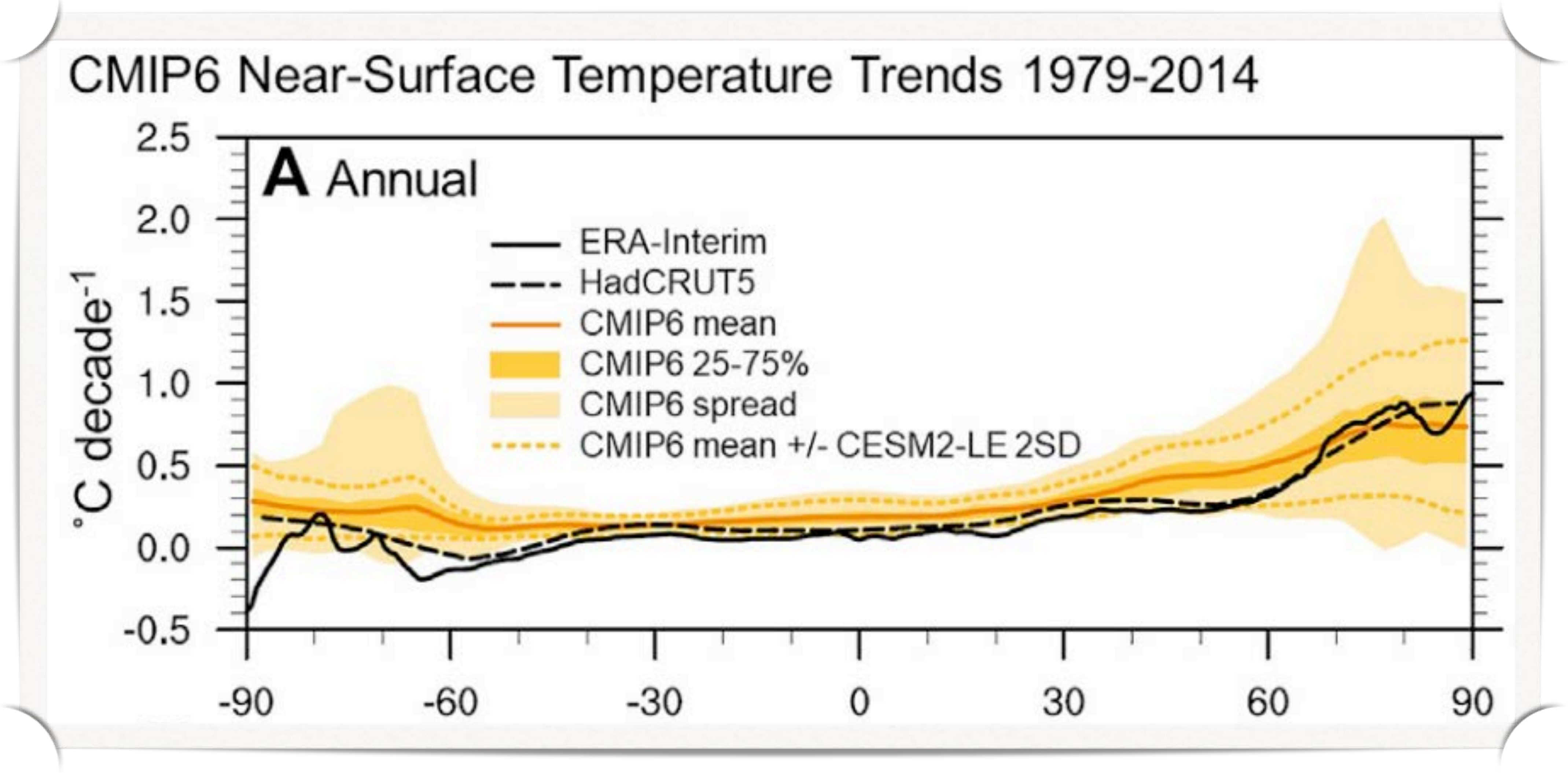
University of Nevada, Reno

Non-local impacts of observed and projected high-latitude climate change

US CLIVAR Polar Amplification Workshop 2024

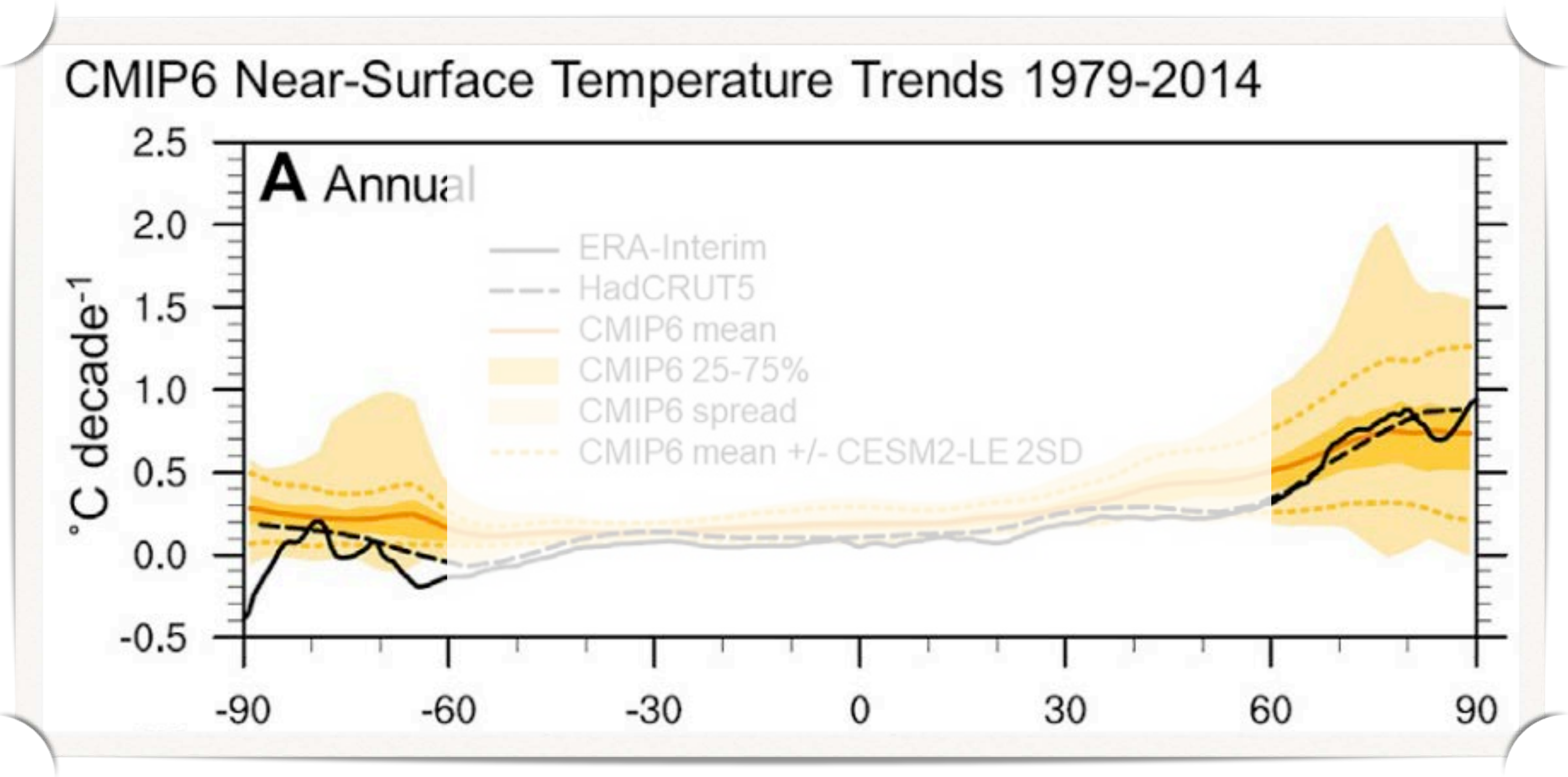
Xiyue (Sally) Zhang | January 19, 2024

Observed high-latitude climate changes



Hahn et al. (2021); Smith et al. (2019); NSIDC; Rignot et al. (2019)

Observed high-latitude climate changes



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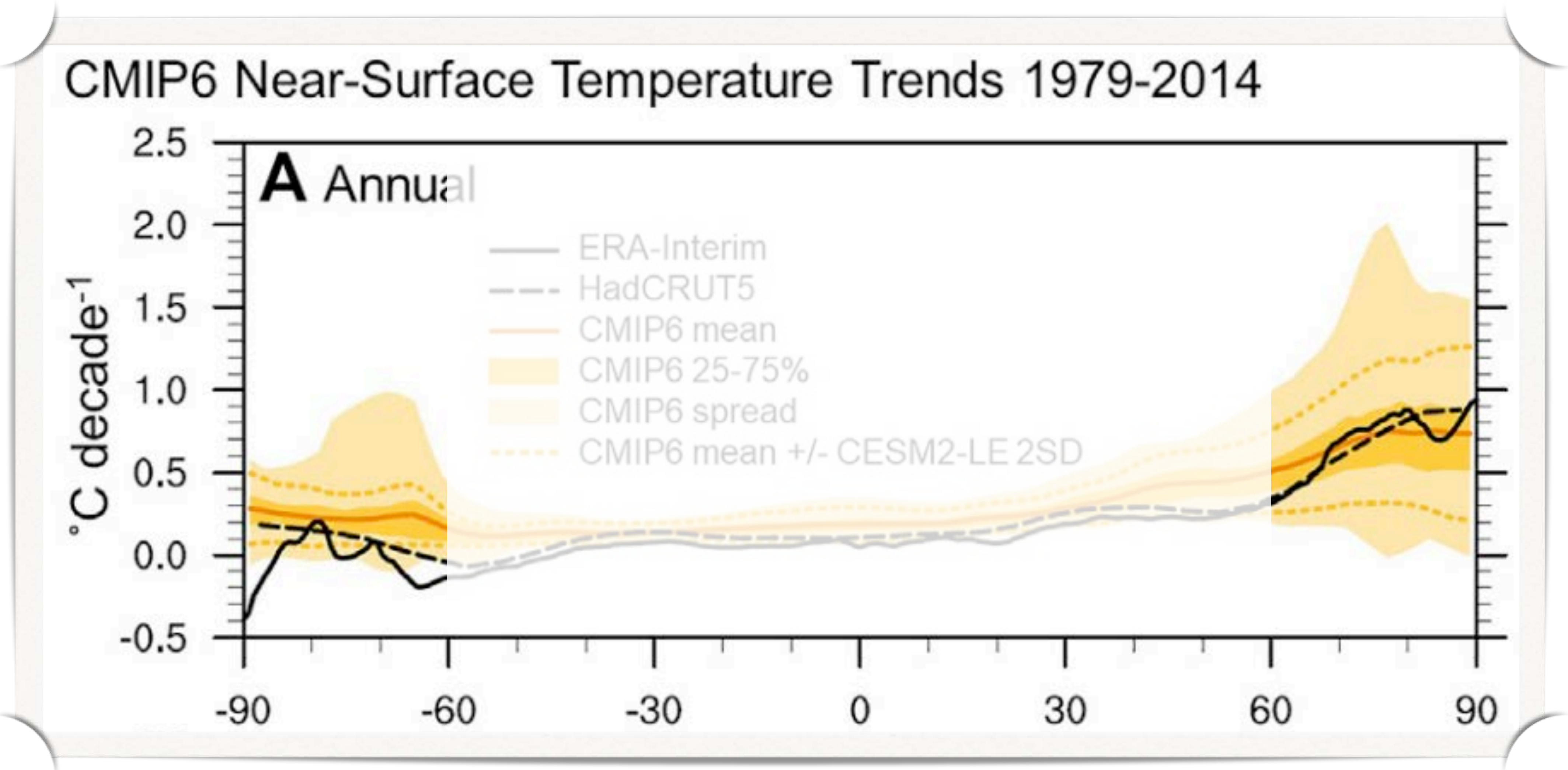
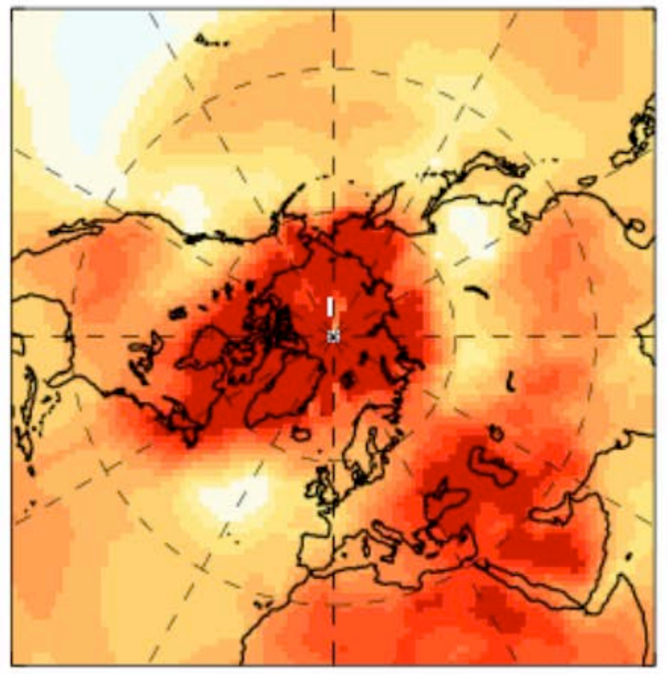
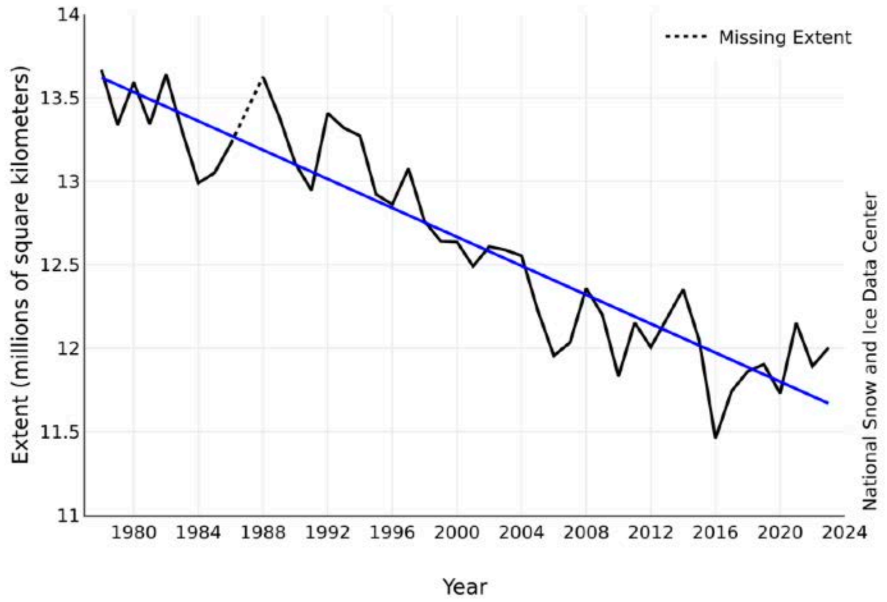


