How de-coupling cloud radiative feedbacks strengthens the AMOC

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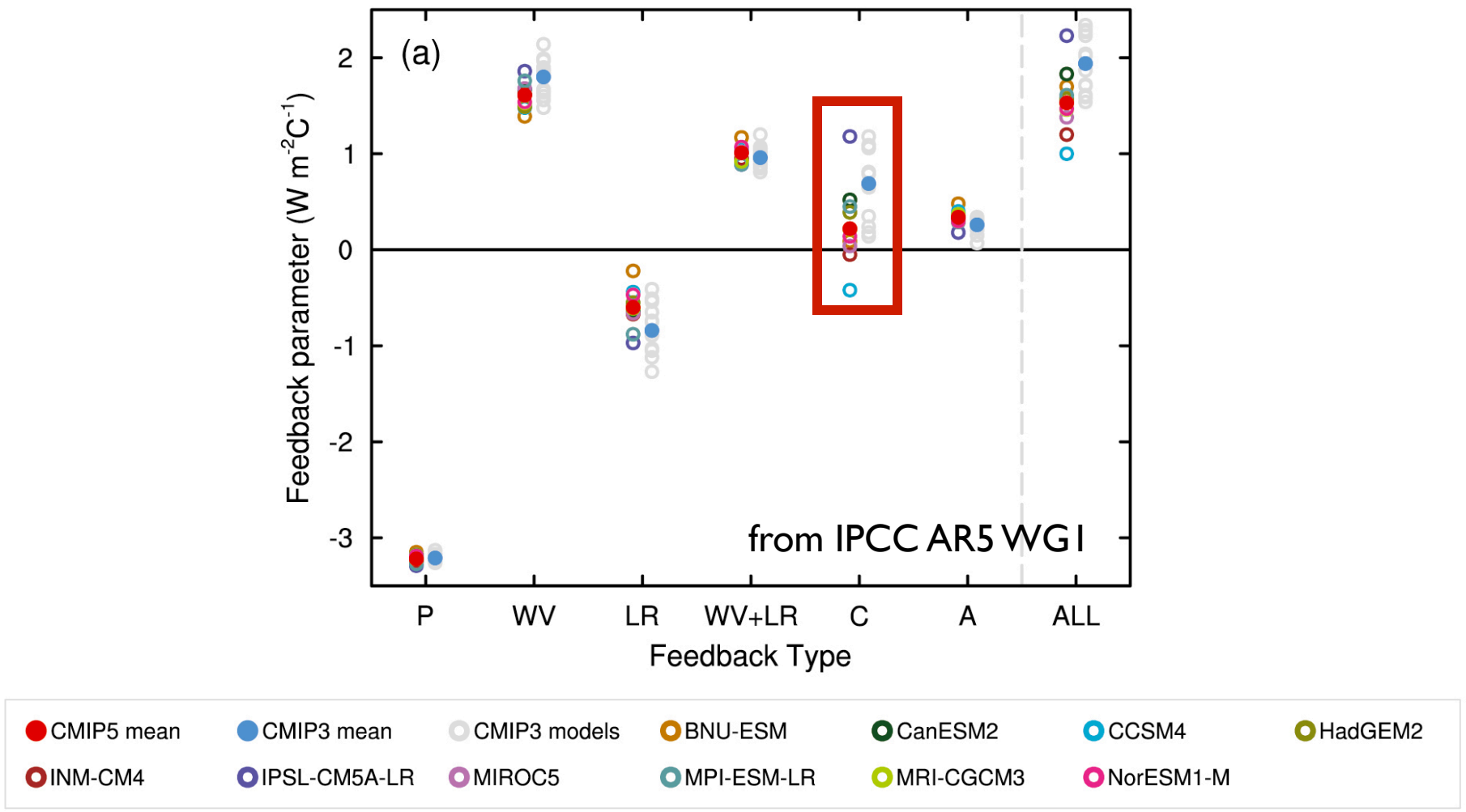
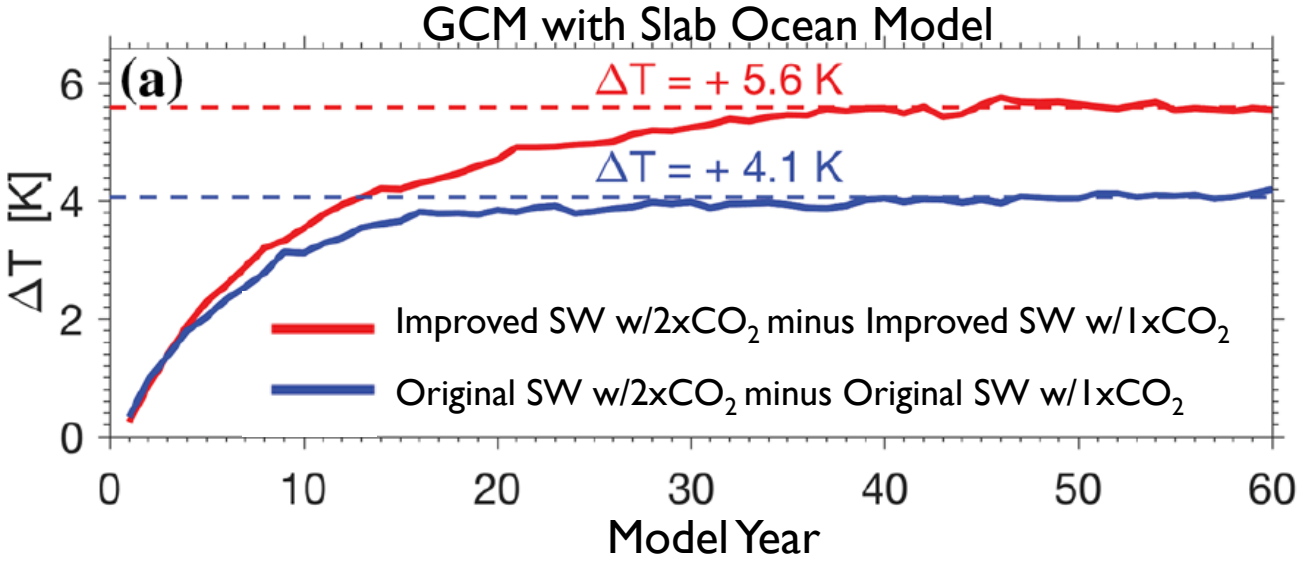
Cloud radiative feedbacks: the largest source of spread in model climate sensitivity.

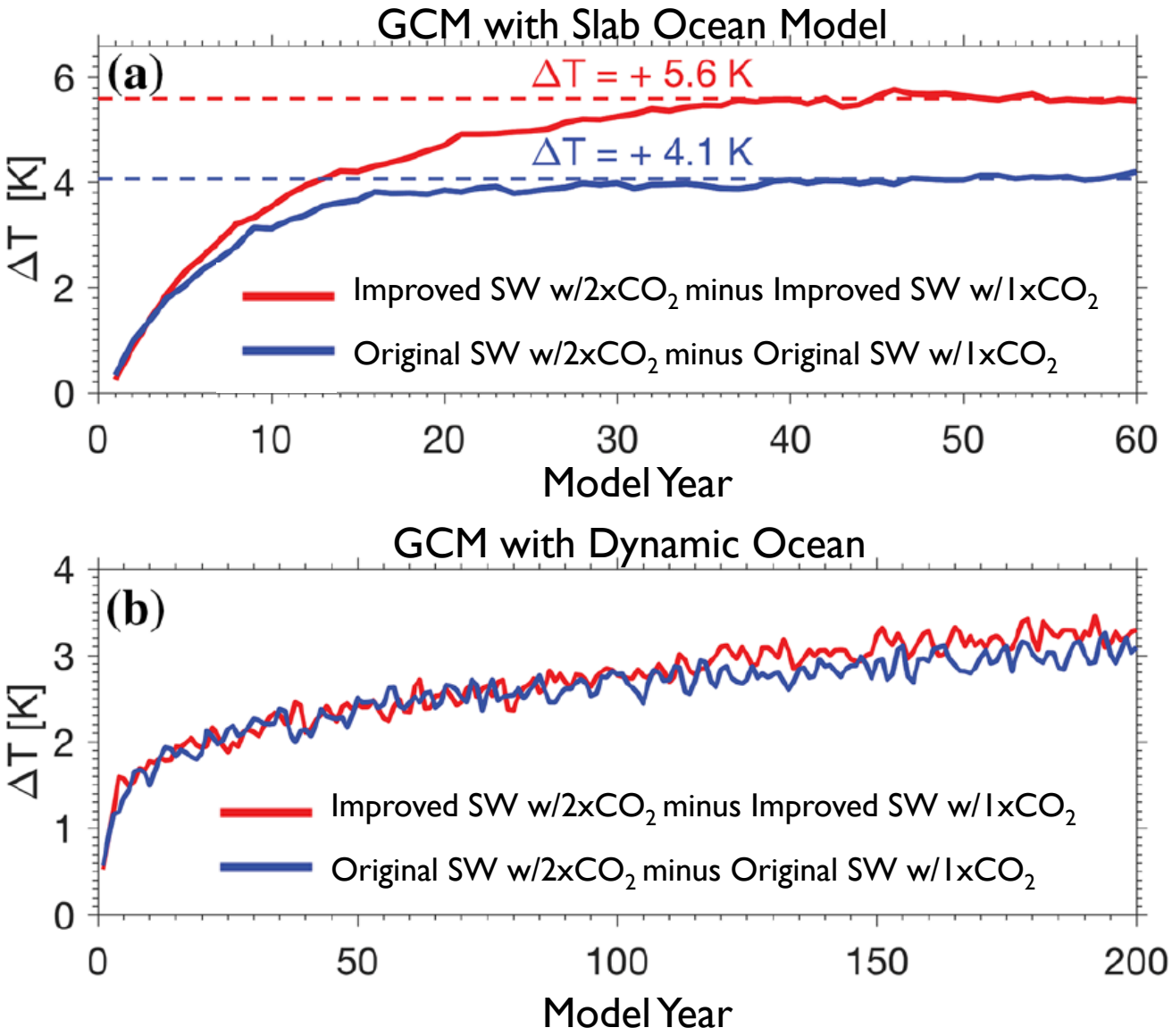


More positive Southern Ocean shortwave radiation biases should increase transient warming



From Frey and Kay, 2017

Additional warming from larger shortwave feedback long delayed in CESM with a dynamic ocean



From Frey and Kay, 2017

Cloud-locking decouples cloud radiation from surface temperature

CESM Control simulation with constant forcing

Cloud-locking decouples cloud radiation from surface temperature

CESM Control simulation with constant forcing

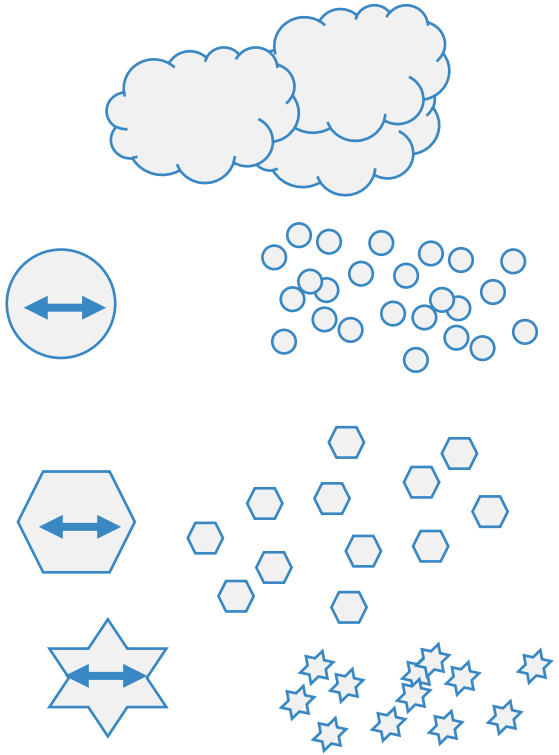
Collect from every 2 hours at every location for one full year:

