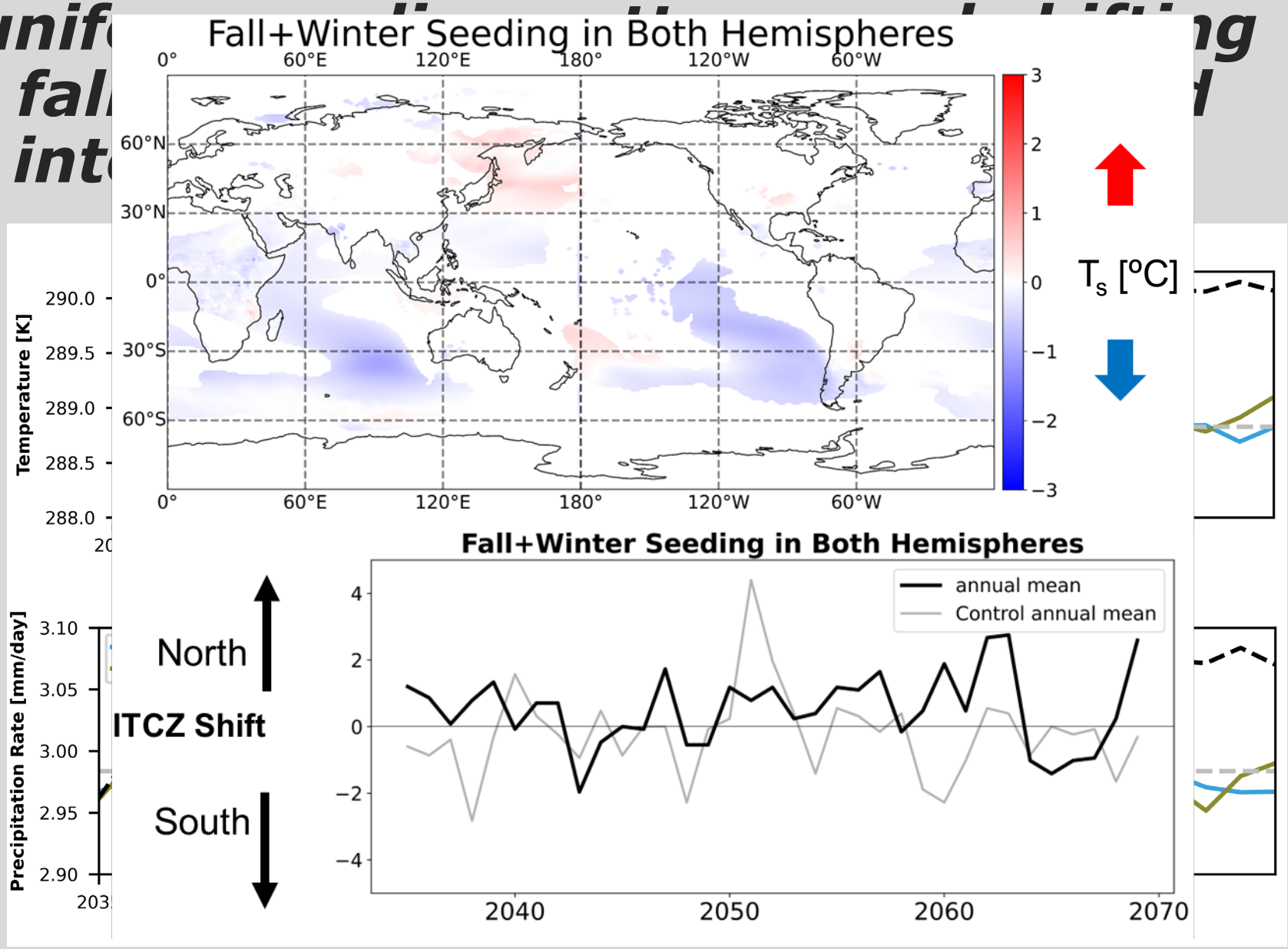
And shifts the ITCZ.





