

Diverse Eurasian Temperature Responses to Arctic Sea Ice Loss in Models Due to Varying Balance Between Dynamical Cooling and Thermodynamical Warming

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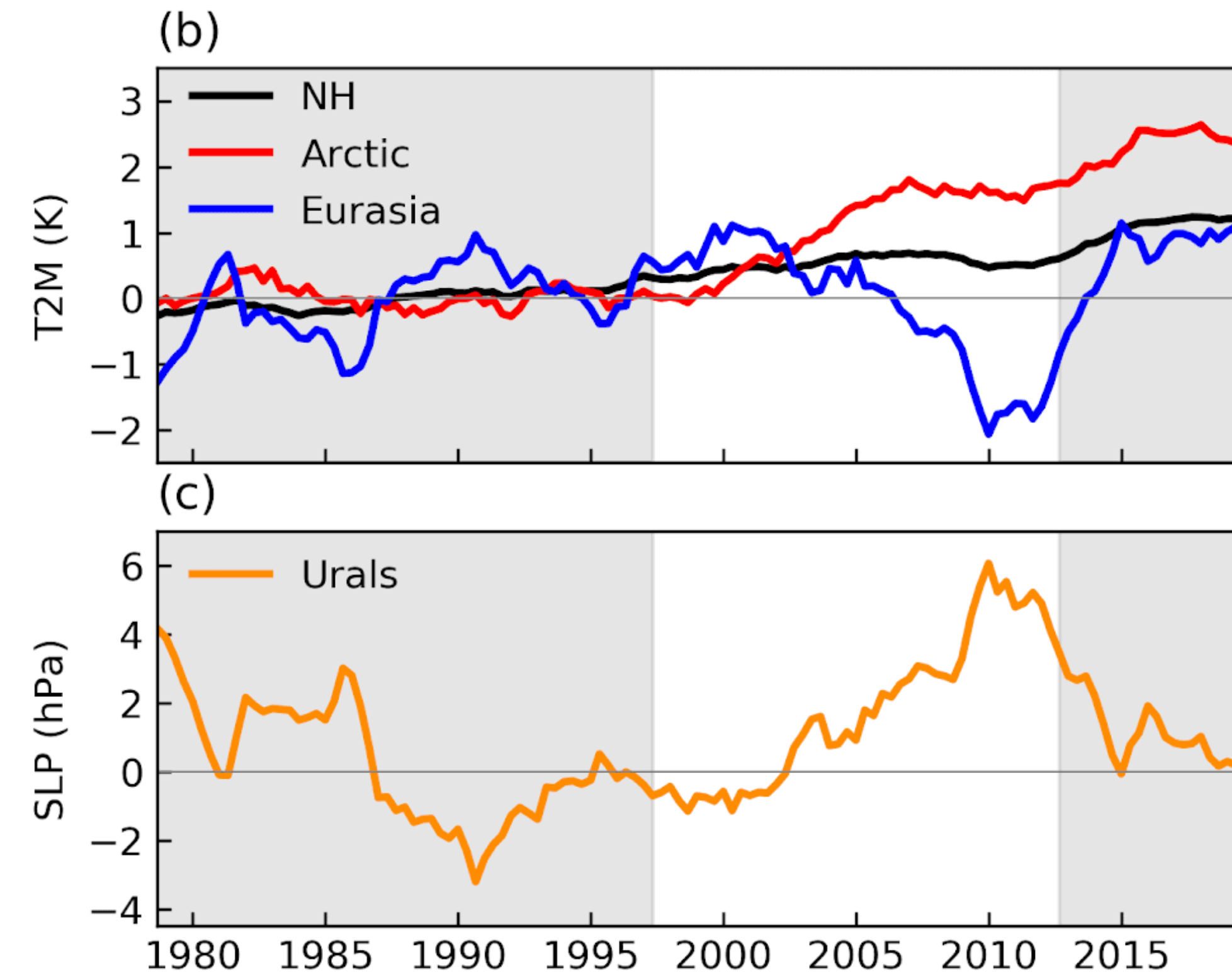
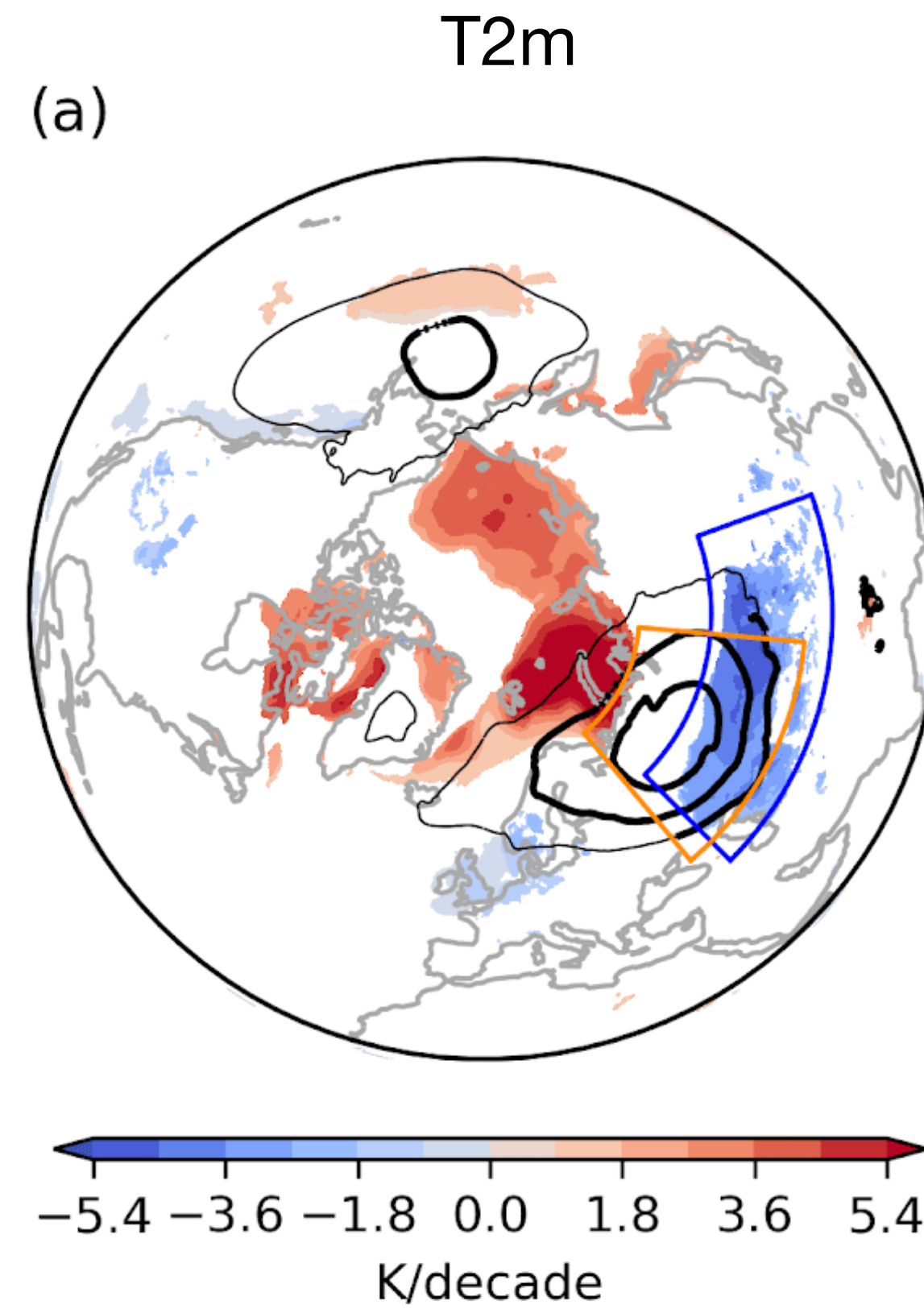
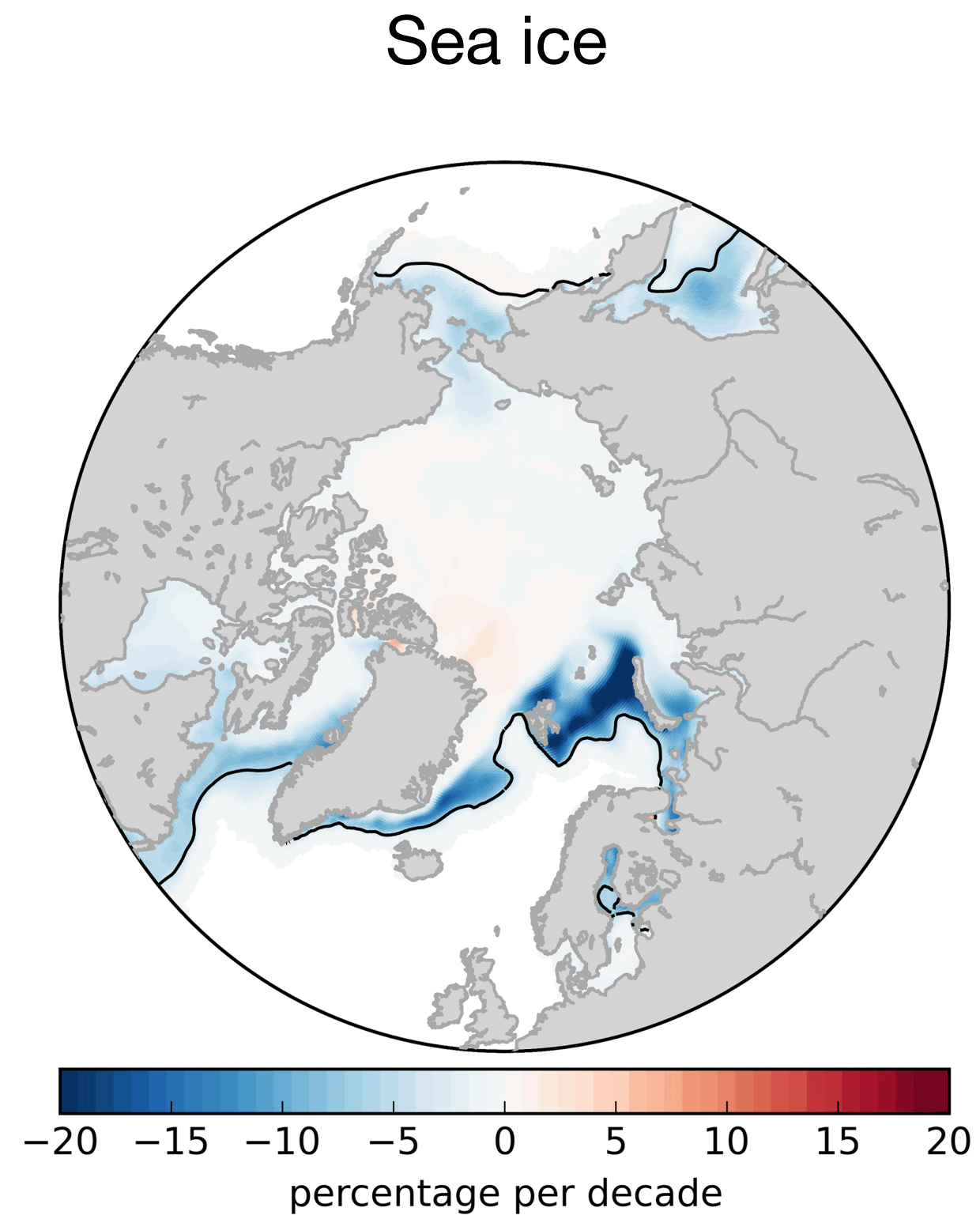
³Department of Meteorology and Atmospheric Sciences, Pennsylvania State University, University Park, Pennsylvania, United States

Background

Warm Arctic-Cold Eurasia pattern:

High (year-to-year) correlation between warm Arctic and severe cold winters over Eurasia

Walsh 2014; Cohen et al., 2014; Overland et al., 2011



Outten et al., 2023

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Is the pattern primarily driven by sea ice loss? Internal variability/tropical forcing also playing a role?

Matsumura & Kosaka, 2019; Warner et al., 2020; Blackport et al., 2019; McCusker et al., 2016; Sun et al., 2016

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Warm Arctic-Cold Eurasia pattern:

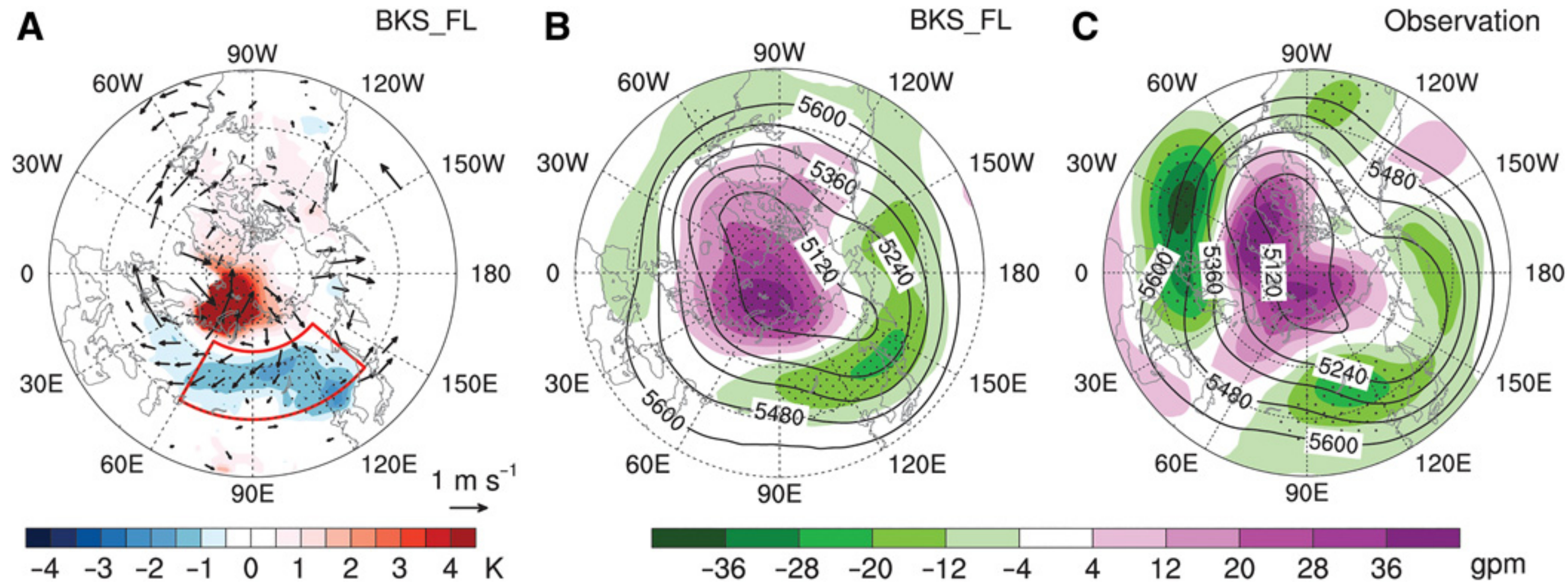
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At least some climate models simulates Eurasian cooling when sea ice is reduced over the Arctic



Sea ice loss over Barrents-Kara Sea (BKS)
50-year WACCM4 simulation

Zhang et al., 2018

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Warm Arctic-Cold Eurasia pattern:

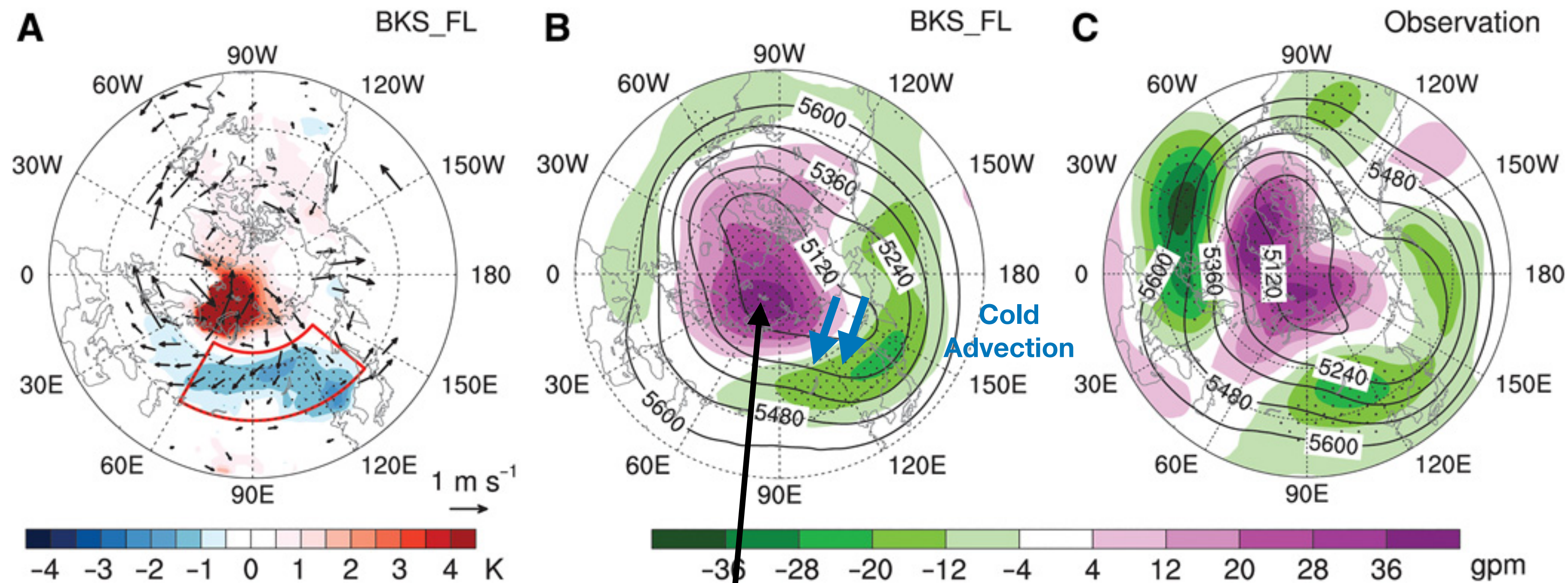
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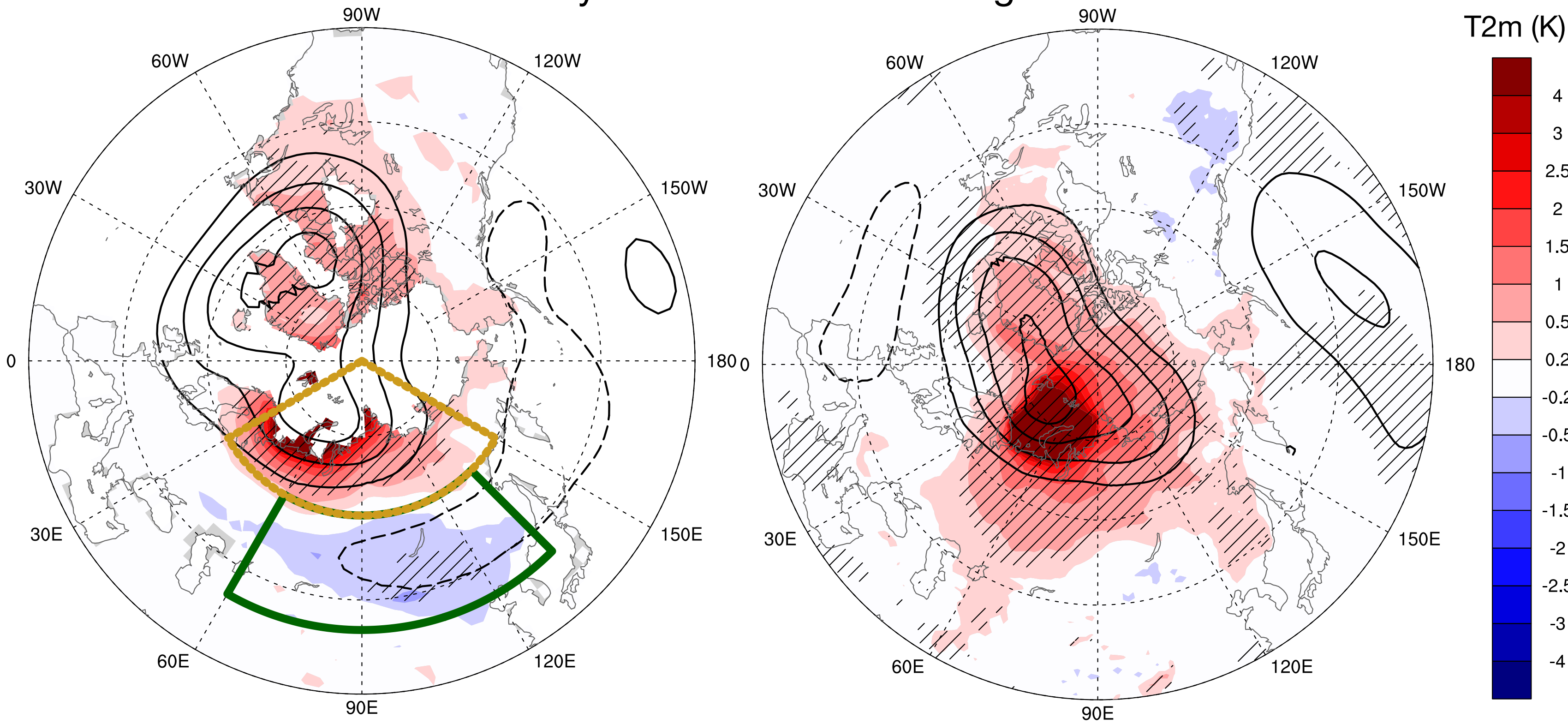
Sea ice reduction → Anti-cyclonic circulation over BKS and Urals
Via Tropospheric/Stratospheric Circulation

Zhang et al., 2018

Sea ice loss over Barrents-Kara Sea (BKS)
50-year WACCM4 simulation

WACCM6 Simulations

Very similar SIC/SST forcing



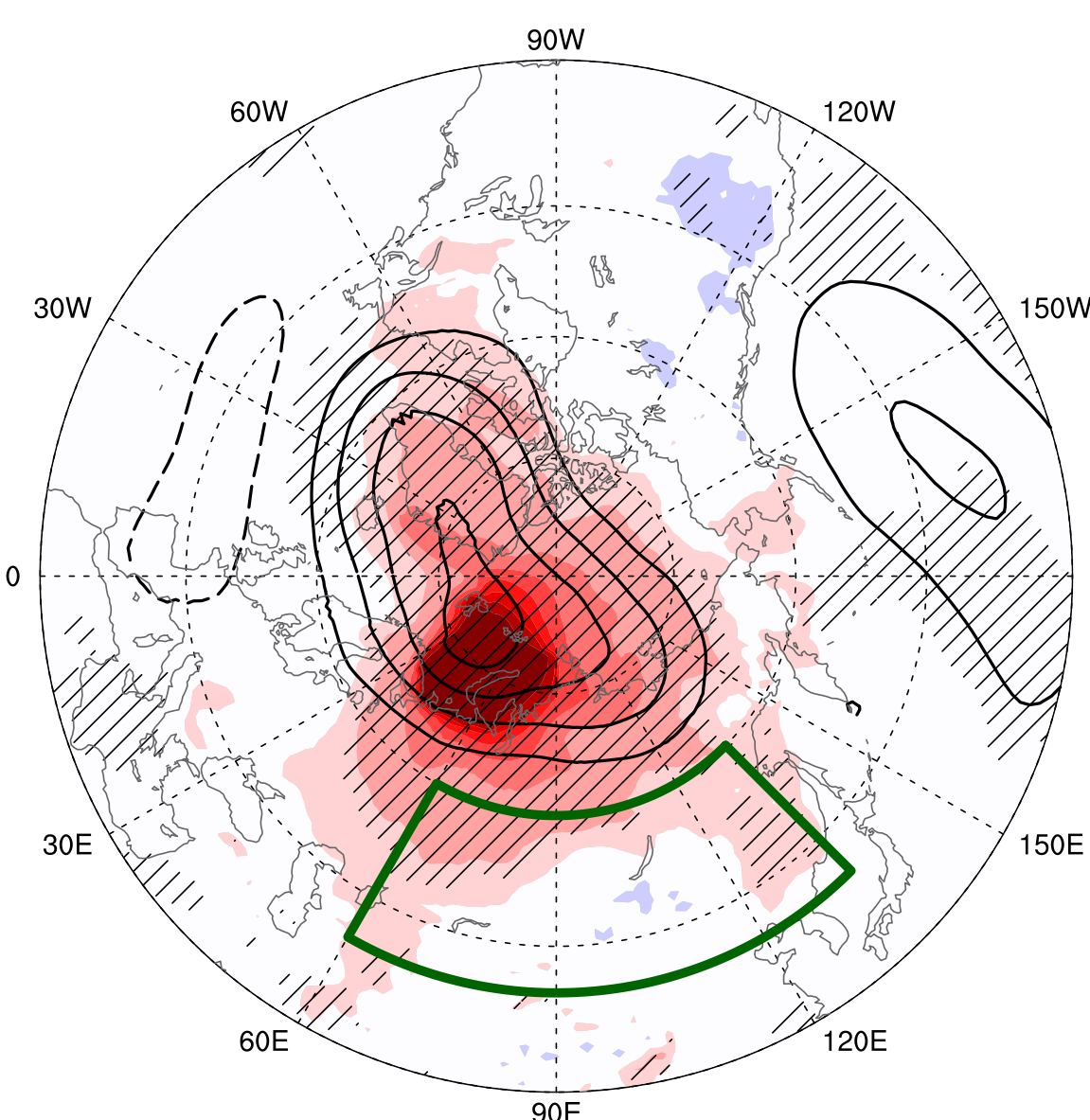
WACCM4: 225-year simulation
(Zhang et al., 2020)

WACCM6: 200-year simulation

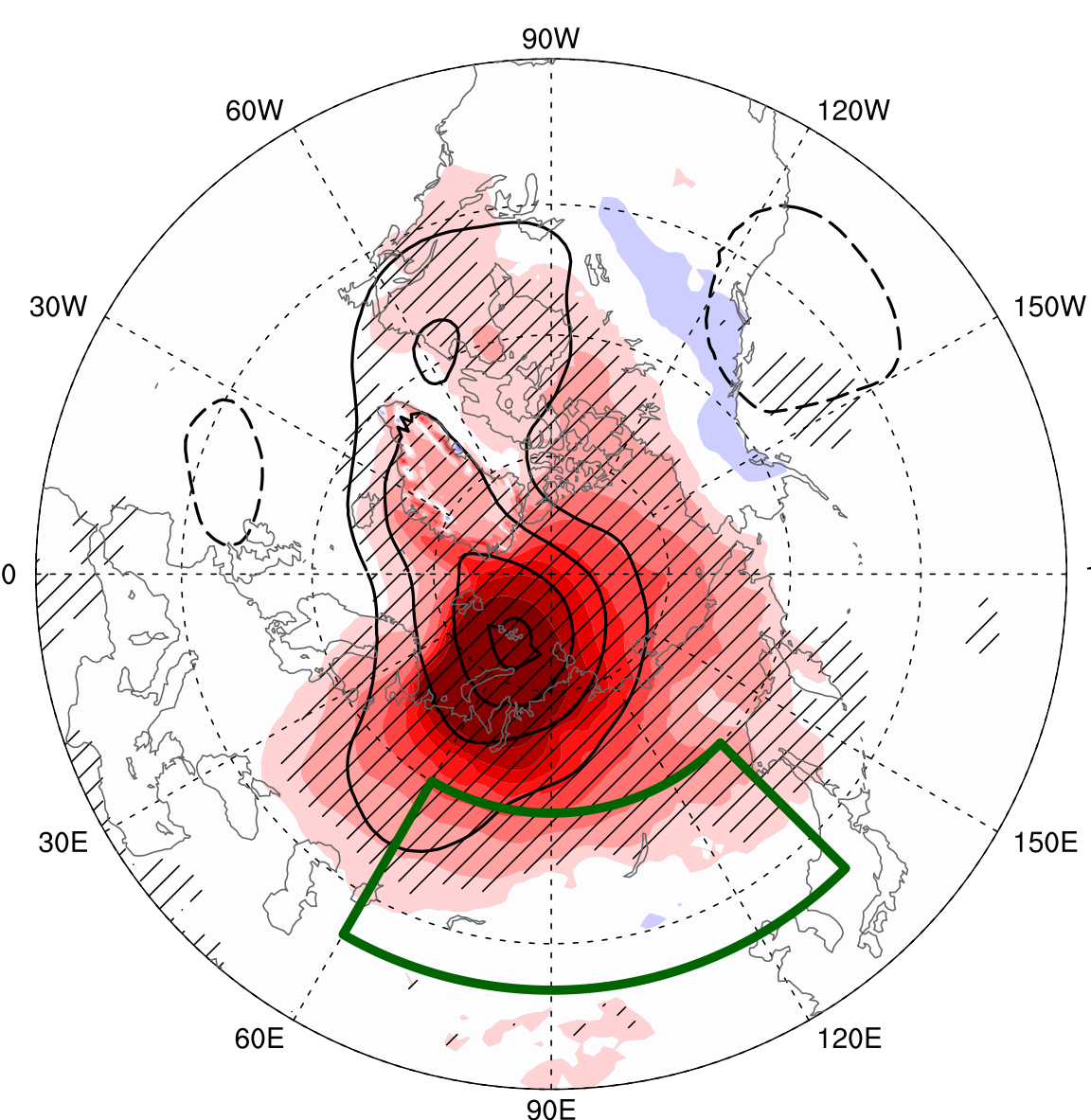
Future BKS SIC/SST:
CMIP5 CESM1-WACCM4 rcp85
Last 20 years of 21st century

Control (BKS & elsewhere):
last 20 years of CMIP5 CESM1-WACCM4
historical run

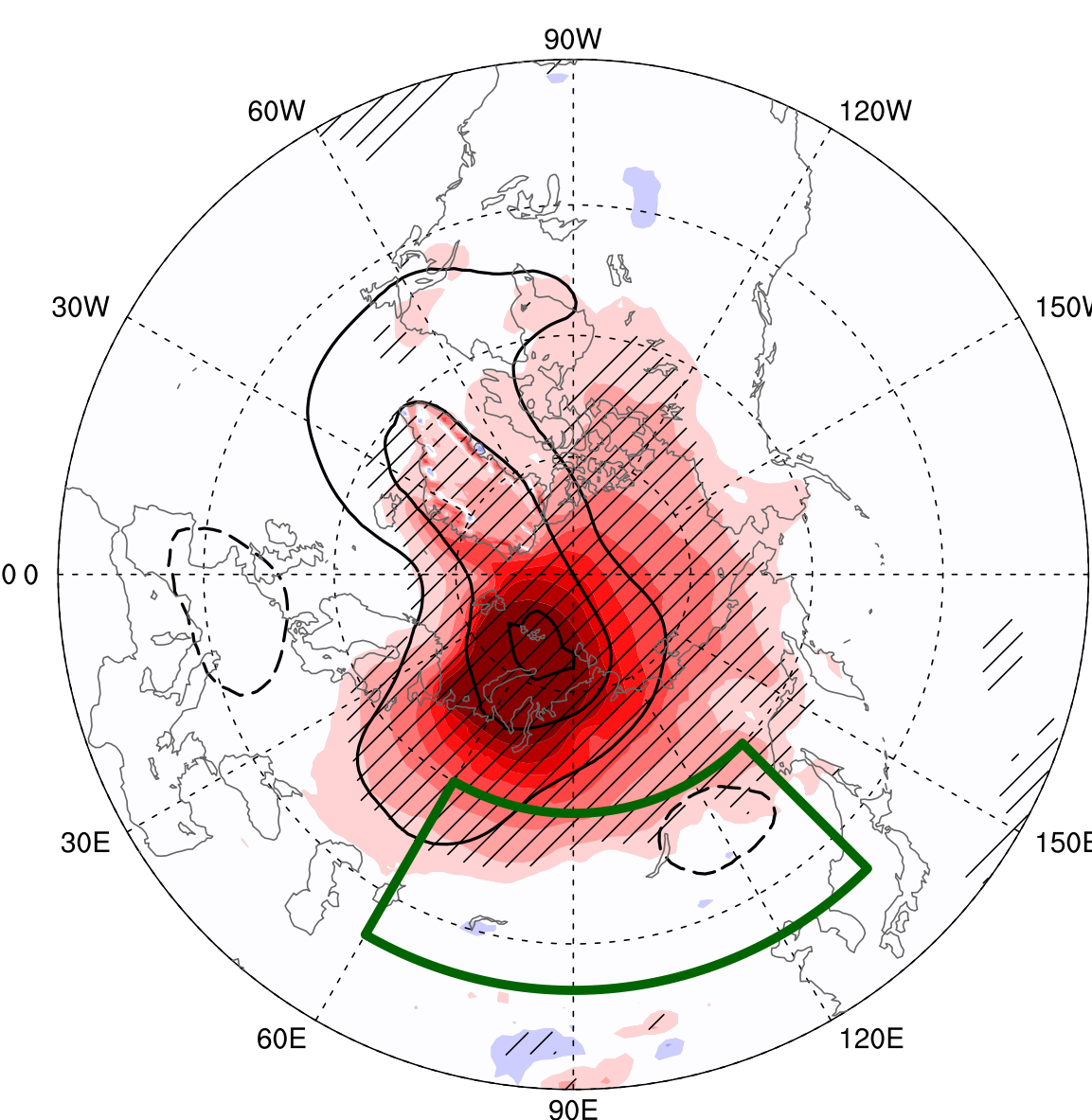
a) WACCM6_CESM1_BKS_FU
- WACCM6_CESM1_control



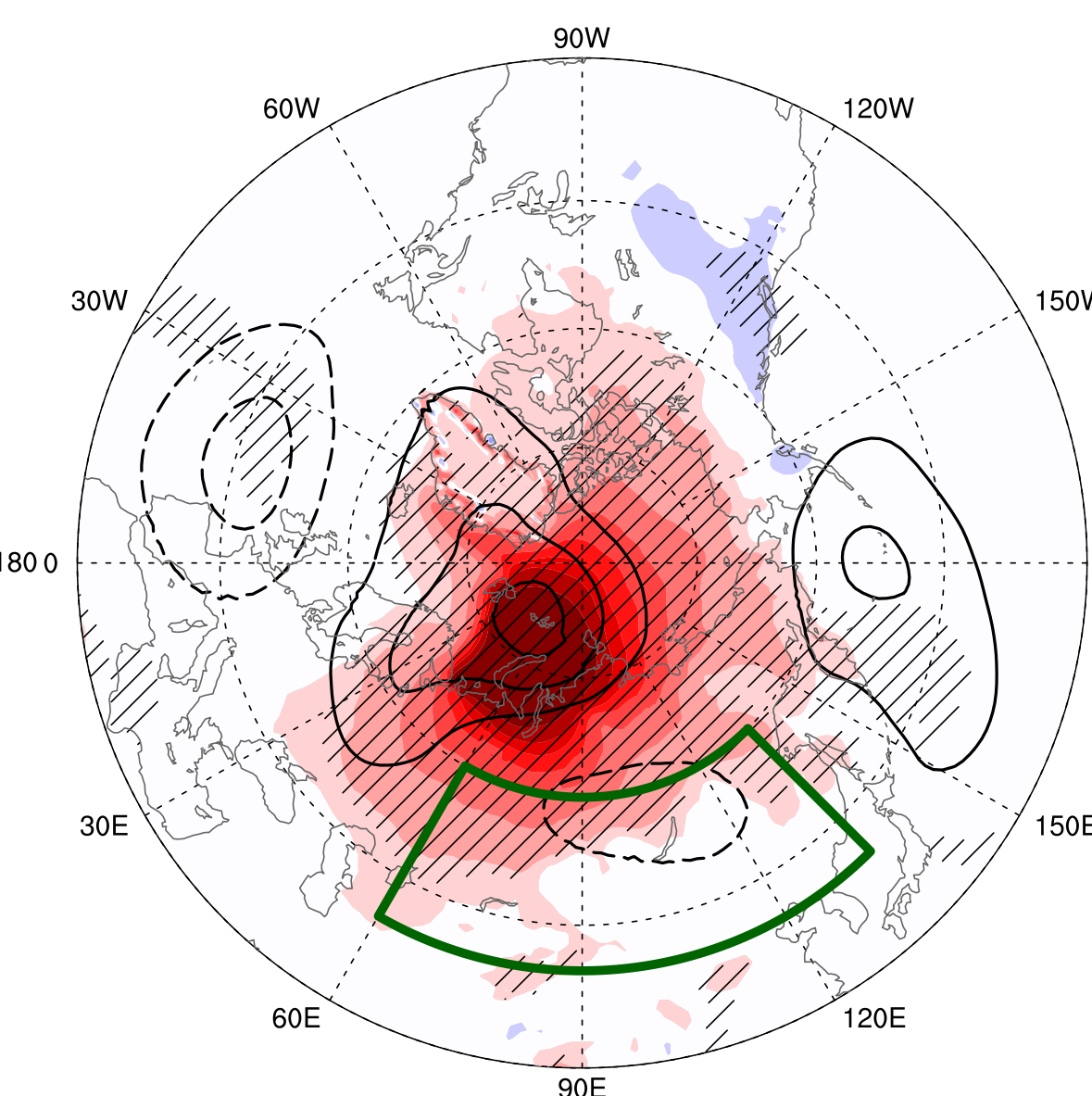
b) WACCM6_CESM2_BKS_1%
- WACCM6_CESM2_control