Arctic amplified warming



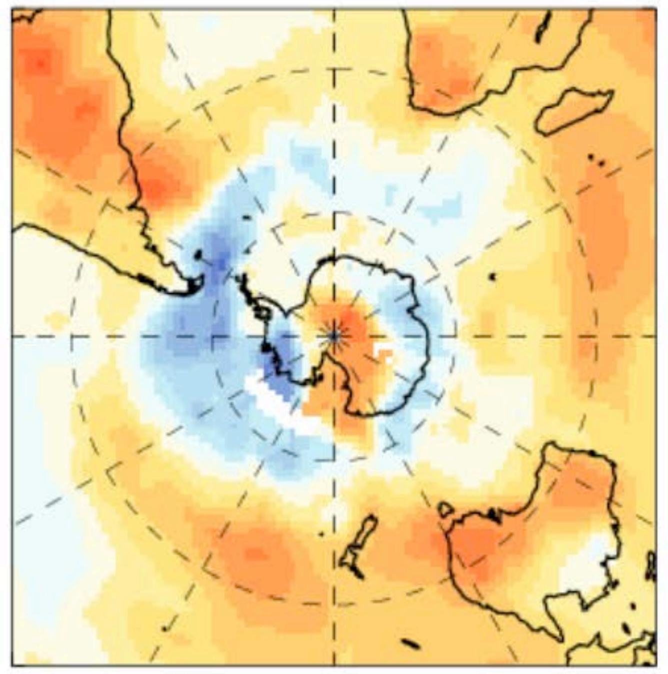
Arctic sea ice loss



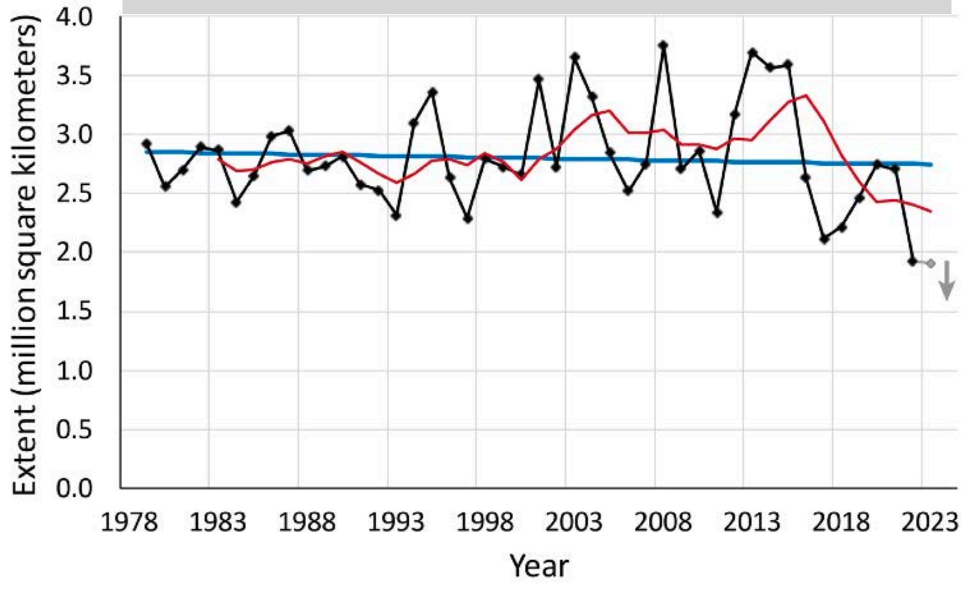
Hahn et al. (2021); Smith et al. (2019); NSIDC; Rignot et al. (2019)

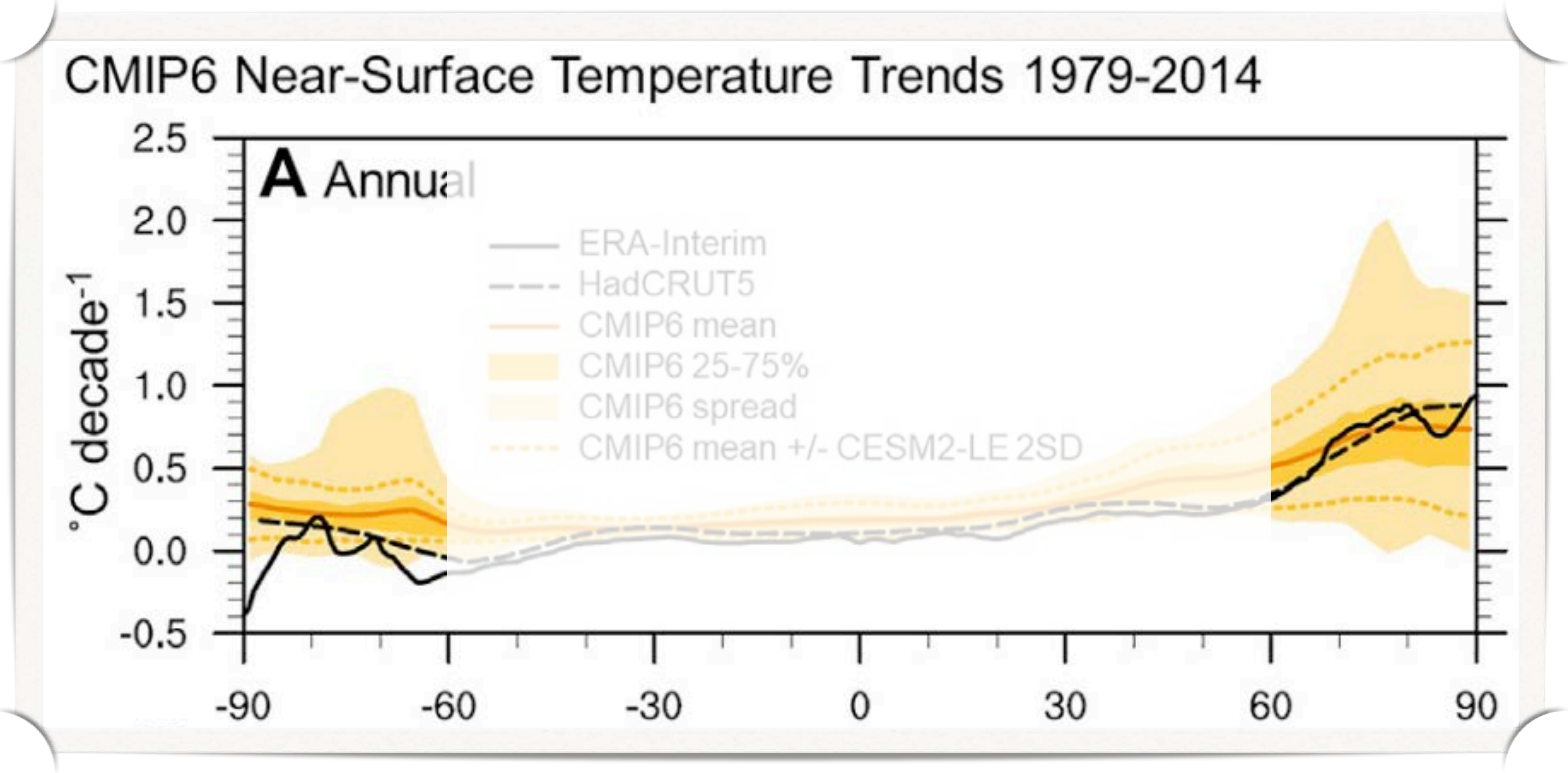
Observed high-latitude climate changes

Southern Ocean cooling

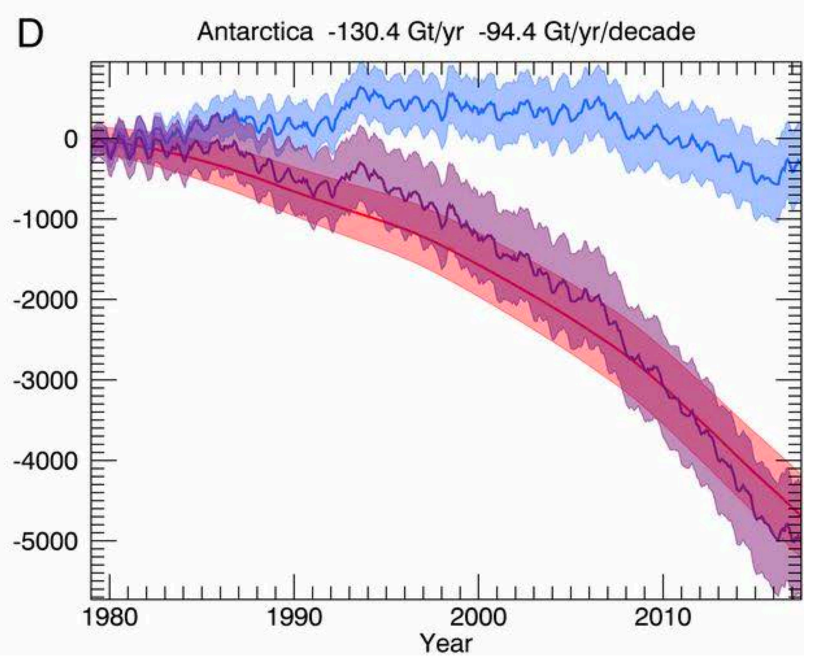


Minimal Antarctic sea ice trends

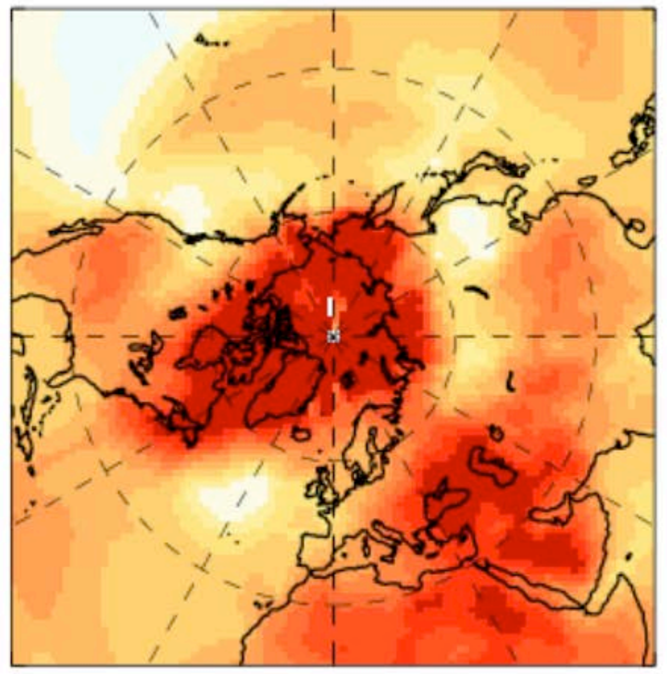




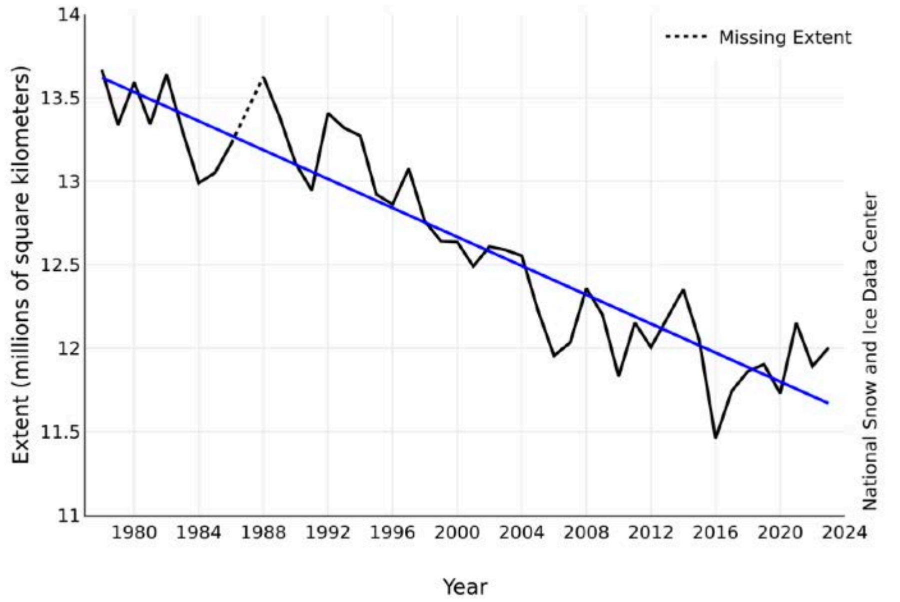
Loss of Antarctica ice mass



Arctic amplified warming



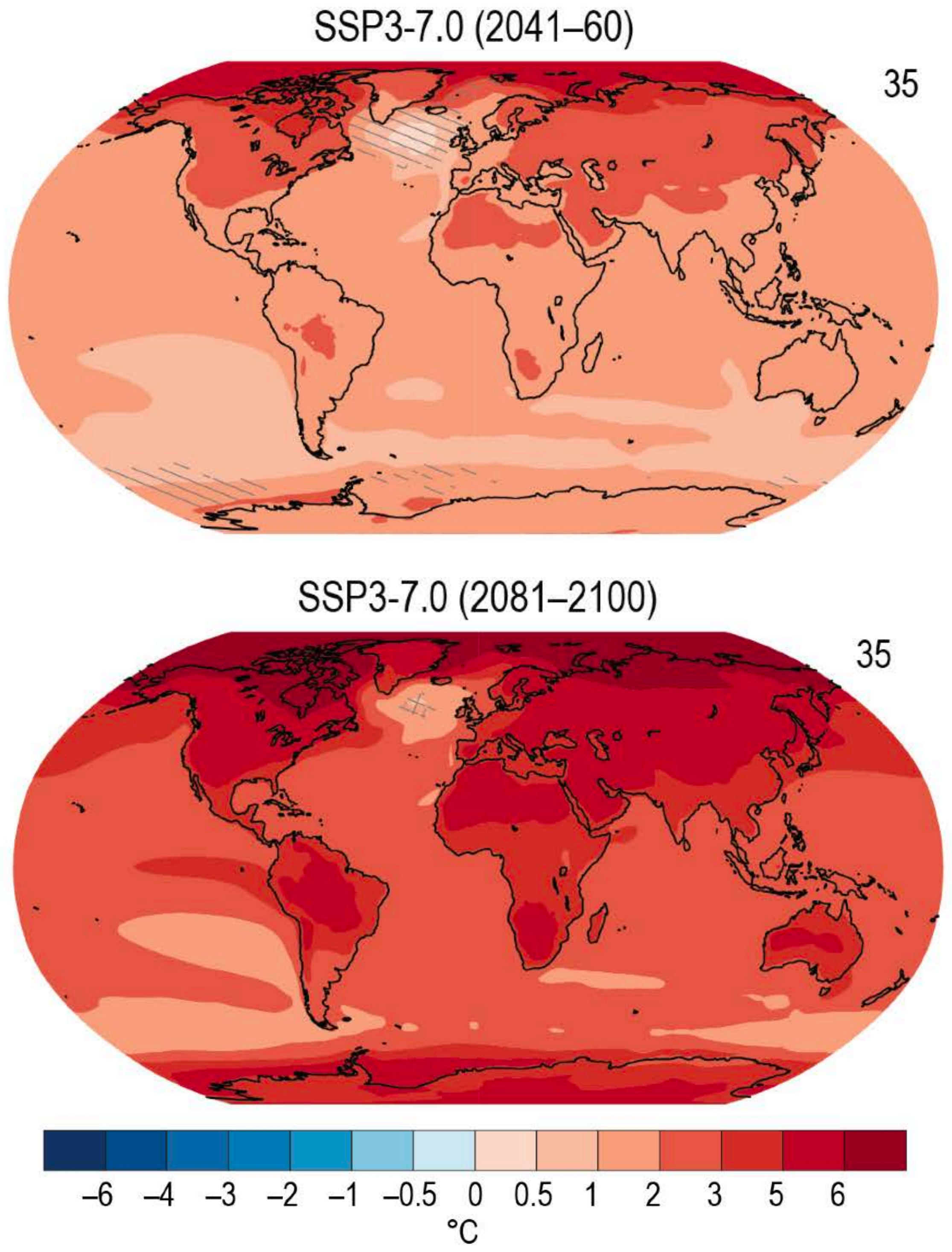
Arctic sea ice loss



Hahn et al. (2021); Smith et al. (2019); NSIDC; Rignot et al. (2019)