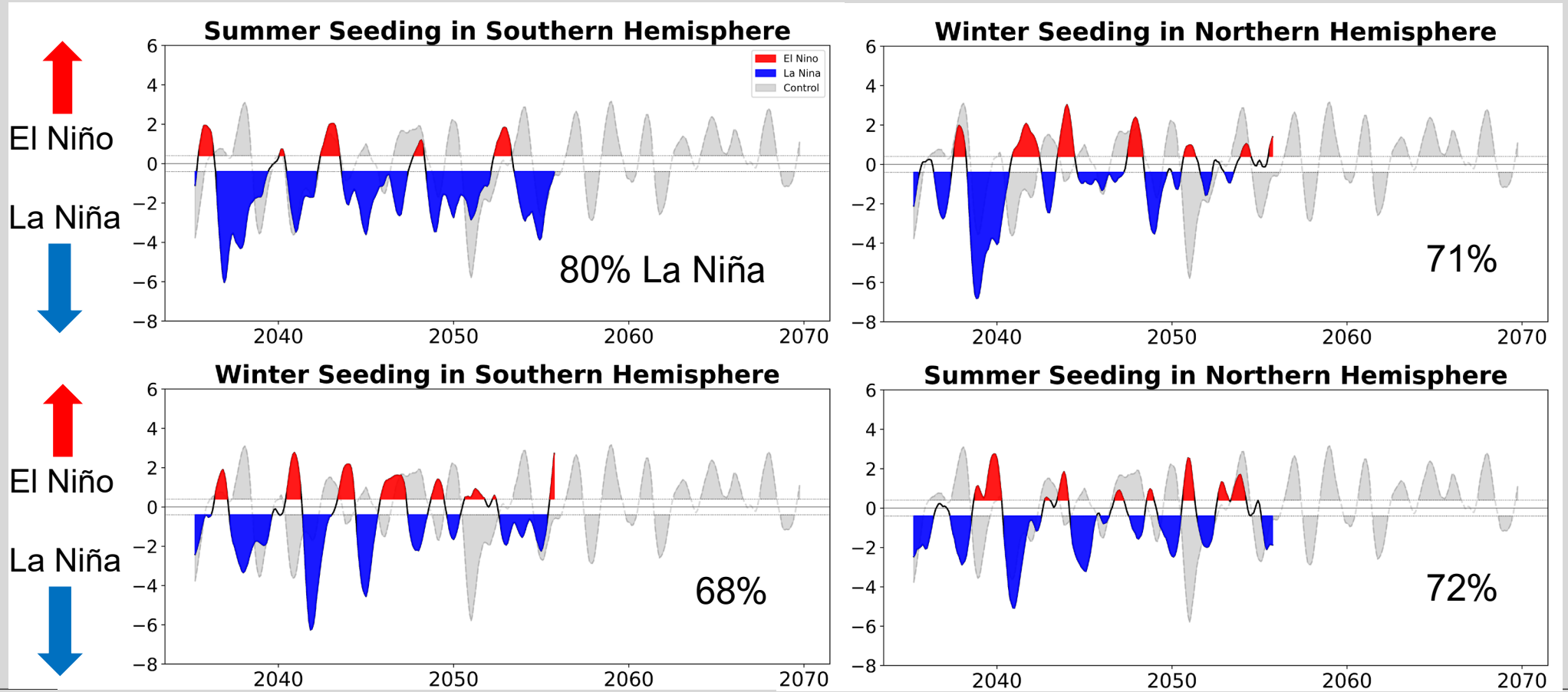
To avoid non-unif… …ng the ITCZ, the fal… …d int…

- It demonstrates a similar performance to the 20% least susceptible scheme from Chen et al. (2024), but with slightly more intense cooling
- The combined scheme demonstrates the most effective restoration of present-day surface temperatures and precipitation rate (of experiments tested here).



The Niño 3.4 Index Shows the impact of the MCB experiments on the El Niño Southern Oscillation.

Control (2035-2055) is in La Niña 62% of the time



Conclusions

- More **organized cloud seeding masks** with equal cloud seeding area can **deliver a similar climate outcome**
- The seasonality of MCB deployment is important for climate outcomes
  - Depending on the seasonality of deployment, **single hemisphere MCB** deployment can lead to **uneven cooling and shifting the ITCZ**
  - Southern Hemisphere MCB deployment (in summer and fall+winter months) triggers more frequent La Niña than Northern Hemisphere deployment
  - The seasonality of Southern Hemisphere MCB deployment is important for ENSO impacts
- Of the experiments tested here, **fall+winter seeding in both hemispheres** delivers the **most effective restoration of present-day surface temperature and precipitation**

Acknowledgements

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Thank you!
Questions?