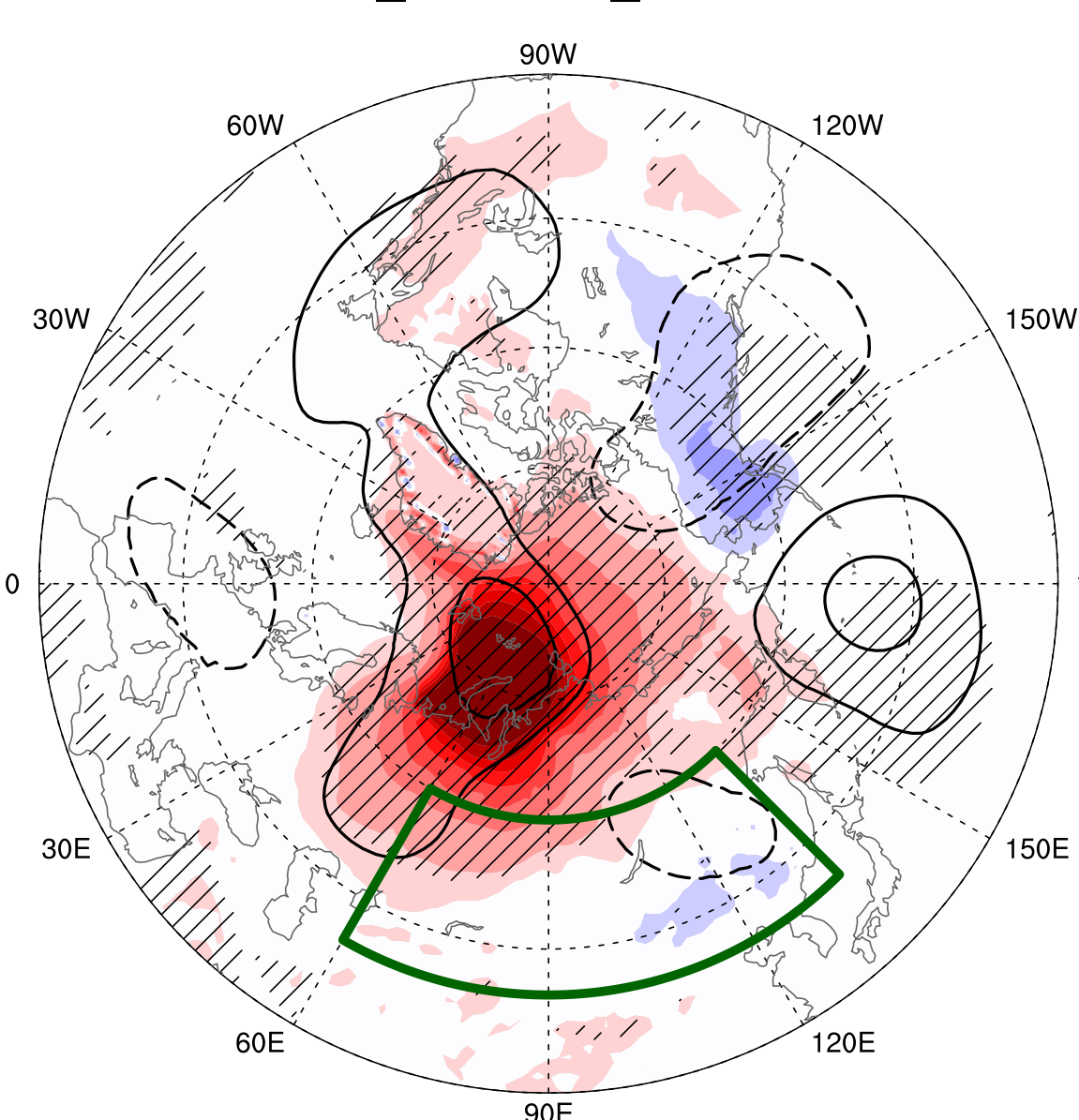
c) WACCM6_CESM2_BKS_20%
- WACCM6_CESM2_control



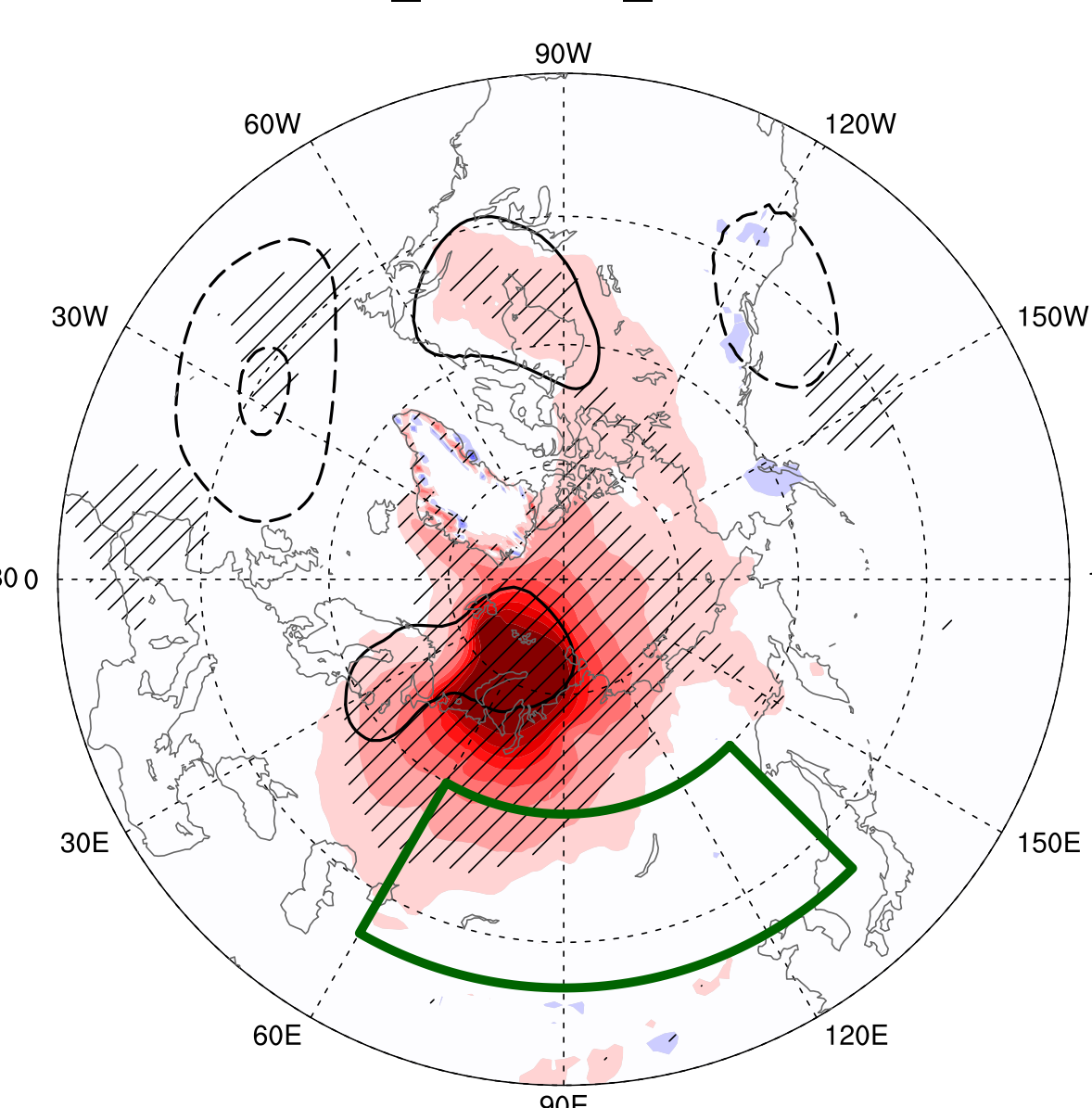
d) WACCM6_CESM2_BKS_40%
- WACCM6_CESM2_control



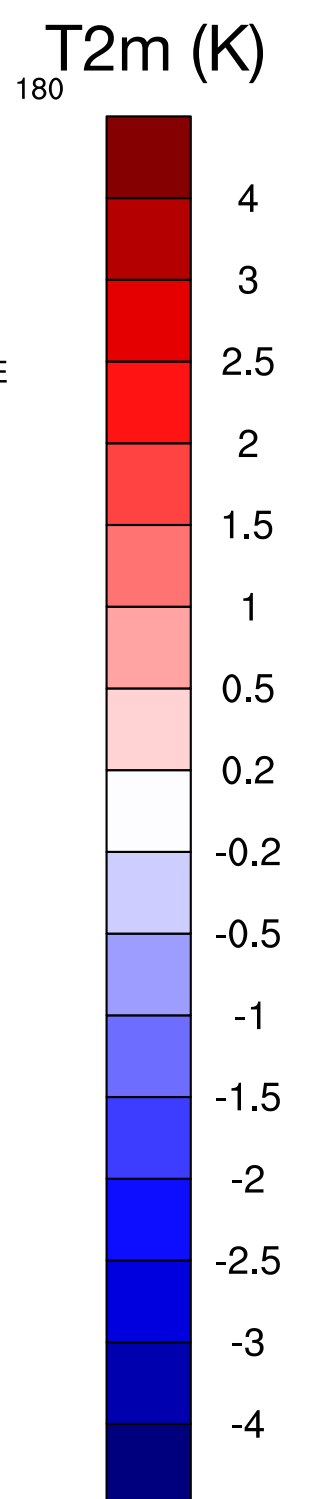
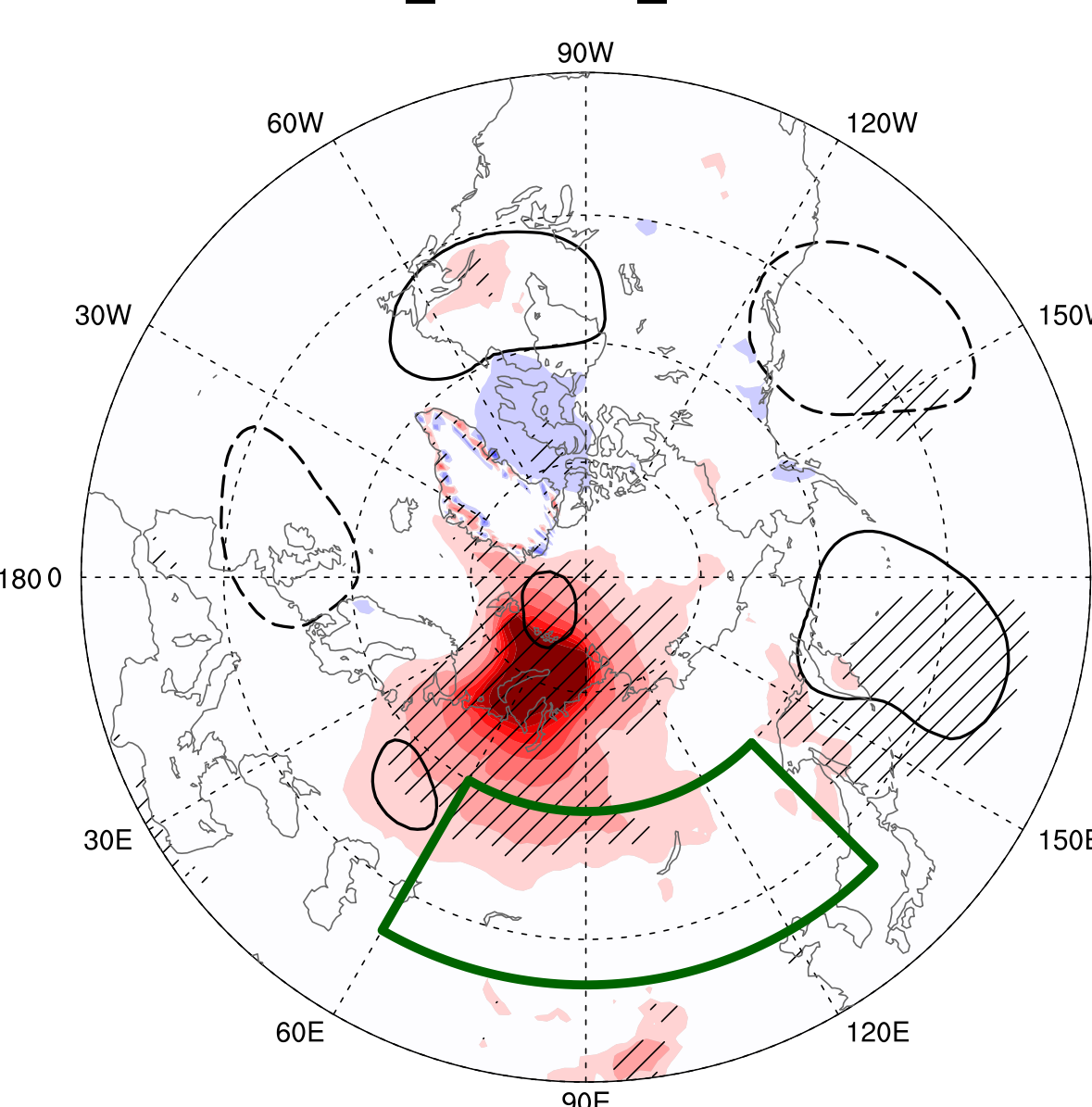
e) WACCM6_CESM2_BKS_60%
- WACCM6_CESM2_control



f) WACCM6_CESM2_BKS_80%
- WACCM6_CESM2_control

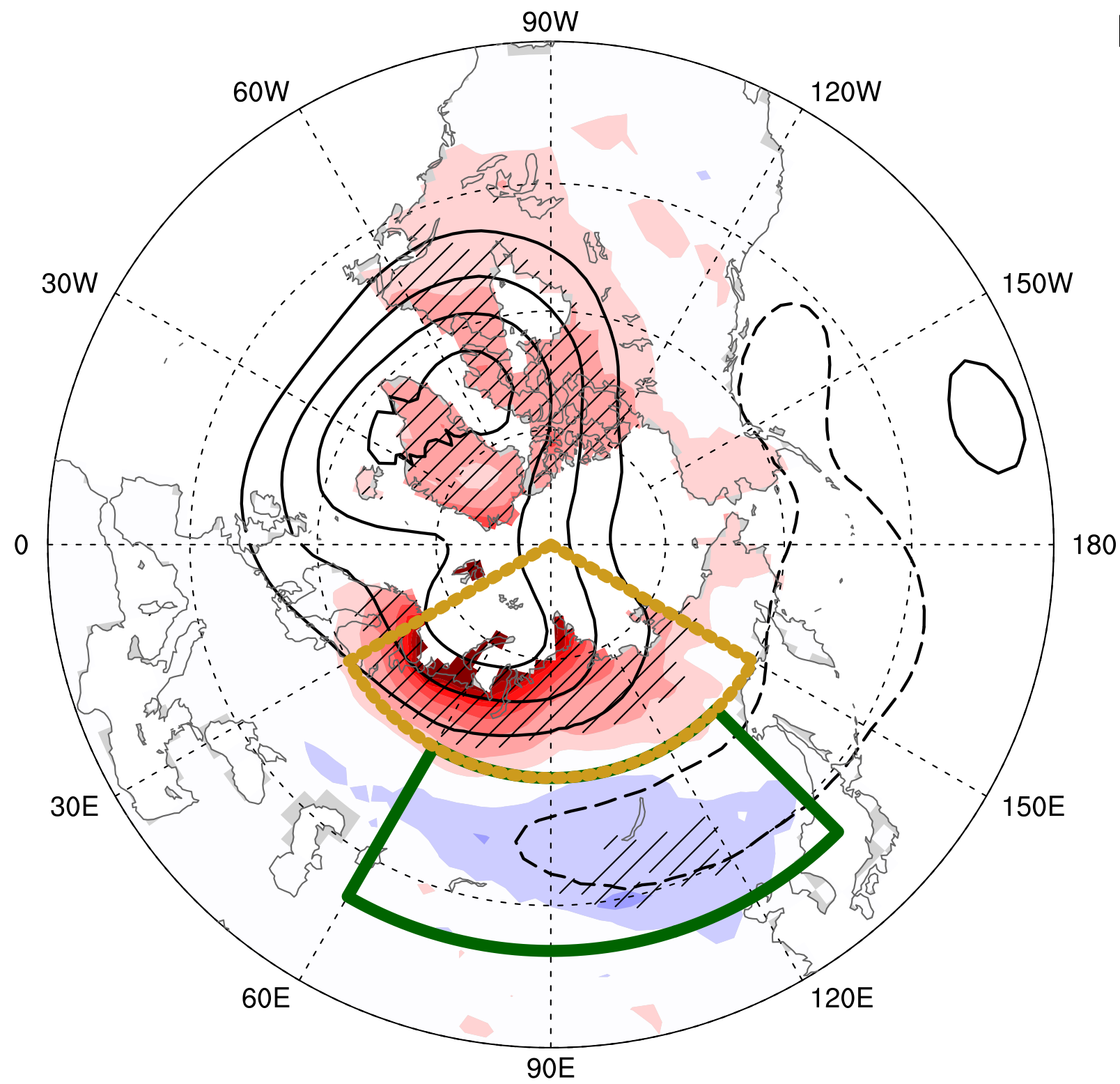


g) WACCM6_CESM2_BKS_90%
- WACCM6_CESM2_control



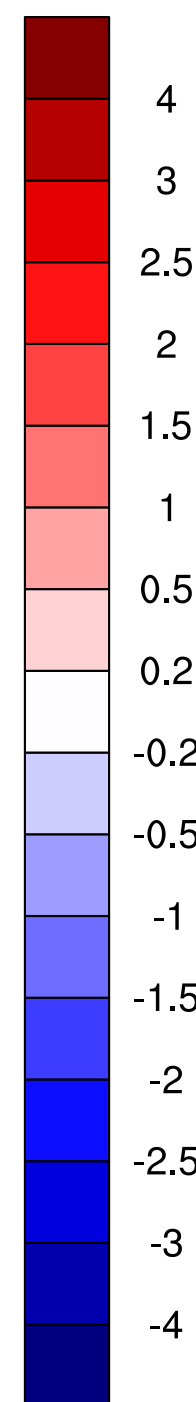
Different BKS sea ice loss setups in WACCM6
No cooling over Eurasia