Cloud amount

Parameters for liquid drop size distribution and liquid water path

Ice effective size and ice water path

Snow effective size and snow water path



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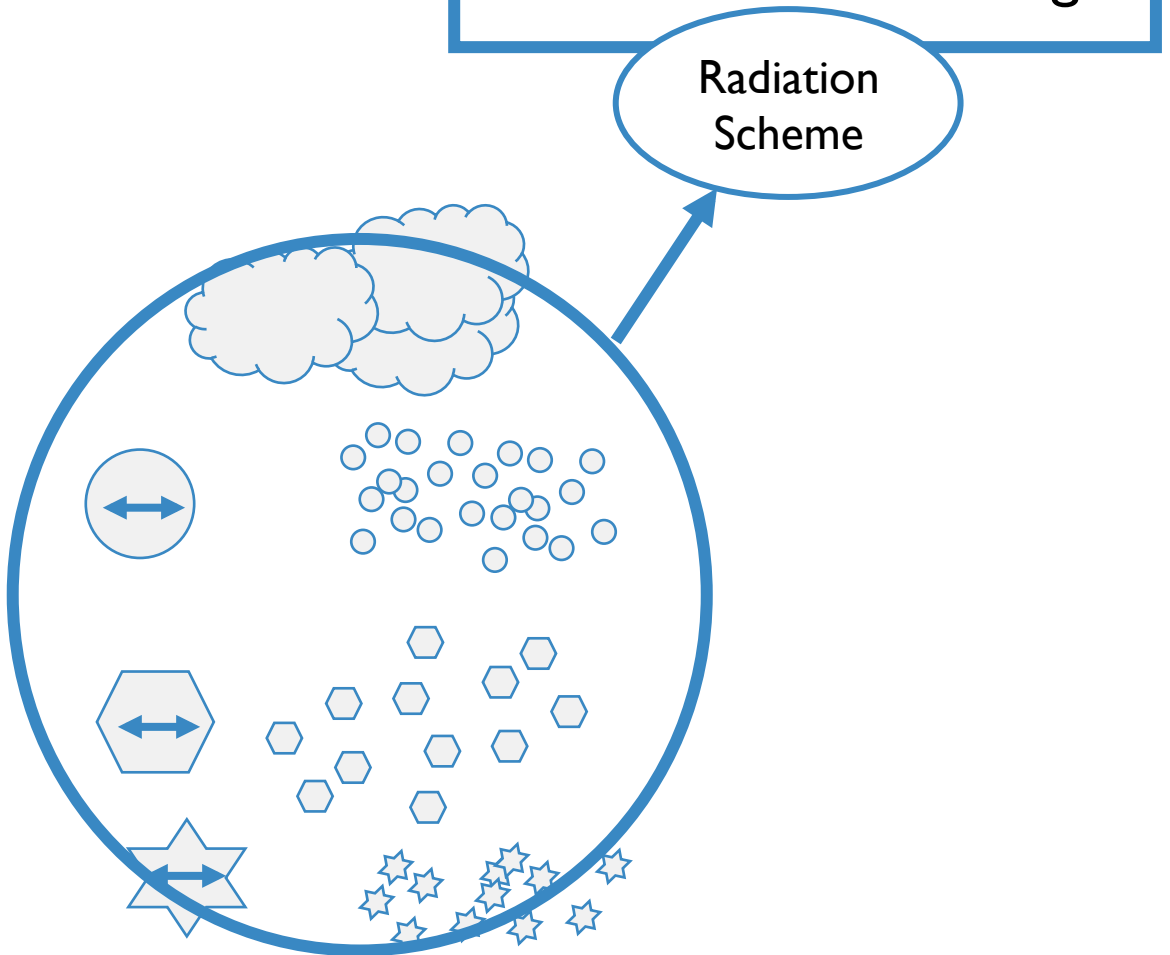
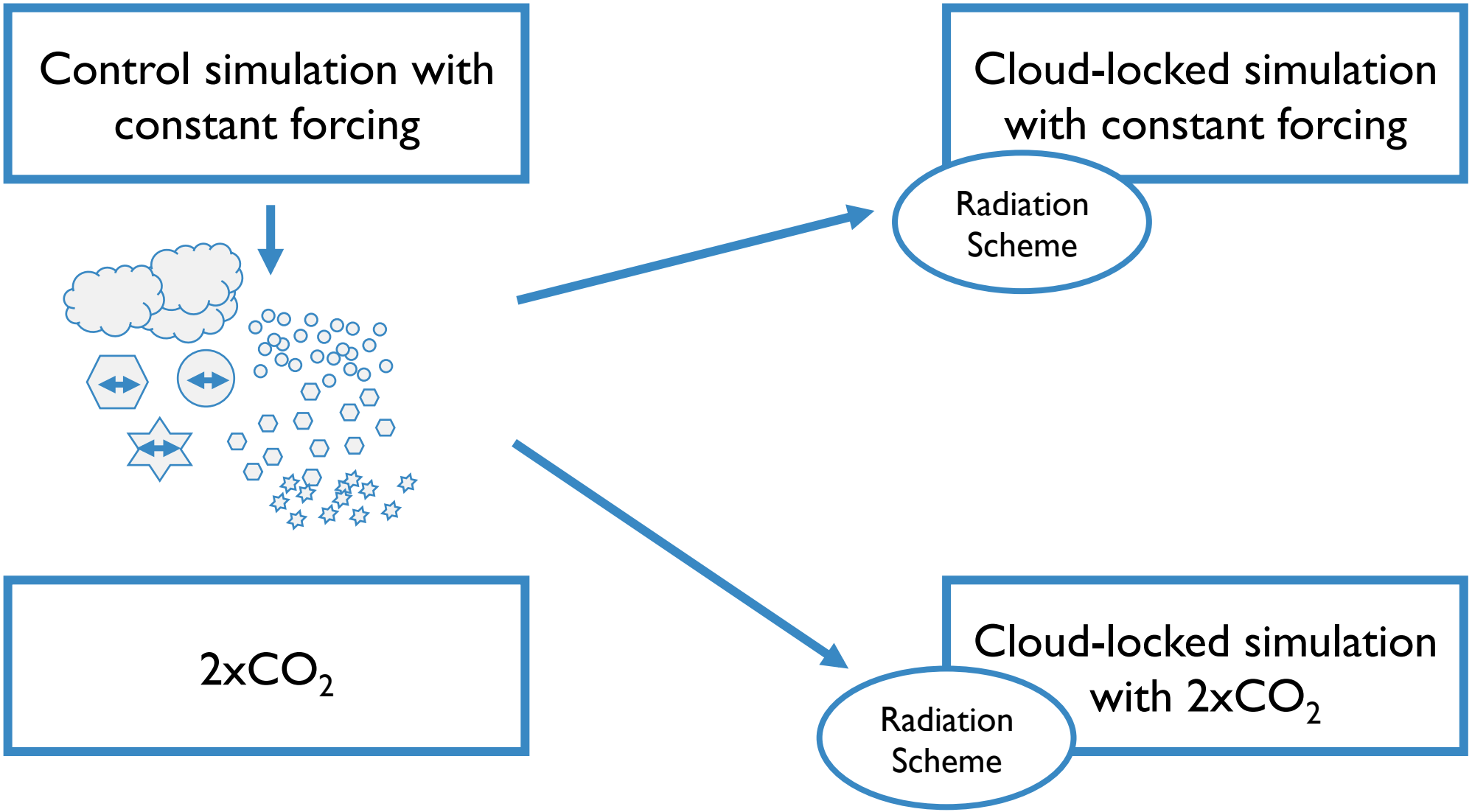
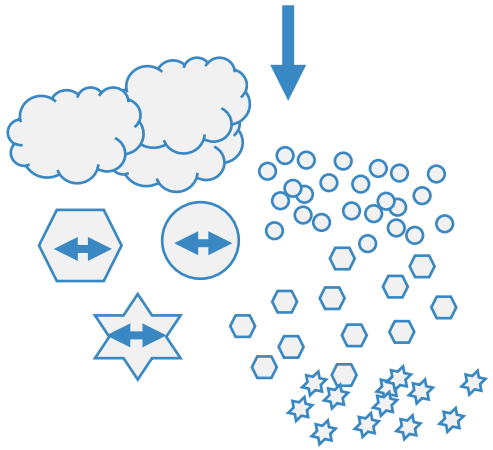
Cloud-locked simulation with constant forcing




Control simulation with constant forcing
Cloud-locked simulation with constant forcing
Radiation Scheme
2xCO2
Cloud-locked simulation with 2xCO2
Radiation Scheme

effect of de-coupling cloud radiation/
removing interannual cloud radiation
variability

Control simulation with constant forcing



Cloud-locked simulation with constant forcing

Radiation Scheme

$2xCO_2$

Cloud-locked simulation with $2xCO_2$

Radiation Scheme

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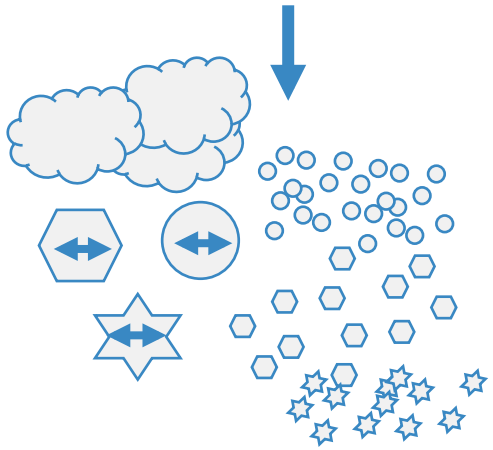