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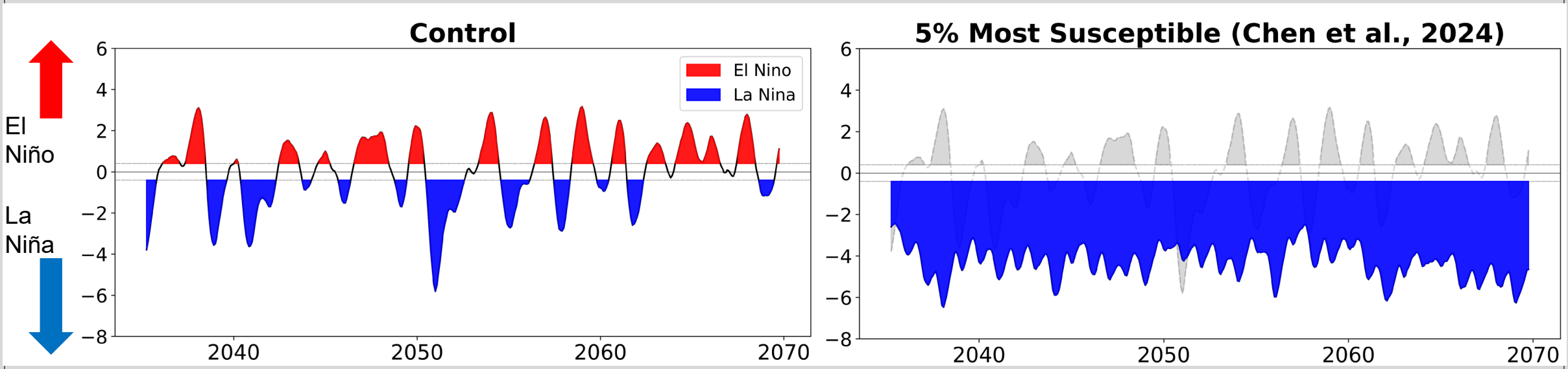
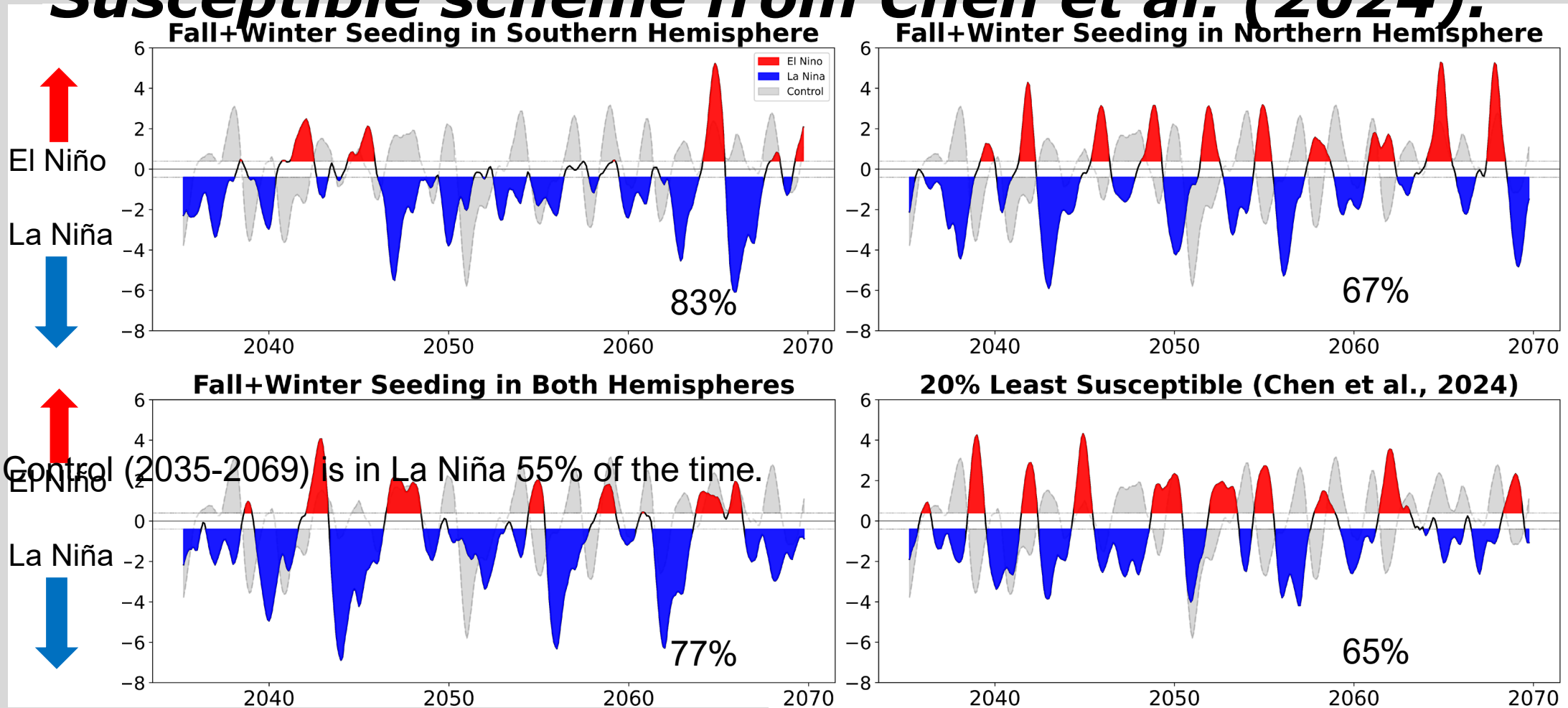
The Niño 3.4 Index Shows the impact of the MCB experiments on the El Niño Southern Oscillation.

The most susceptible 5% scheme from Chen et al. (2024) clearly shows a triggering of perpetual La Niña.



Fall+Winter Seeding in Both Hemispheres triggers more frequent La Niña than the 20% least Susceptible scheme from Chen et al. (2024).



Control (2035-2069) is in La Niña 55% of the time.

CESM2 Specifications

Fully Coupled

- CAM6 with finite volume dynamical core of 1.25º (latitude) x 0.9º (longitude), and 32 vertical levels with 40 km model top
- 3-D POP2
  - 1.25º zonal resolution
  - Varying meridional resolution (0.27º to 0.64º in Northern Hemisphere and 0.27º to 0.53º in Southern Hemisphere)
  - 60 vertical levels with a maximum depth of 5500m and uniform 10-m resolution in upper 160m
- Active land (CLM5) with biogeochemistry
- Active sea ice (CICE5)