WACCM4 Simulations



WACCM4: 225-year simulation
(Zhang et al., 2020)

T_{2m} (K)

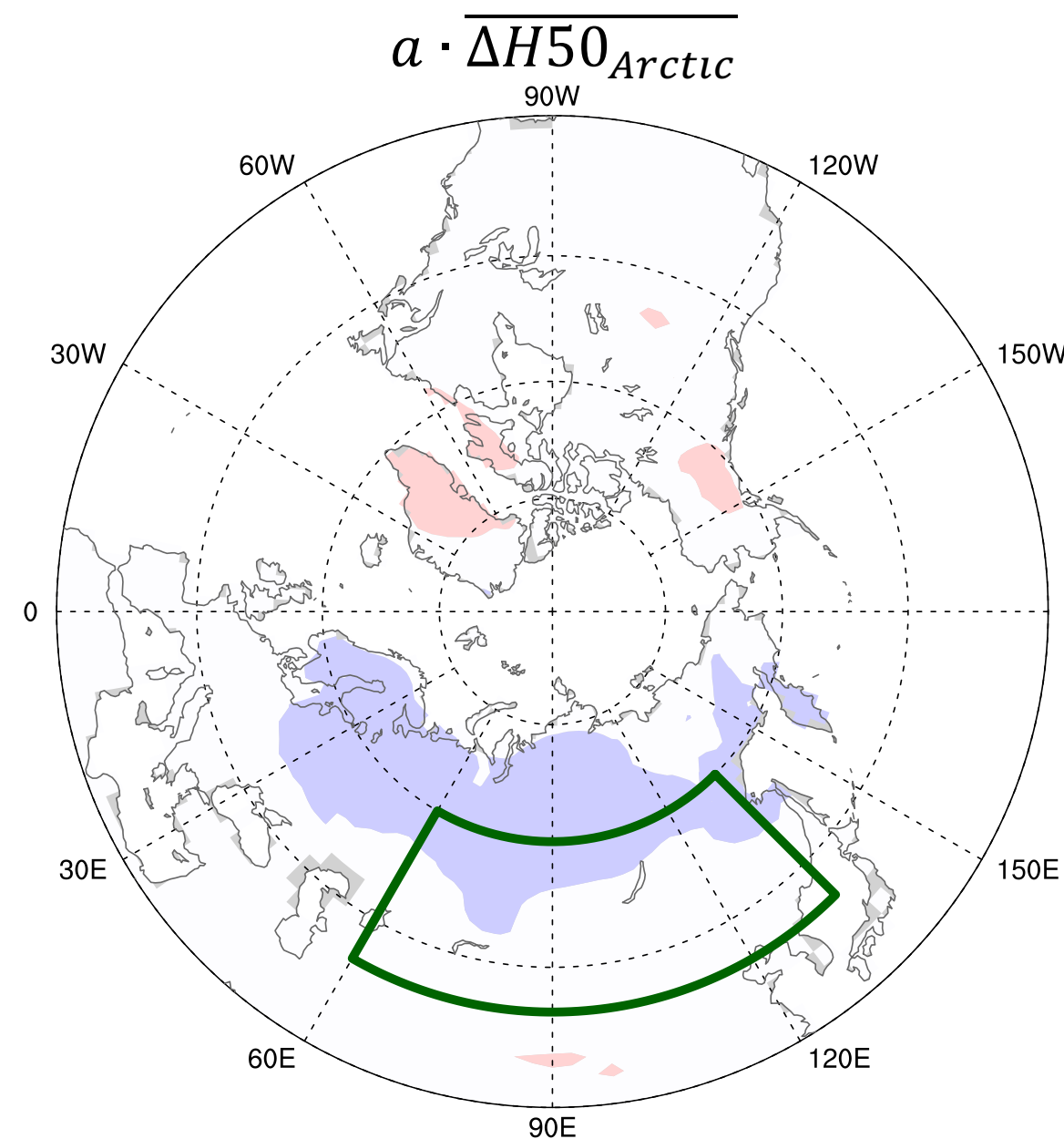


Future BKS SIC/SST:
CMIP5 CESM1-WACCM4 rcp85
Last 20 years of 21st century

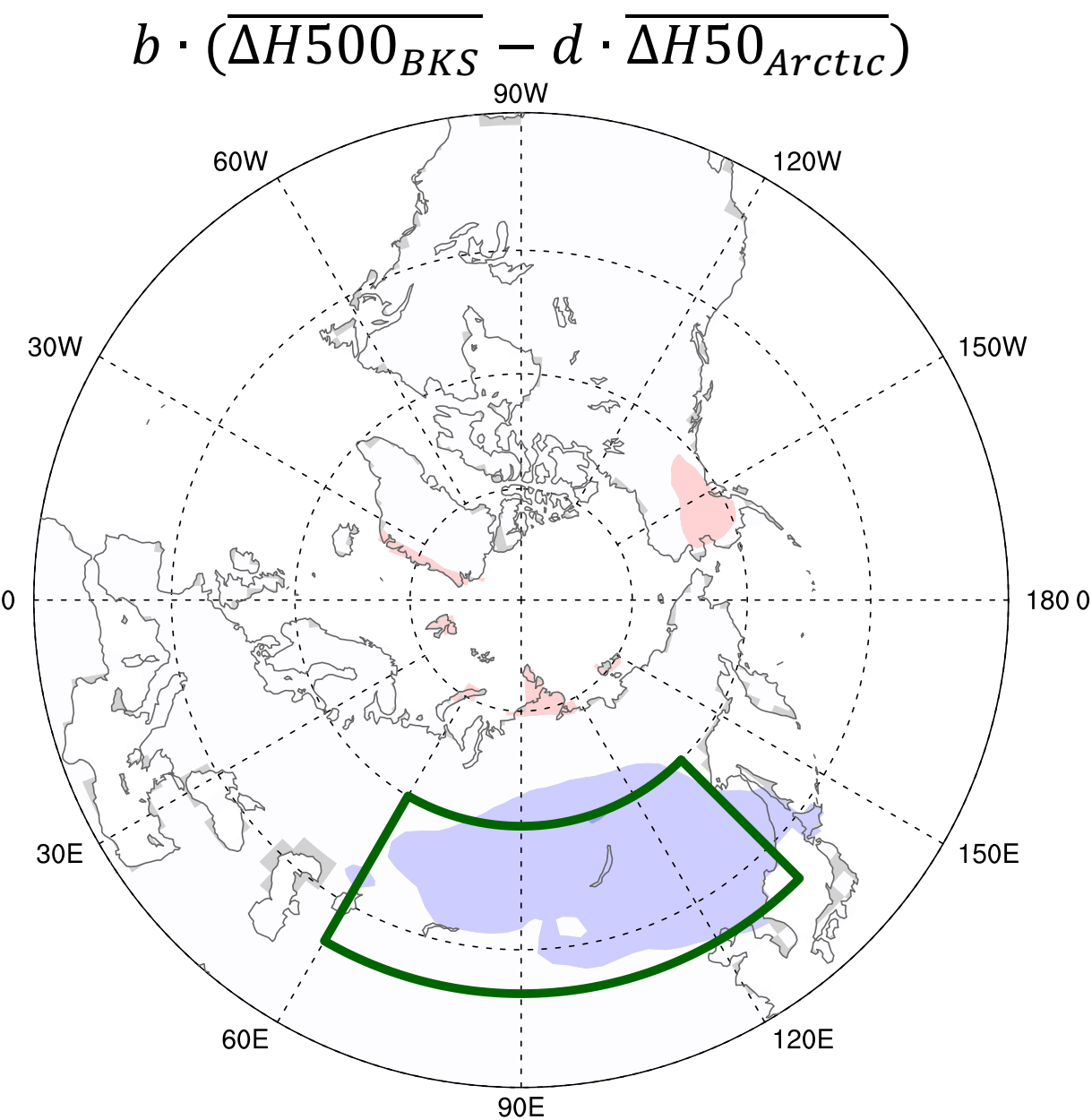
Control (BKS & elsewhere):
last 20 years of CMIP5 CESM1-WACCM4
historical run

Regression Method:
Linear relationship between Eurasian T_{2m} & Ural/BKS Z_{500} from internal variability
—> determine cooling due to atmospheric dynamics (via regression; Z_{500} —> T_{2m})
—> Intercept of the regression (thermodynamical warming)

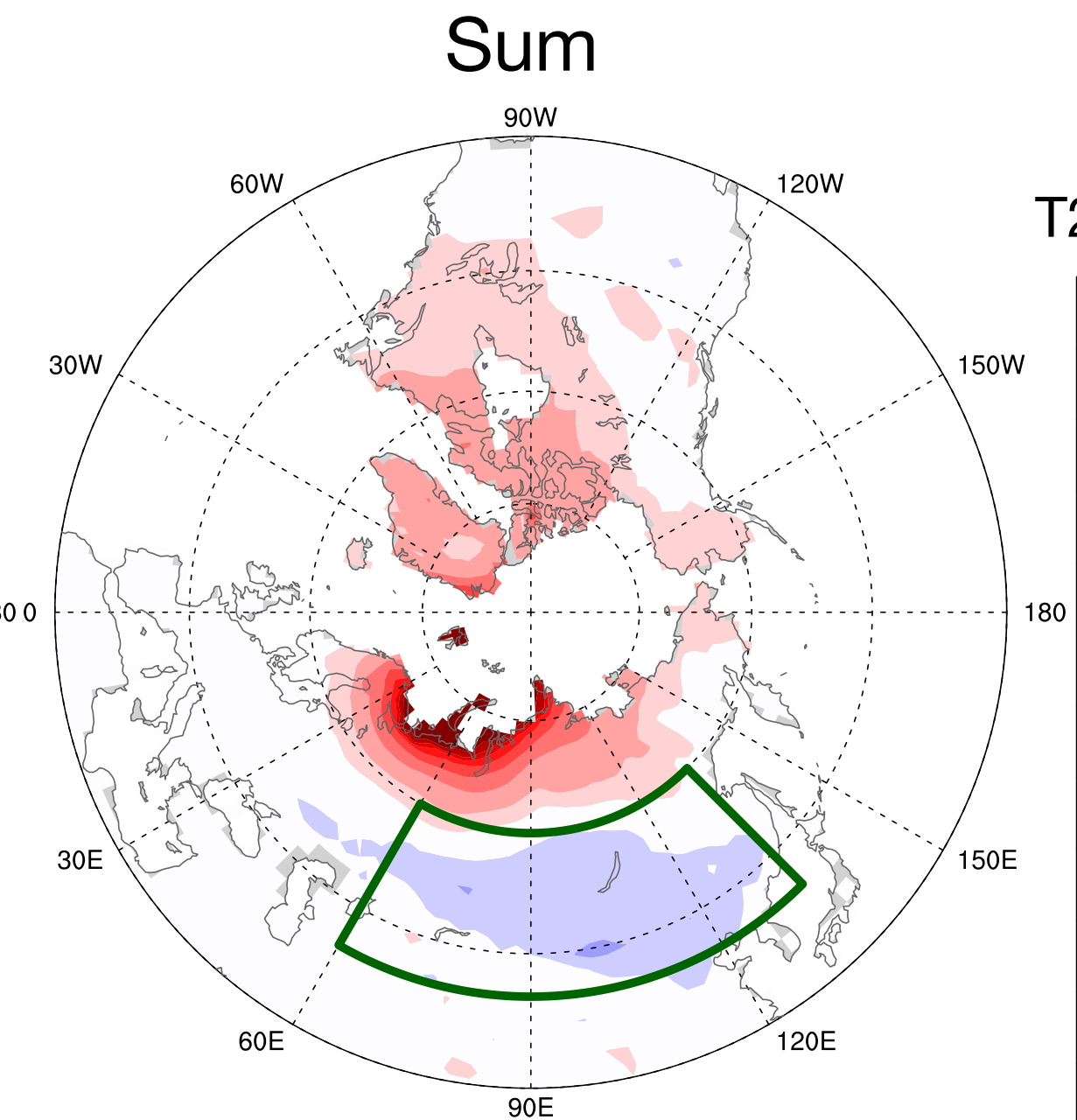
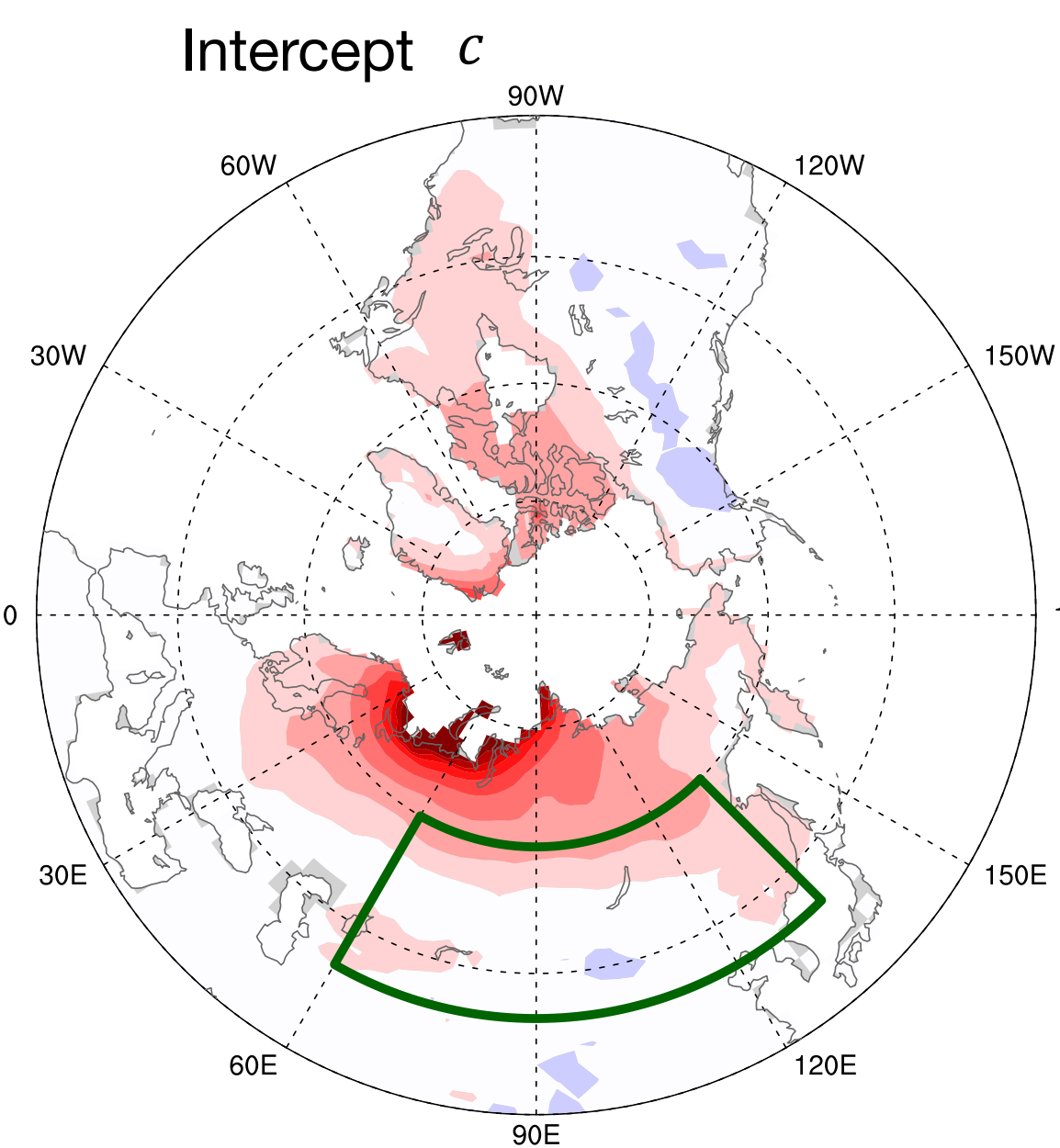
WACCM4 Simulations