Projected high-latitude climate changes

Amplified warming at both poles



Hahn et al. (2021); IPCC AR6 WG1 Ch4; Noël et al. (2023)

Projected high-latitude climate changes

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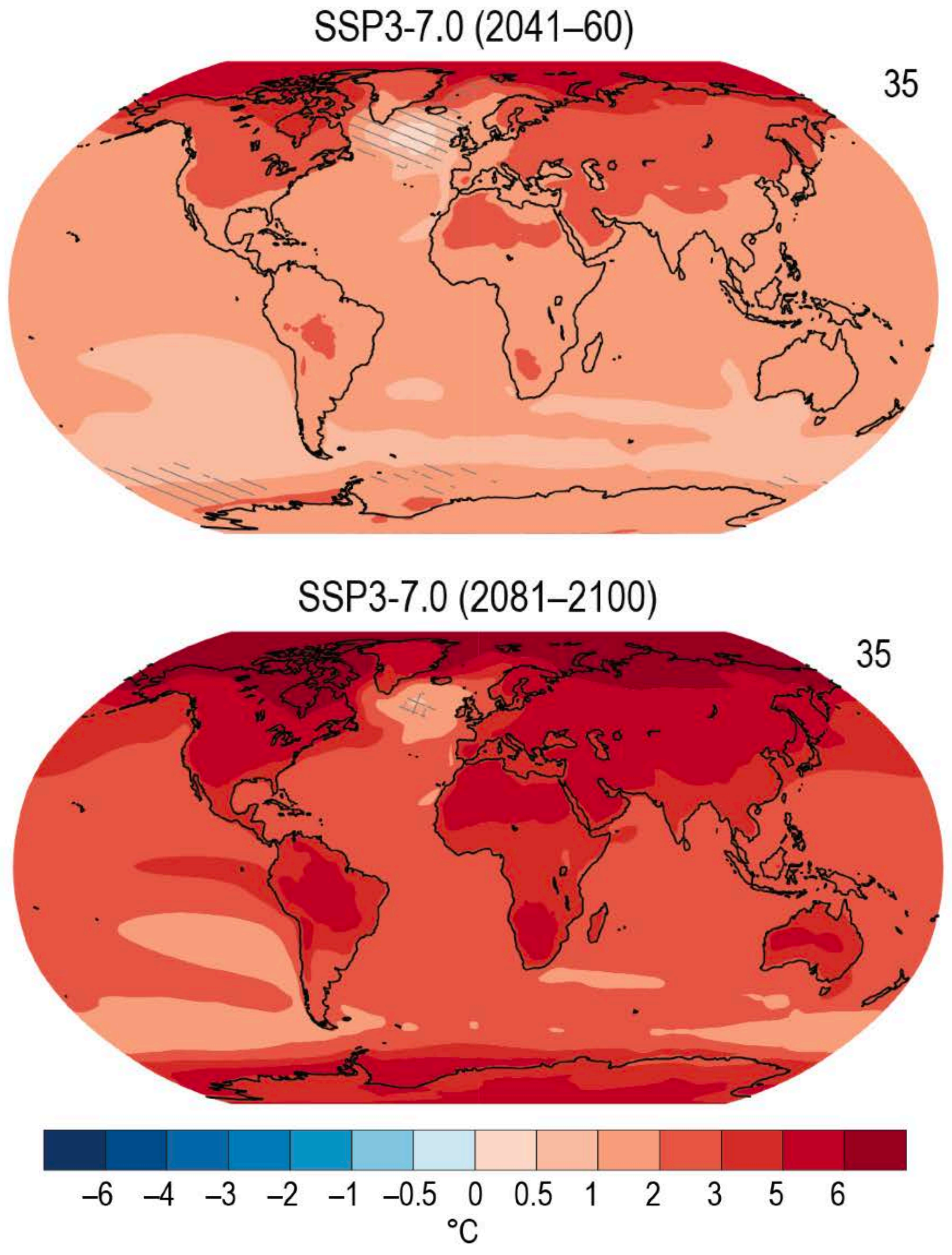
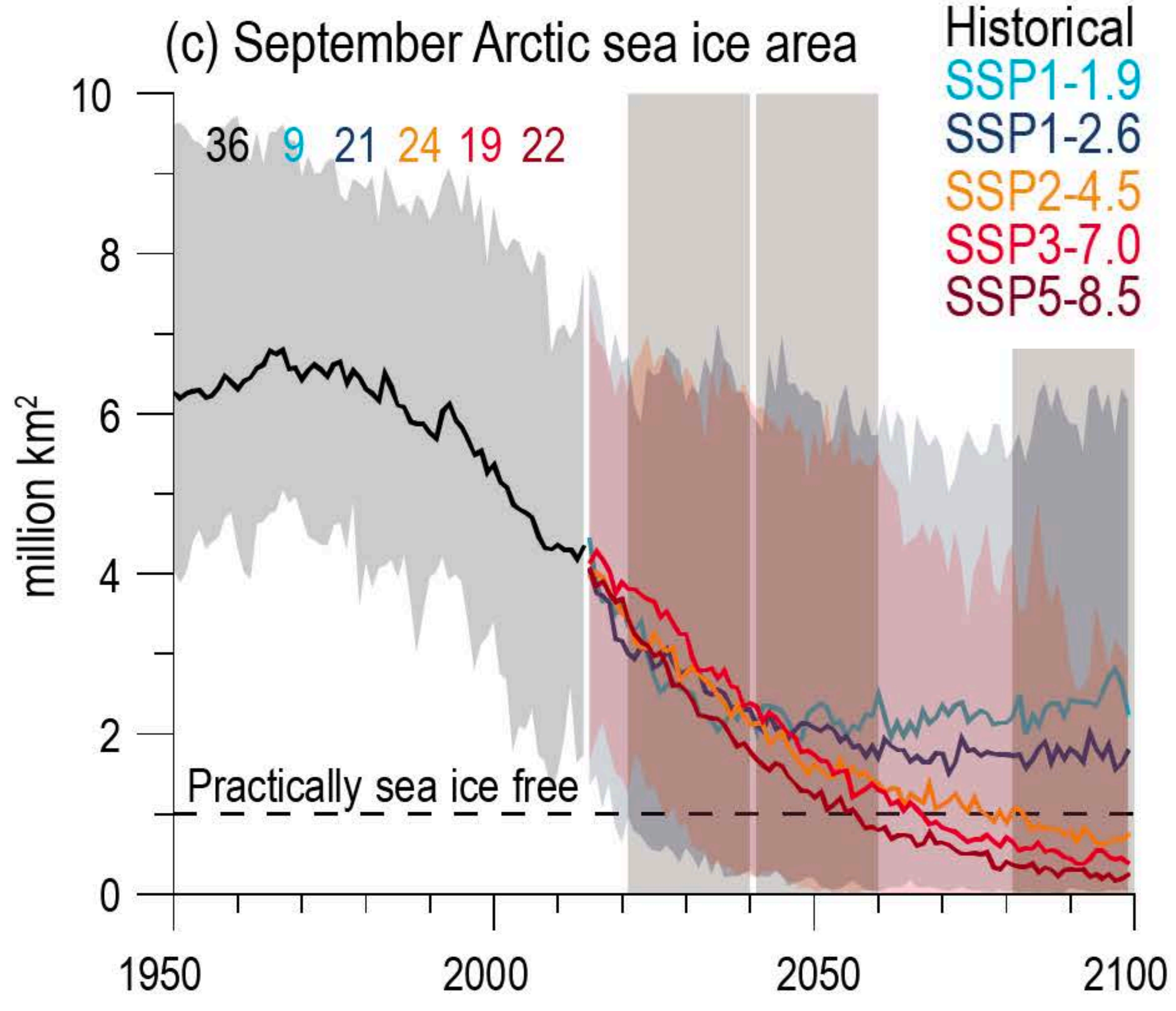


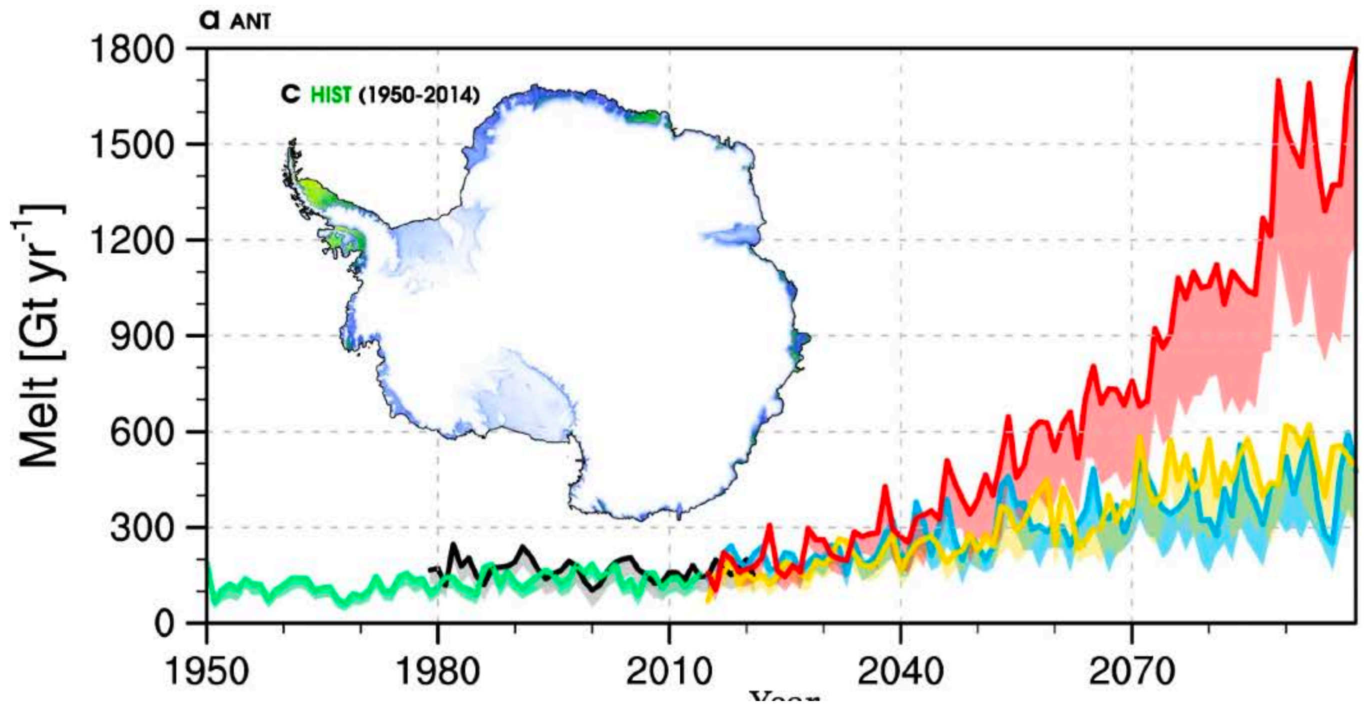
Potentially ice-free Arctic



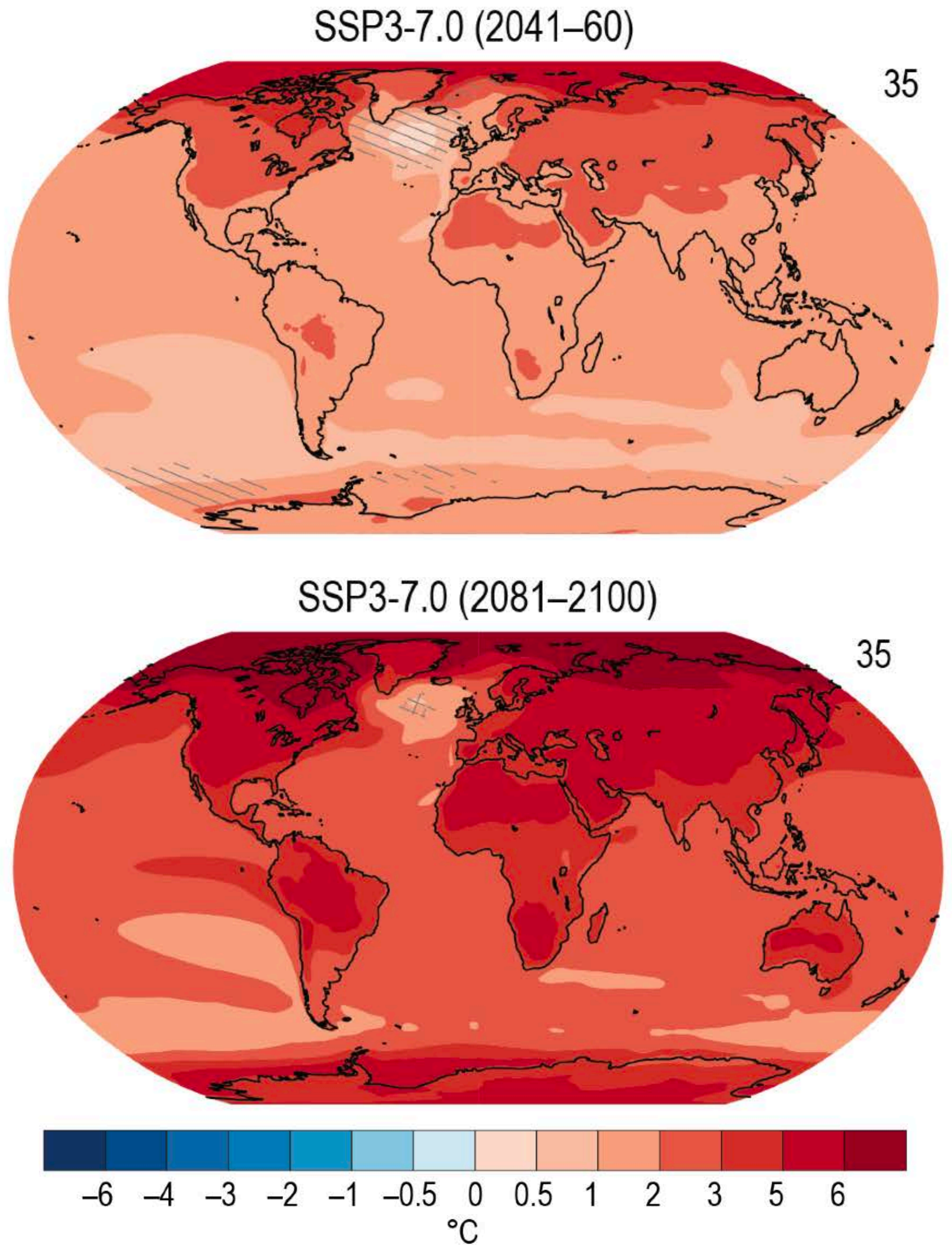
Hahn et al. (2021); IPCC AR6 WG1 Ch4; Noël et al. (2023)