Cloud radiative feedbacks kept constant while climate warms

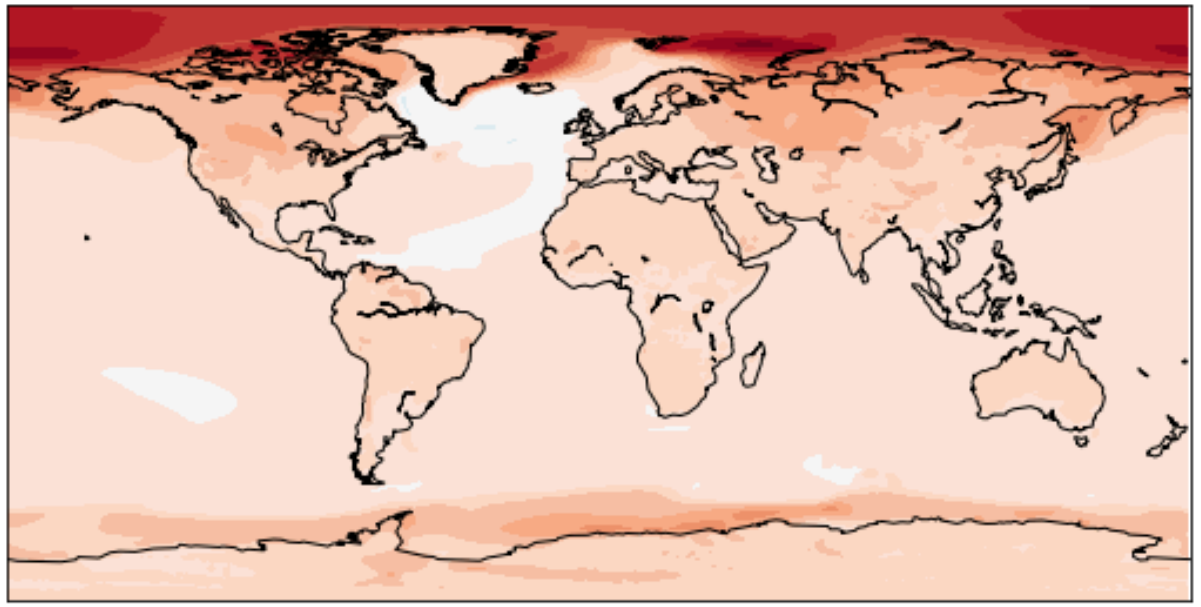
$2xCO_2$

Cloud-locked simulation with $2xCO_2$

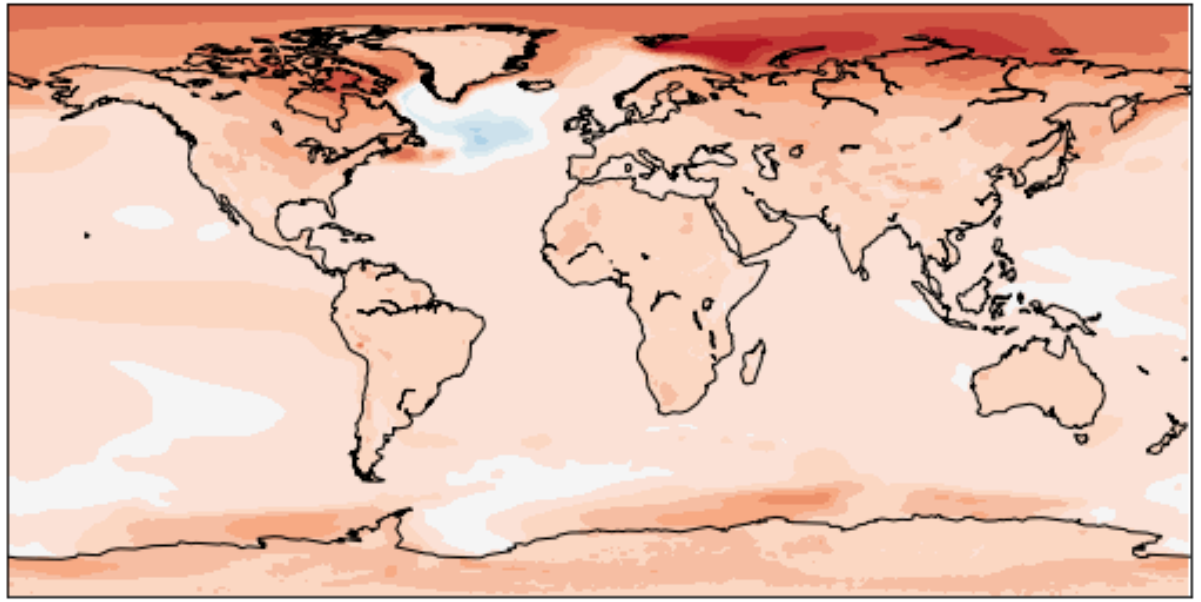
Radiation Scheme

Cloud-locking amplifies cooling in the subpolar gyre

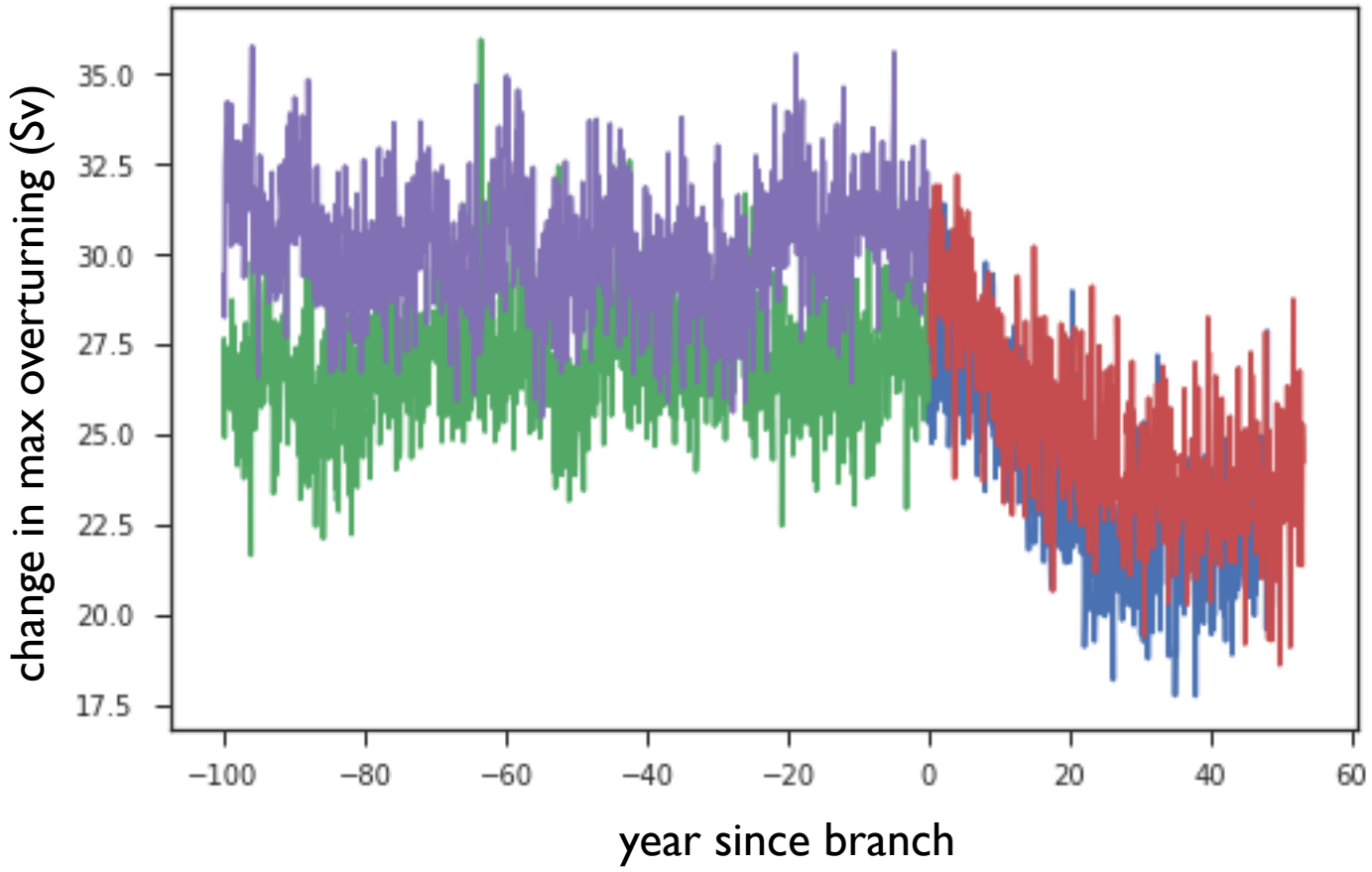
2xCO2 minus Control



Cloud-locked w/2xCO2 minus Cloud-locked



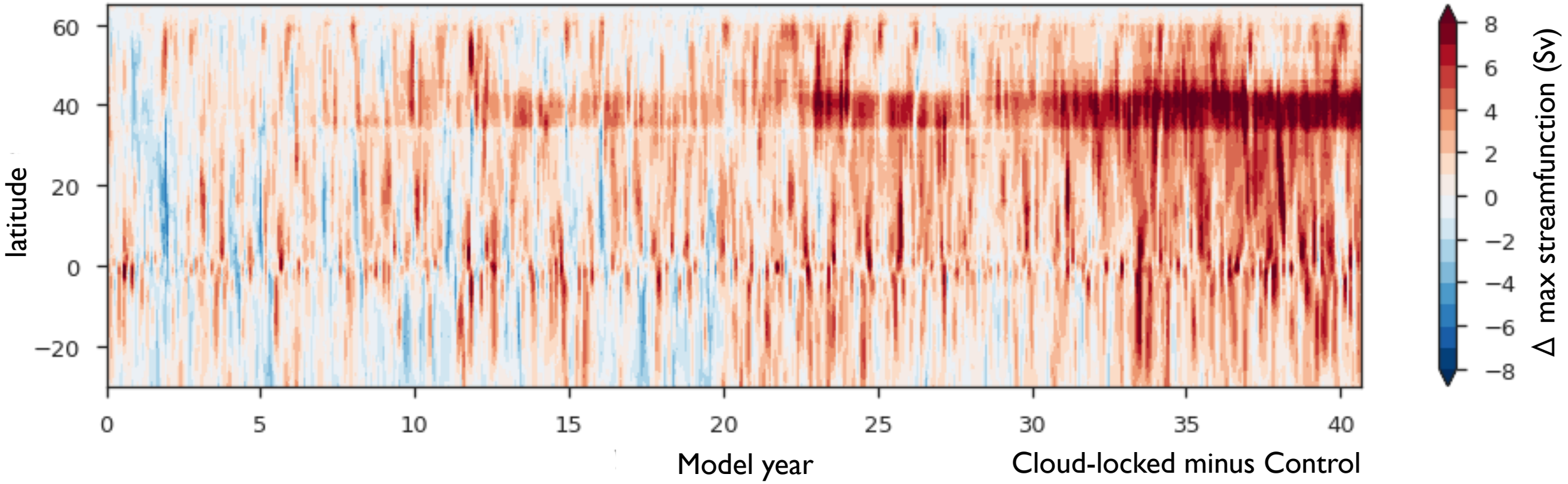
Difference in AMOC weakening mostly due to strengthened AMOC in cloud-locked simulation



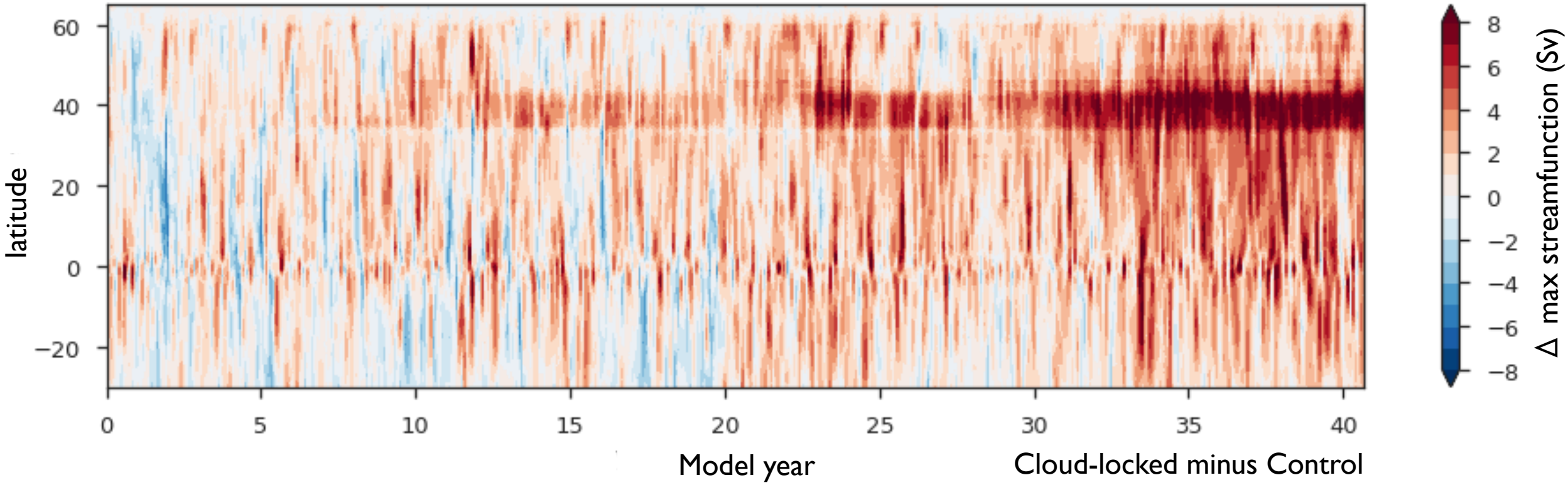
2xCO2 minus Control: -5 Sv
Cloud-locked w/2xCO2 minus Cloud-locked: -7 Sv
Cloud-locked minus Control: +3 Sv