Stratospheric dynamics

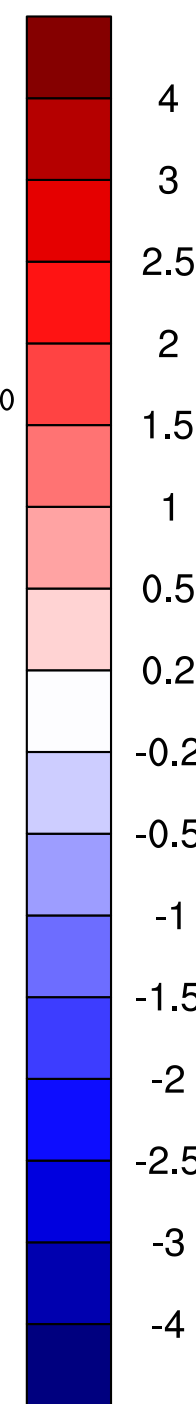


Tropospheric dynamics

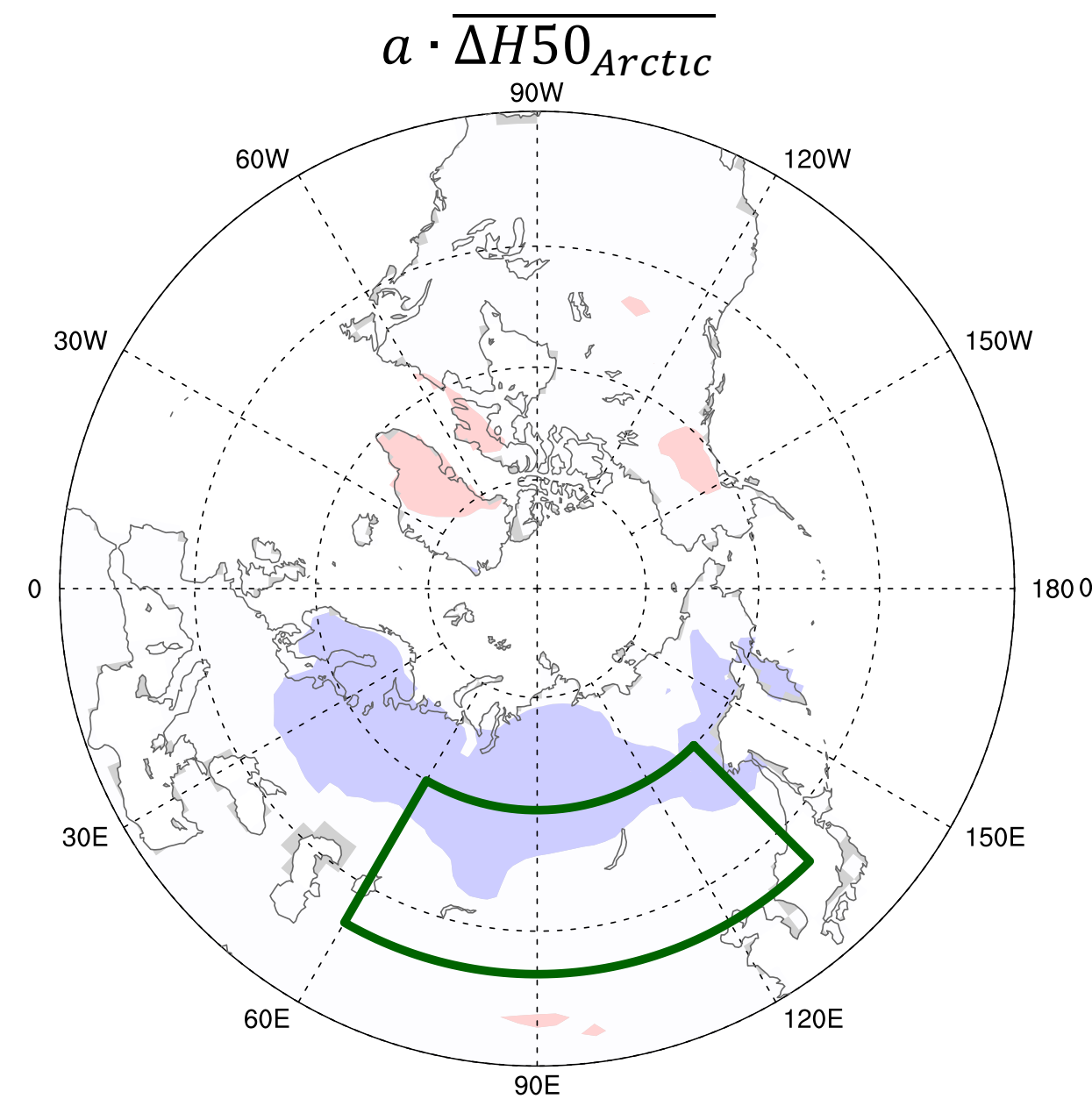


T2m response

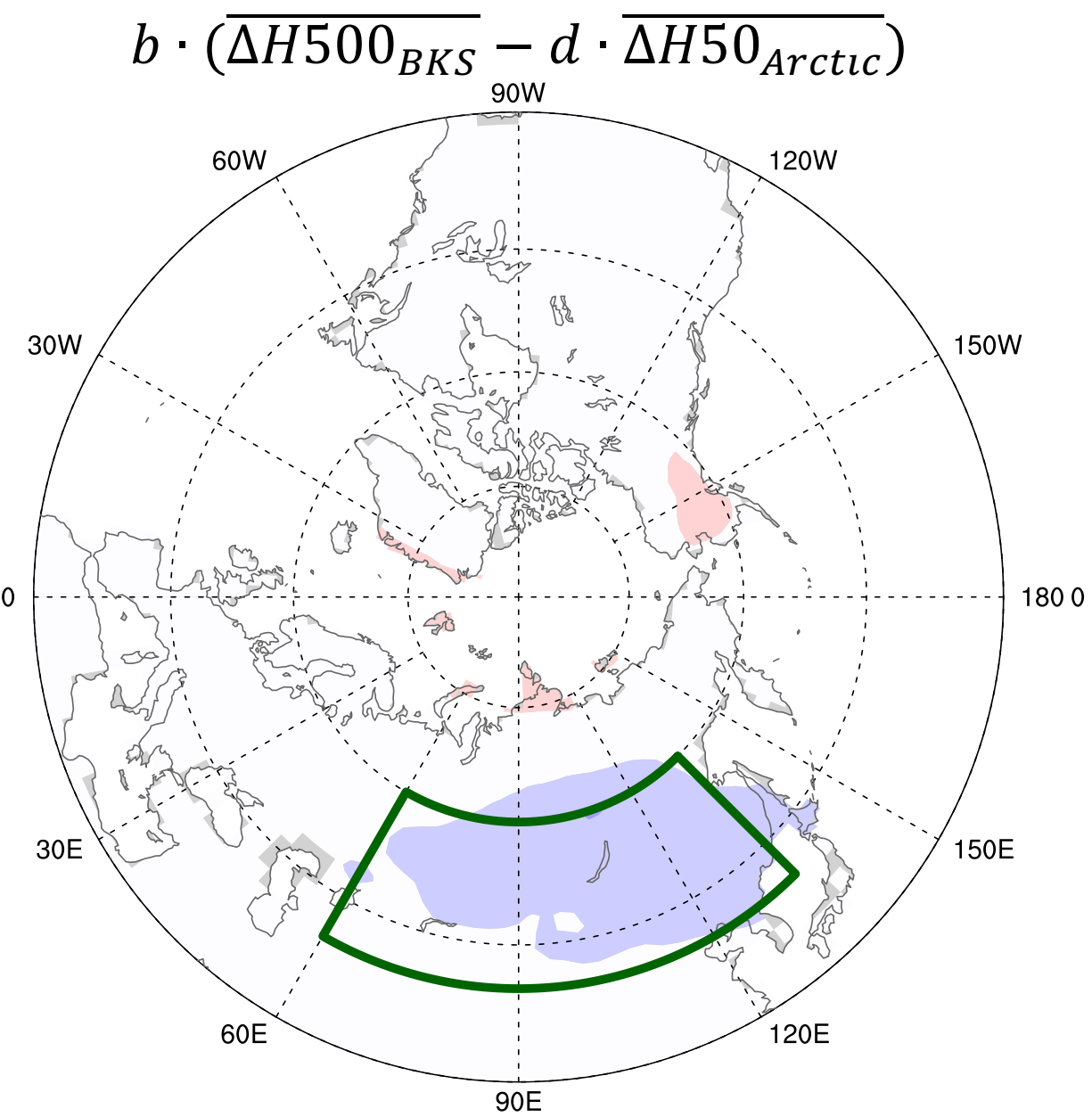
T2m (K)



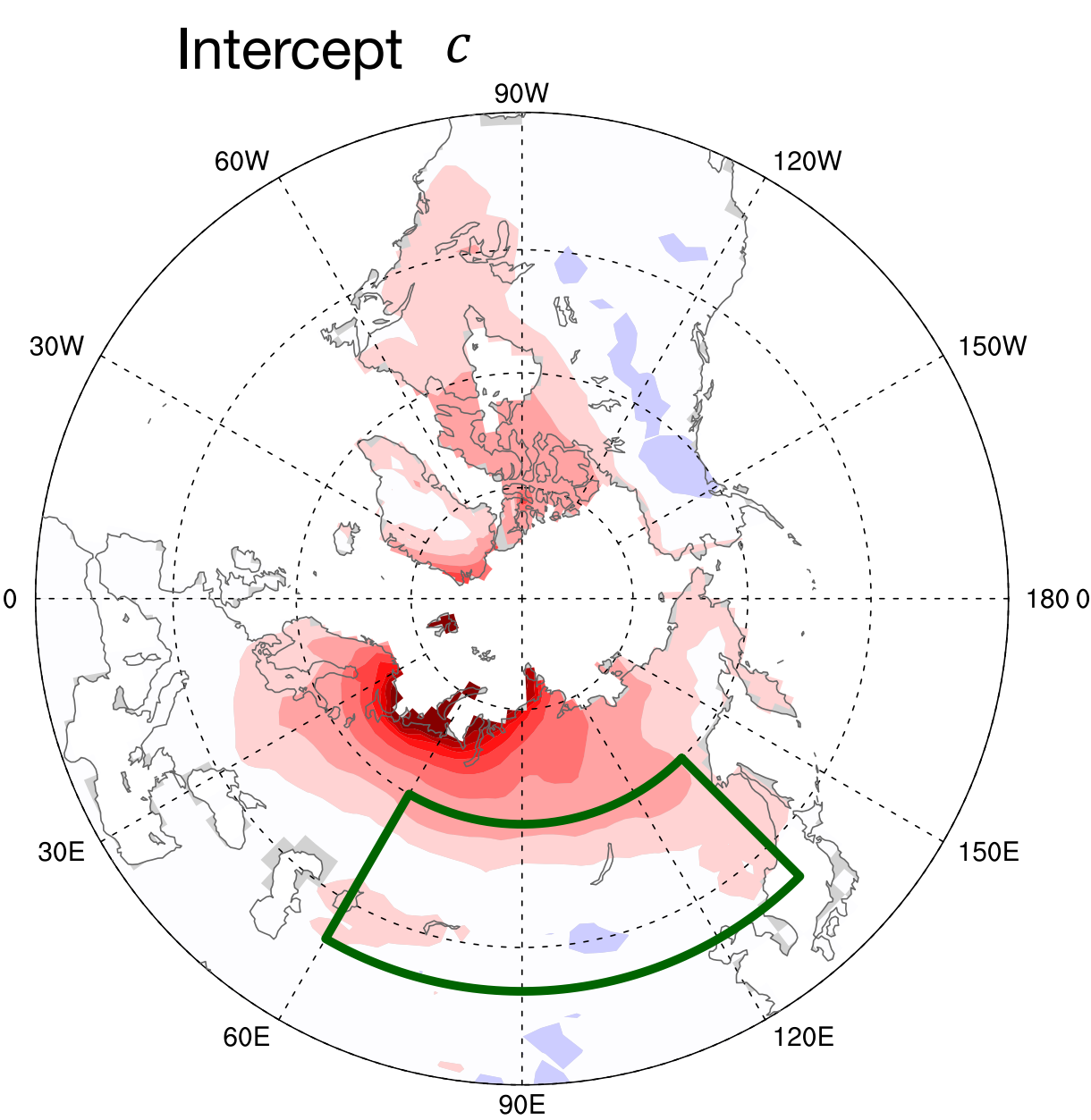
WACCM4 Simulations



Stratospheric dynamics

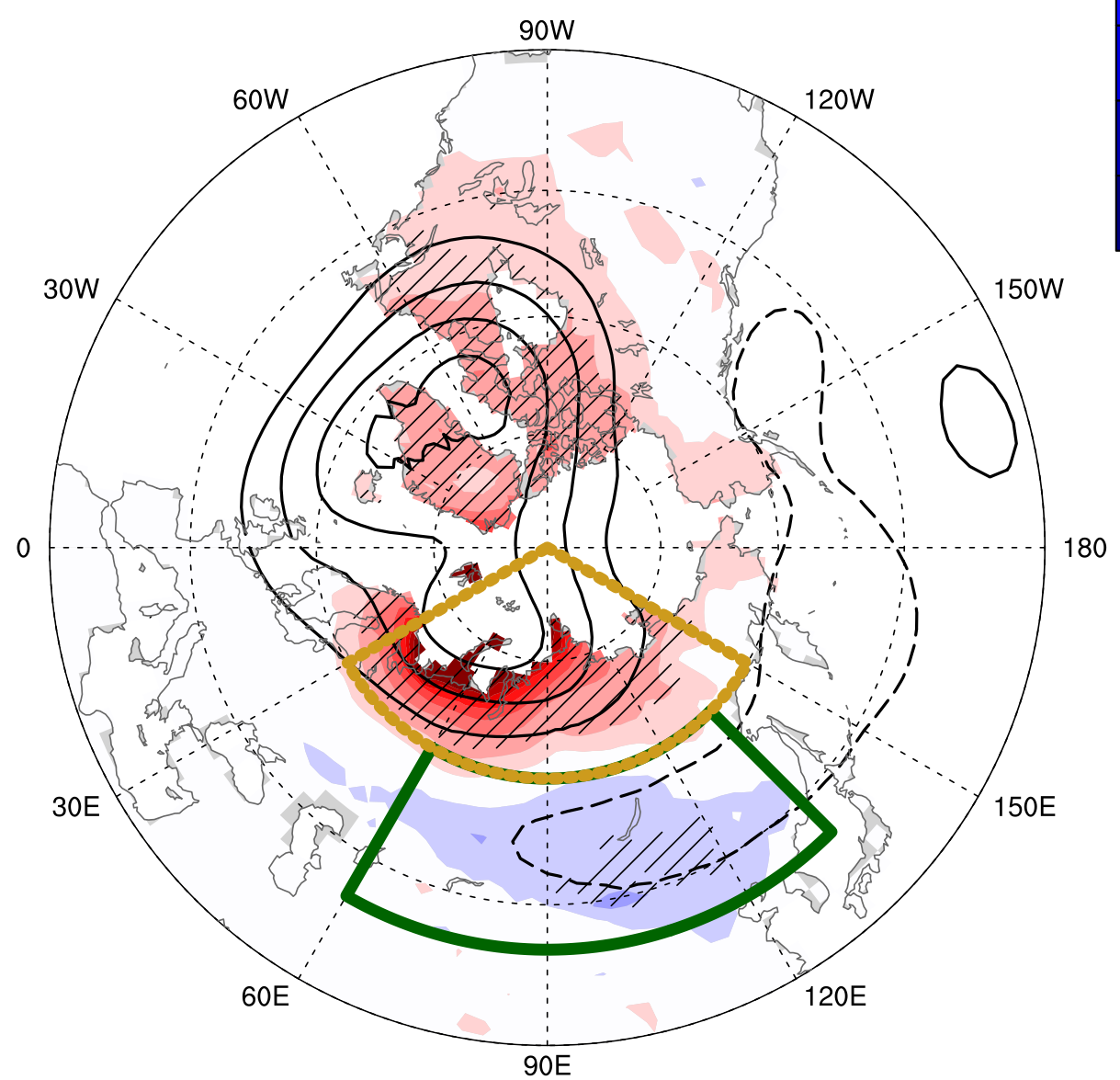
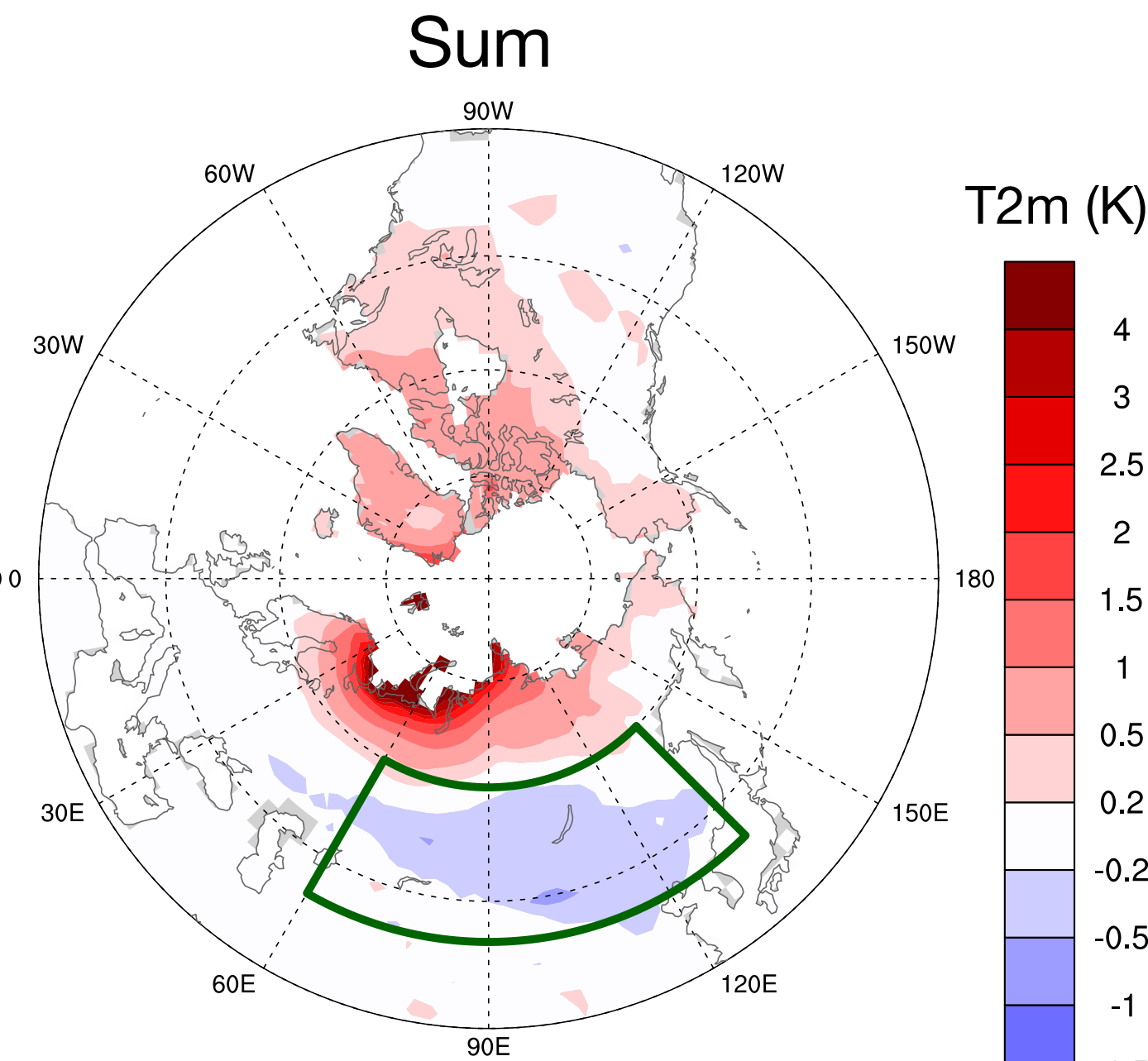


