



2023 CESM Workshop
Land Ice Working group meeting

NorESM2 climate evolution until 2300 with an evolving Greenland ice sheet

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& Heiko Goelzer, Andreas Born, Petra Langebroek and the KeyClim team

NorESM2 with ice sheet module CISM

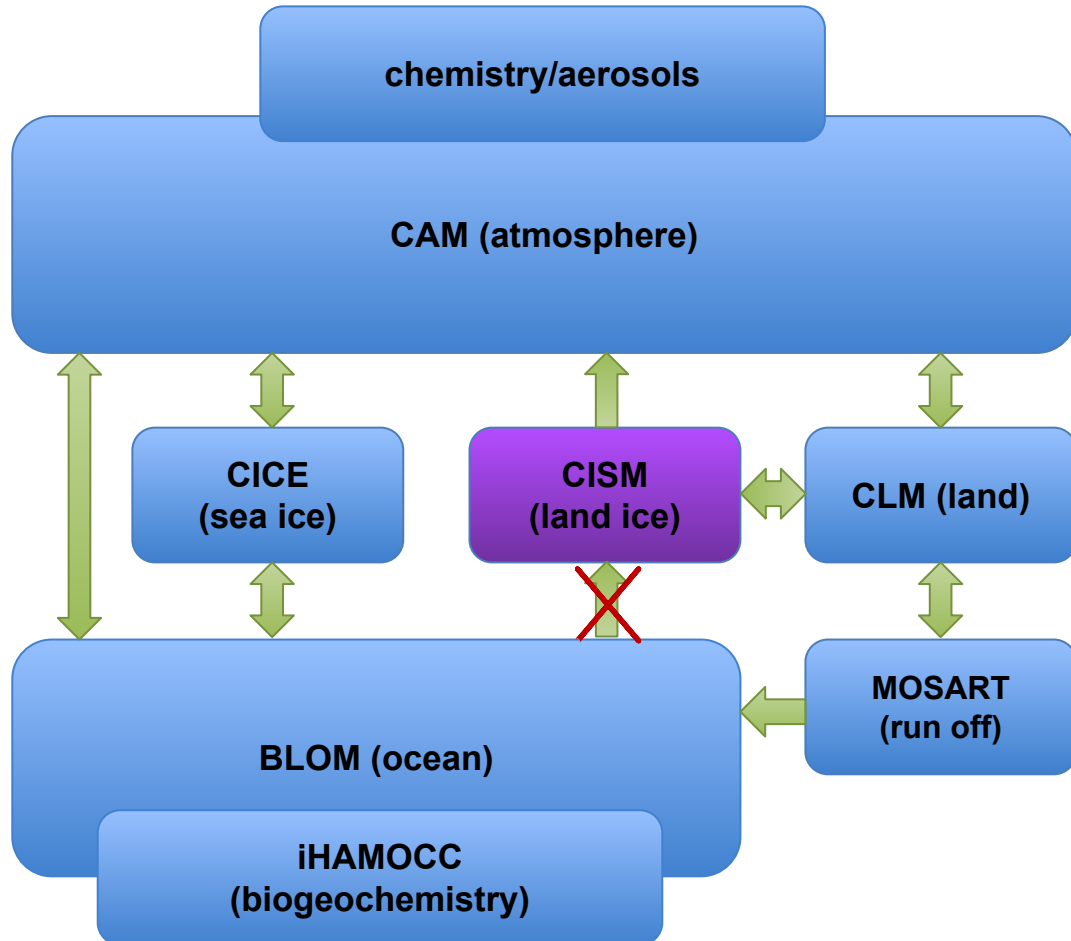
Interactions - based in CESM2:

Ice - Atmosphere/Land

- Surface mass balance - elevation feedback through downscaling (every year)
- Atmospheric changes through ice area and ice elevation change (every 5 years)

Ice - Ocean:

- No direct ice-ocean interactions (due to fjord vs. model resolution mismatch)
- Changes in freshwater fluxes impact ocean informed via land and run off modules



What effect has an evolving ice sheet to the global climate?

Here: Greenland ice sheet (CISM) coupled to NorESM

3 simulations: based on NorESM CMIP6 extended to 2300:

- NorESM
- NorESM-CISM
- control (no forcing)

Forcing: SSP585 extended with

- CO₂ emissions reduced linearly starting in 2100 to less than 10 GtC yr⁻¹ in 2250
- Other emissions are held constant at 2100 levels

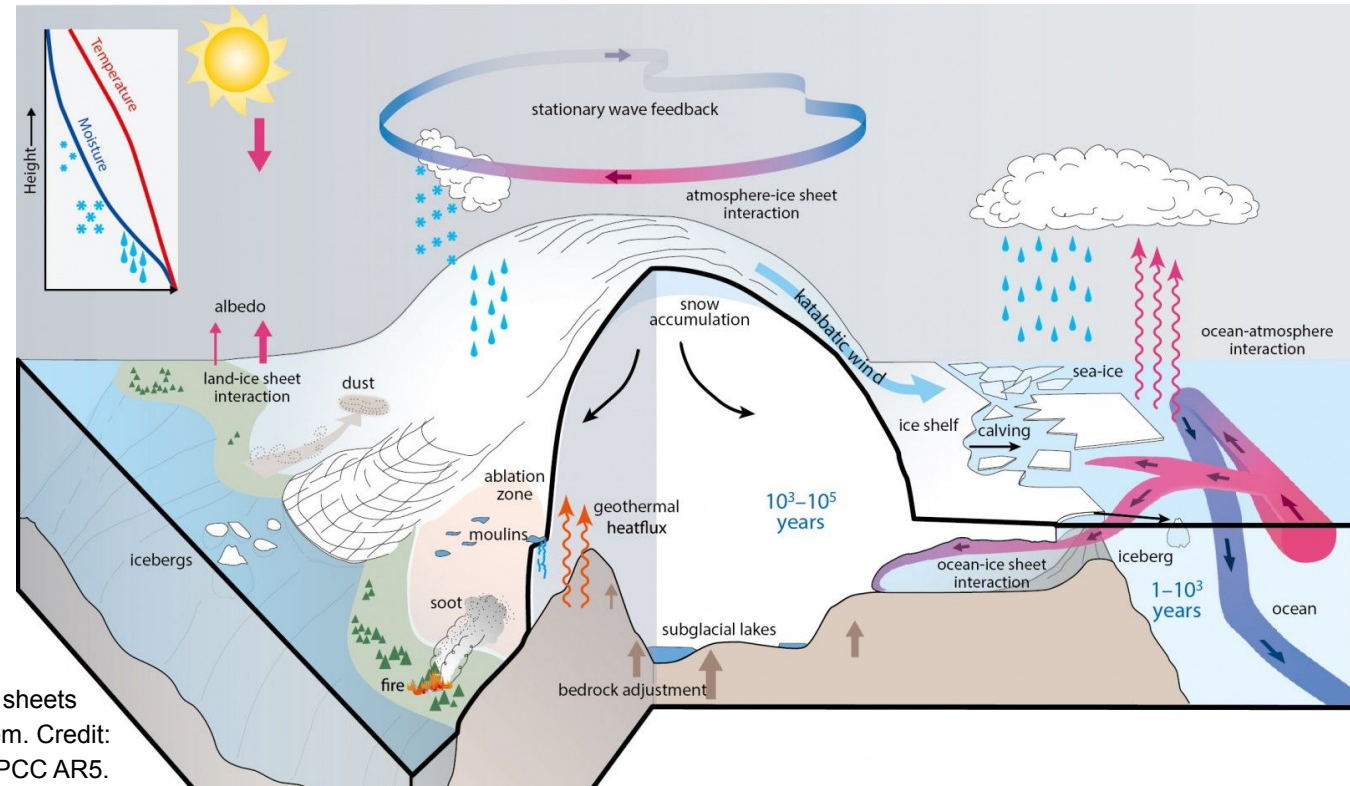
Resolution NorESM:

4km Land ice

1deg Ocean

1deg Atmosphere/Land

≈ 111km x 13-55km over Greenland



The interaction of ice sheets with the climate system. Credit: Figure 1 in Box 5.2, IPCC AR5.



Initialization

Ice sheet model initialization approach: Relax CISM to NorESM surface mass balance

- › Tuning of basal friction coefficients to match the observed present geometry
- › All ice outside of the observed ice sheet extent is removed and routed to the ocean
- › Relax to NorESM pre-industrial SMB
- › Assign initial state to 1800