Projected high-latitude climate changes

Increased ice melting from Antarctica



Amplified warming at both poles



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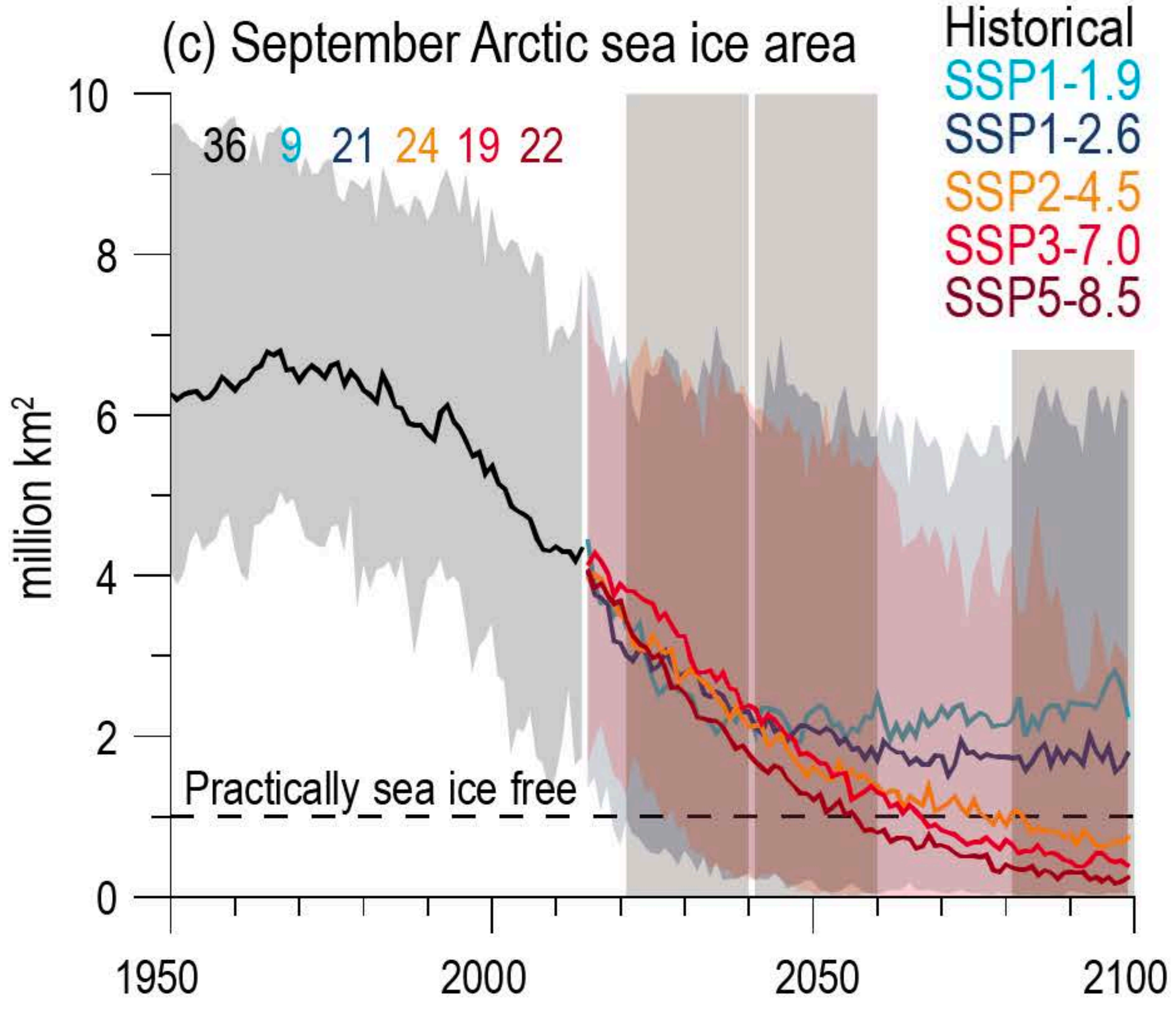


Hahn et al. (2021); IPCC AR6 WG1 Ch4; Noël et al. (2023)

Teleconnection pathways

Perturbation/anomaly at high latitudes

Atmosphere

- Circulation changes due to changes in meridional temperature gradient
- Troposphere-stratosphere interaction

Air-sea interaction

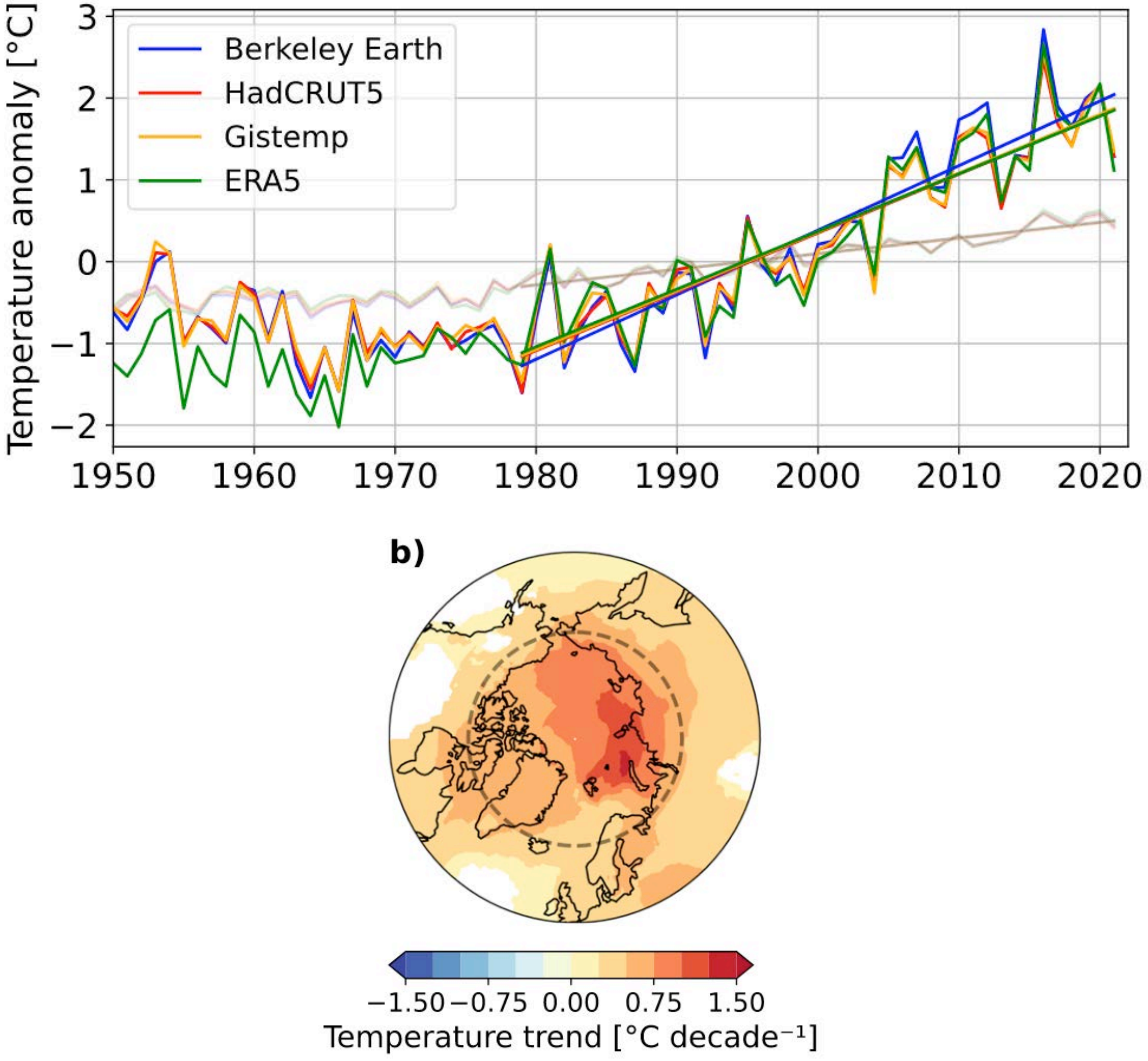
- Wind-evaporation-SST feedback
- Seasonal footprinting mechanism

Ocean

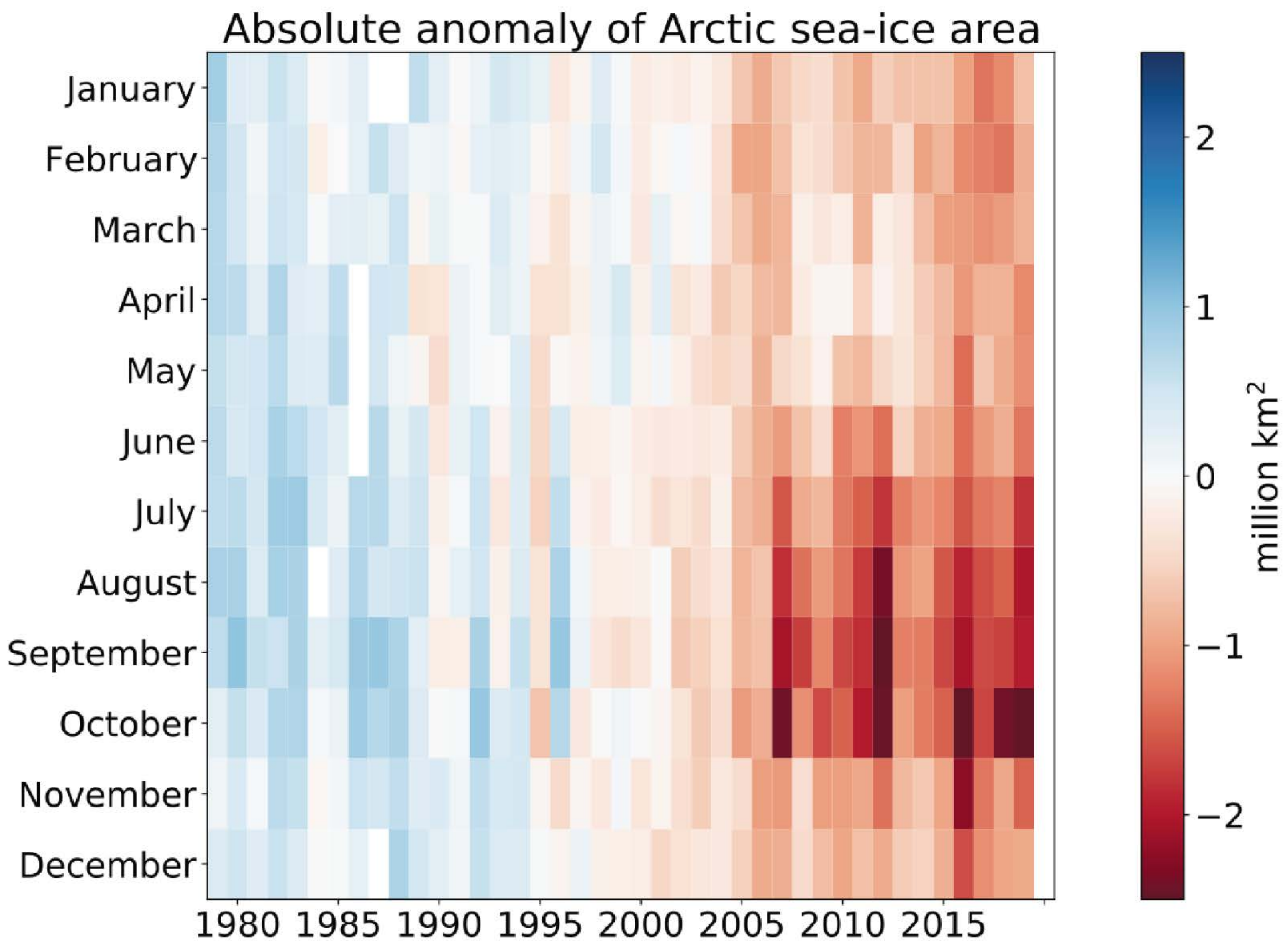
- Deep (overturning) and shallow (gyre, subtropical cell) circulation
- Equatorward ventilation
- Ocean waves

Liu and Alexander (2007)