Tropospheric dynamics



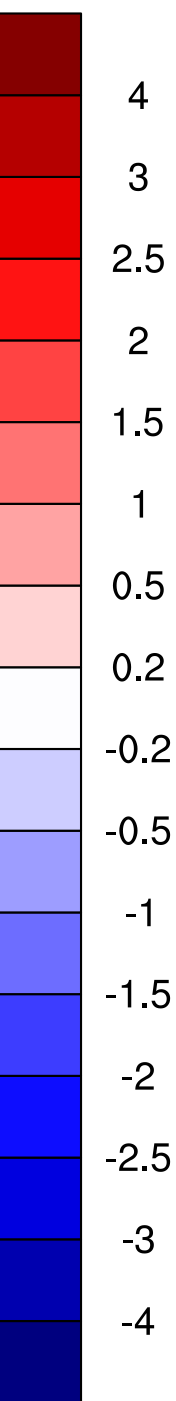
Eddy diffusive transport of warming (induced by sea ice loss)

Tropospheric thermodynamics



T2m response

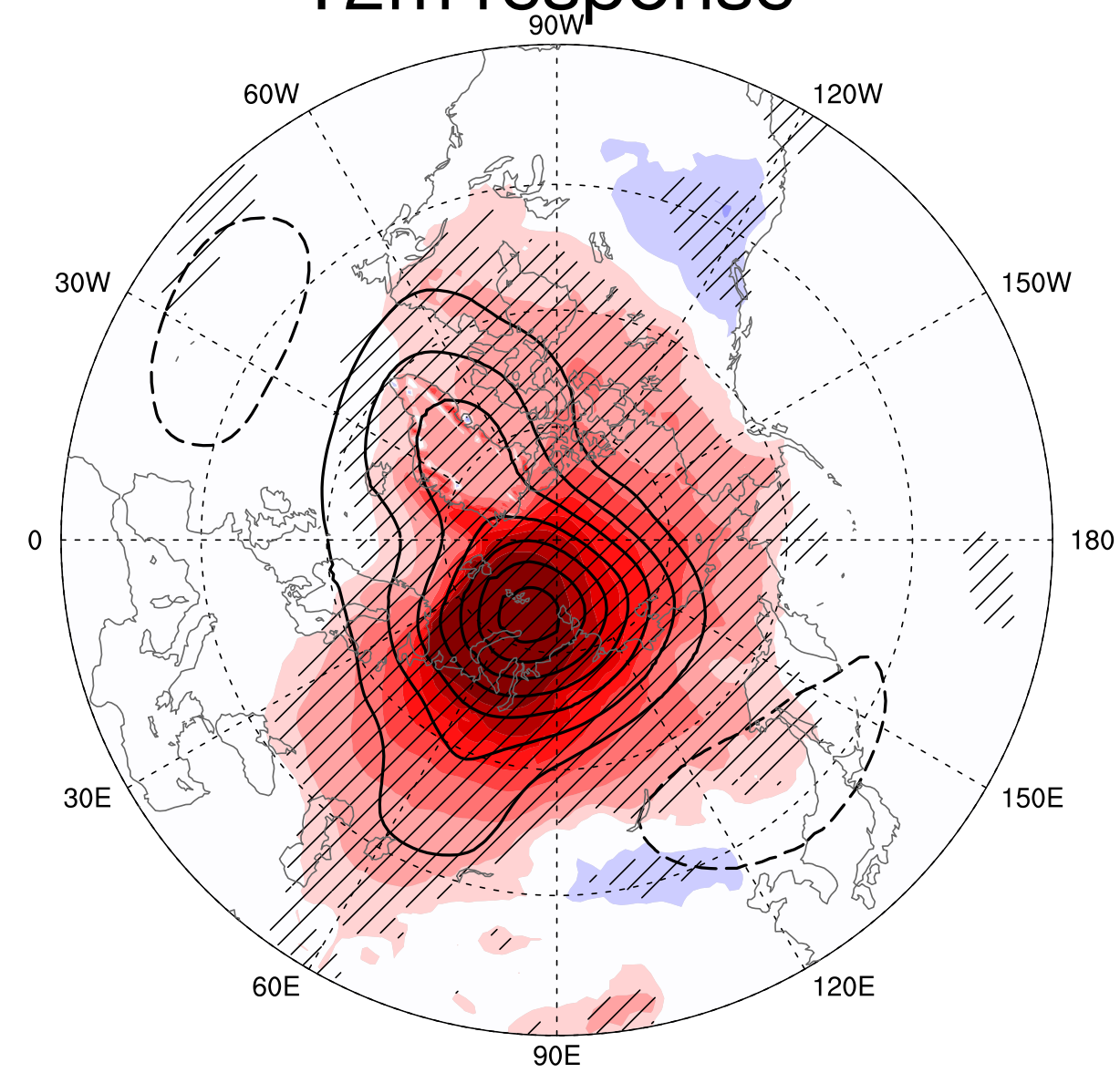
T2m (K)



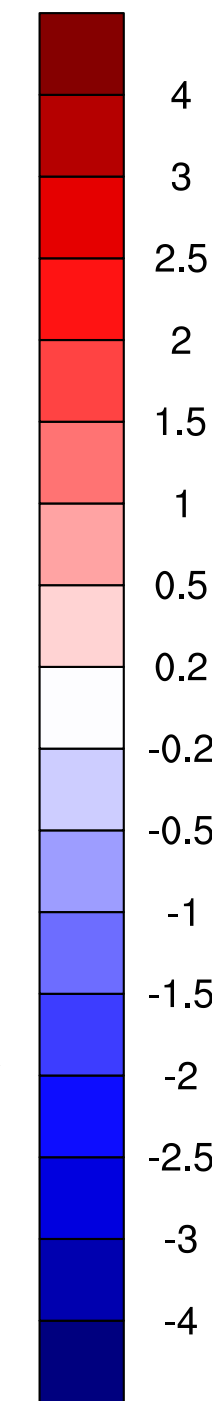
WACCM6 Simulations

2-step regression

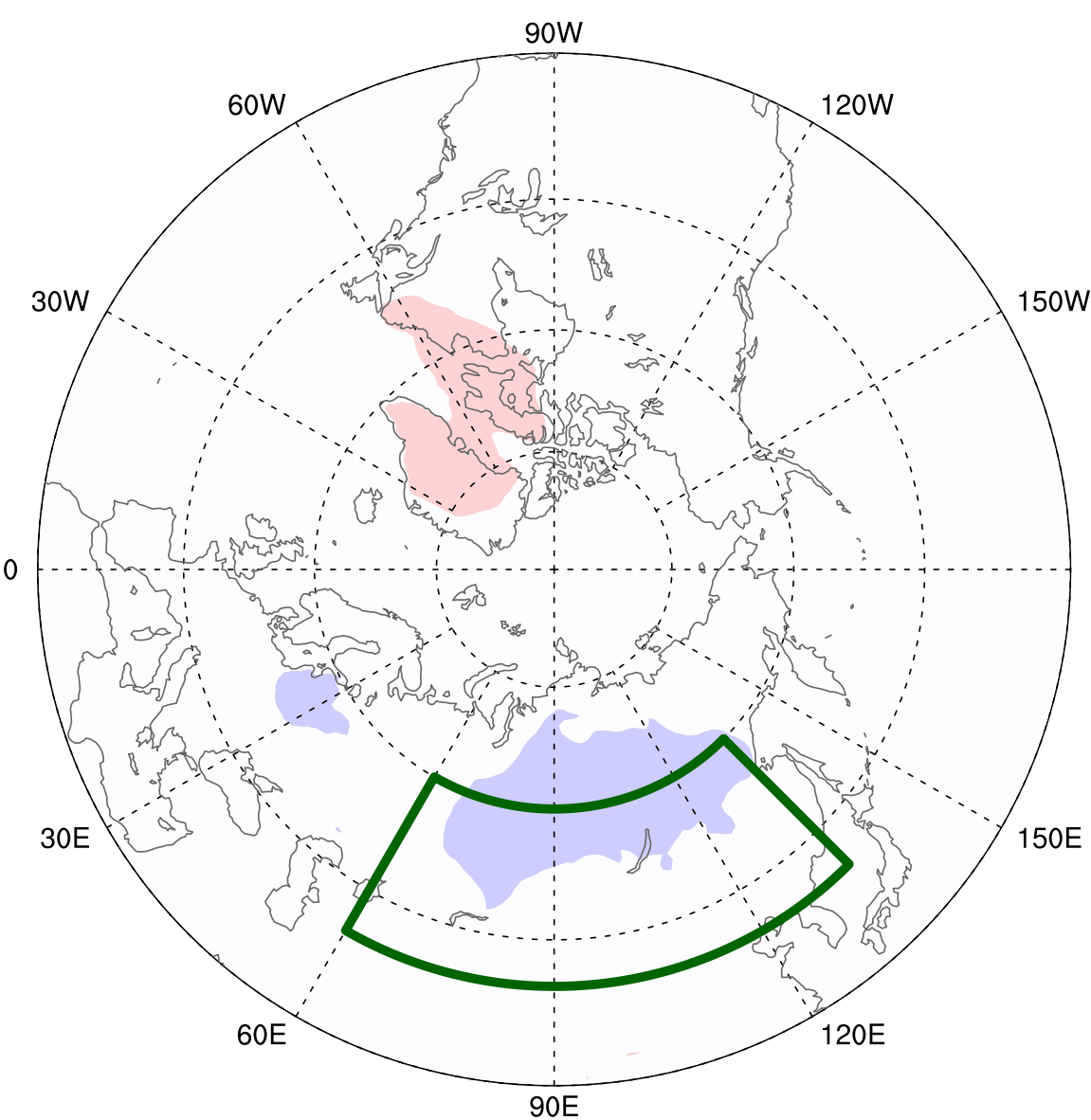
T2m response



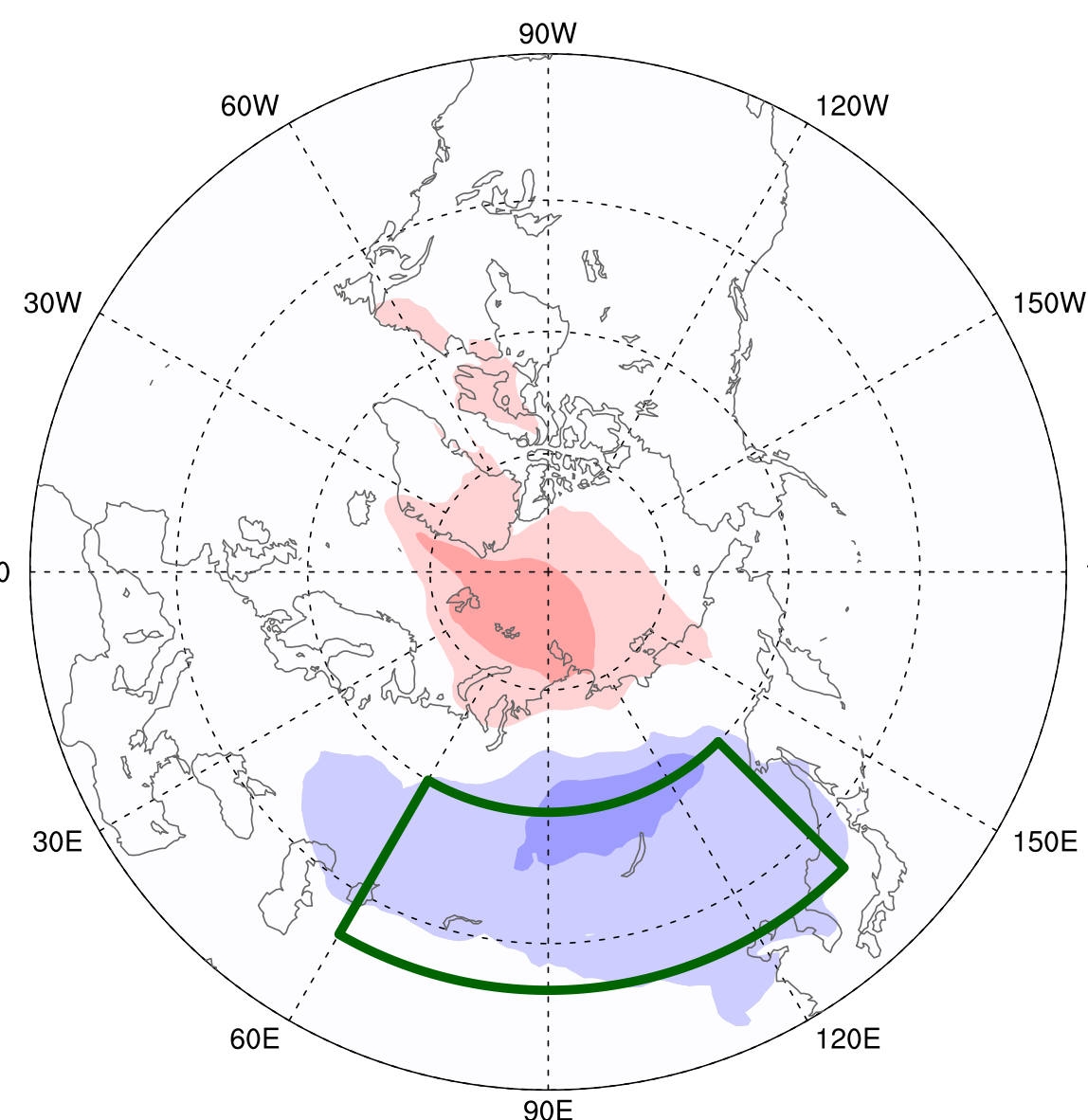
T2m (K)



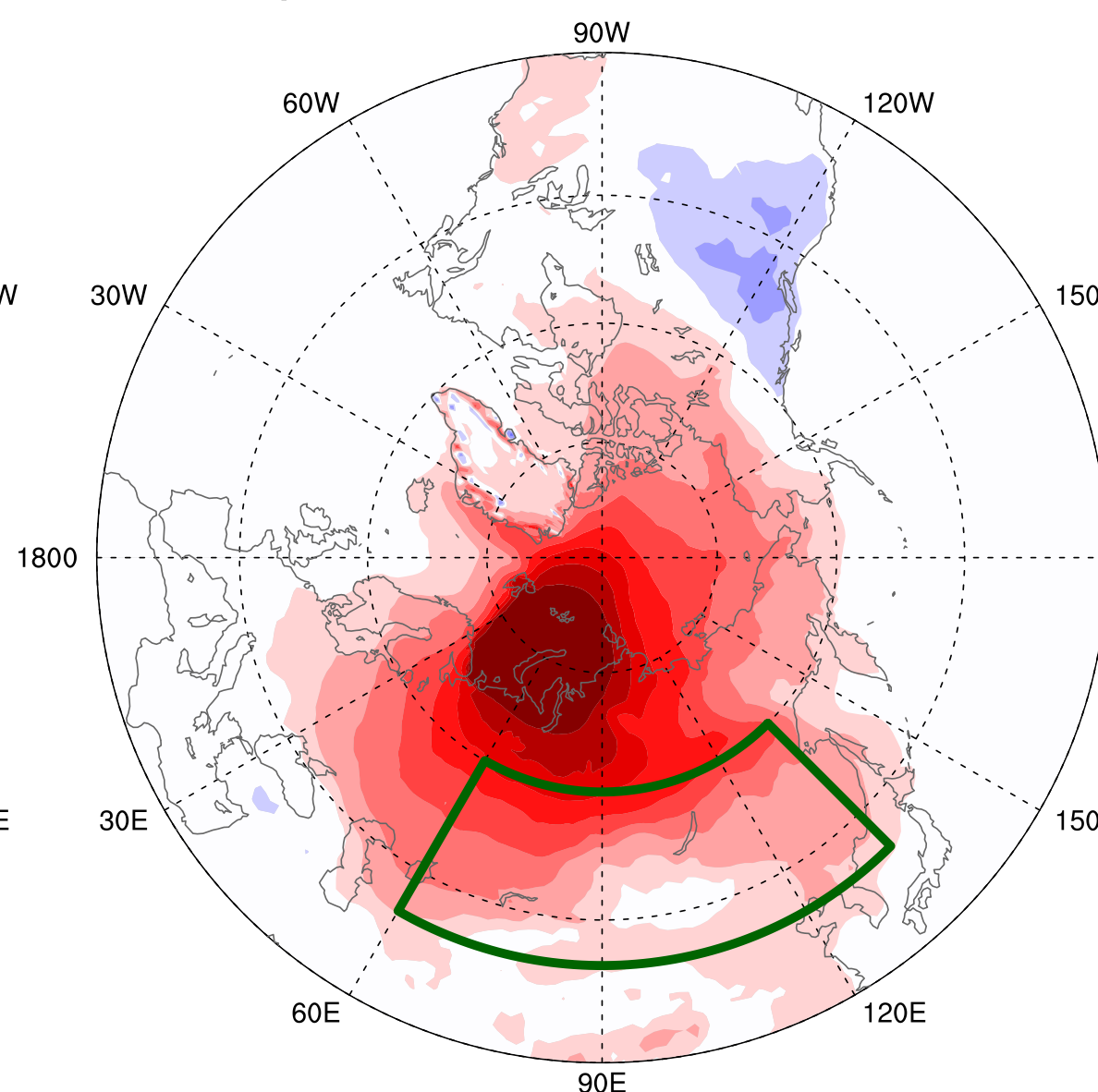
$$a \cdot \overline{\Delta H50_{Arctic}}$$