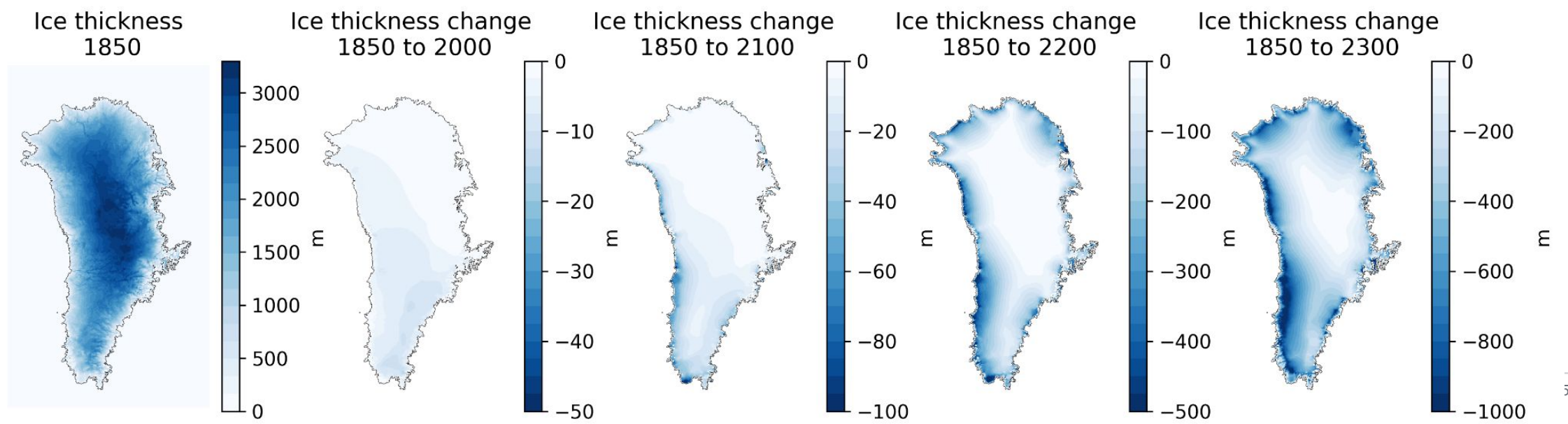
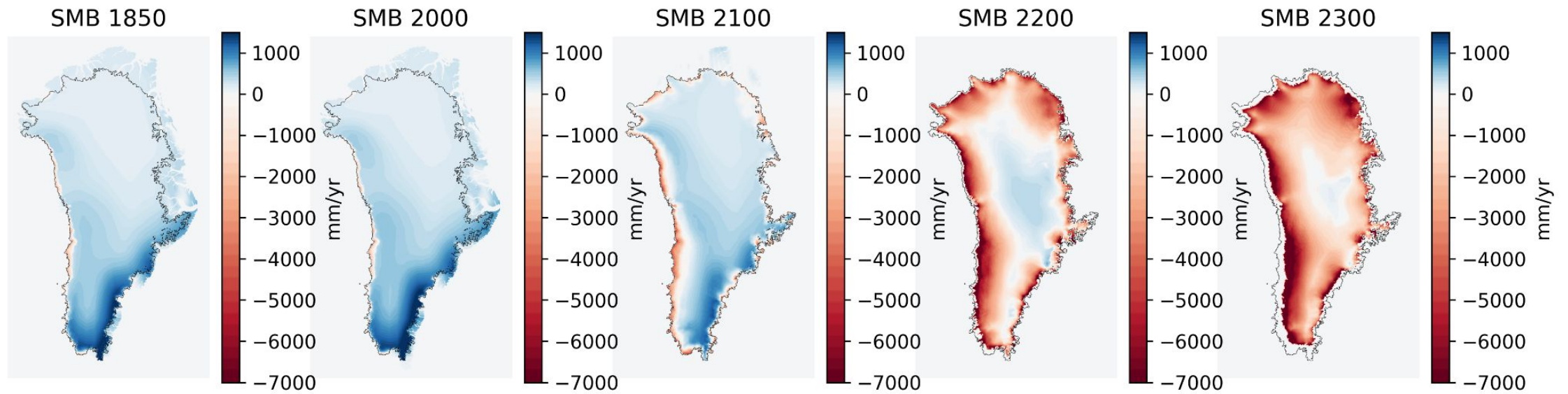
NorESM
CMIP6
simulation



The coupled ice - sheet climate system has to be initialized

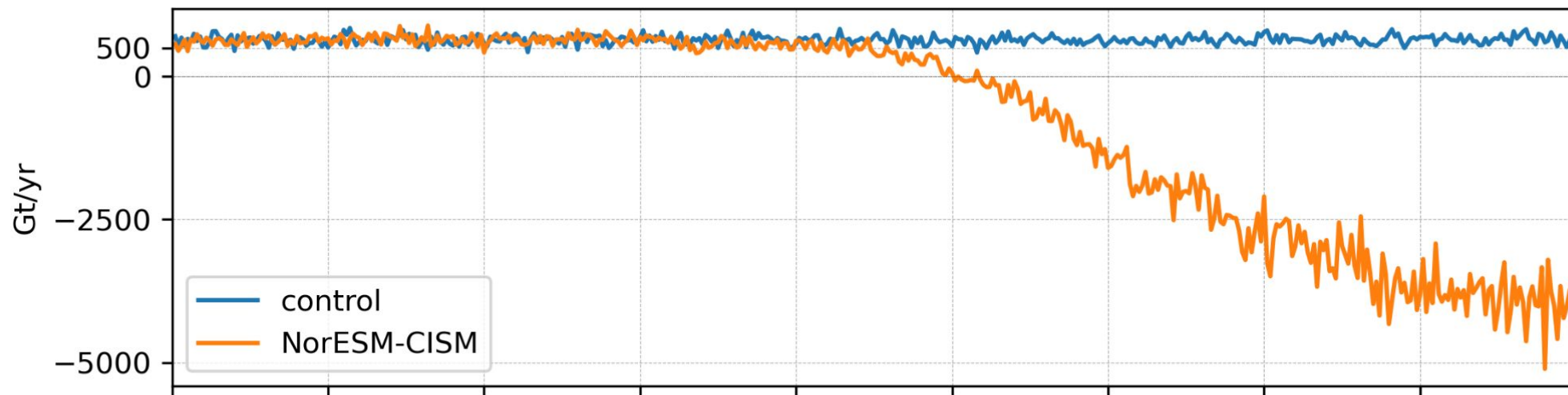
- › NorESM has to be relaxed to the CISM geometry, albedo and freshwater fluxes
- › NorESM-CISM run together for 50years to relax

Changes on the ice sheet

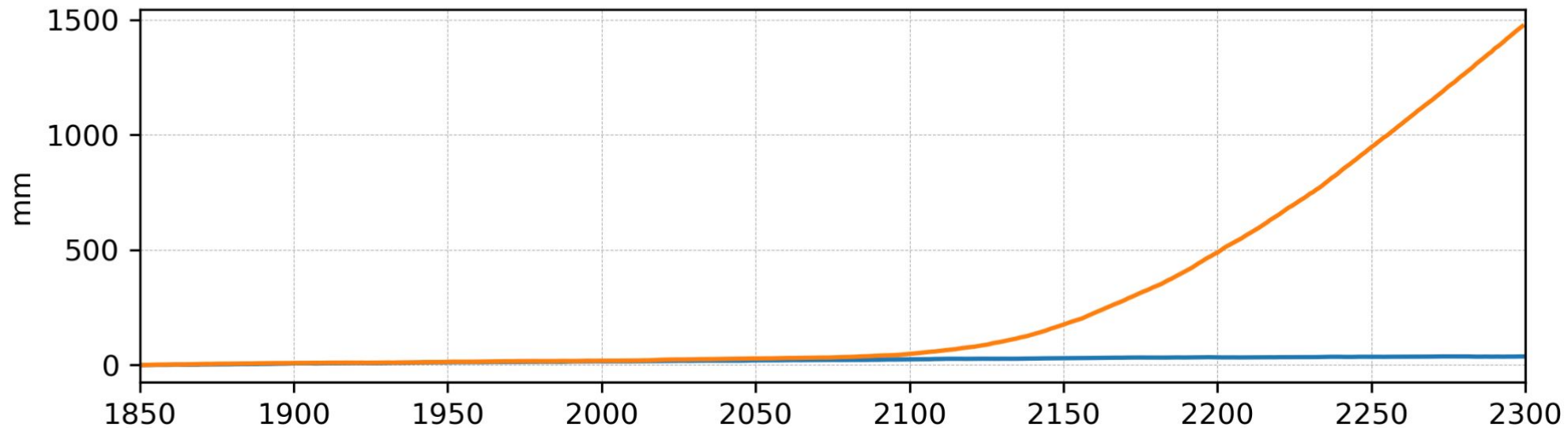




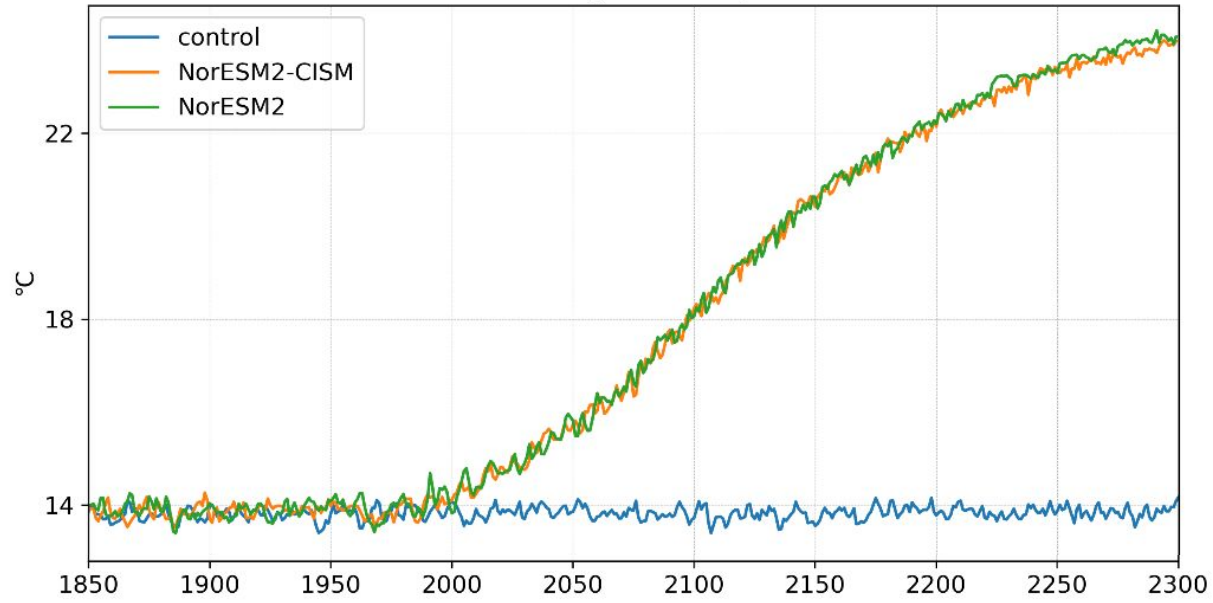
Greenland ice sheet surface mass balance