2xCO2
Control
Cloud-locked w/2xCO2
Cloud-locked

Overturning strengthens within 10 years



Overturning strengthens within 10 years

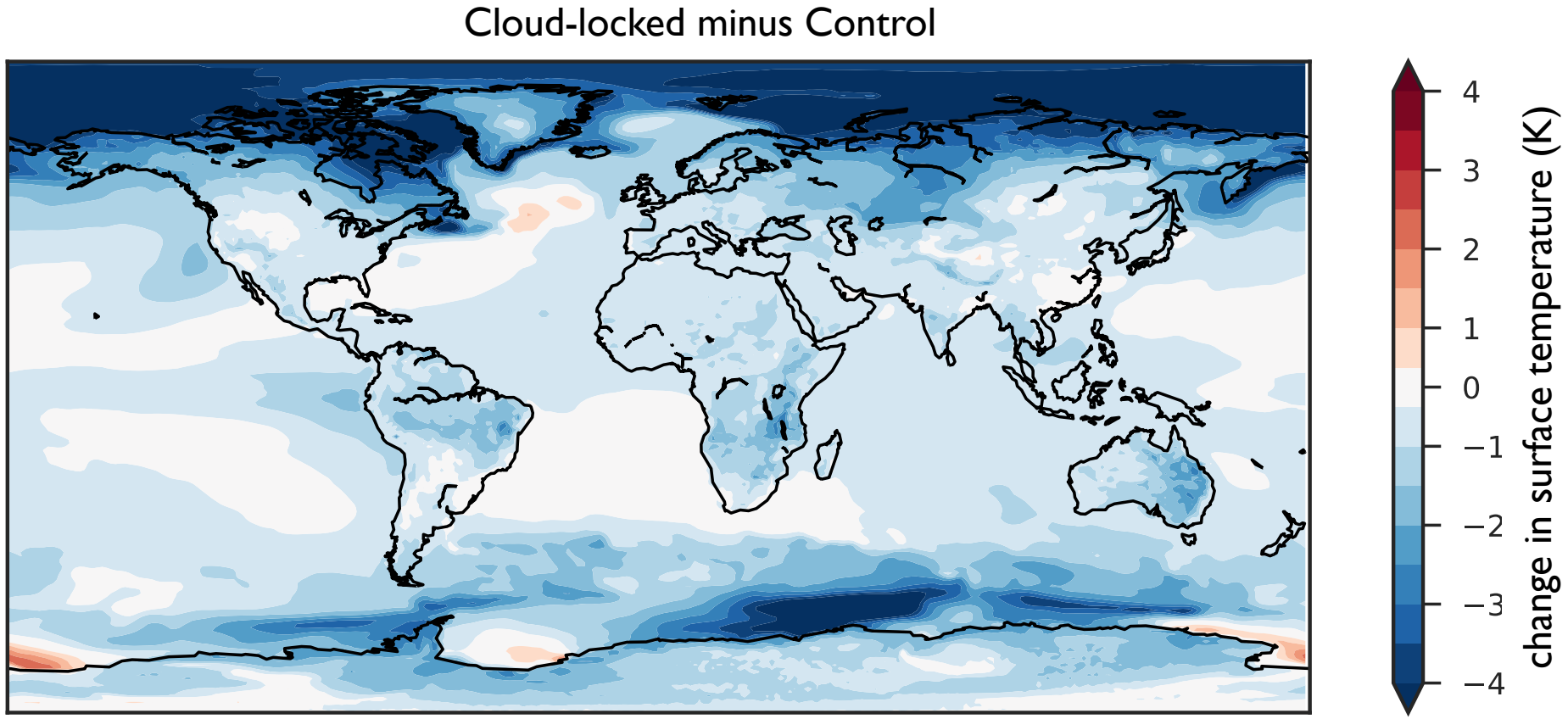


<u>Two possibilities for why there's strengthening:</u>

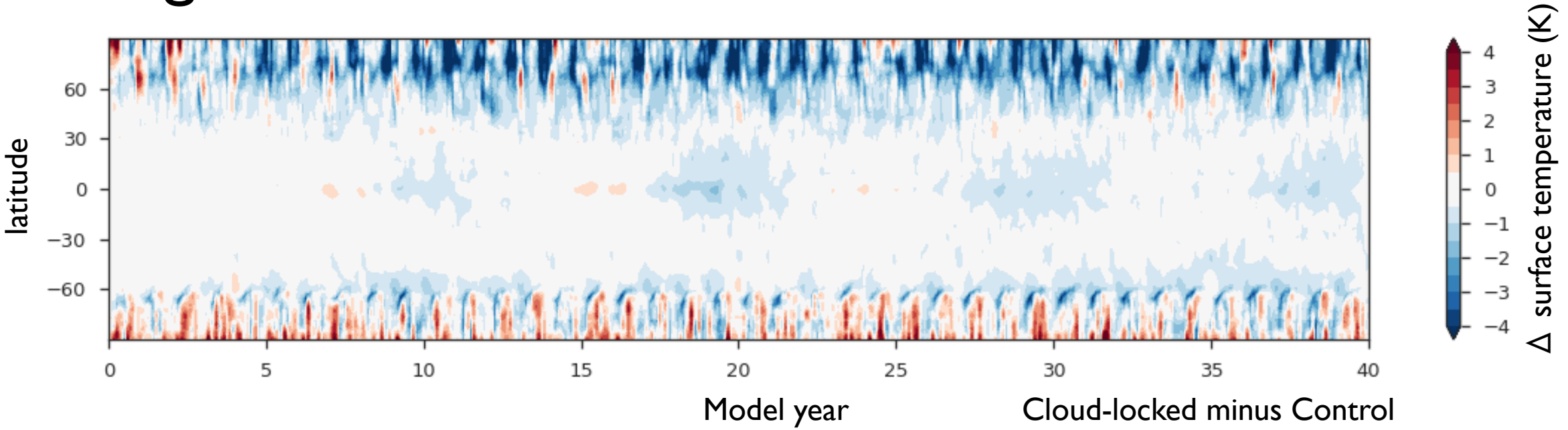
De-coupling cloud radiation alters surface climate or heat fluxes