Observed warming and sea ice loss in the Arctic



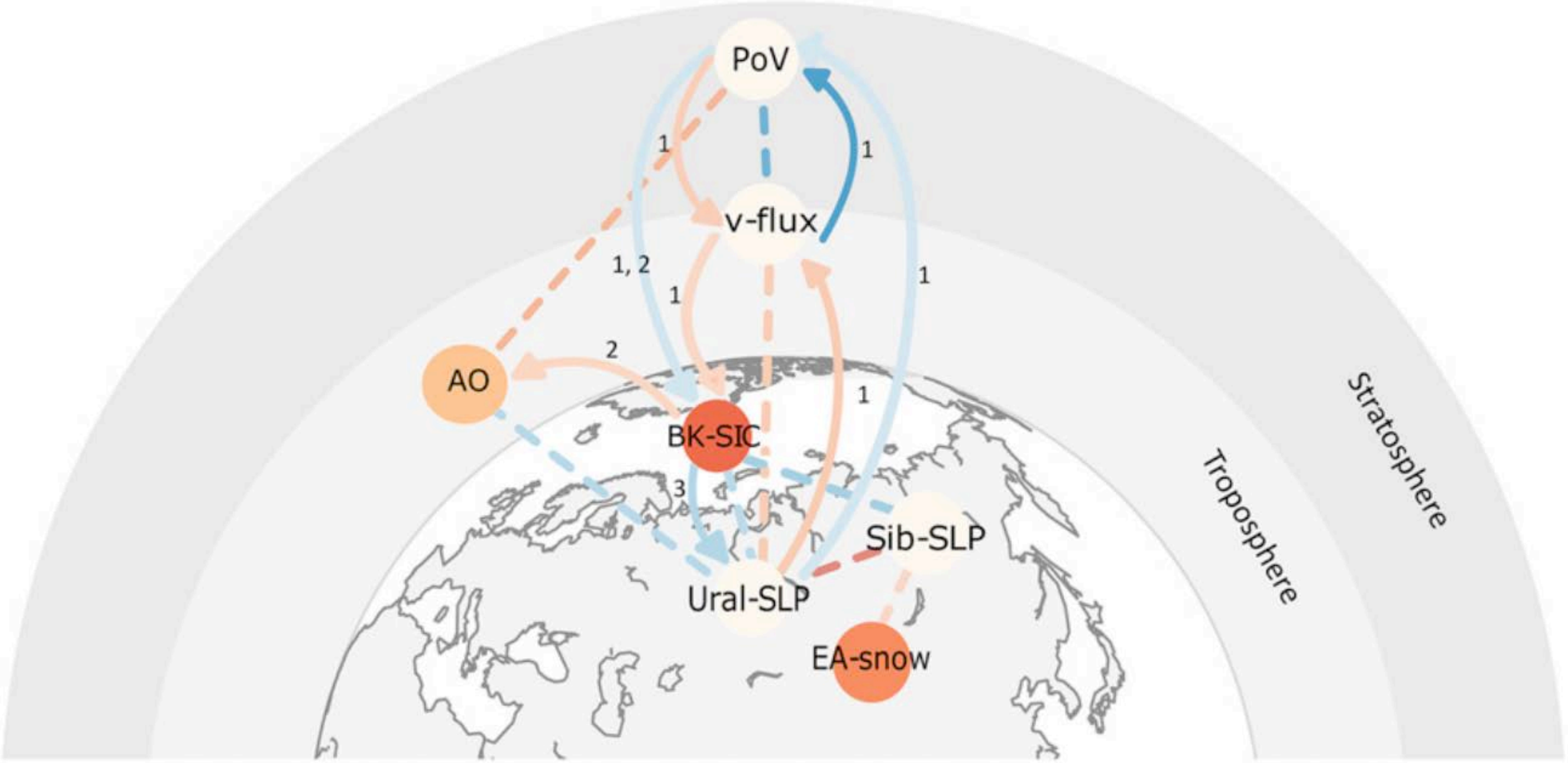
Rantanen et al. (2022)



IPCC AR6 WG1 Ch9

Arctic/midlatitude weather linkages

Observational studies support winter linkage

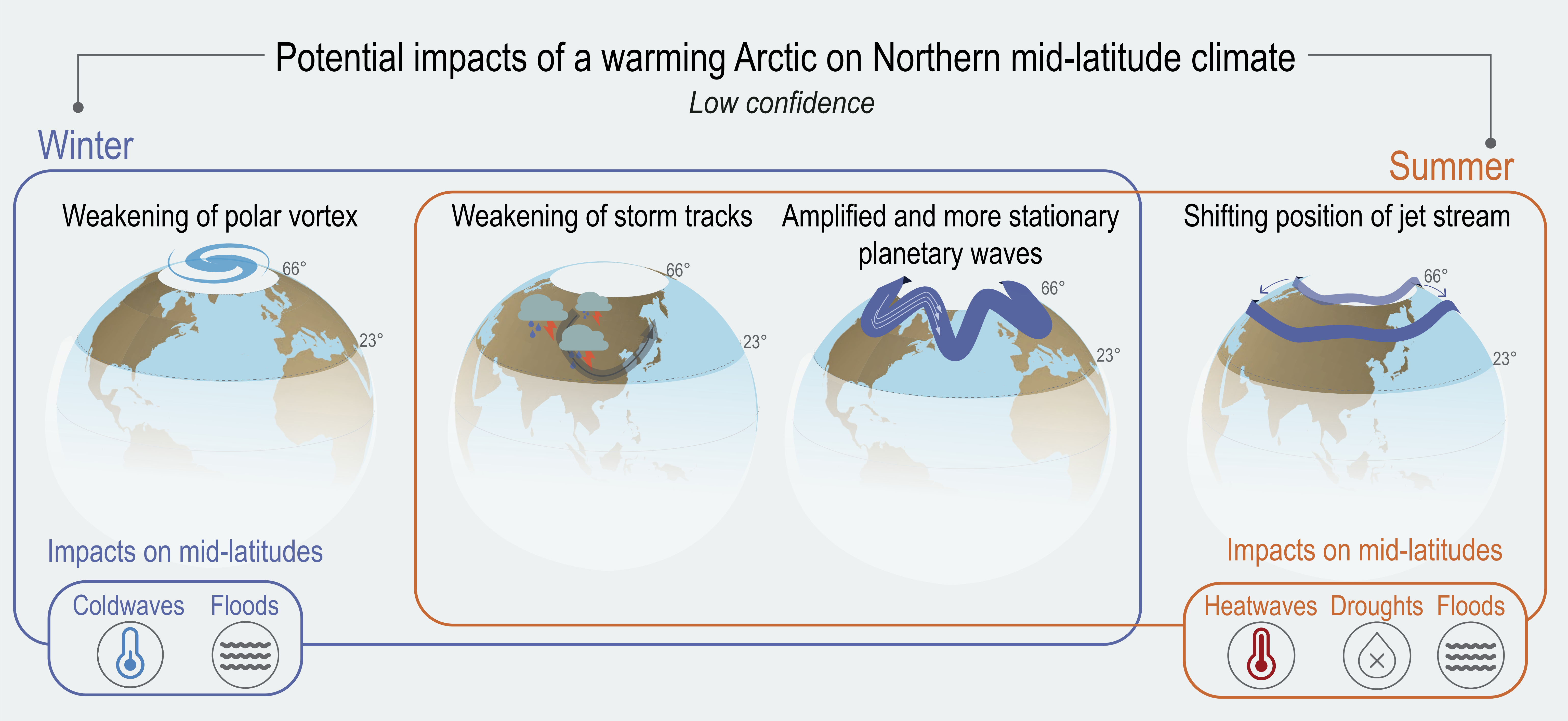


Kretschmer et al. (2016)

- Inferring causality from observations (or reanalyses) is challenging
- Decoupling from internal atmospheric variability is difficult

Arctic/midlatitude weather linkages

Modeling studies are inconclusive

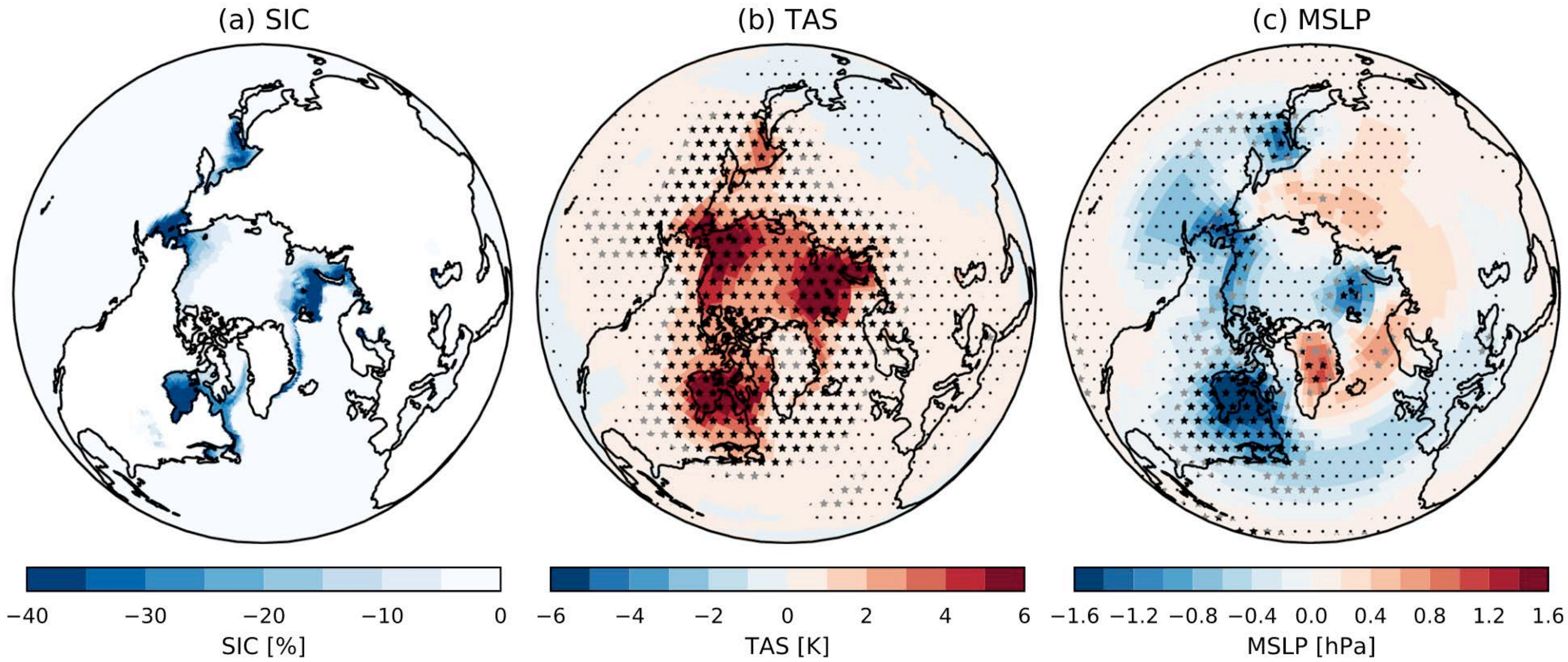


- Modeling studies suggest many mechanisms and plausible pathways
- Models have biases (e.g., underestimate the observed eddy feedback strength)
- Different modeling protocols and setup can lead to different conclusions

IPCC AR6 WG1 Ch10; see also Cohen et al. (2020) for review

Non-local impacts of projected sea ice loss

Polar Amplification Multi-model Intercomparison (PAMIP)

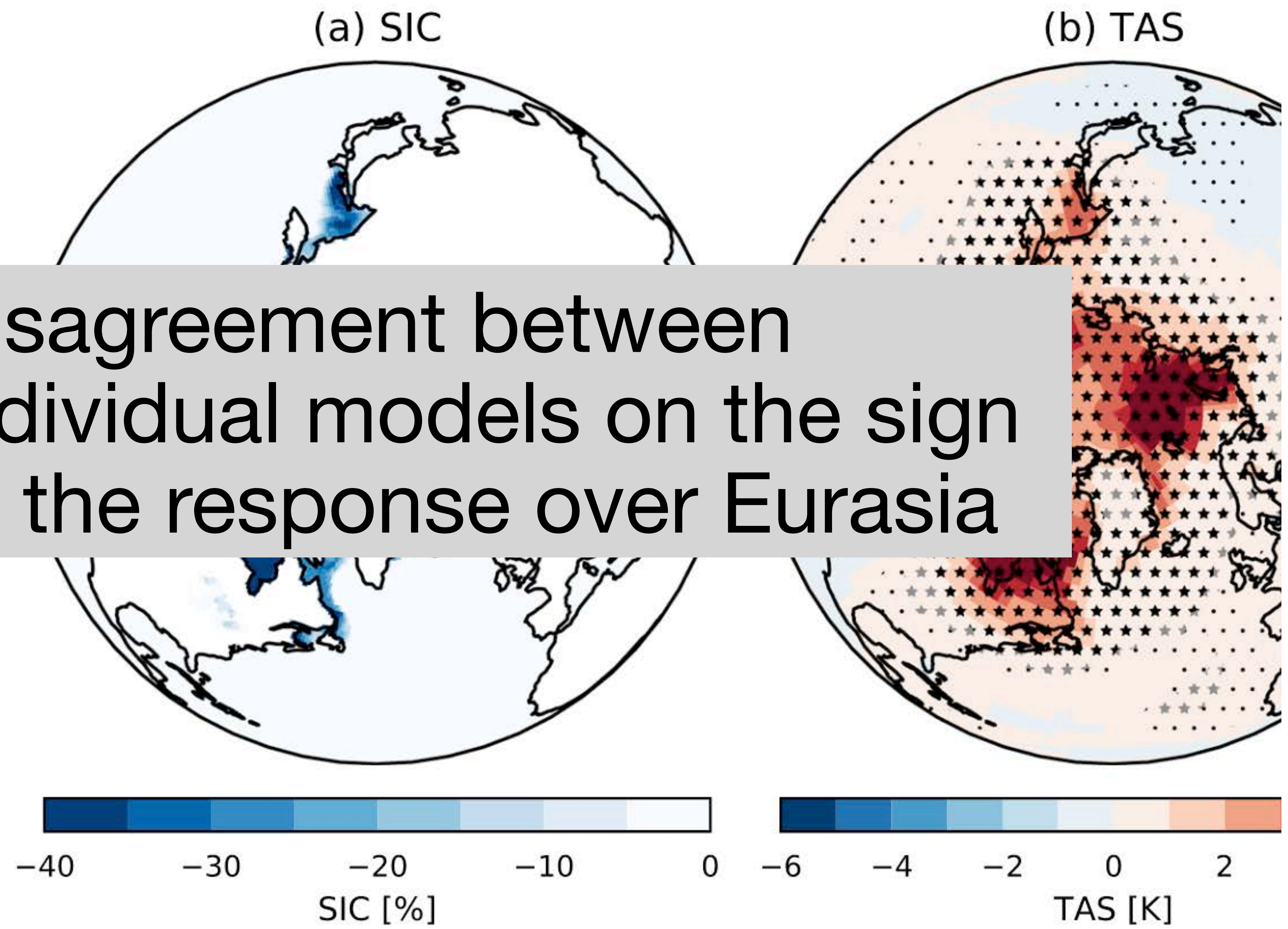


- Coordinated modeling effort from 16 models
- Each model has 98–300 ensemble members