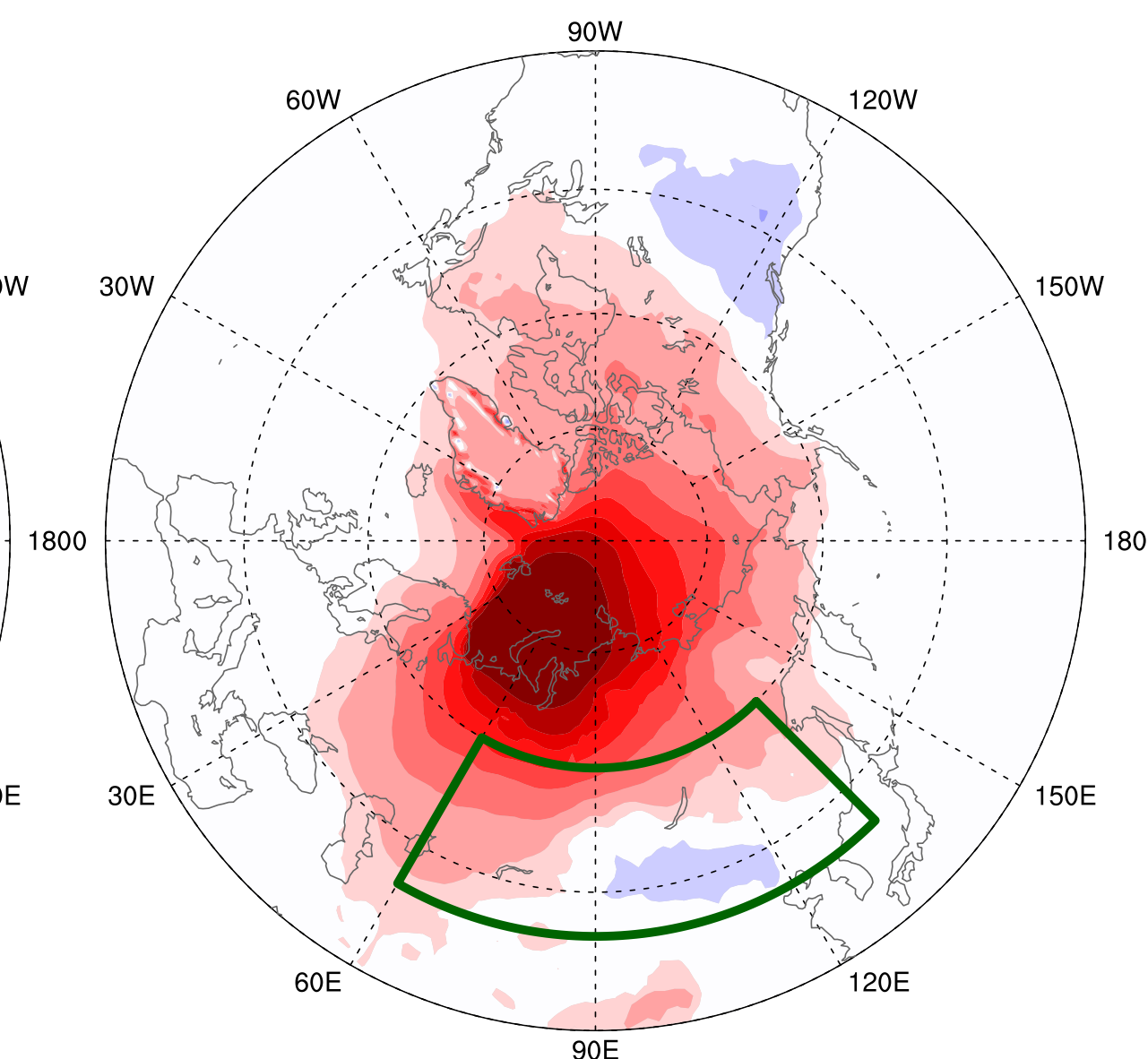
$$b \cdot (\overline{\Delta H50_{BKS}} - d \cdot \overline{\Delta H50_{Arctic}})$$



Intercept c



$$a \cdot \overline{\Delta H50_{Arctic}} + b \cdot (\overline{\Delta H50_{BKS}} - d \cdot \overline{\Delta H50_{Arctic}}) + c$$



Stratospheric dynamics

Tropospheric dynamics

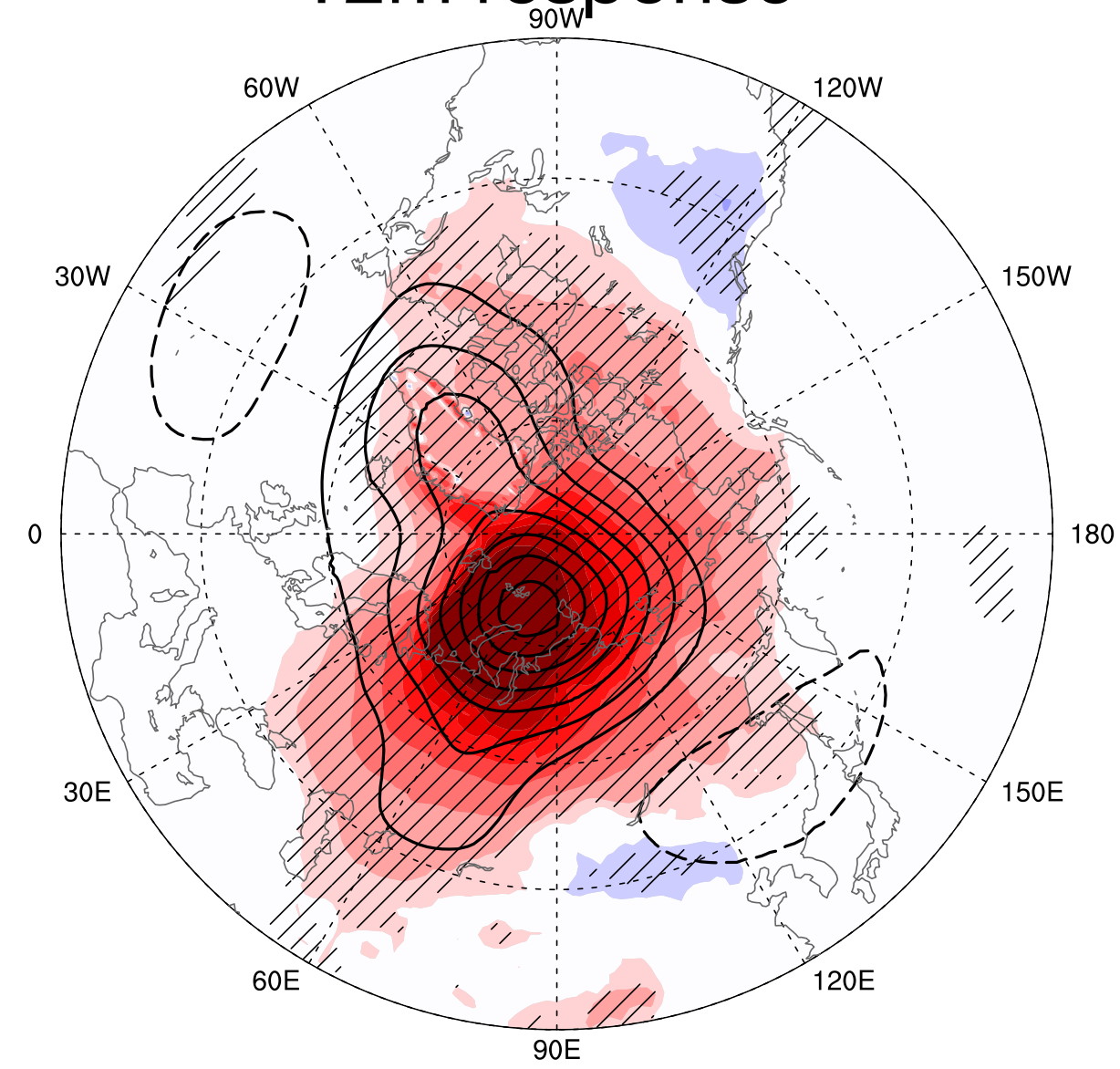
Tropospheric thermodynamics

Sum

WACCM6 Simulations

2-step regression

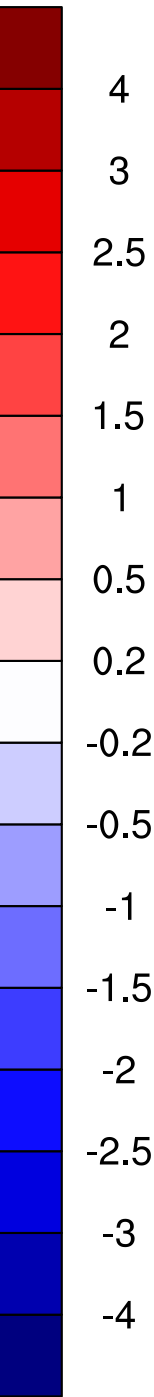
T2m response



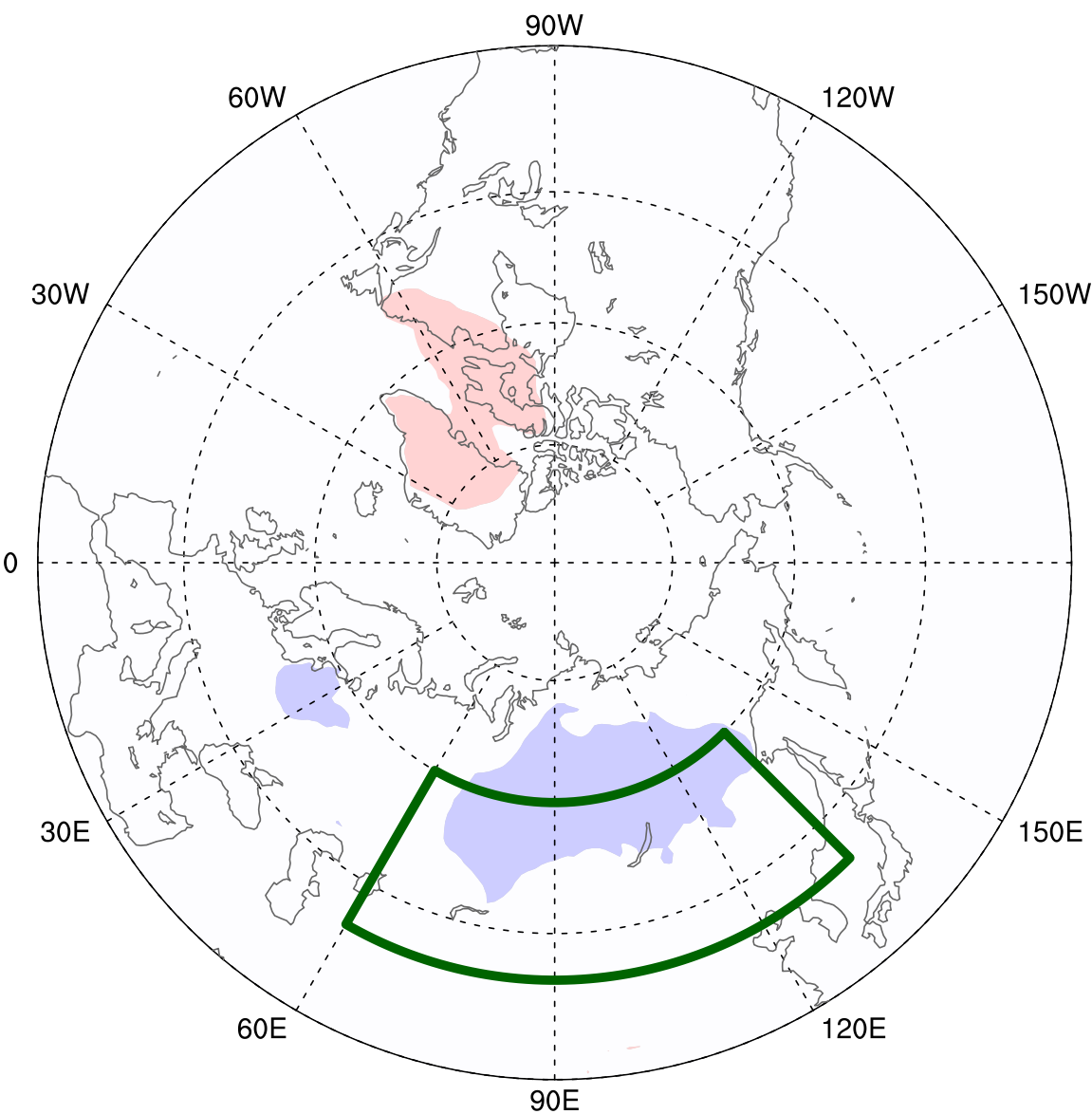
Stronger and extends more equator-ward versus WACCM4

Overwhelms the cooling signal

T2m (K)