Cloud-locking affects the mean climate

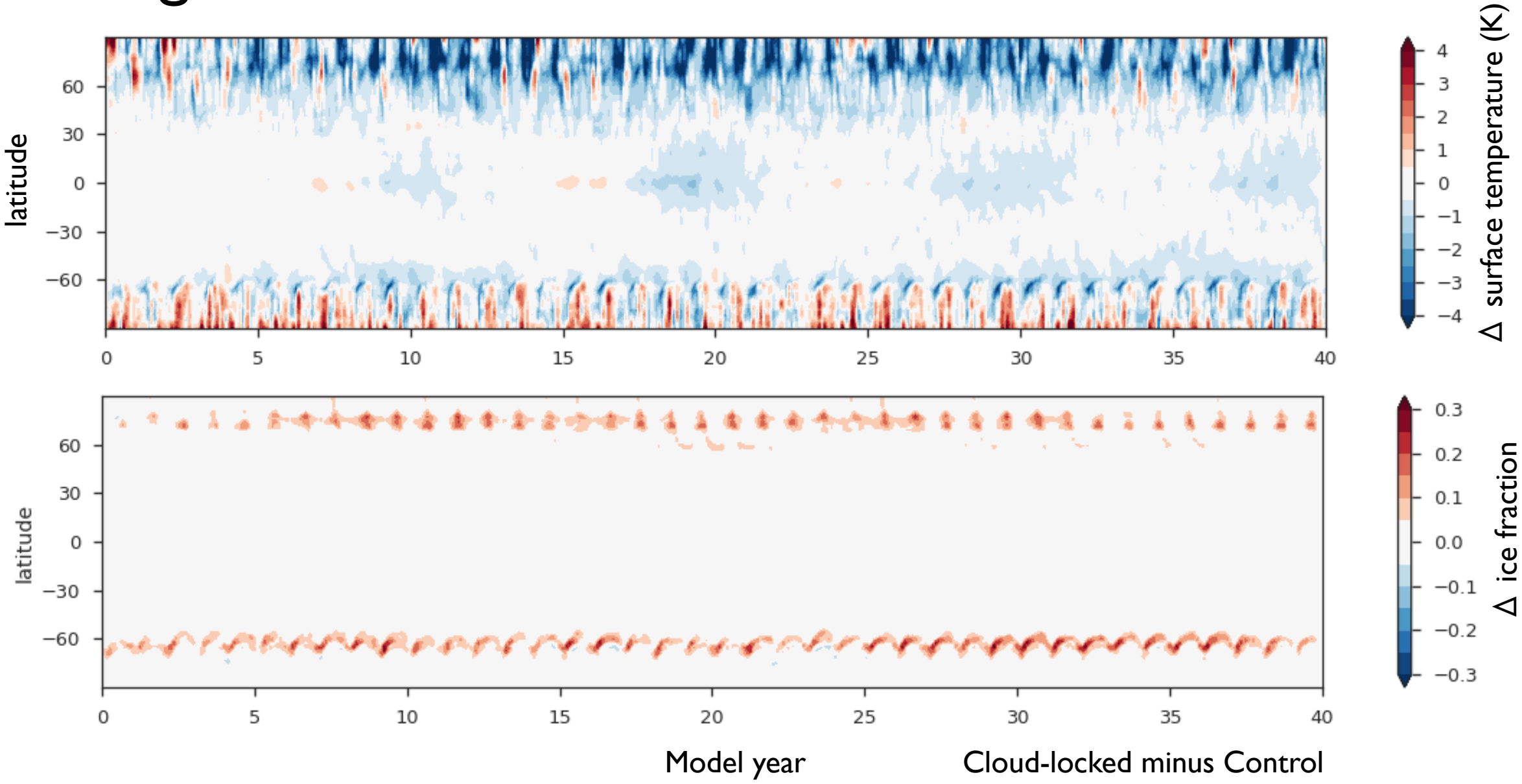
Cloud-locking causes global cooling



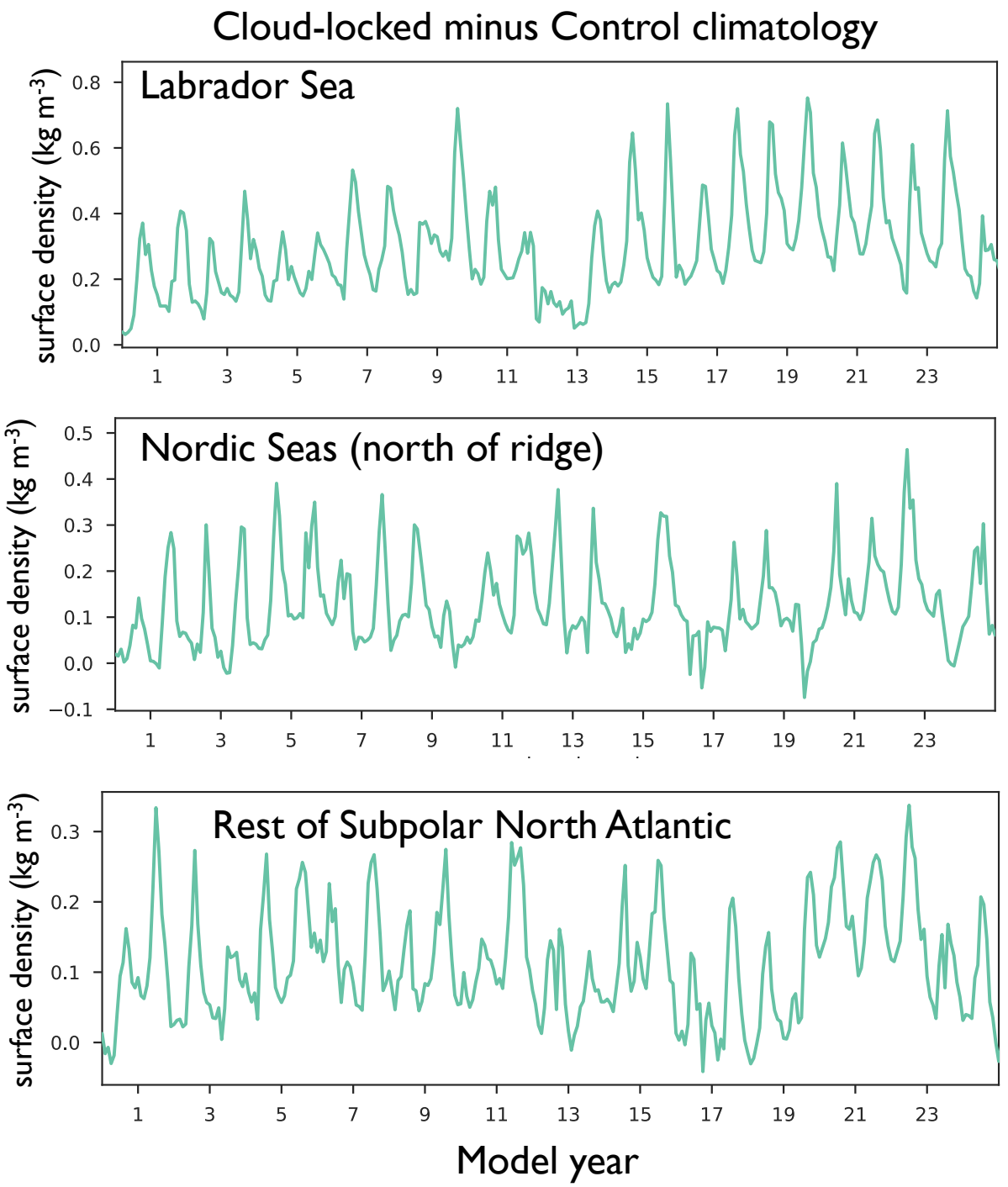
Cooling starts in the Arctic and Antarctic



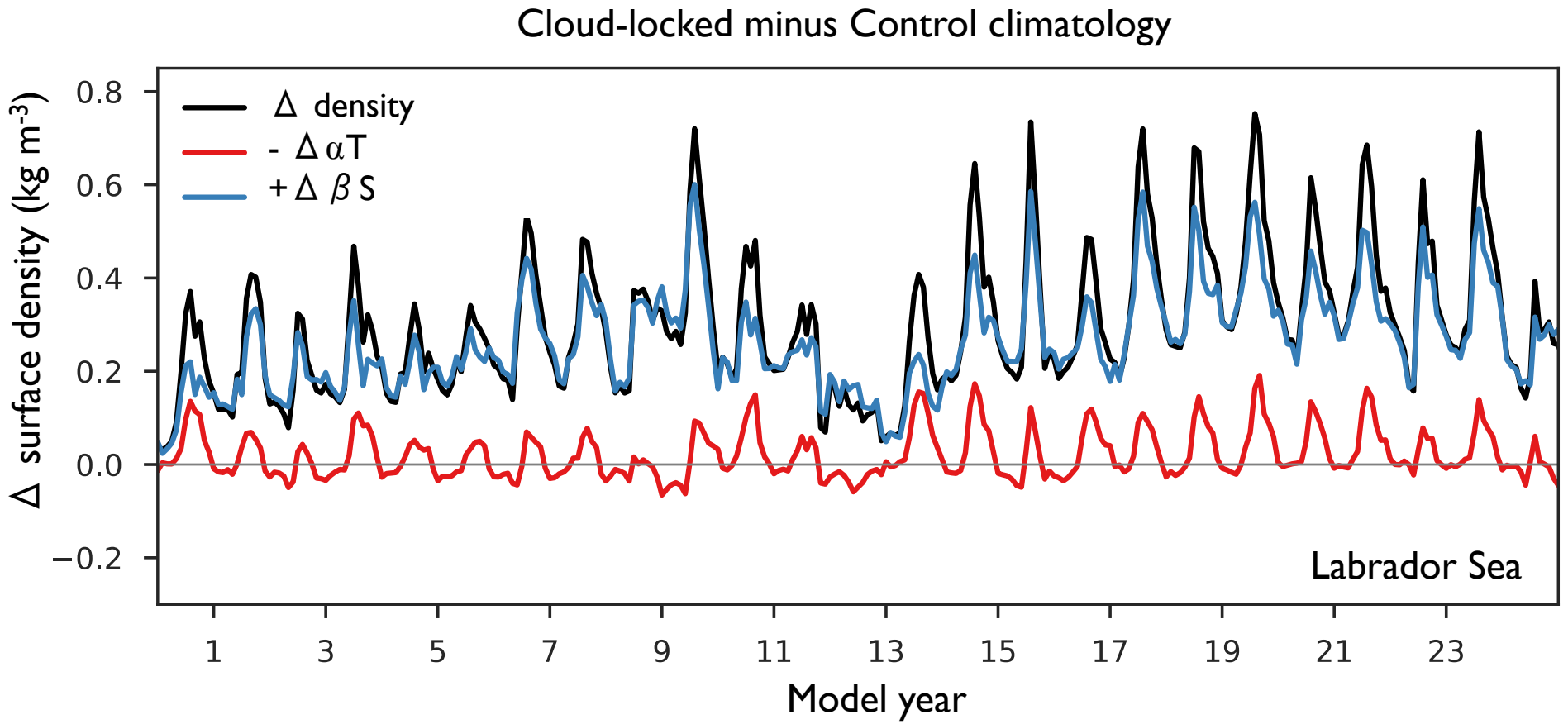
Cooling starts in the Arctic and Antarctic due to sea ice



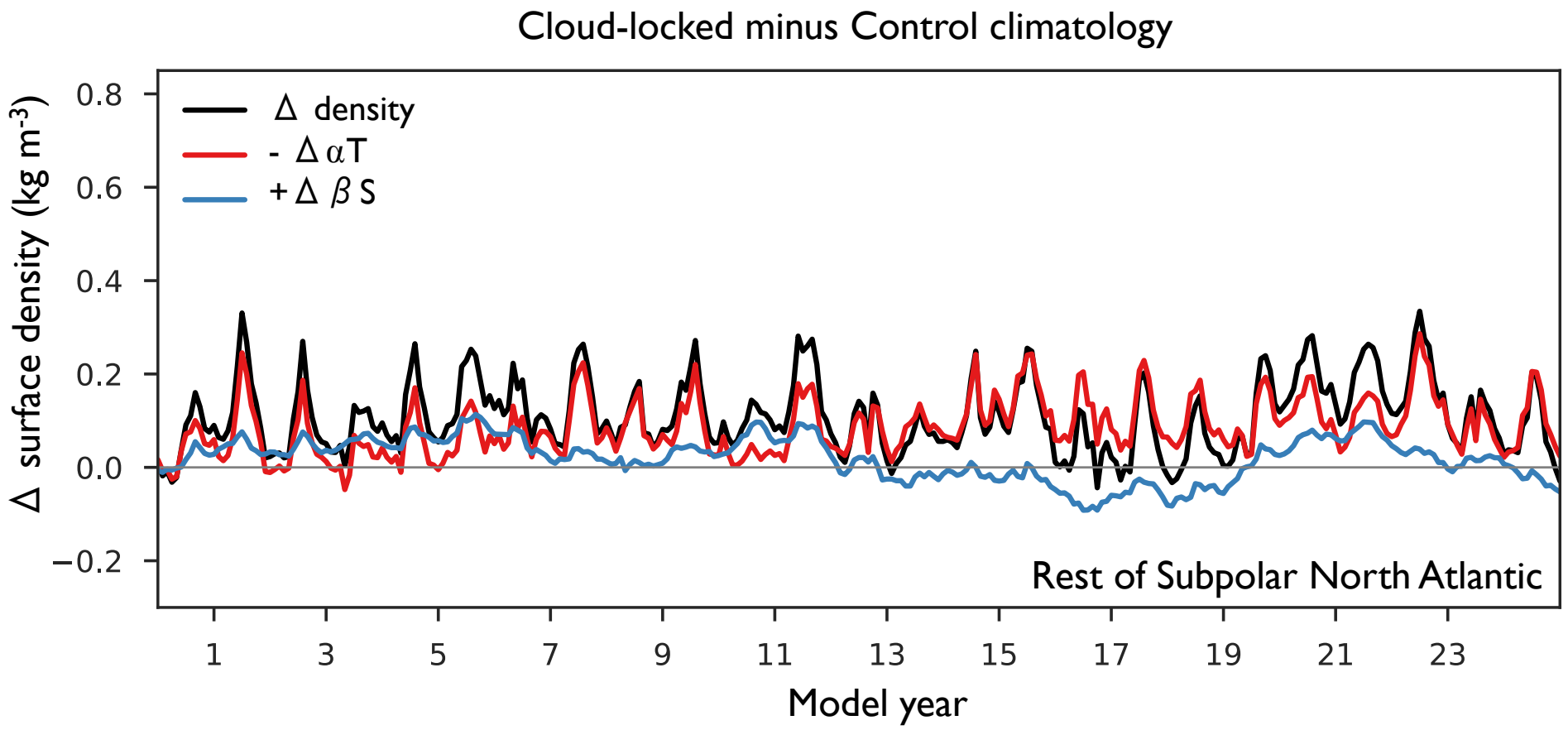
Density increases immediately and increases most in the Labrador Sea