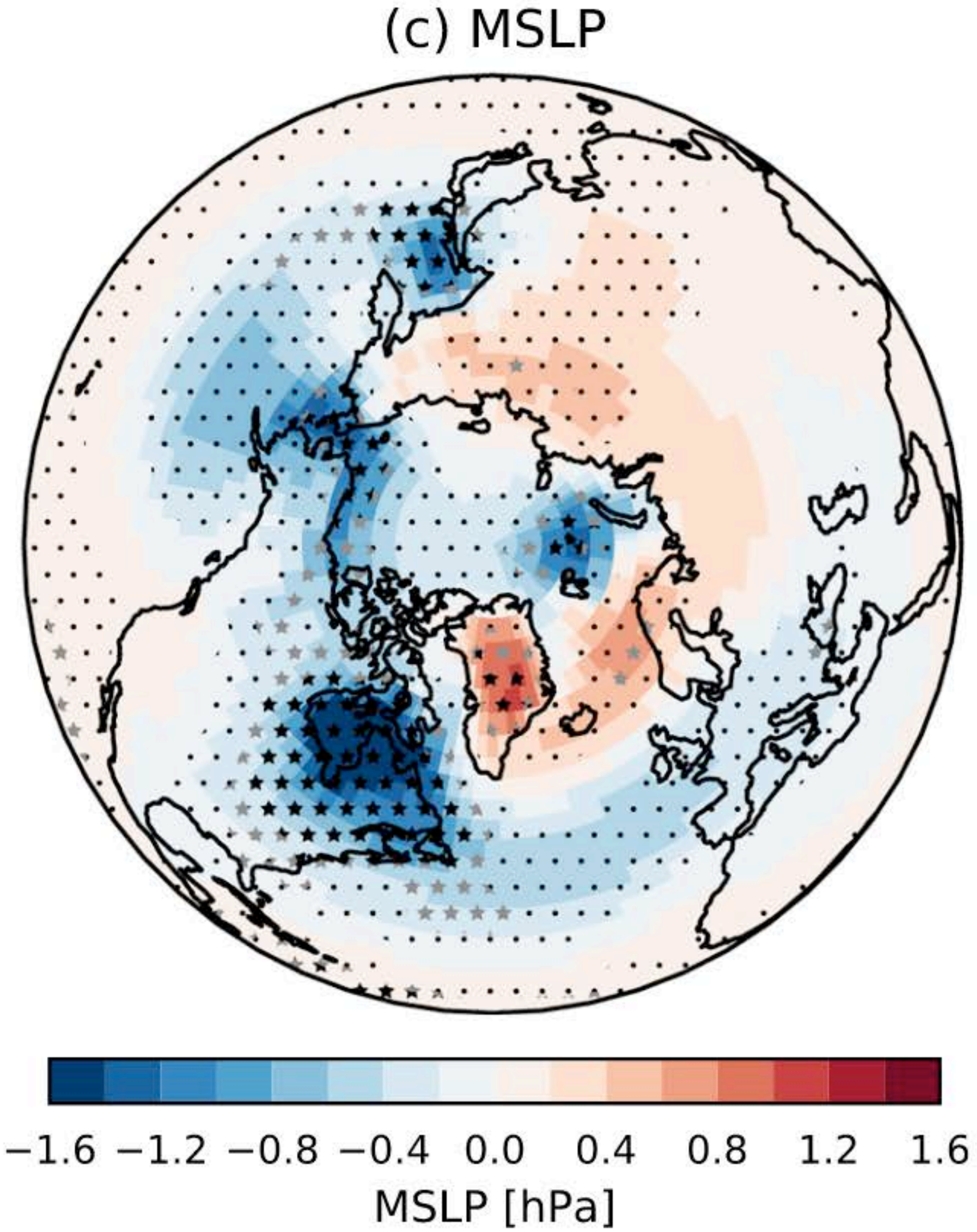
Smith et al. (2022)

Non-local impacts of projected sea ice loss

Polar Amplification Multi-model Inter



Disagreement between individual models on the sign of the response over Eurasia



- Coordinated modeling effort from 16 models
- Each model has 98–300 ensemble members

Smith et al. (2022)

Summary: Non-local impacts of Arctic amplification

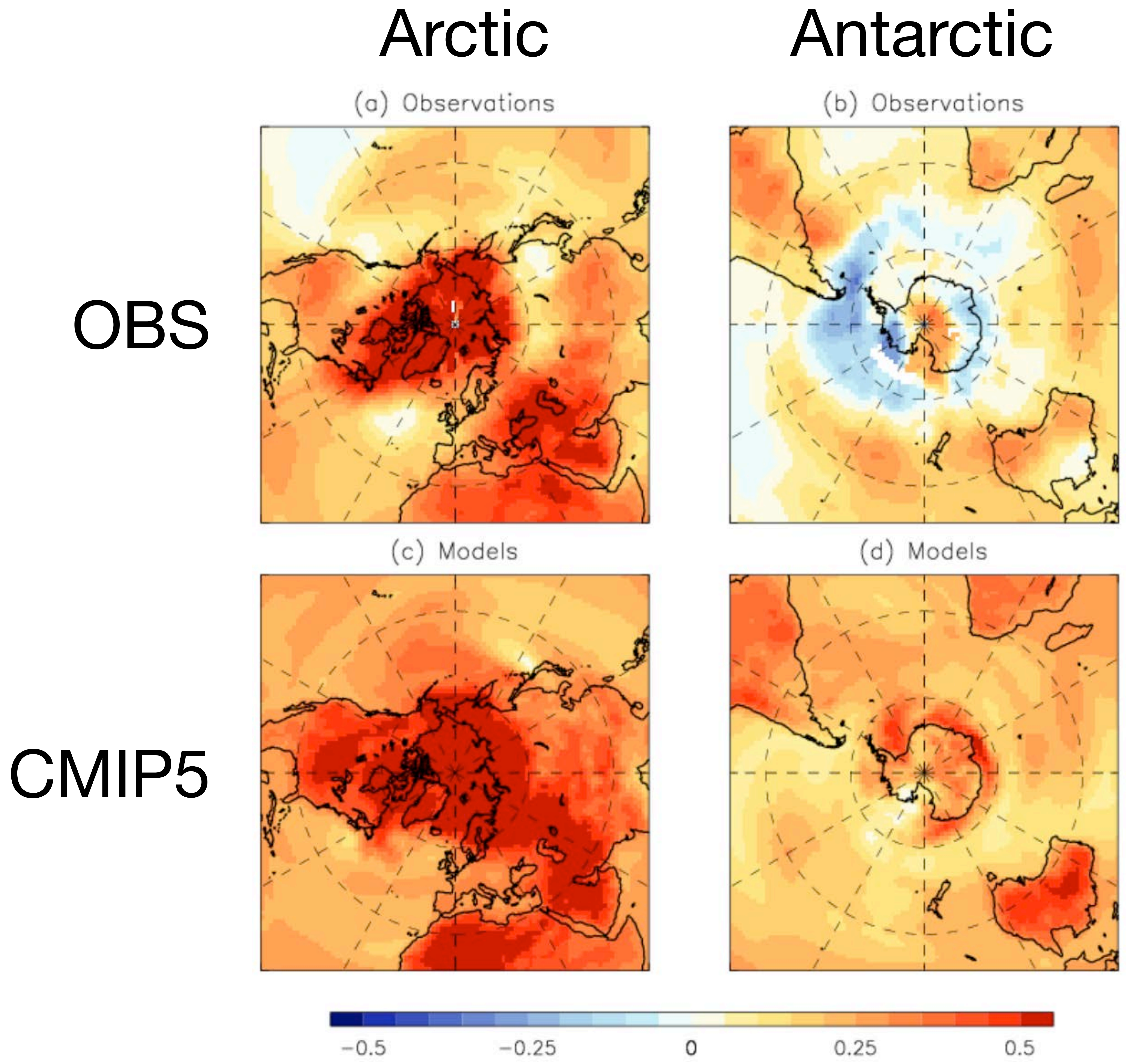
Barnes & Screen (2015)

Do rapid Arctic warming and sea ice loss have a tangible impact on midlatitude weather?

- *Can it?* Modeling studies suggest so, yet disagreement on the response remains.
- *Has it?* Perhaps, but small compared to internal atmospheric variability.
- *Will it?* Arctic amplification is one of many factors that will influence midlatitude weather.

> "…there is *low confidence* in the relative contribution of Arctic warming to mid-latitude atmospheric changes compared to other drivers."
>
> – IPCC AR6 WG1 Ch10

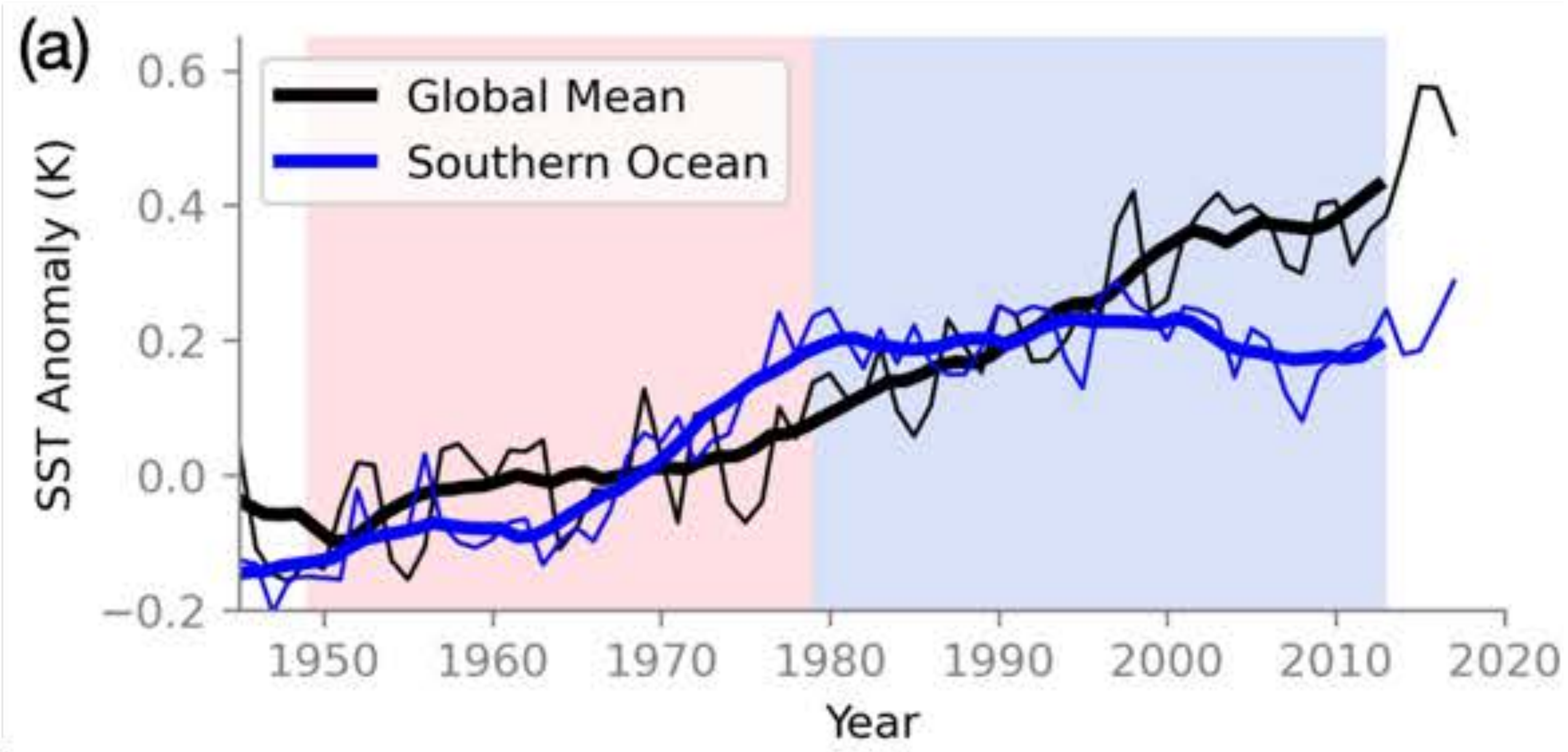
Diverging trends in observed surface temperature



- SO surface temperatures have cooled, as opposed to the Arctic
- Modeled SO surface temperatures warmed, as opposed to observed

Smith et al. (2019)

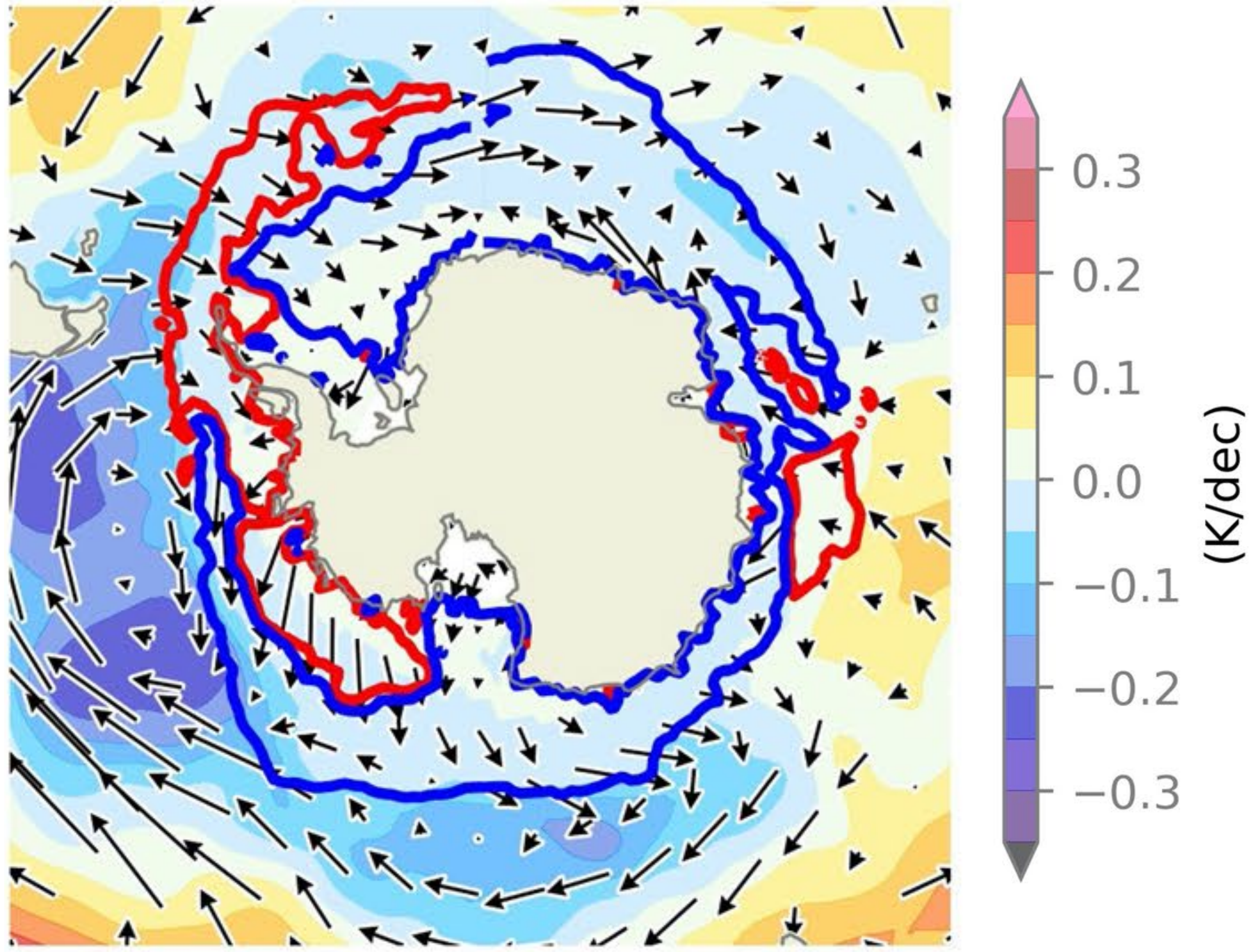
Observed changes in the Southern Ocean (SO)