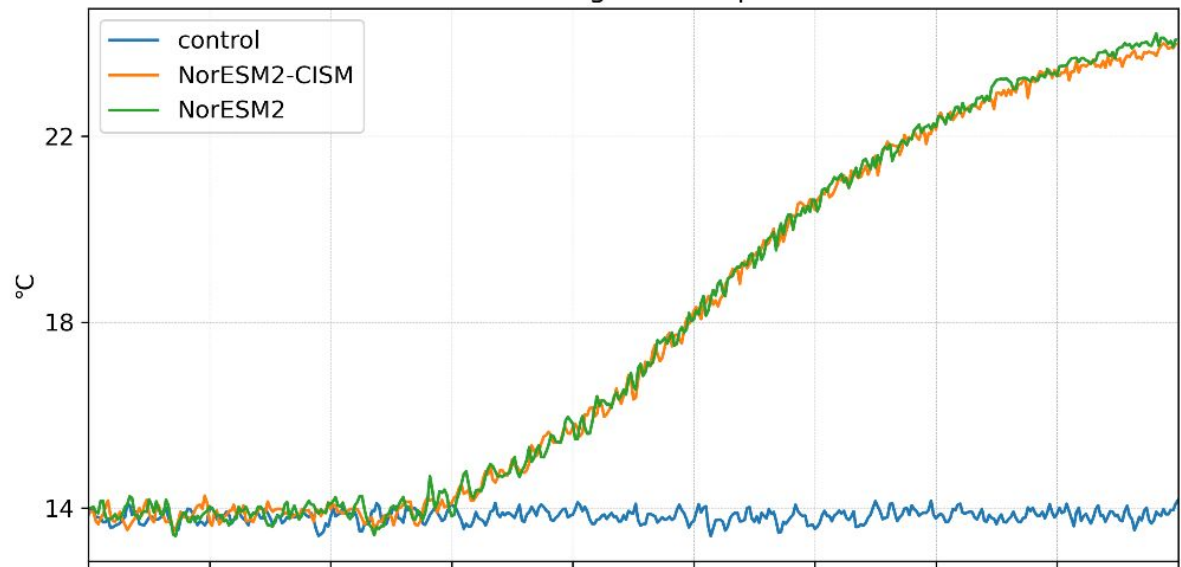
Sea level contribution of Greenland ice sheet (cumulative)



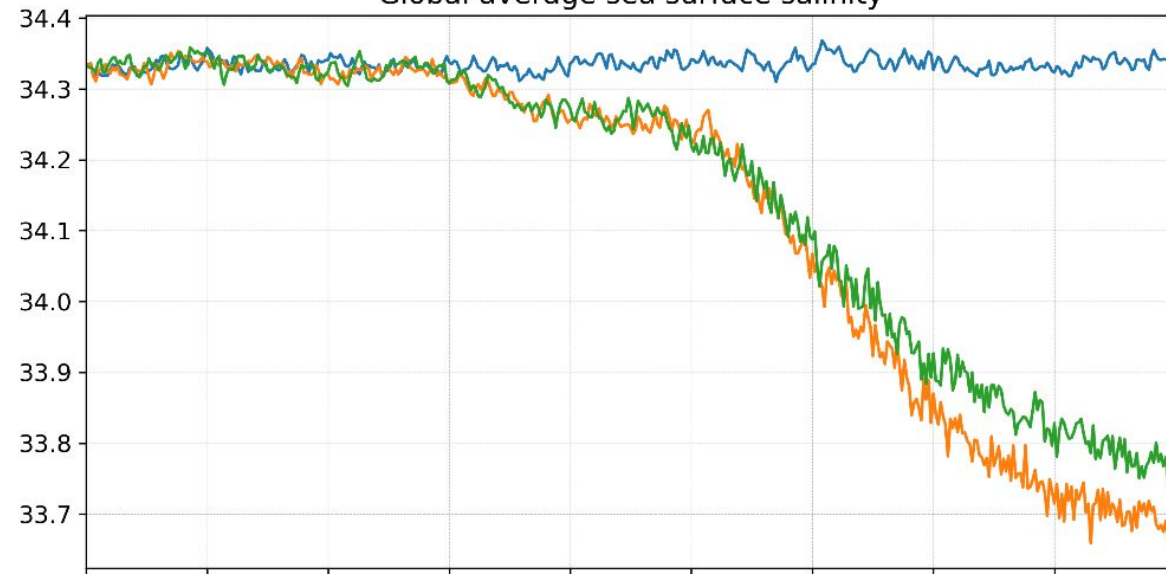
Global average air temperature



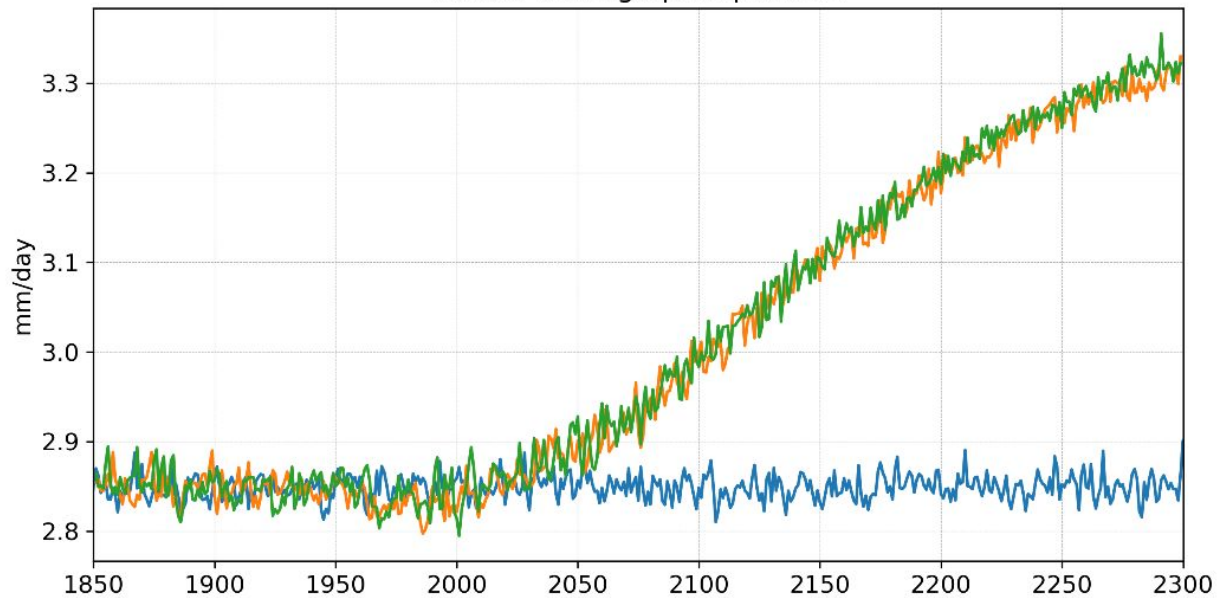
Global average air temperature



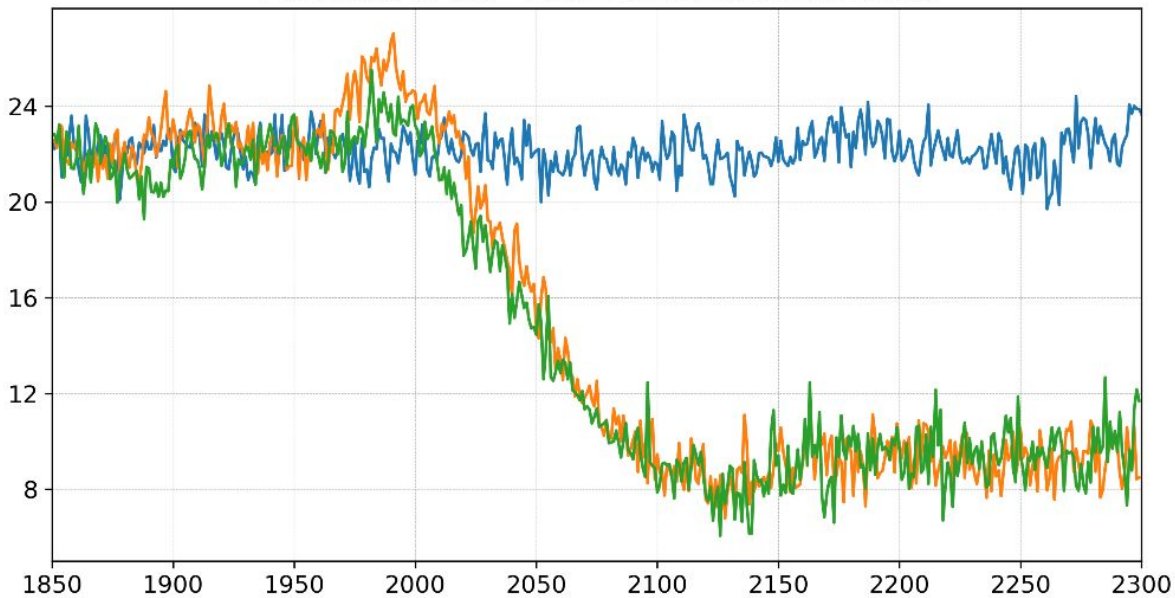
Global average sea surface salinity



Global average precipitation

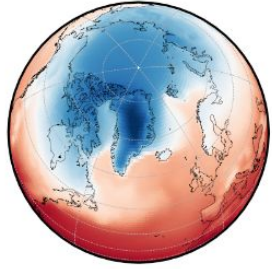


Maximum AMOC - Atlantic/Aarctic ocean 26.5N

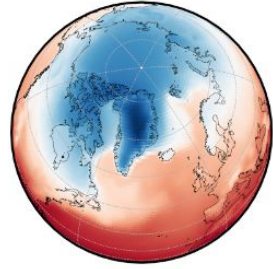


Surface air temperature (°C)

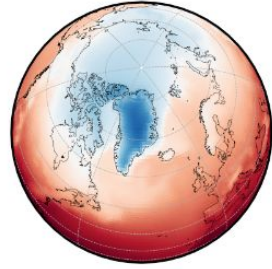
1860
(1850 to 1869)



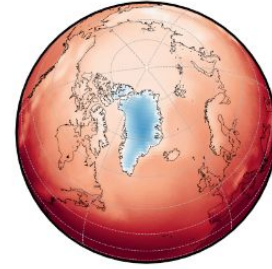
with CISM: 1980
(1970 to 1989)



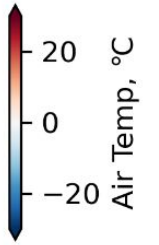
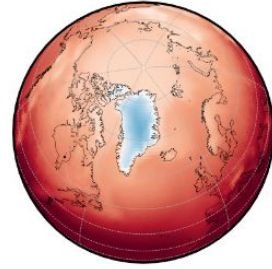
2100
(1981 to 2100)