Increased surface salinity mostly explains increased density in Labrador Sea

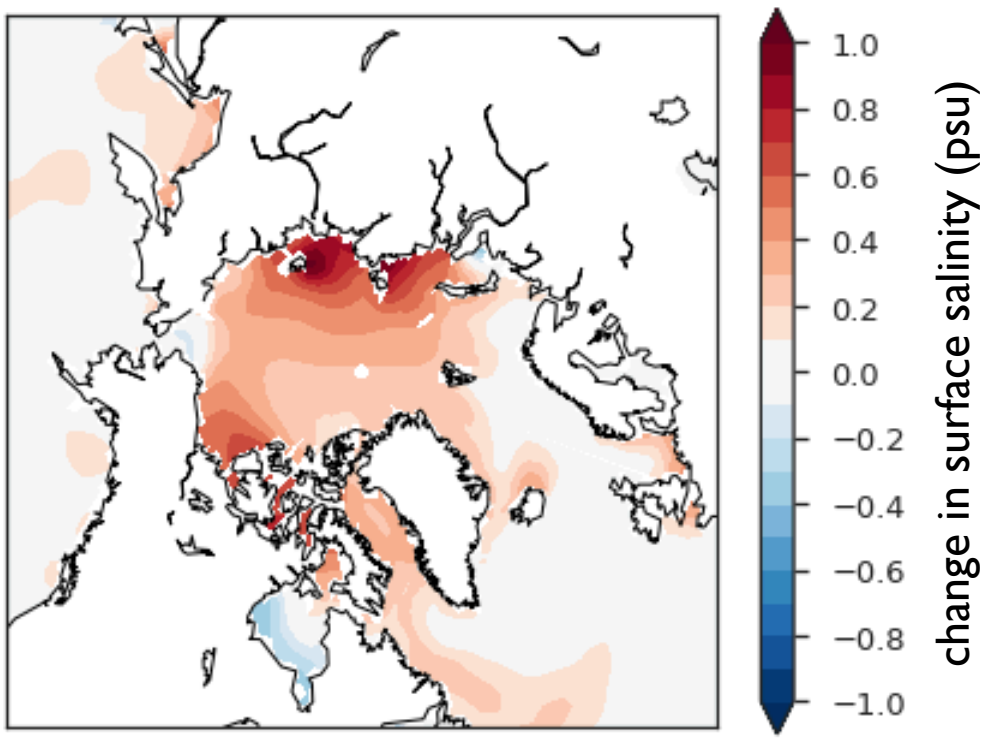


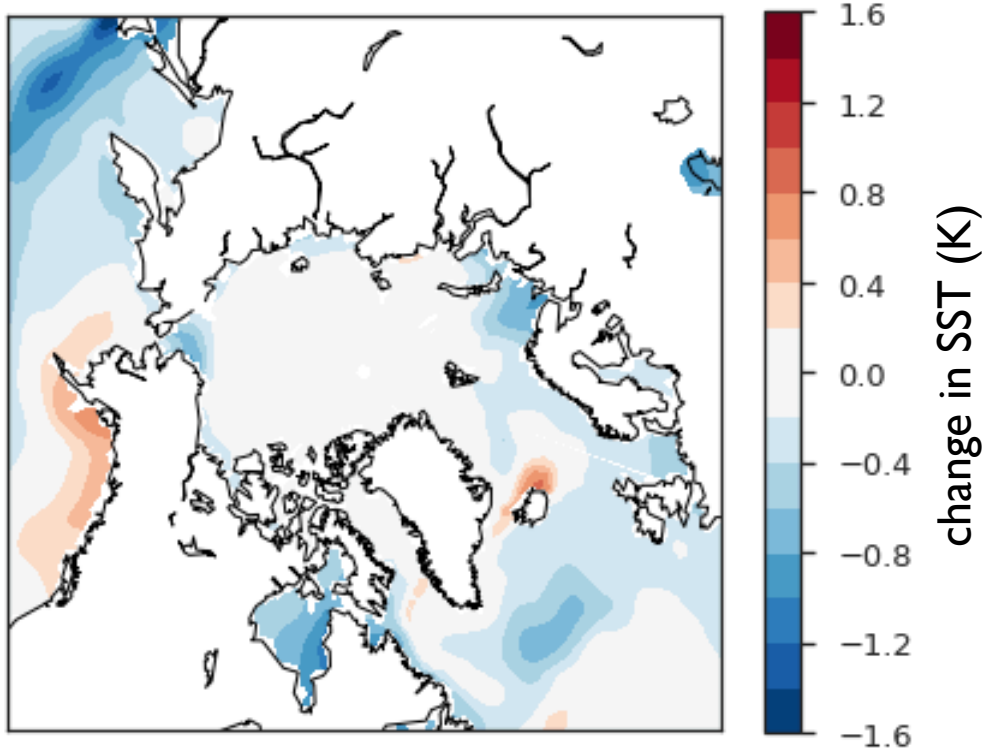
Decreased surface temperature mostly explains increased density outside Labrador Sea



Salinity increases, temperature decreases

First 5 years of Cloud-locked minus Control

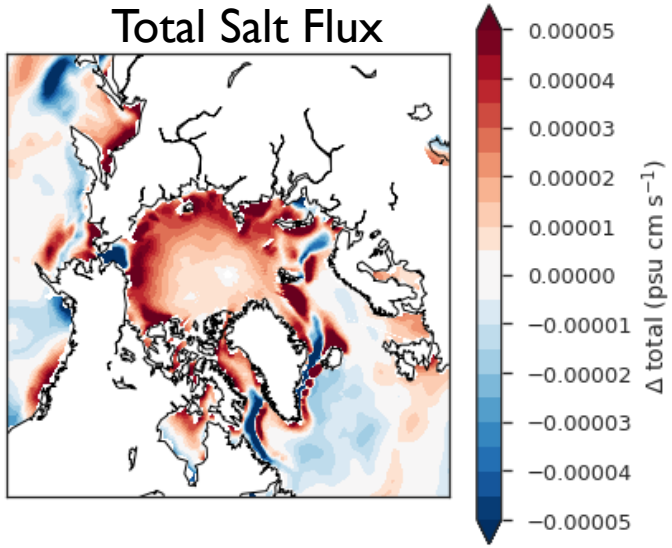




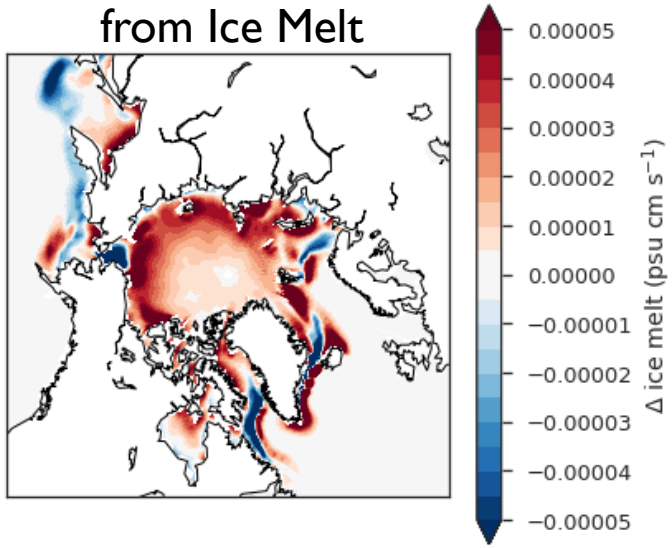
Increased salt flux mostly from decreased sea ice melt

First 5 years of Cloud-locked minus Control

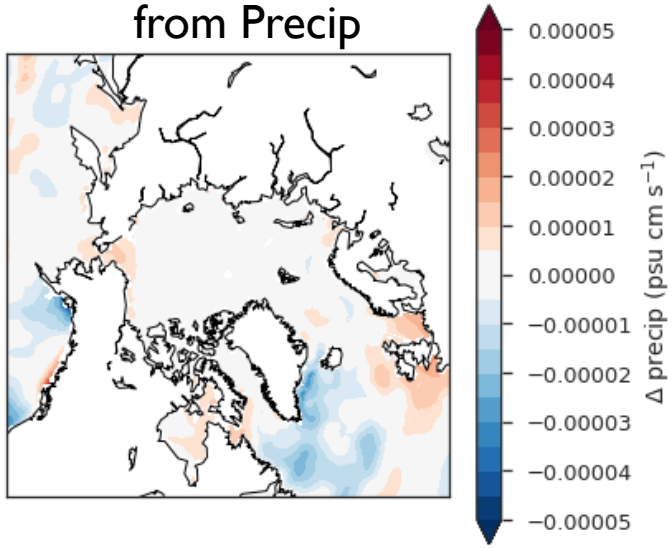
Total Salt Flux



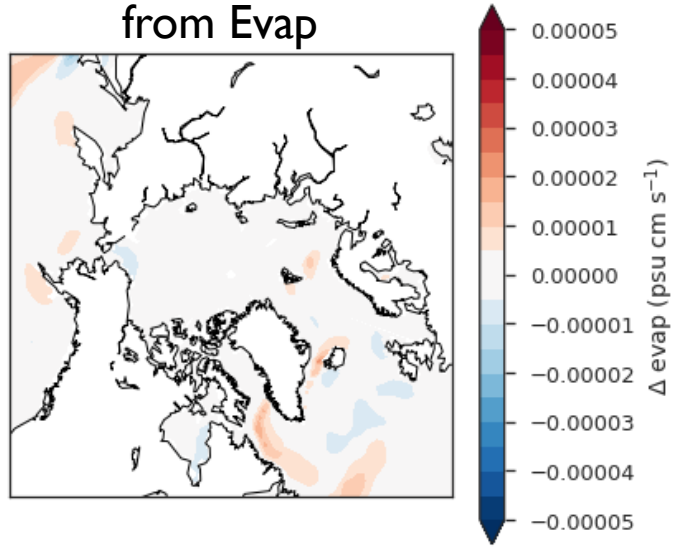
from Ice Melt



from Precip



from Evap



Summary

- Cloud-locking can be used to examine where cloud radiative effects amplify climate variability and forced responses
- Unexpected effects of de-coupling cloud radiation on the mean climate in CESM: TOA imbalance, global cooling, expanded sea ice
- Here, strengthened AMOC due to decreased sea ice melt, *not* from removing the radiative interaction with clouds

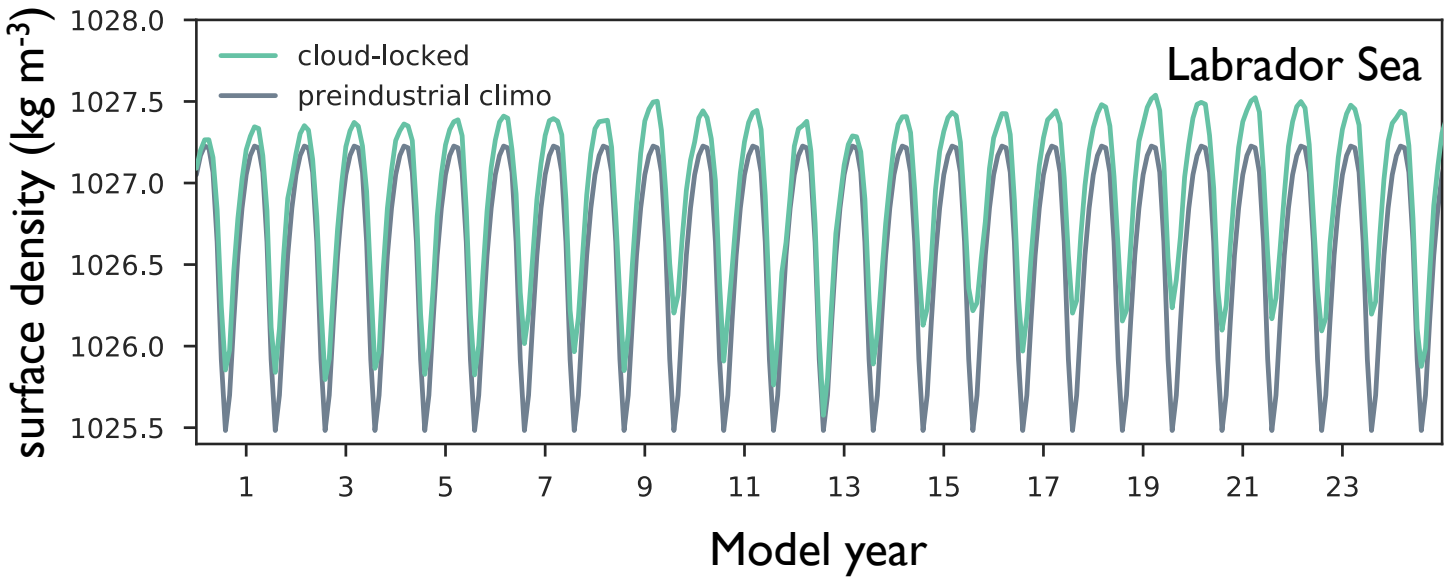
Acknowledgments: This project was funded by the CIRES Visiting Postdoctoral Fellows Program. NCAR is sponsored by the National Science Foundation (NSF). The Community Earth System Model (CESM) is supported by the NSF and the US Department of Energy.