SO Warming

SO Cooling

SST (colors) and sea ice (contour) trends



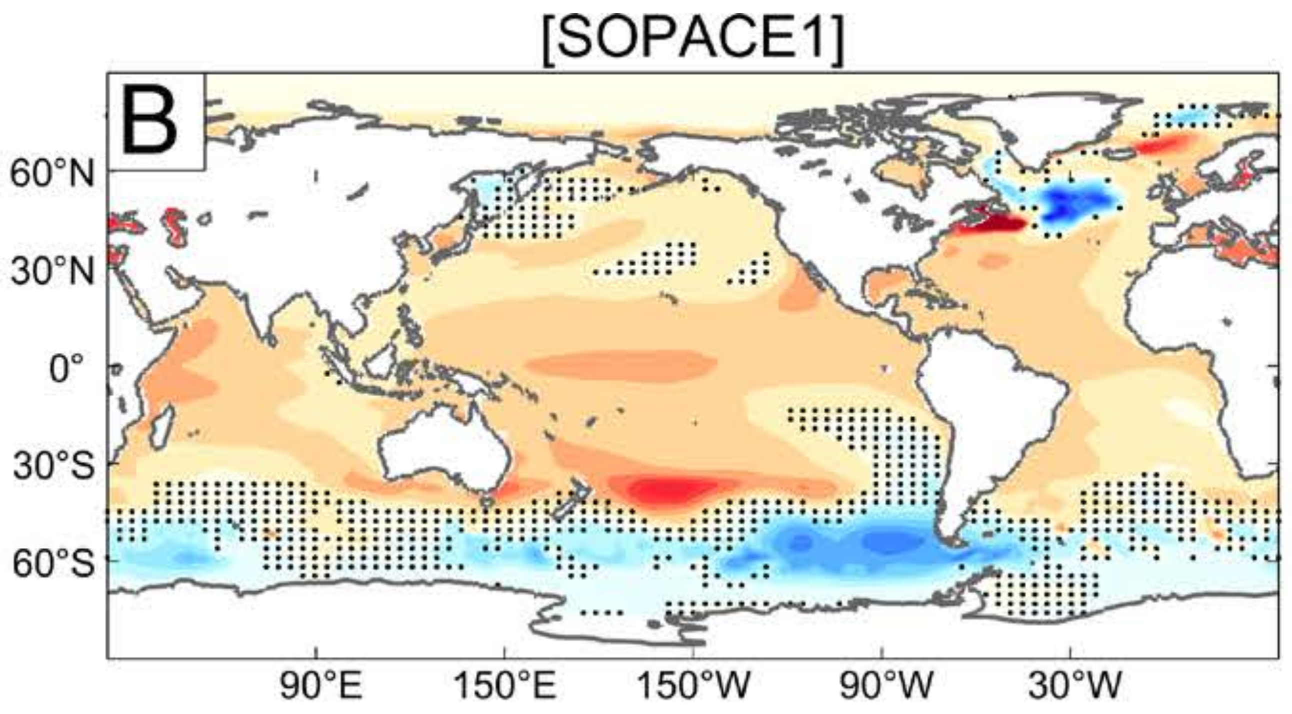
Zhang et al. (2021); Zhang et al. (in review)

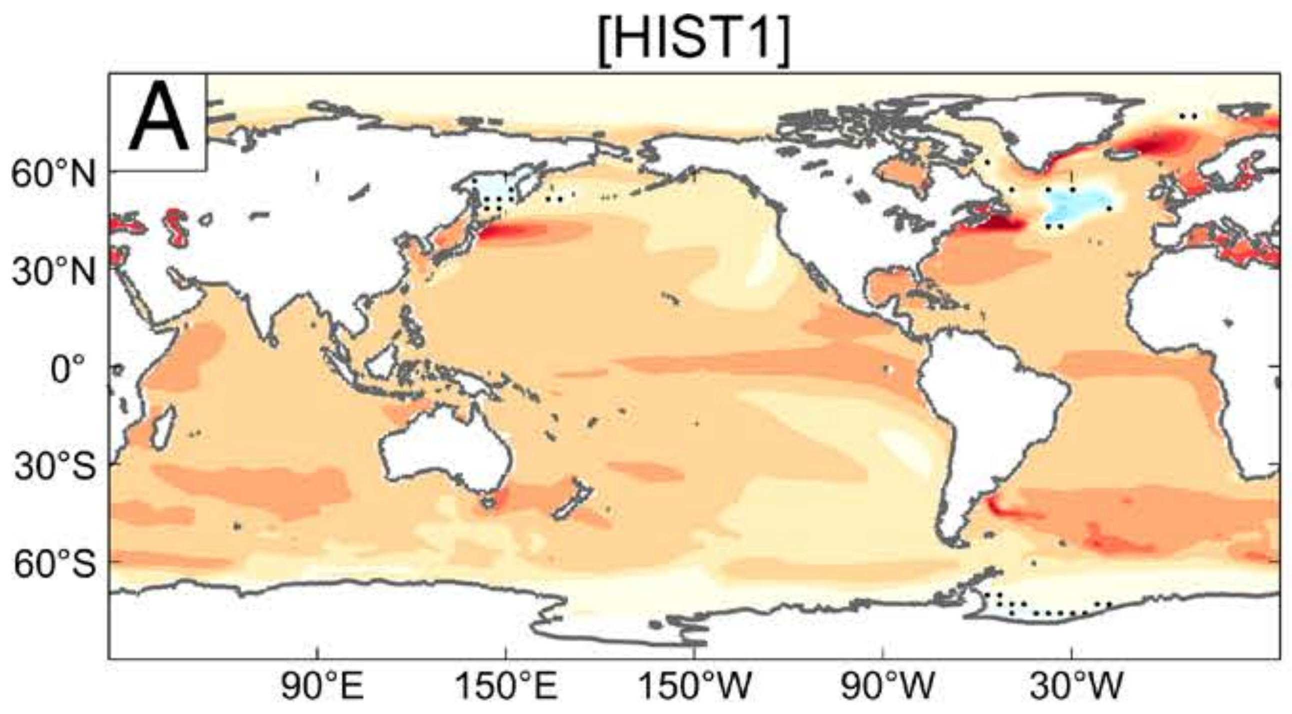
Impacts of observed SO surface cooling

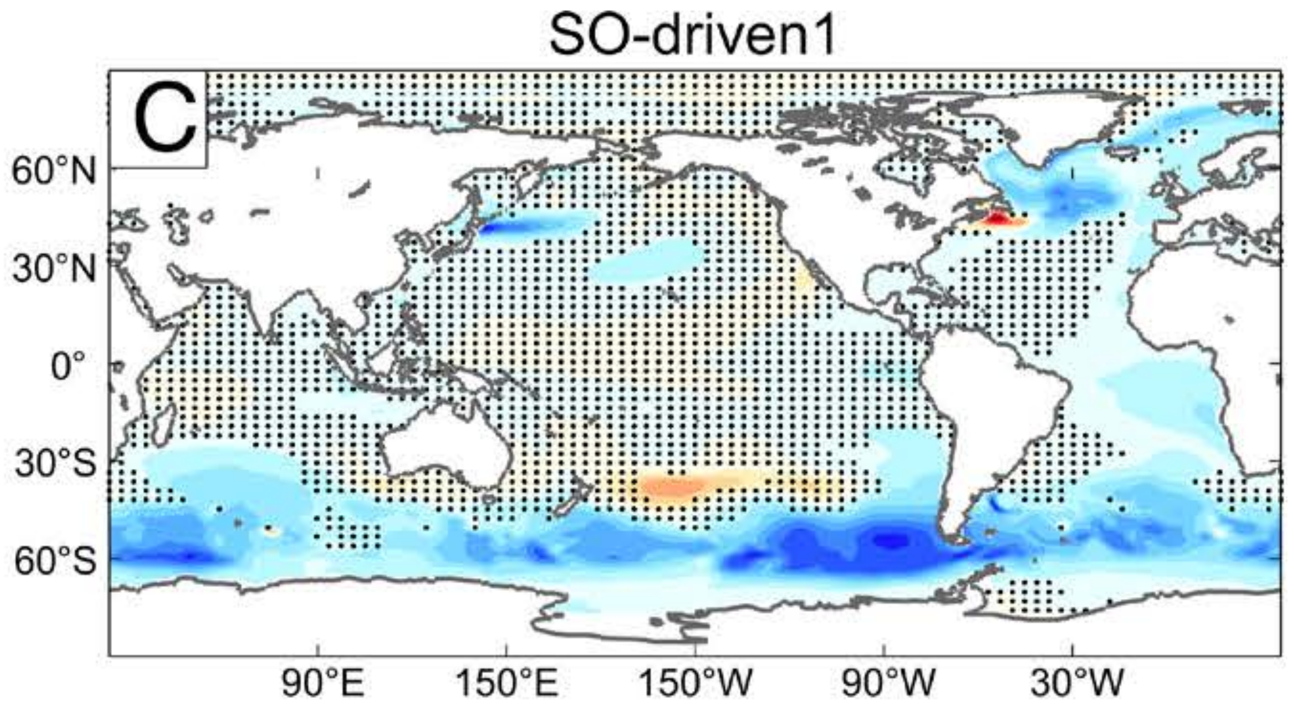
SO pacemaker experiment

Historical simulation with observed SO cooling − Radiatively-forced response = SO-driven response

CESM1







Zhang et al. (2021); Kang et al. (2023)

Impacts of observed SO surface cooling

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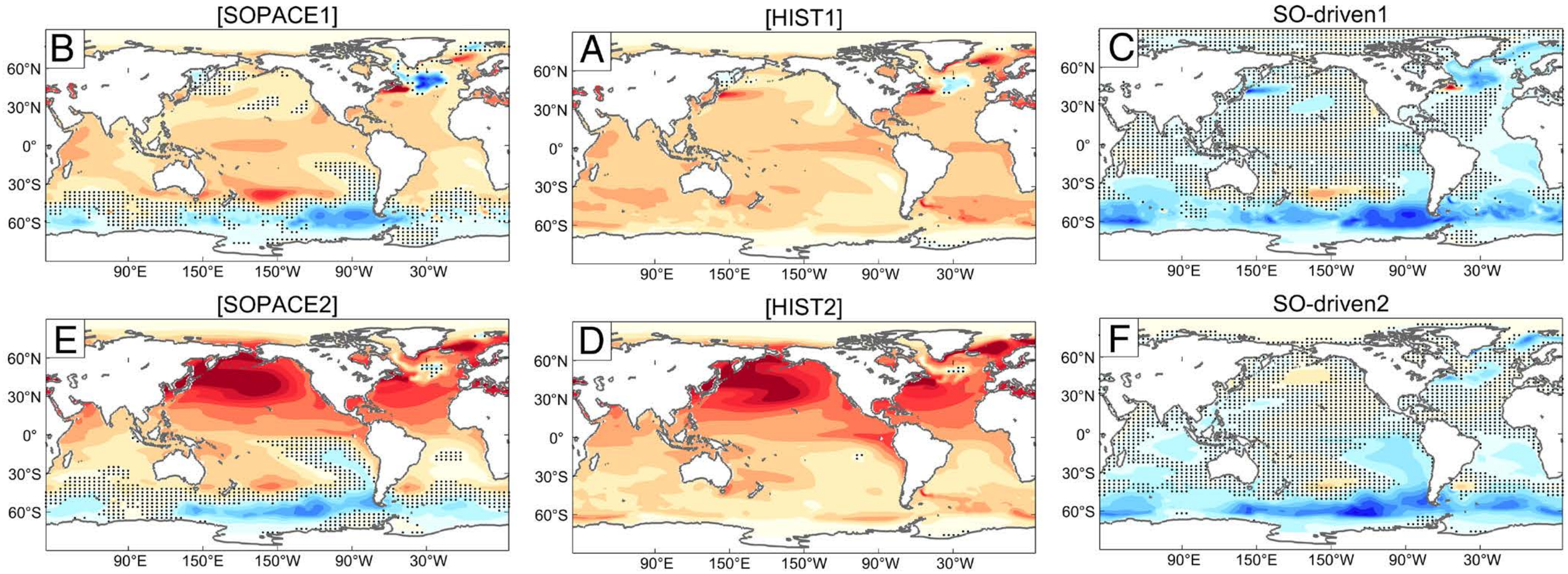
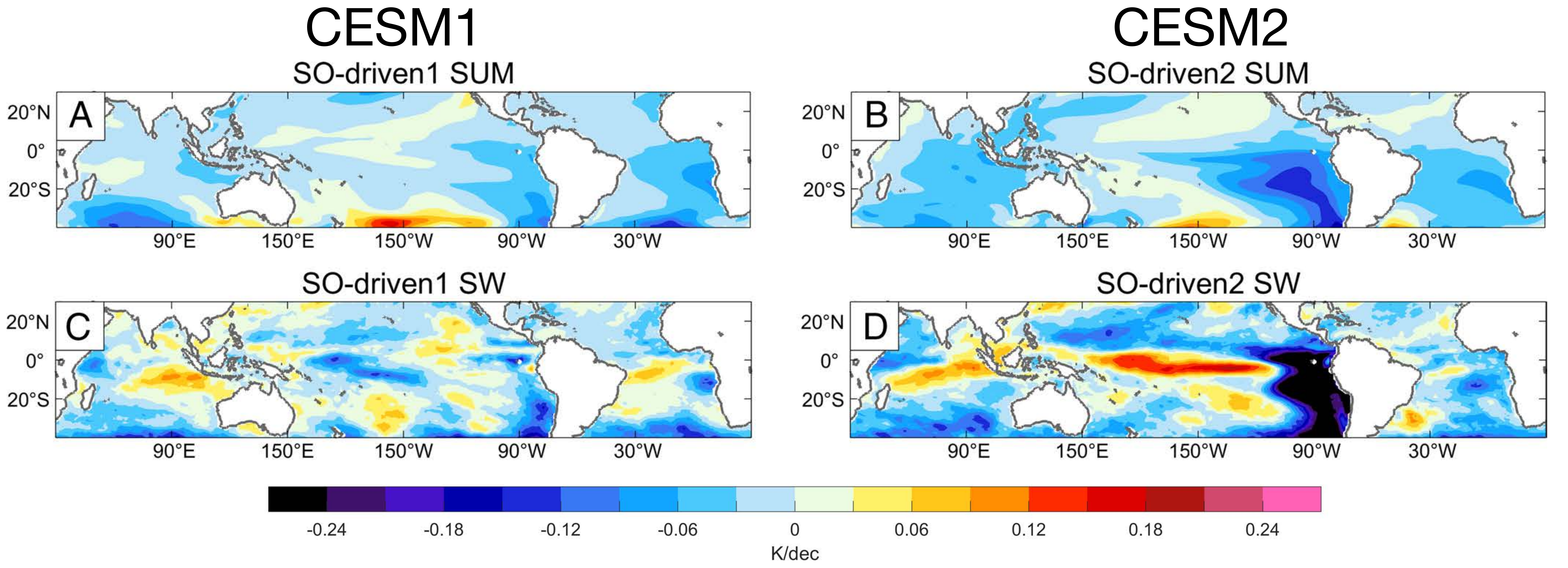
CESM1