2200
(2181 to 2200)



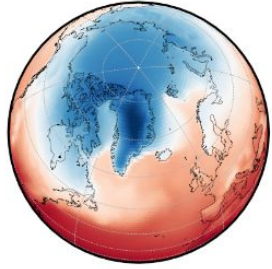
2300
(2281 to 2300)



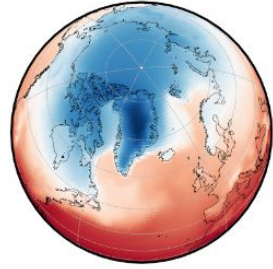
Surface air temperature (°C)

Evolution
NorESM-CISM

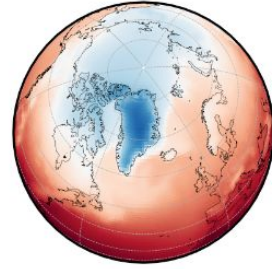
1860
(1850 to 1869)



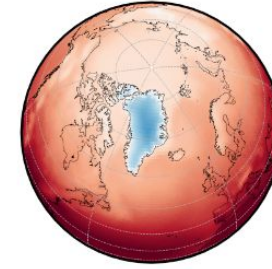
with CISM: 1980
(1970 to 1989)



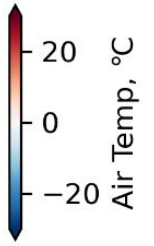
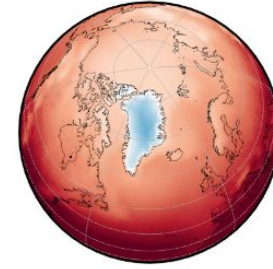
2100
(1981 to 2100)



2200
(2181 to 2200)

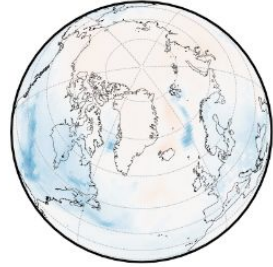


2300
(2281 to 2300)

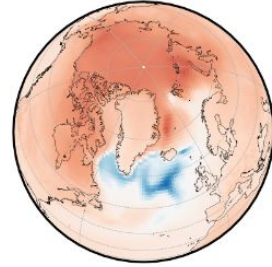


Difference to
initial state
NorESM-CISM

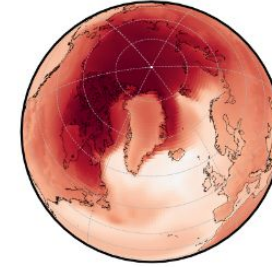
1980 - PI



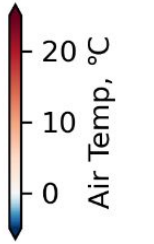
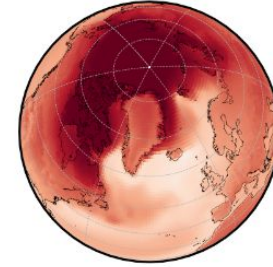
2100 - PI



2200 - PI



2300 - PI



Surface air temperature (°C)

1860
(1850 to 1869)

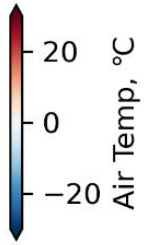
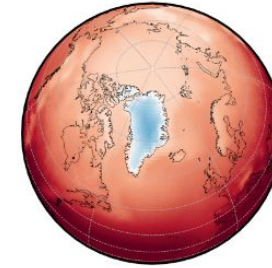
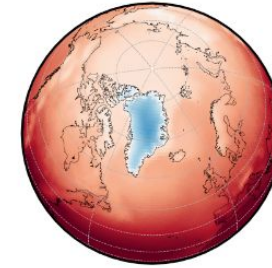
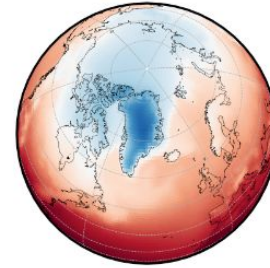
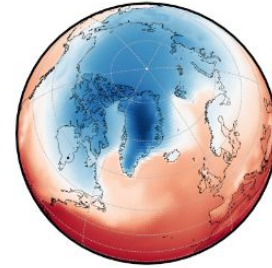
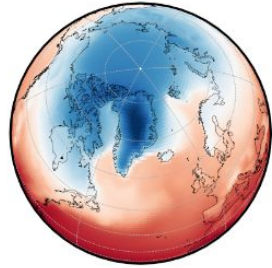
with CISM: 1980
(1970 to 1989)

2100
(1981 to 2100)

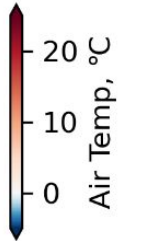
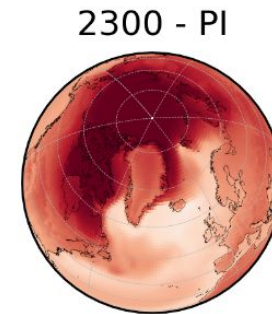
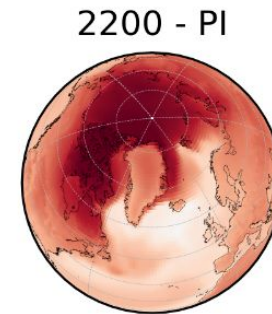
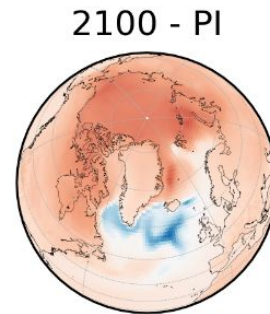
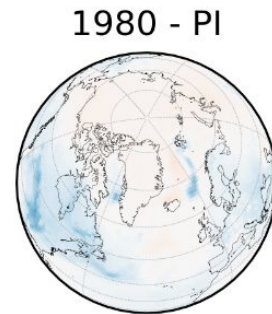
2200
(2181 to 2200)

2300
(2281 to 2300)

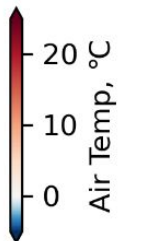
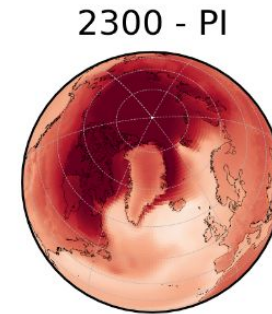
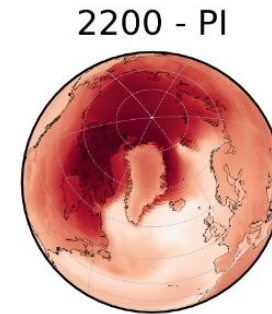
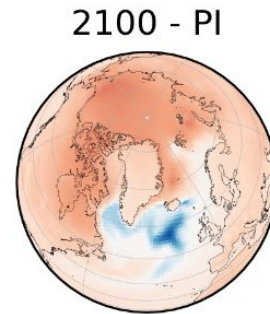
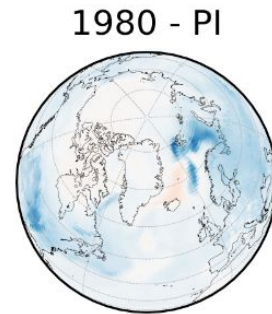
Evolution
NorESM-CISM



Difference to
initial state
NorESM-CISM



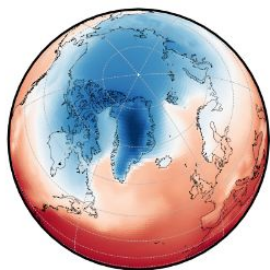
Difference to
initial state
NorESM



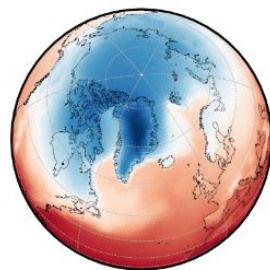
Surface air temperature (°C)

Evolution
NorESM-CISM

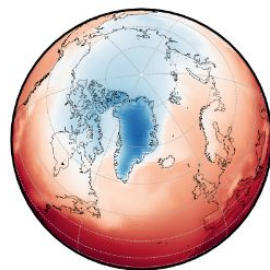
1860
(1850 to 1869)



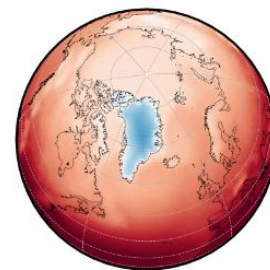
with CISM: 1980
(1970 to 1989)



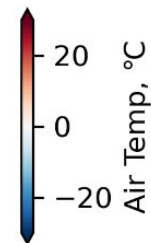
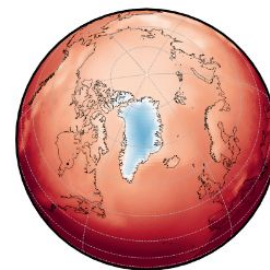
2100
(1981 to 2100)



2200
(2181 to 2200)

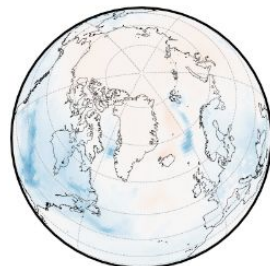


2300
(2281 to 2300)

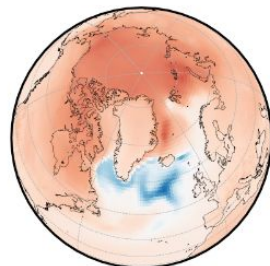


Difference to
initial state
NorESM-CISM

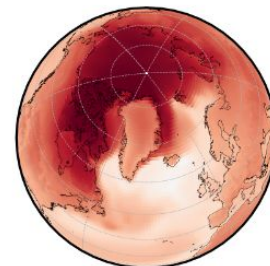
1980 - PI



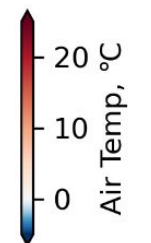
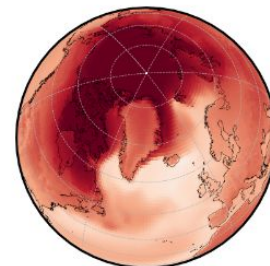
2100 - PI