Ways to determine how cloud radiative feedbacks affect climate in models

1. Use model output to calculate feedback strength (via kernels, approximate/full partial radiative perturbation, etc.)

2. Alter cloud mechanisms in the model

North Atlantic surface density increases immediately



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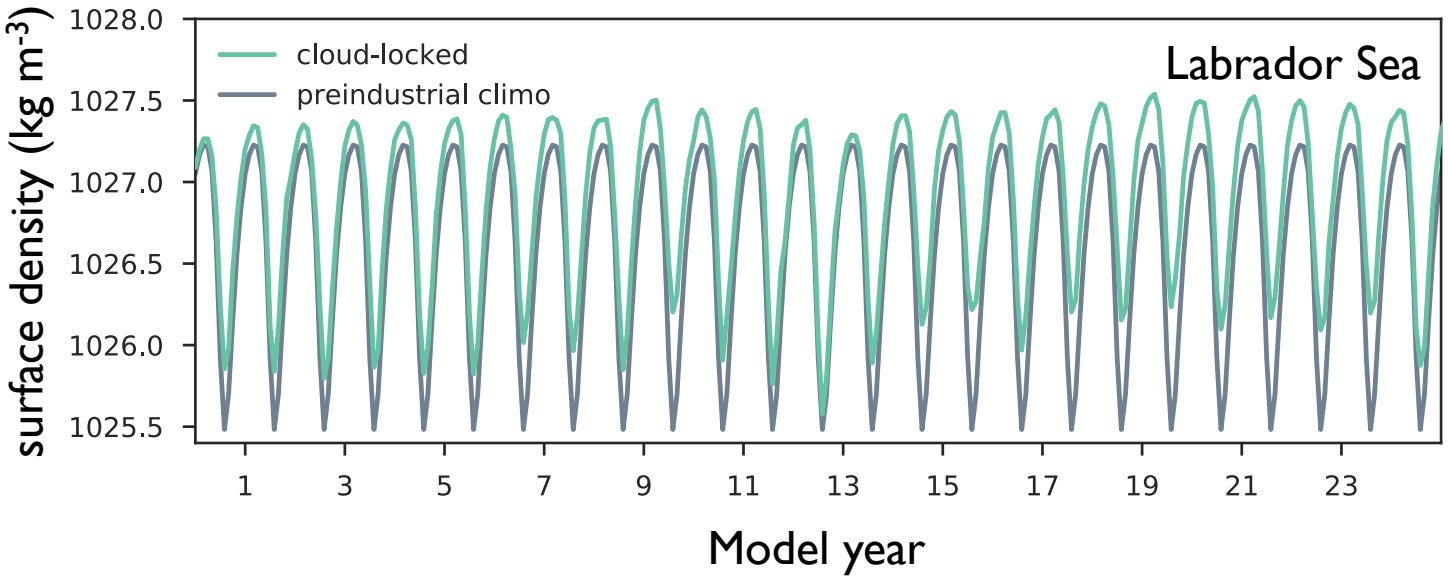
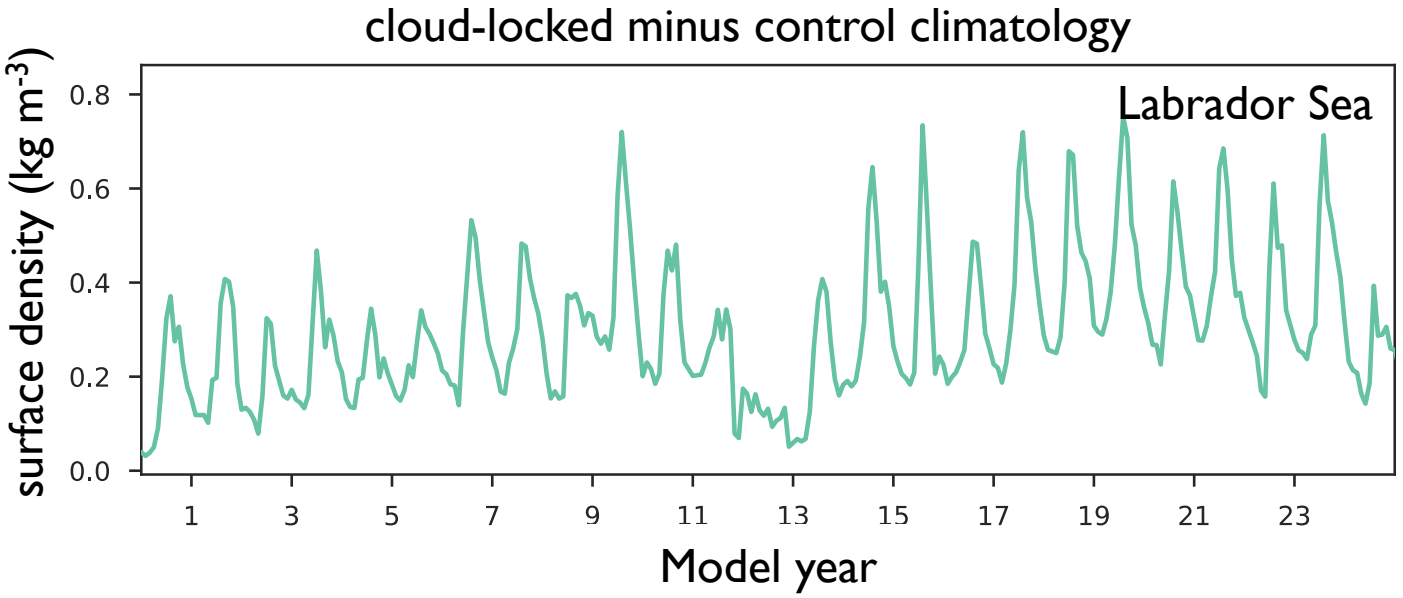
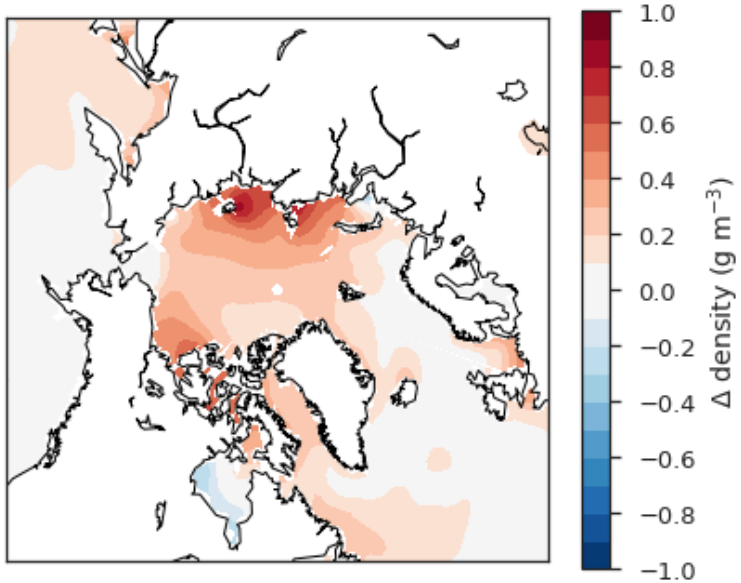
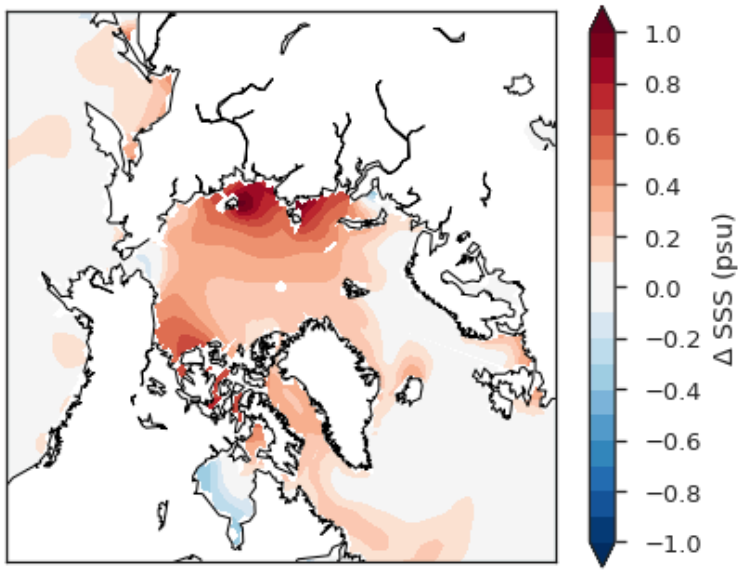
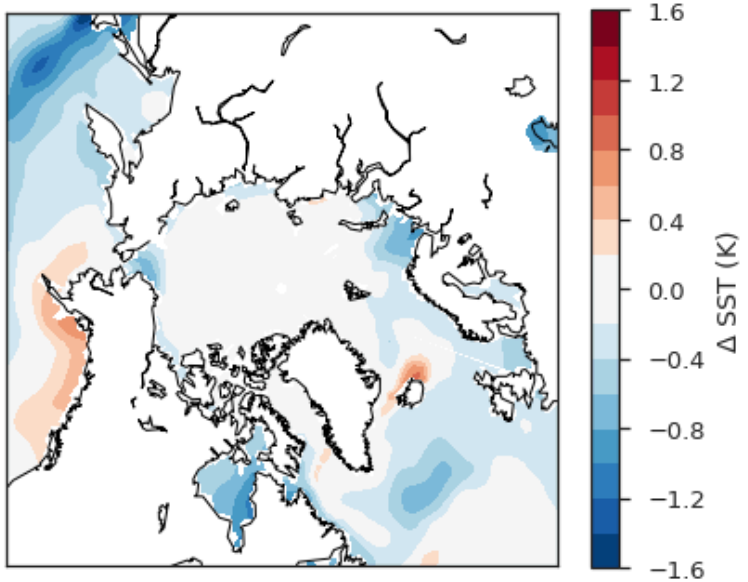




NOT DONE: Cloud-locking leads to increased salt flux due to increased sea ice formation