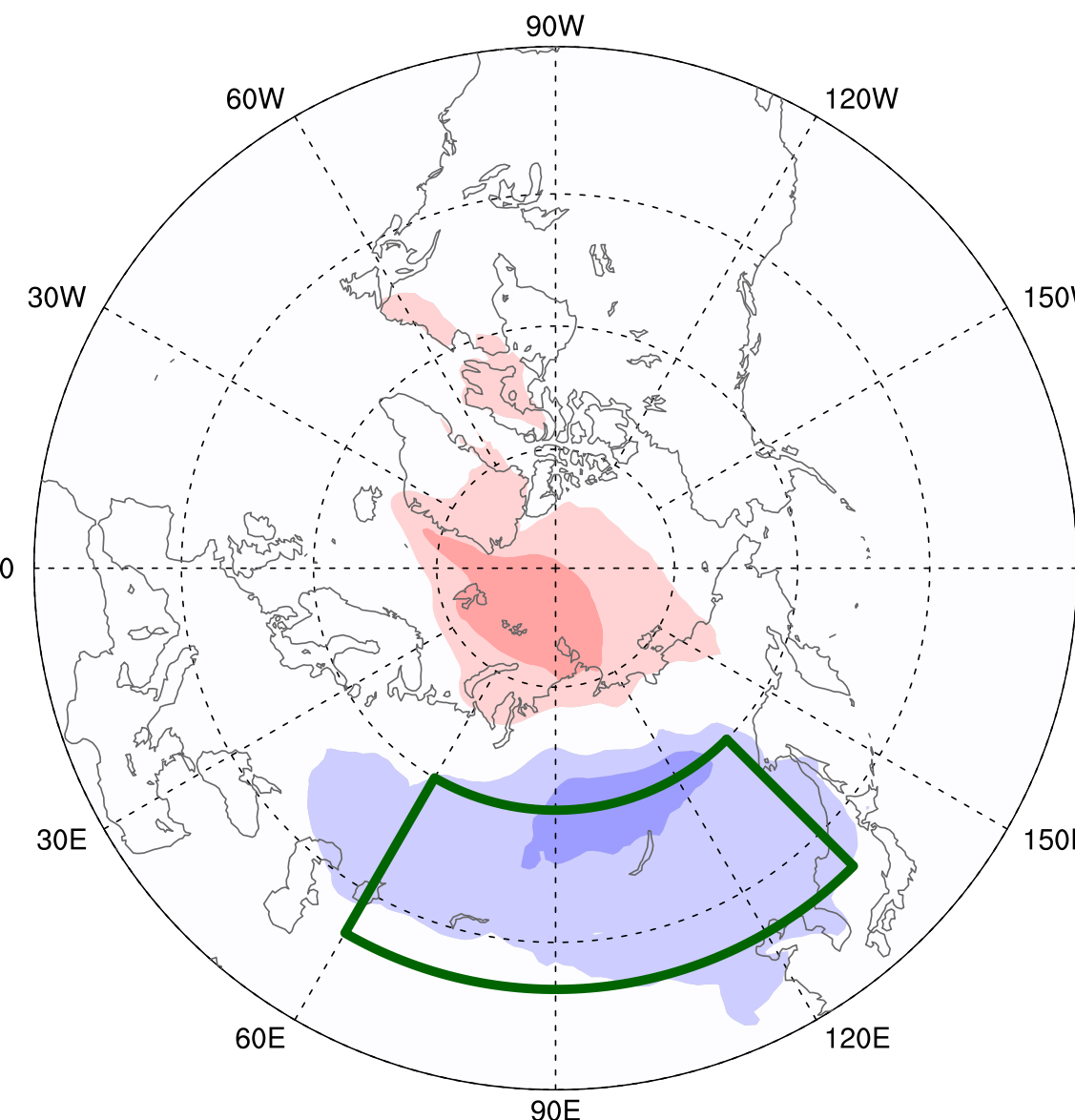


$$a \cdot \overline{\Delta H50_{Arctic}}$$



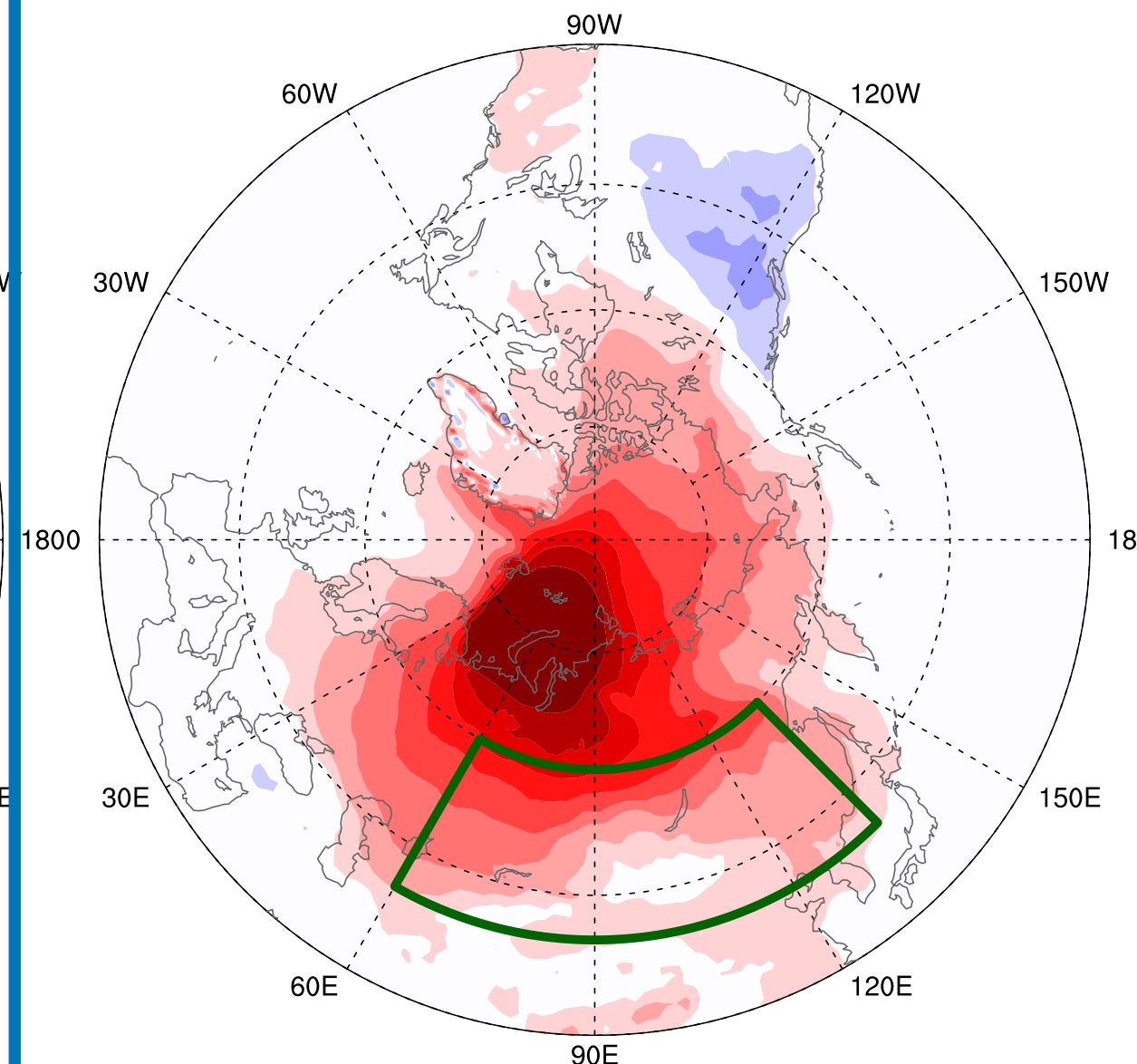
Stratospheric dynamics

$$b \cdot (\overline{\Delta H500_{BKS}} - d \cdot \overline{\Delta H50_{Arctic}})$$



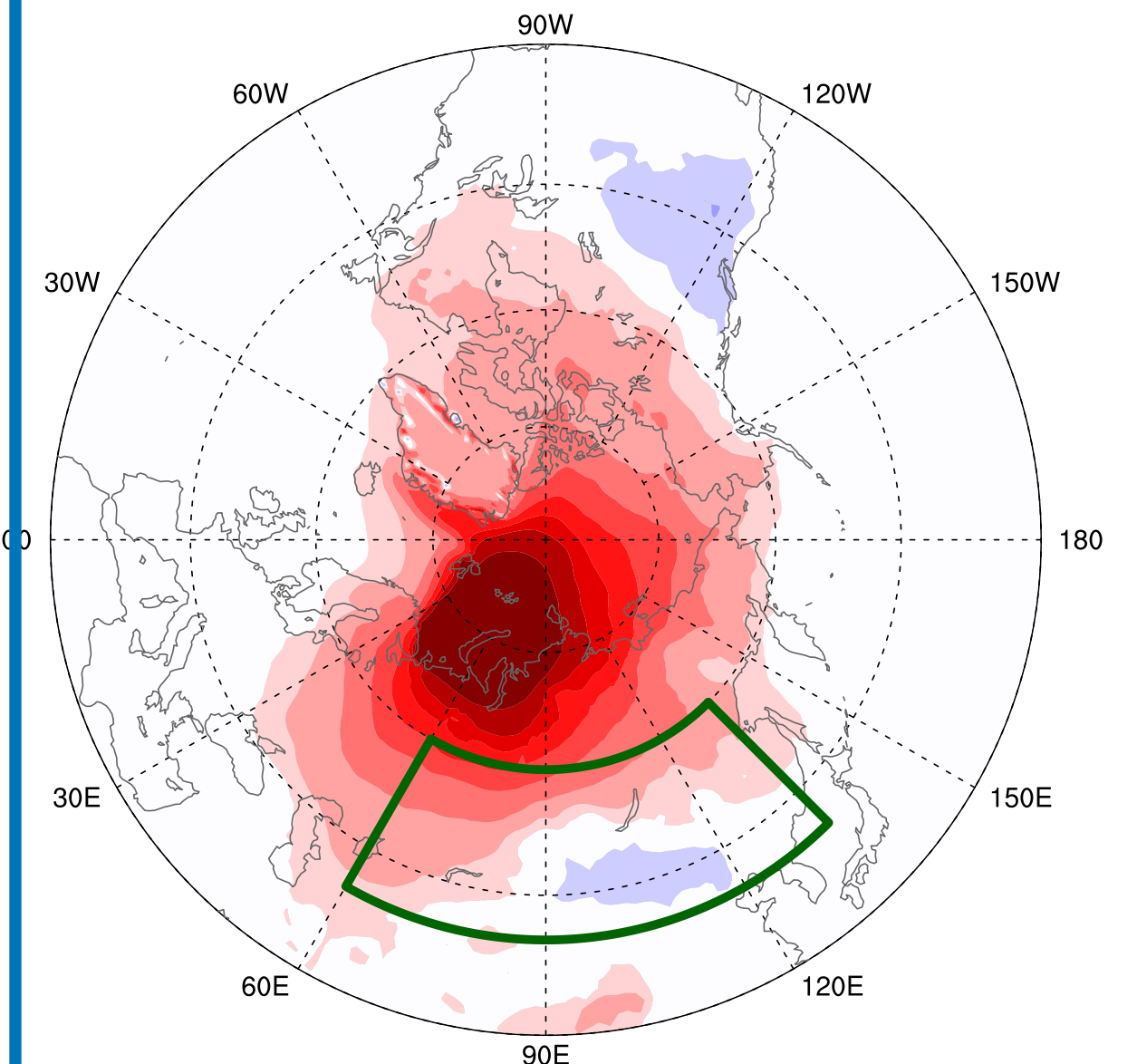
Tropospheric dynamics

Intercept c



Tropospheric thermodynamics

$$a \cdot \overline{\Delta H50_{Arctic}} + b \cdot (\overline{\Delta H500_{BKS}} - d \cdot \overline{\Delta H50_{Arctic}}) + c$$



Sum

WACCM4 vs WACCM6

Differences in tropospheric thermodynamics term likely drive the different T2m response in WACCM4 and WACCM6.
Diffusive warming extends further equatorward in WACCM6

Currently, it is not clear what (model physics) is driving the differences between WACCM4 and WACCM6...particularly for the tropospheric thermodynamics term.

Land model improvement in CESM2?

Cold bias over high latitude continents in CESM1 which reduces the diffusive transport of the warming?

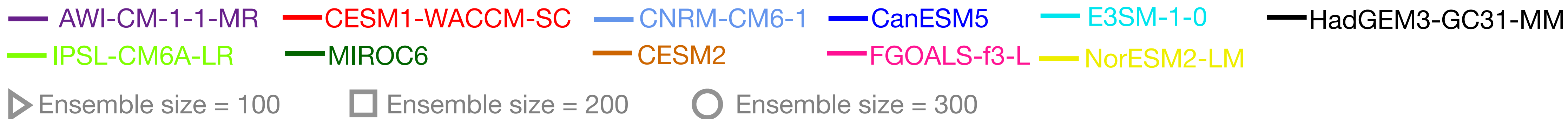
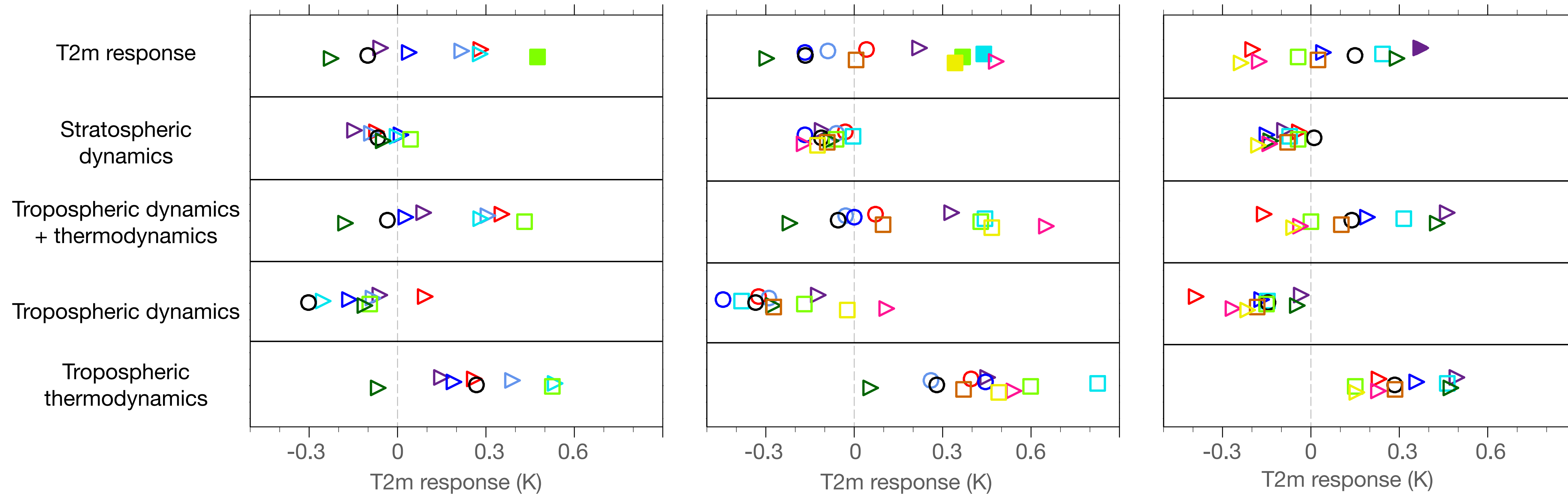
Other possibilities? Within the atmospheric component? Surface interactions between the atmospheric model and sea ice?

CMIP6 (PAMIP experiments)

Reduce sea ice in BKS

Reduce sea ice in the Arctic
2°C warming versus present-day

Reduce sea ice in the Arctic
present-day versus pre-industrial

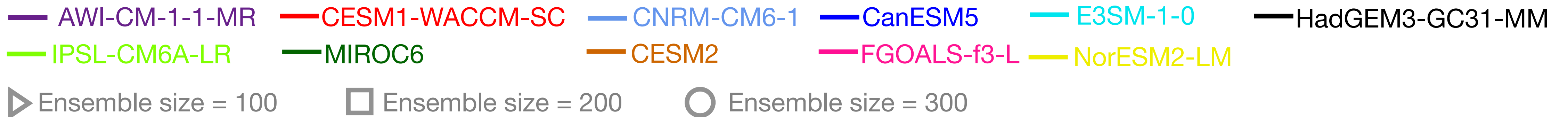
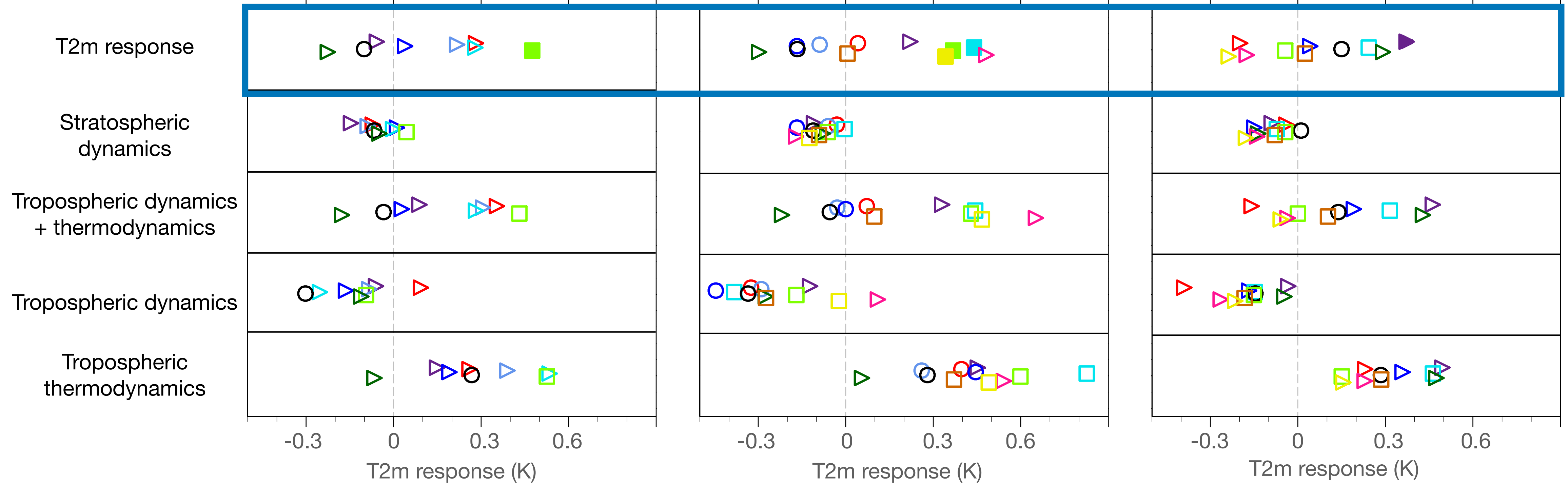


CMIP6 (PAMIP experiments)

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CMIP6 (PAMIP experiments)

Reduce sea ice in BKS

Reduce sea ice in the Arctic
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Reduce sea ice in the Arctic
present-day versus pre-industrial

T2m response

Stratospheric
dynamics

Tropospheric dynamics
+ thermodynamics

Tropospheric dynamics

Tropospheric
thermodynamics

-0.3 0 0.3 0.6

T2m response (K)

-0.3 0 0.3 0.6

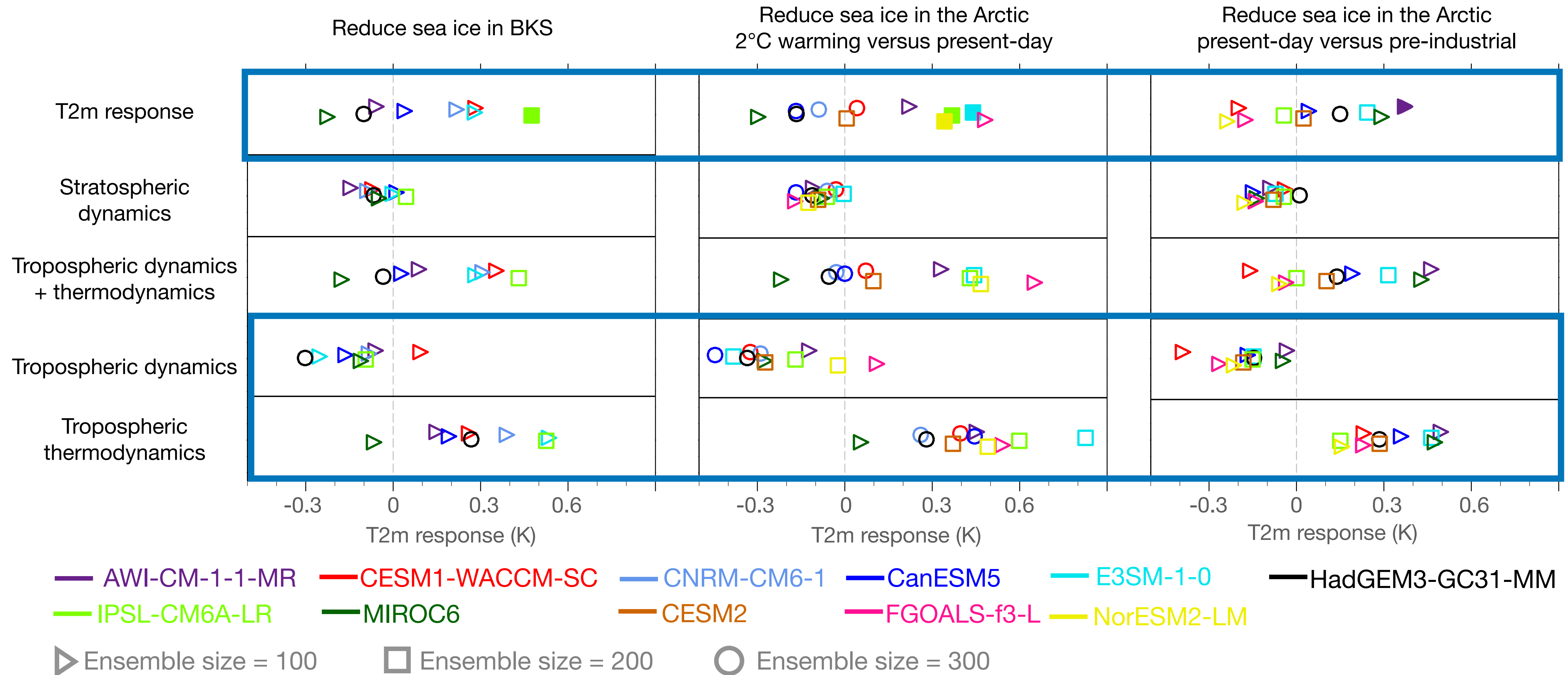
T2m response (K)

-0.3 0 0.3 0.6

T2m response (K)



CMIP6 (PAMIP experiments)



CMIP6 models (no consistent/robust response across different models): T2m response due to sea ice loss (warming or cooling / smaller or larger amplitude), depends on the balance/competition in dynamical cooling and thermodynamical warming