2200 - PI

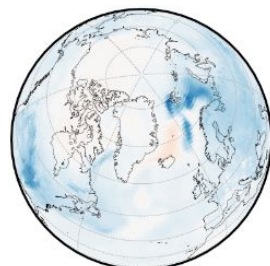


2300 - PI

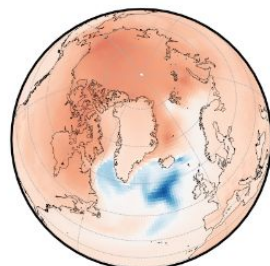


Difference to
initial state
NorESM

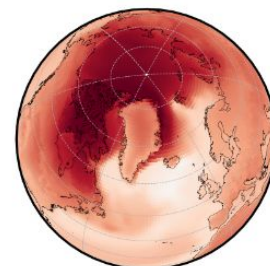
1980 - PI



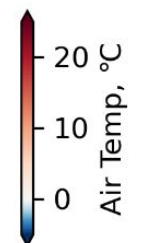
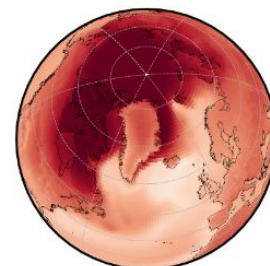
2100 - PI



2200 - PI

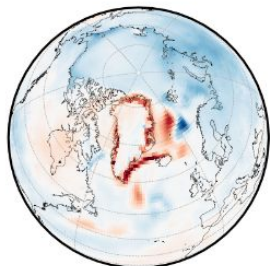


2300 - PI

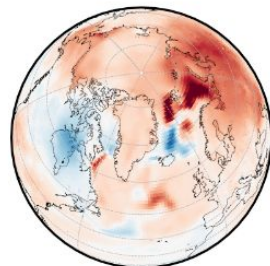


Difference
NorESM-CISM
NorESM

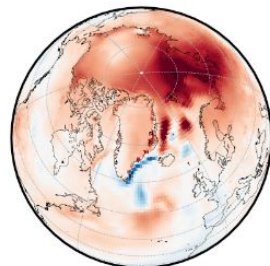
1860



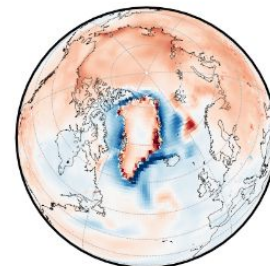
1980



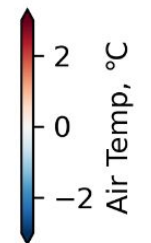
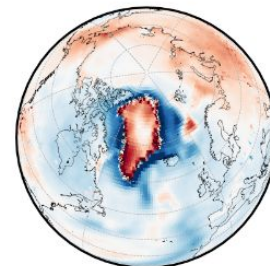
2100



2200



2300



525hPa air temperature (°C) (~5km above sea level)

Evolution
NorESM-CISM

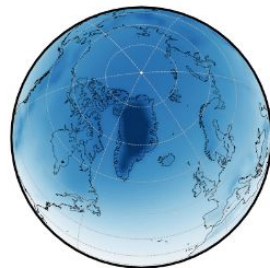
1860
(1850 to 1869)



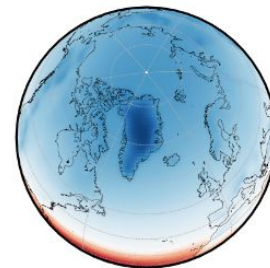
with CISM: 1980
(1970 to 1989)



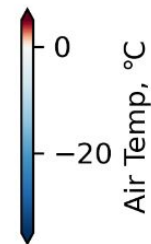
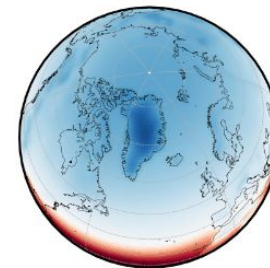
2100
(1981 to 2100)



2200
(2181 to 2200)



2300
(2281 to 2300)

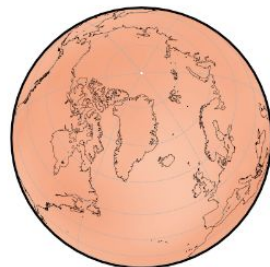


Difference to
initial state
NorESM-CISM

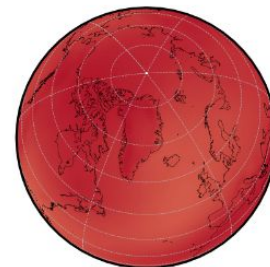
1980 - PI



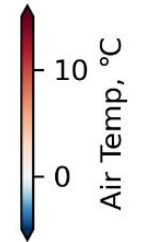
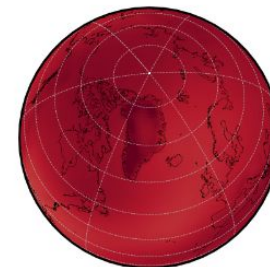
2100 - PI



2200 - PI



2300 - PI

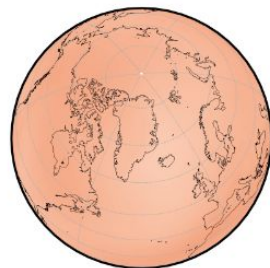


Difference to
initial state
NorESM

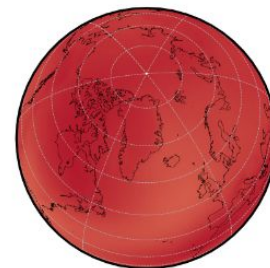
1980 - PI



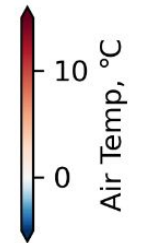
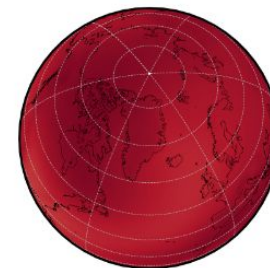
2100 - PI



2200 - PI



2300 - PI



Difference
NorESM-CISM
NorESM

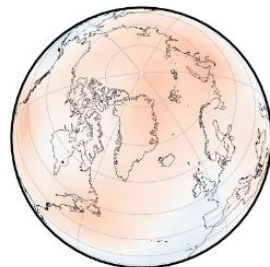
1860



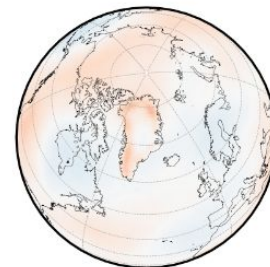
1980



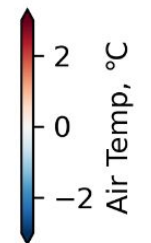
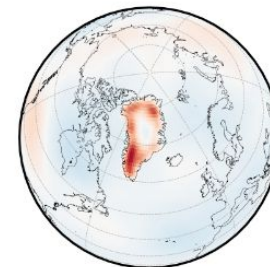
2100



2200



2300





Summary

- First coupled long-term NorESM-CISM results (450yrs)
- Overall warming (SSP585) dominates global climate
- 1.5m sea level contribution by 2300 from Greenland ice sheet
- Initialization crucial for comparison

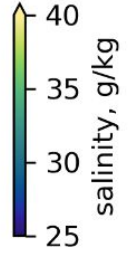
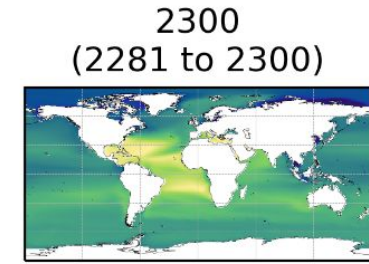
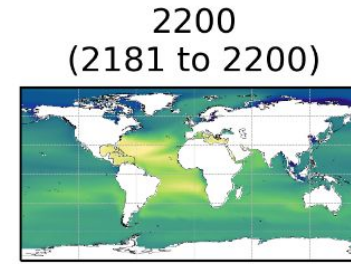
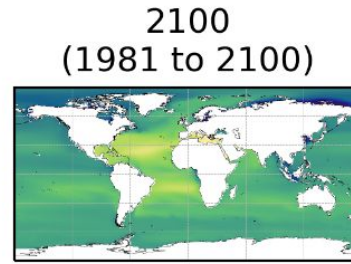
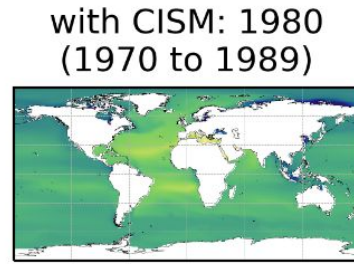
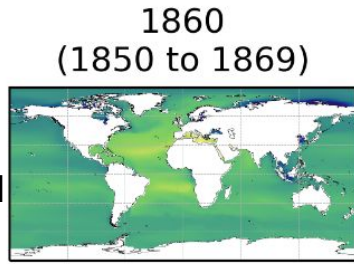
Thoughts on possible next experiments: coupling short term with different components to study effect of elevation feedback or long-term simulation with lower emission forcing



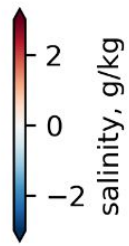
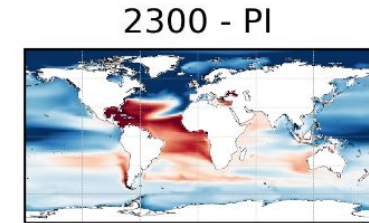
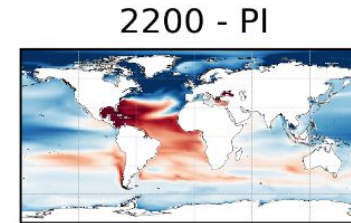
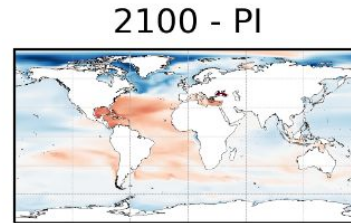
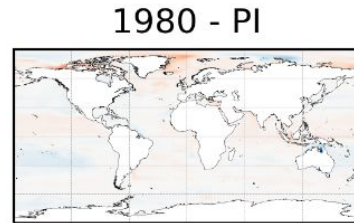
Questions?