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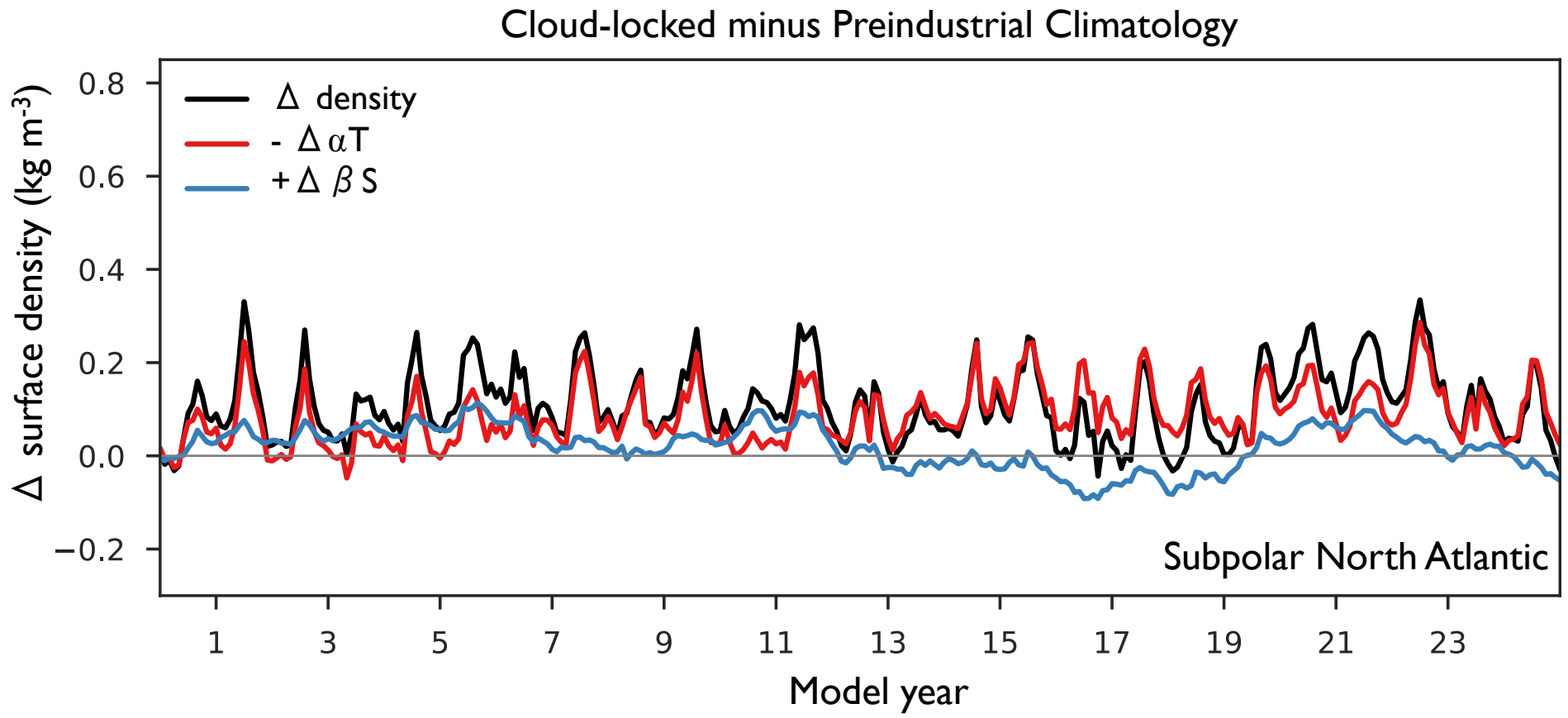
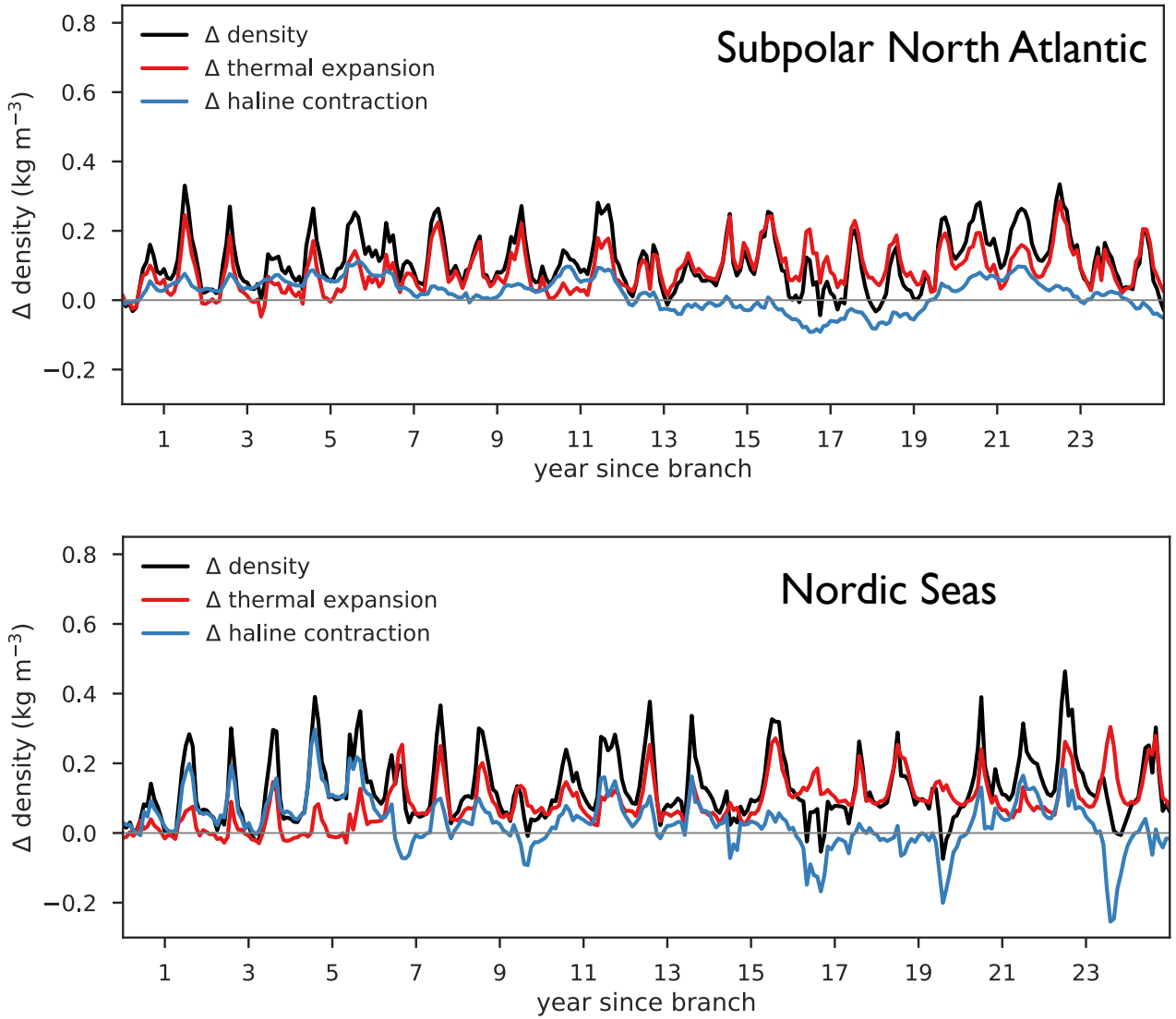
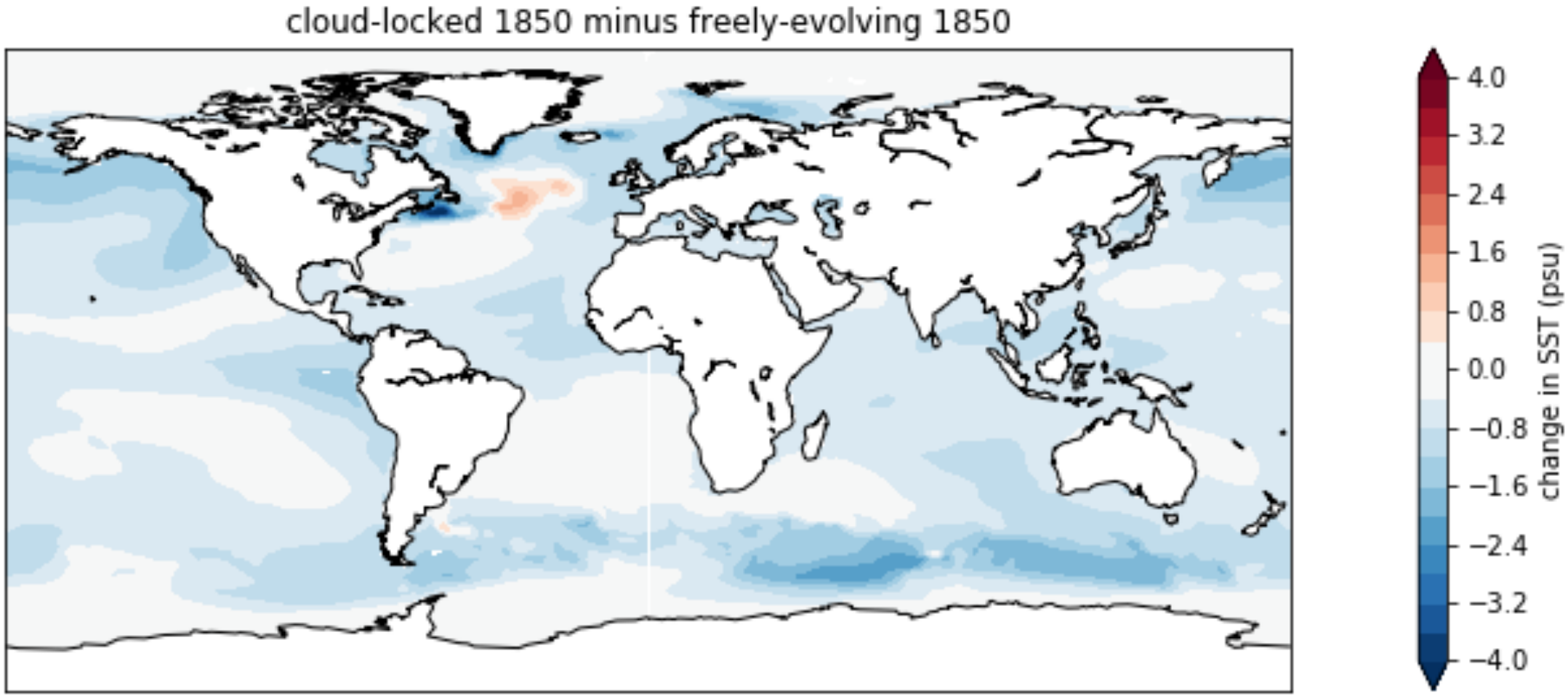



Subpolar North Atlantic
Δ density
Δ thermal expansion
Δ haline contraction
Δ density (kg m^{-3})
0.8
0.6
0.4
0.2
0.0
−0.2
1
3
5
7
9
11
13
15
17
19
21
23
year since branch
Nordic Seas
Δ density
Δ thermal expansion
Δ haline contraction
Δ density (kg m^{-3})
0.8
0.6
0.4
0.2
0.0
−0.2
1
3
5
7
9
11
13
15
17
19
21
23
year since branch

Cloud-locked 1850 minus freely-evolving 1850 5m temperature



Time series of AMOC in preindustrial and cloud-locked (1850 forcing) at 26.5N