Salinity at surface

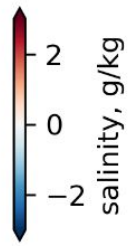
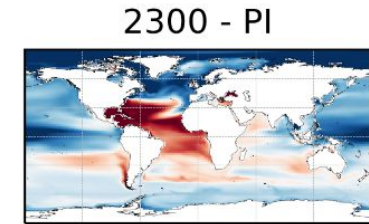
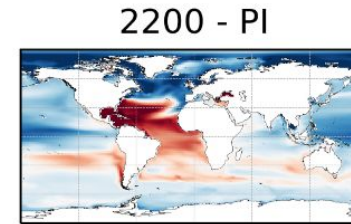
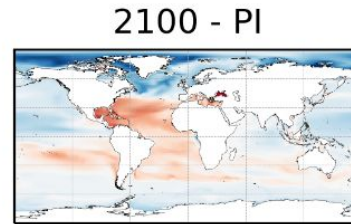
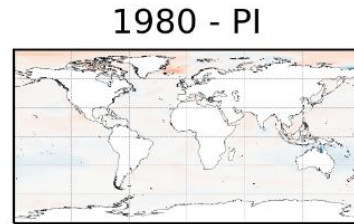
Evolution
NorESM-CISM



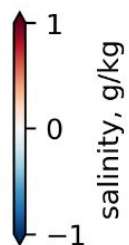
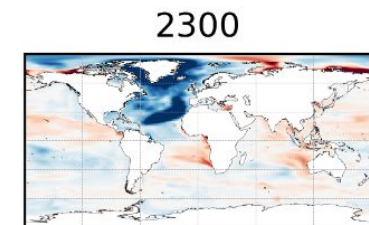
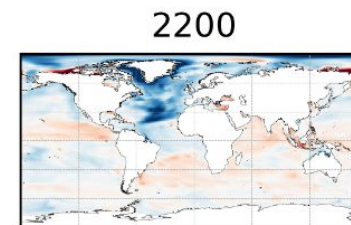
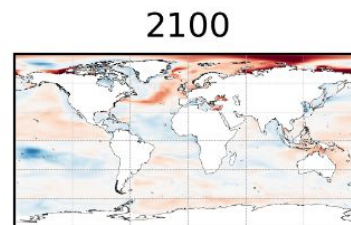
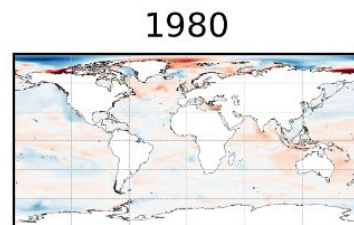
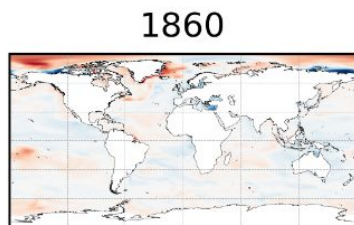
Difference to
initial state
NorESM-CISM



Difference to
initial state
NorESM

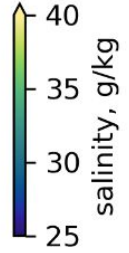
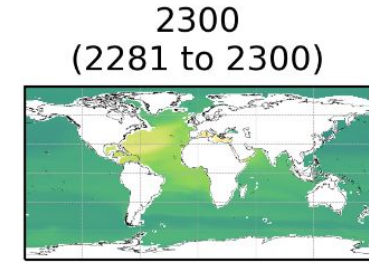
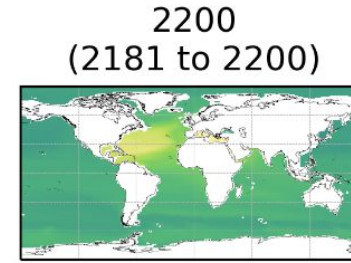
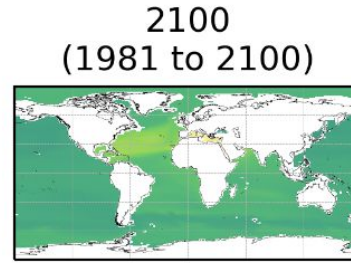
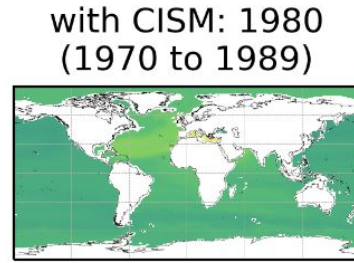
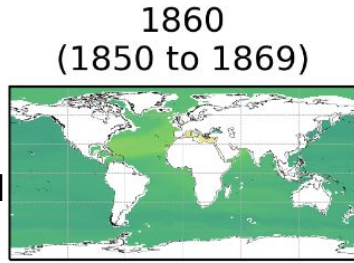


Difference
NorESM-CISM
NorESM

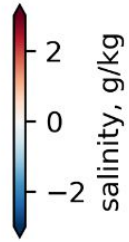
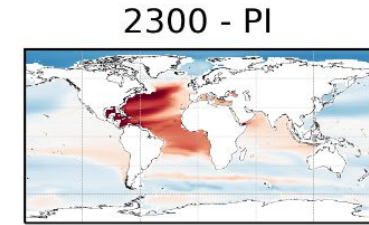
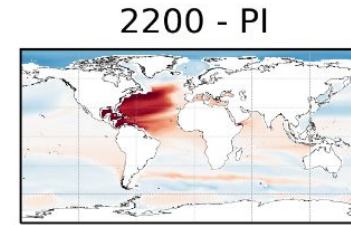
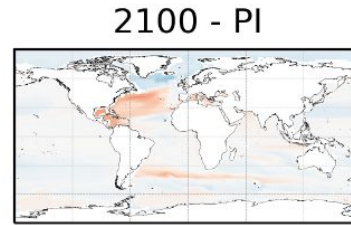
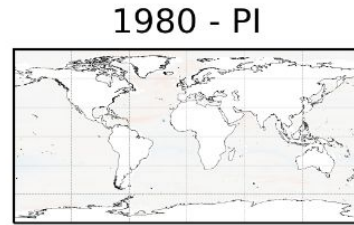


Salinity at 400m depth

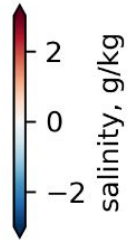
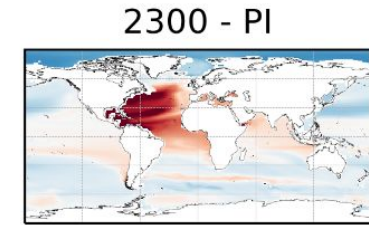
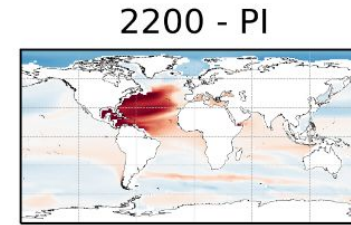
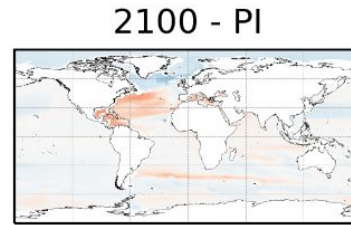
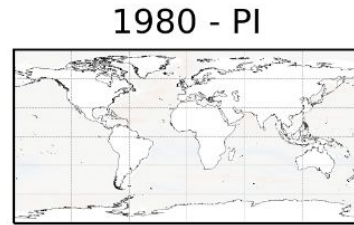
Evolution
NorESM-CISM



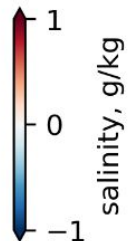
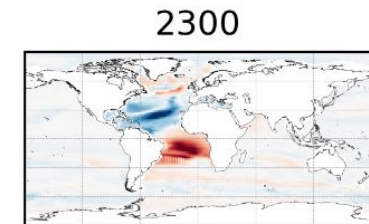
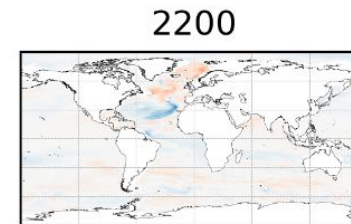
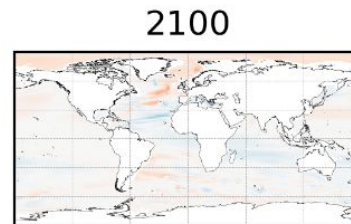
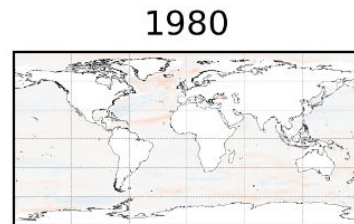
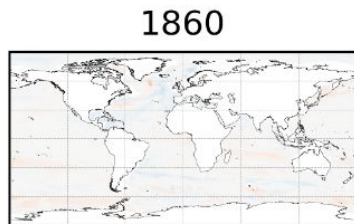
Difference to
initial state
NorESM-CISM



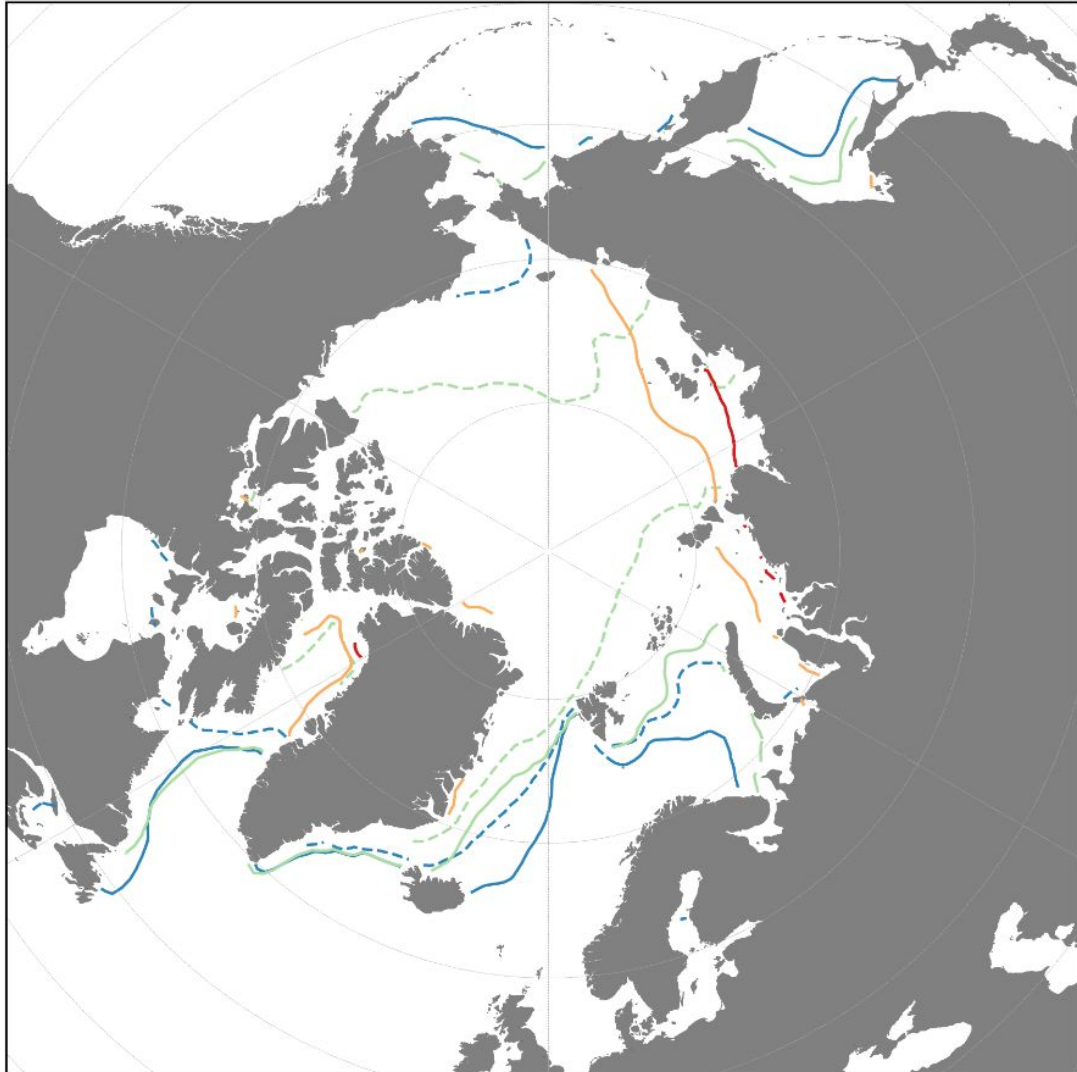
Difference to
initial state
NorESM



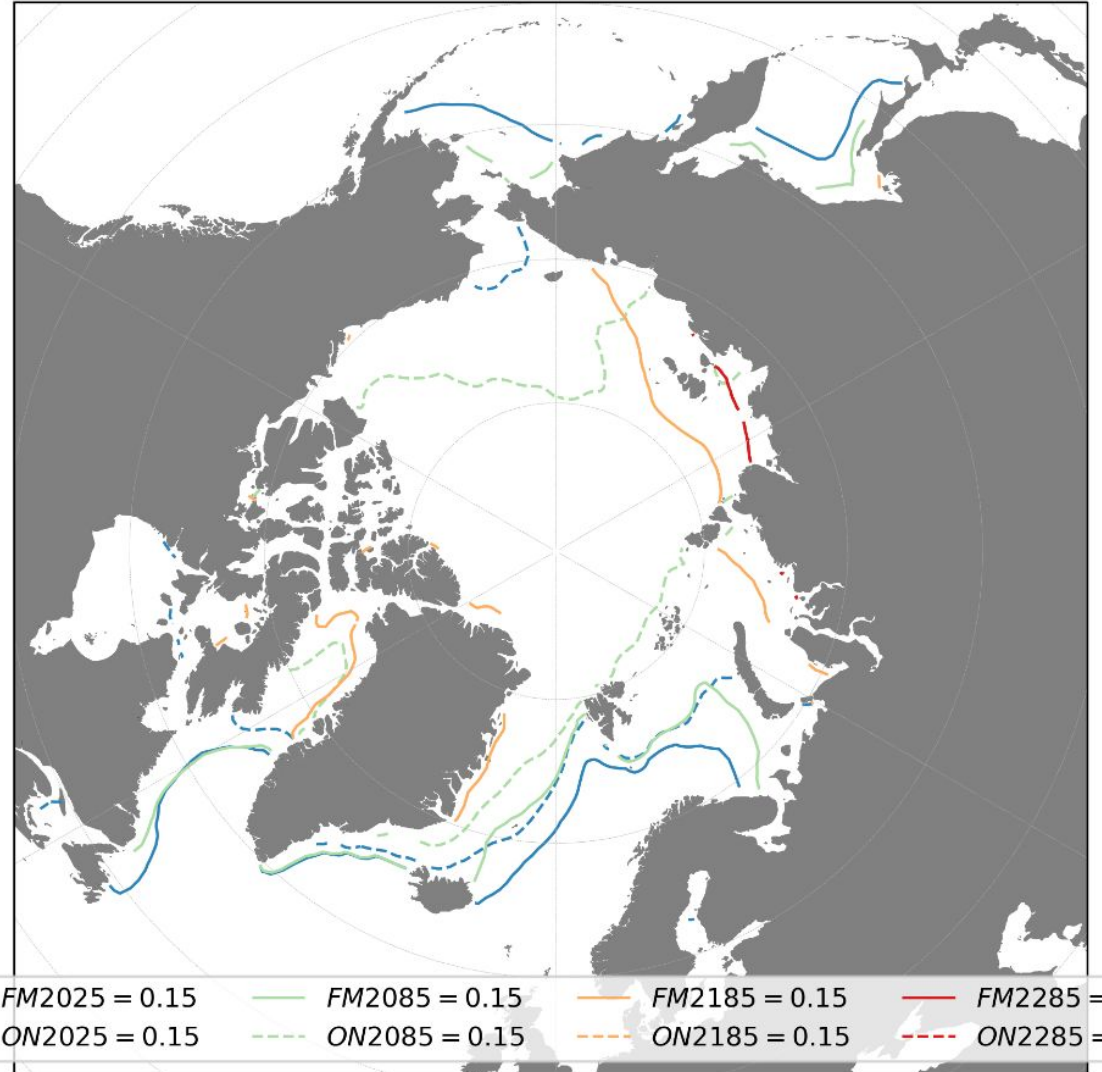
Difference
NorESM-CISM
NorESM



Max and min sea ice extent NorESM2-MM-CISM
Northern Hemisphere

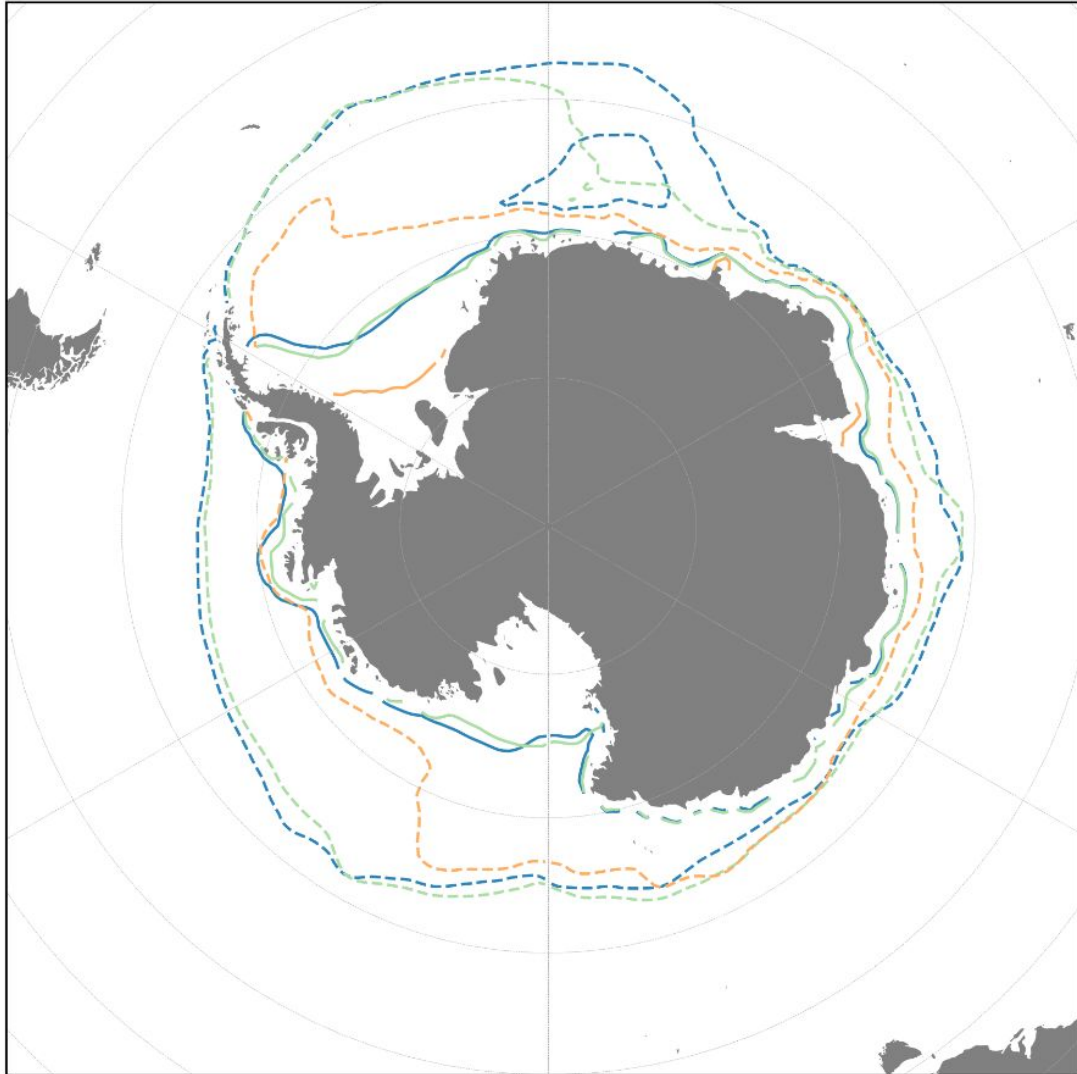


Max and min sea ice extent NorESM2-MM
Northern Hemisphere

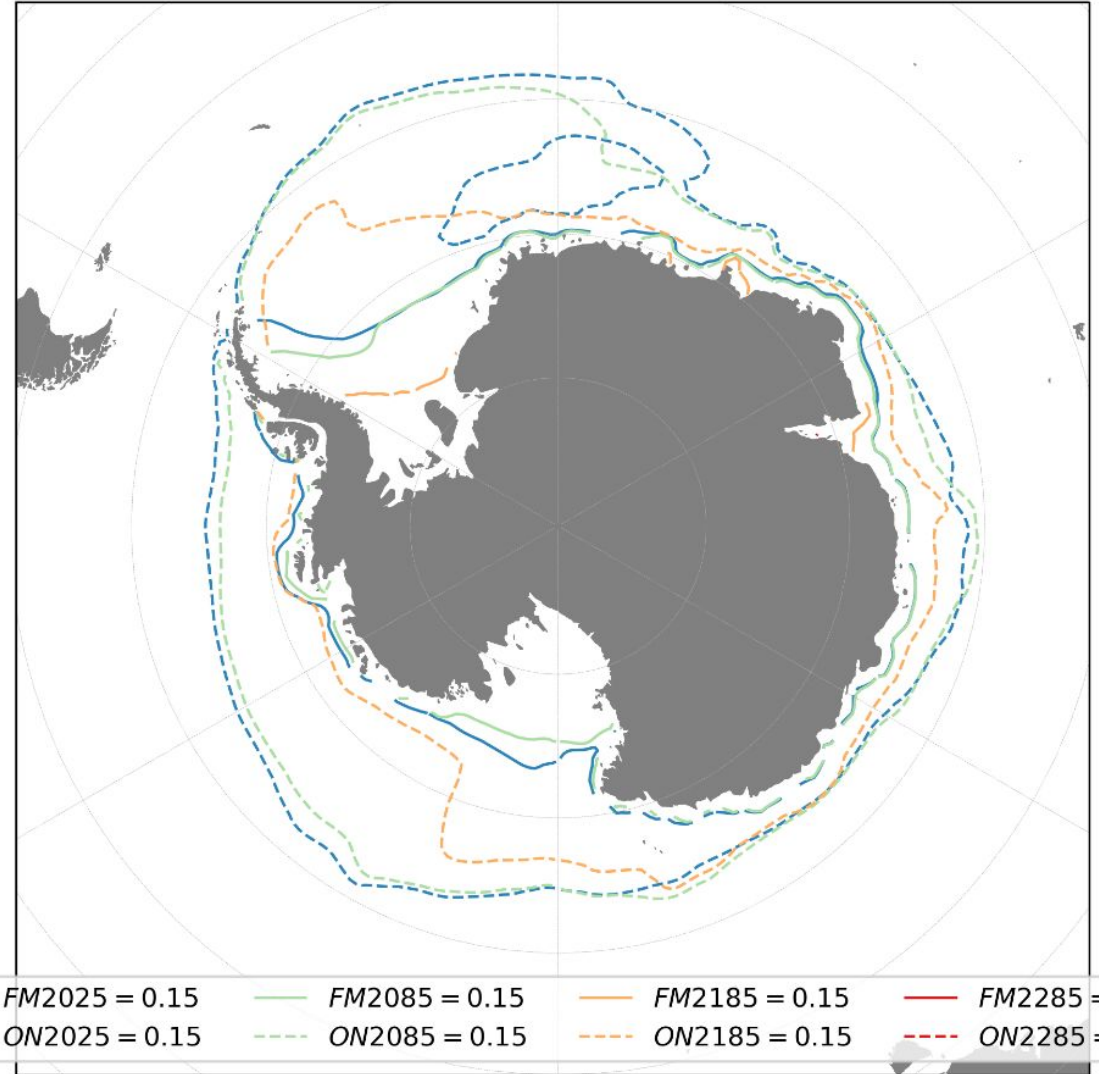


— FM2025 = 0.15	— FM2085 = 0.15	— FM2185 = 0.15	— FM2285 = 0.15
- - - ON2025 = 0.15	- - - ON2085 = 0.15	- - - ON2185 = 0.15	- - - ON2285 = 0.15

Max and min sea ice extent NorESM2-MM-CISM
Southern Hemisphere



Max and min sea ice extent NorESM2-MM
Southern Hemisphere





NorESM



O'Neill et al.
(2016)

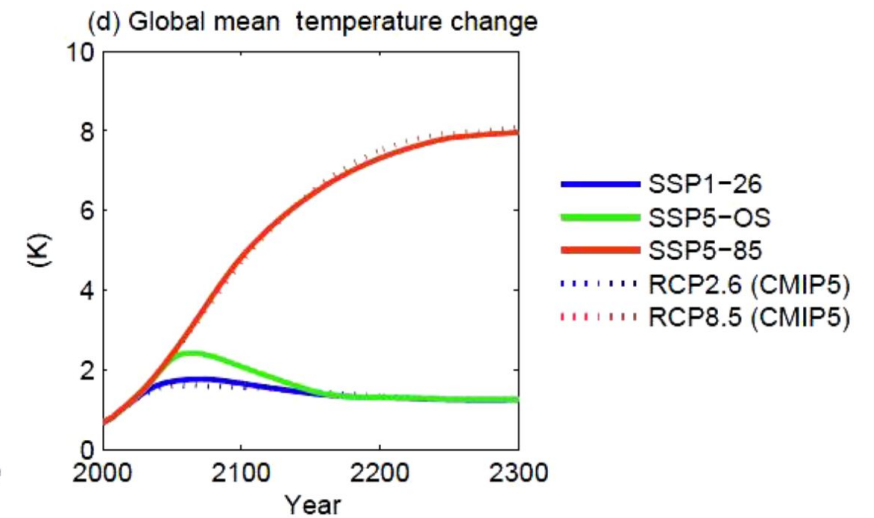
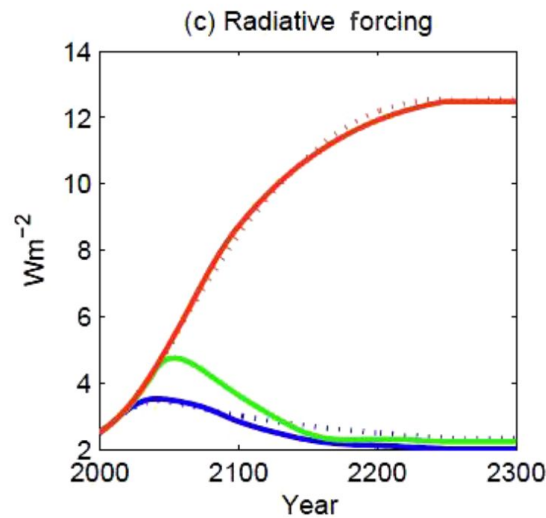
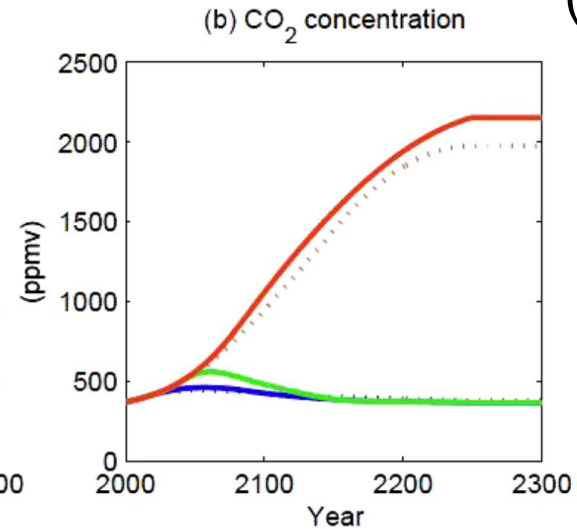
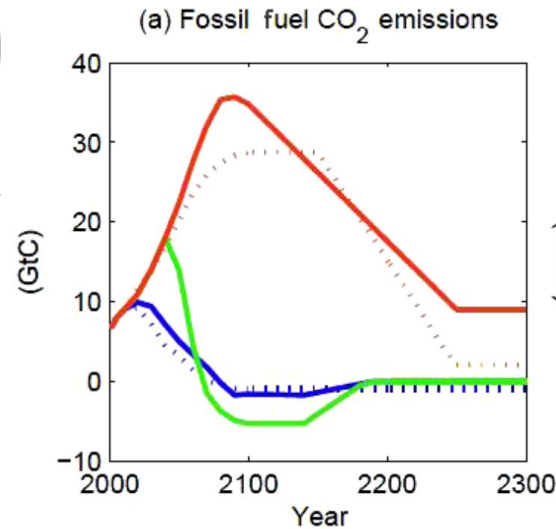
Experimental setup

- › N1850: 1800 – 1850 (spinup)
- › N1850: 1850 – 2300 (control)

- › NHIST: 1850 – 2014

- › NSSP585: 2015 – 2100
- › NSSP585Ext: 2101 – 2300

- › The ScenarioMIP prolongation SSP585Ext extends SSP585 up to year 2300
- › CO₂ emissions are reduced linearly starting in 2100 to less than 10 GtC yr⁻¹ in 2250
- › Other emissions are held constant at 2100 levels



- SSP1-26
- SSP5-OS
- SSP5-85
- ⋯ RCP2.6 (CMIP5)
- ⋯ RCP8.5 (CMIP5)