CESM2



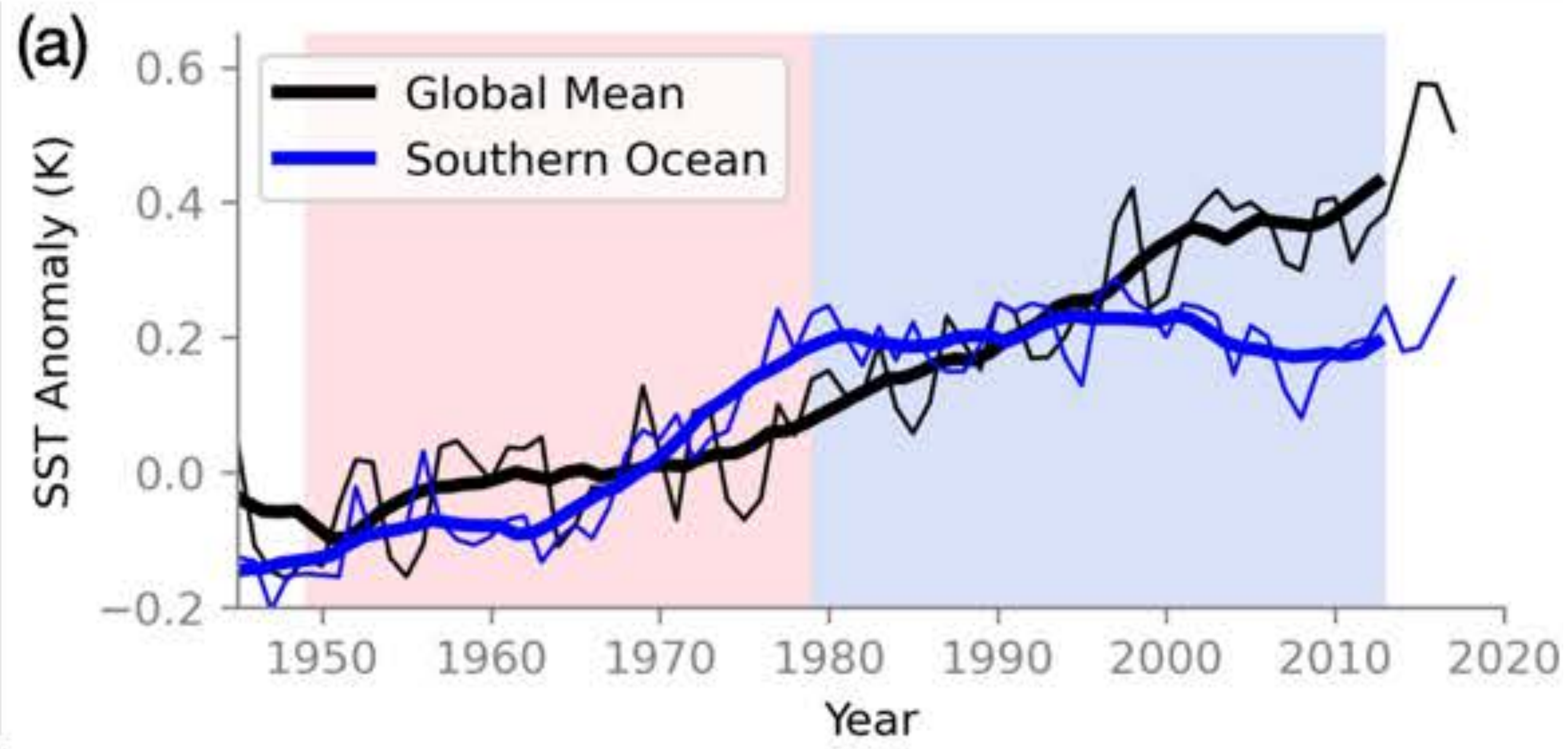
Zhang et al. (2021); Kang et al. (2023)

Stronger subtropical low-cloud feedback leads to stronger SO-driven tropical response

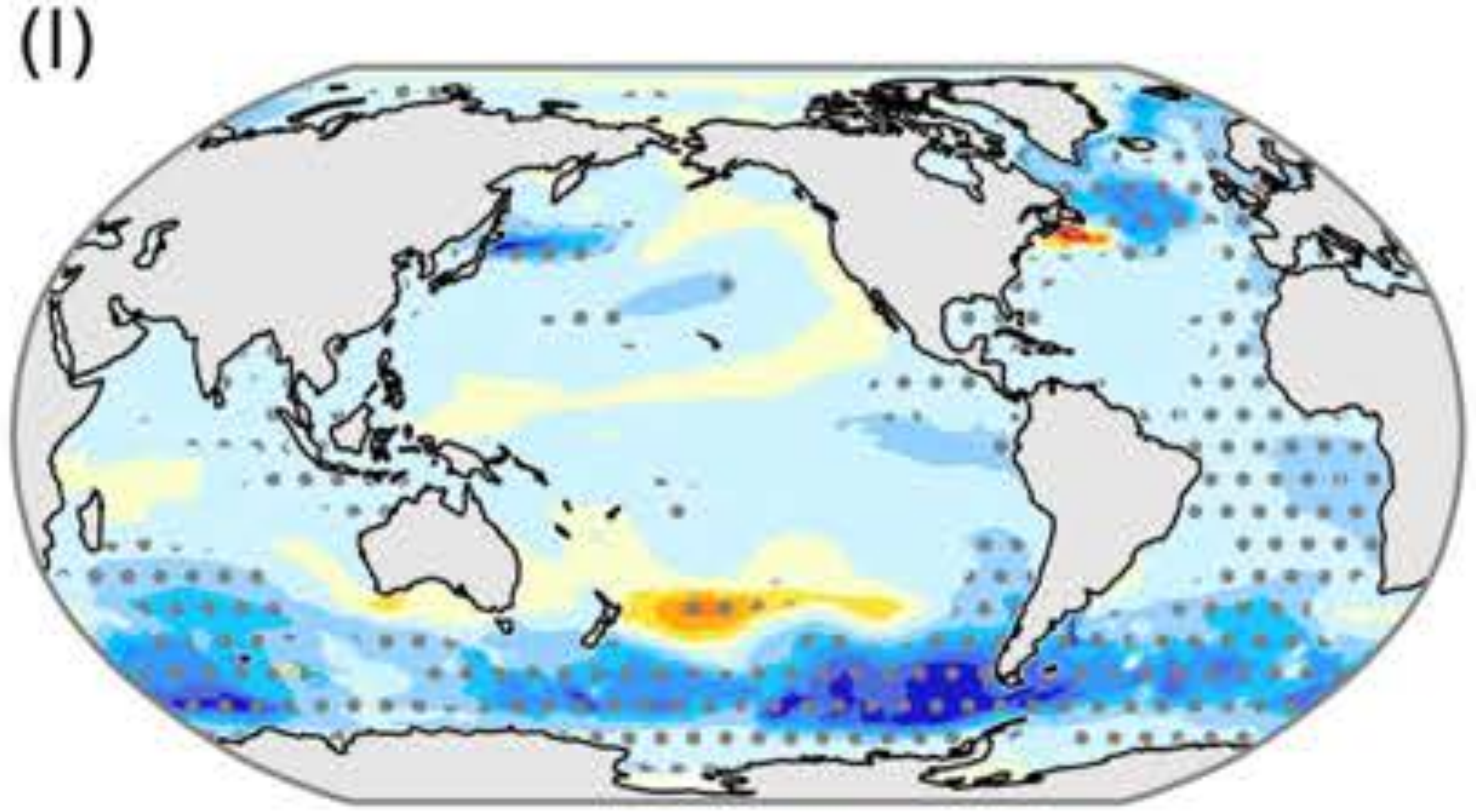


Kang et al. (2023); Kim et al. (2022)

Impacts of observed SO warming

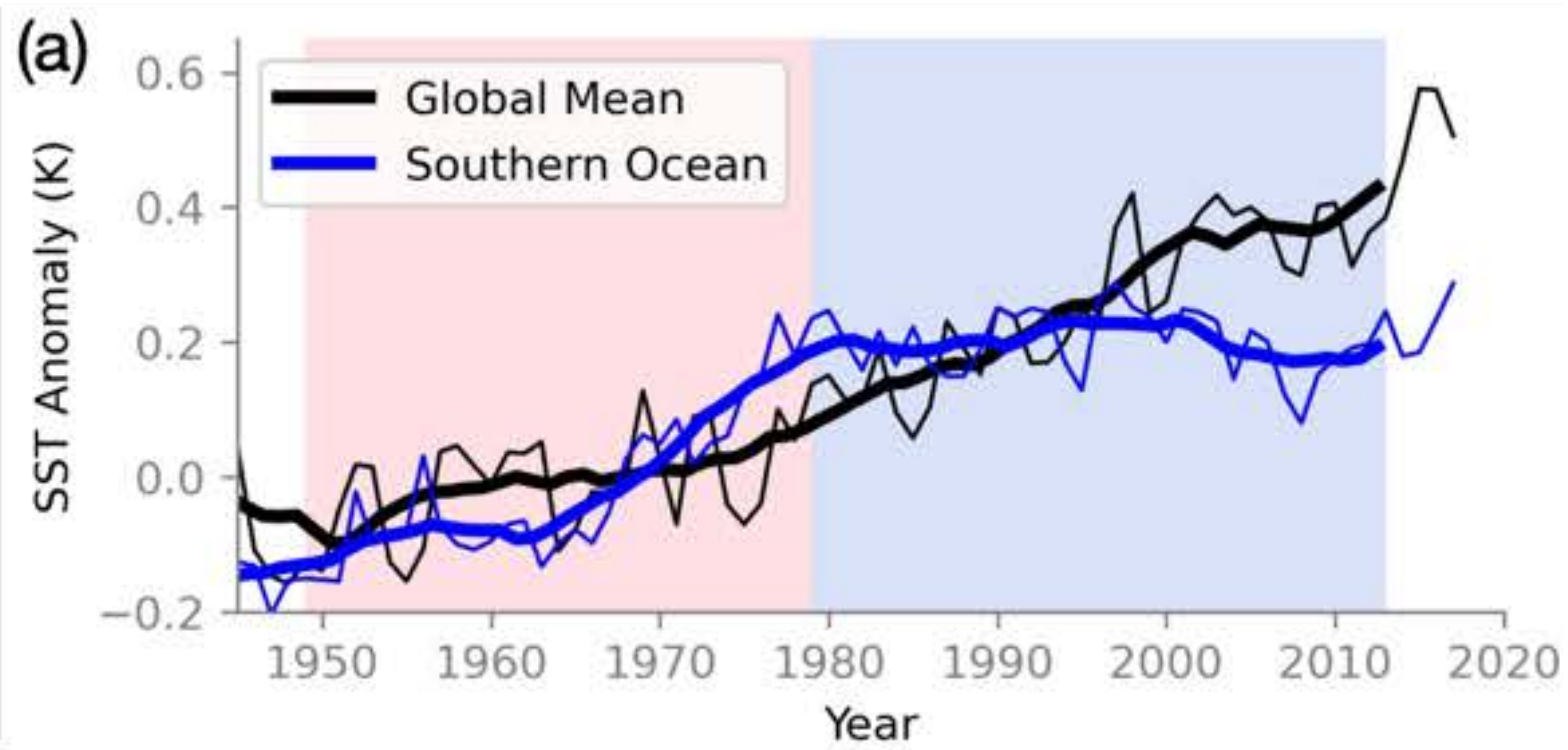


SO cooling-driven response

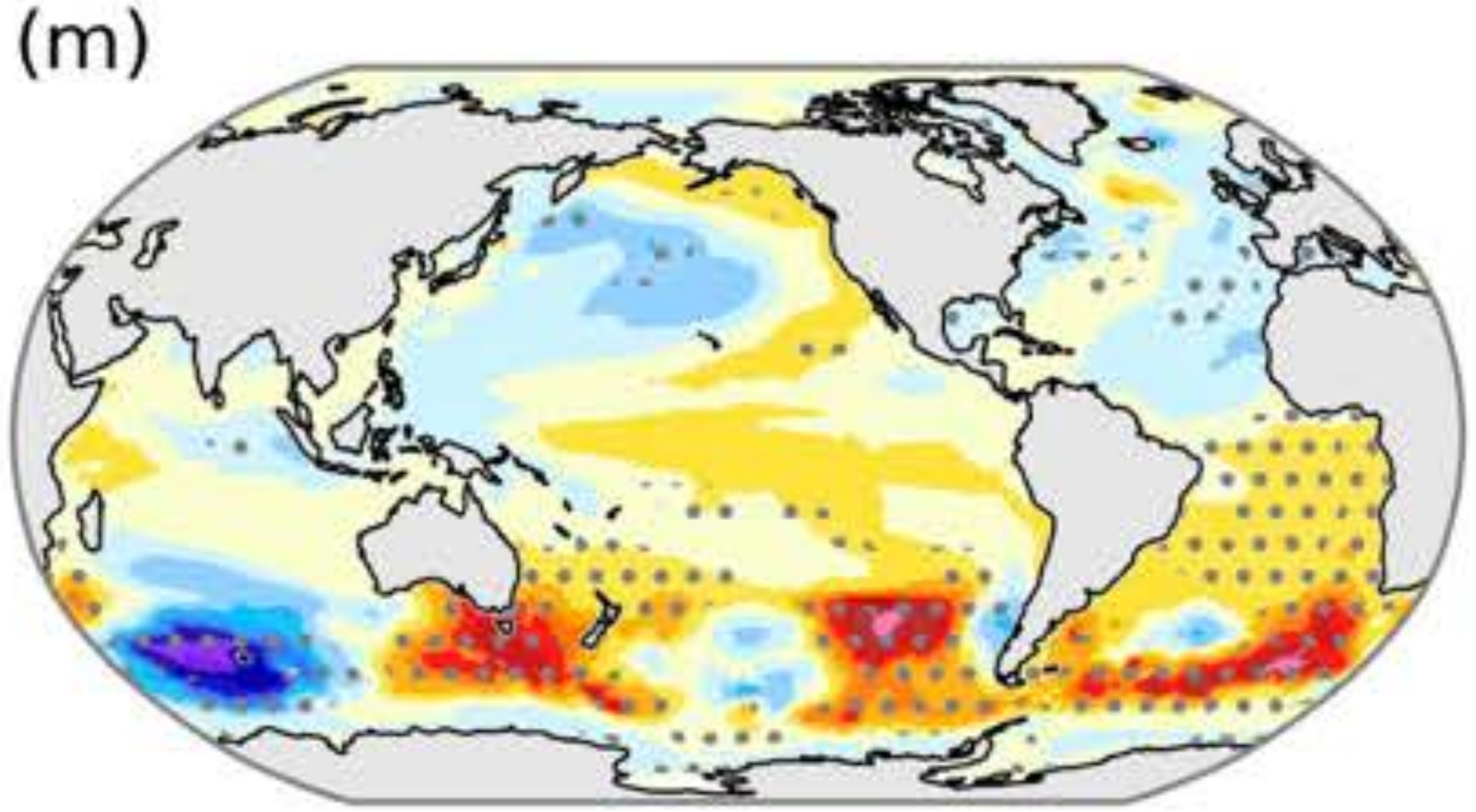


Zhang et al. (in review)

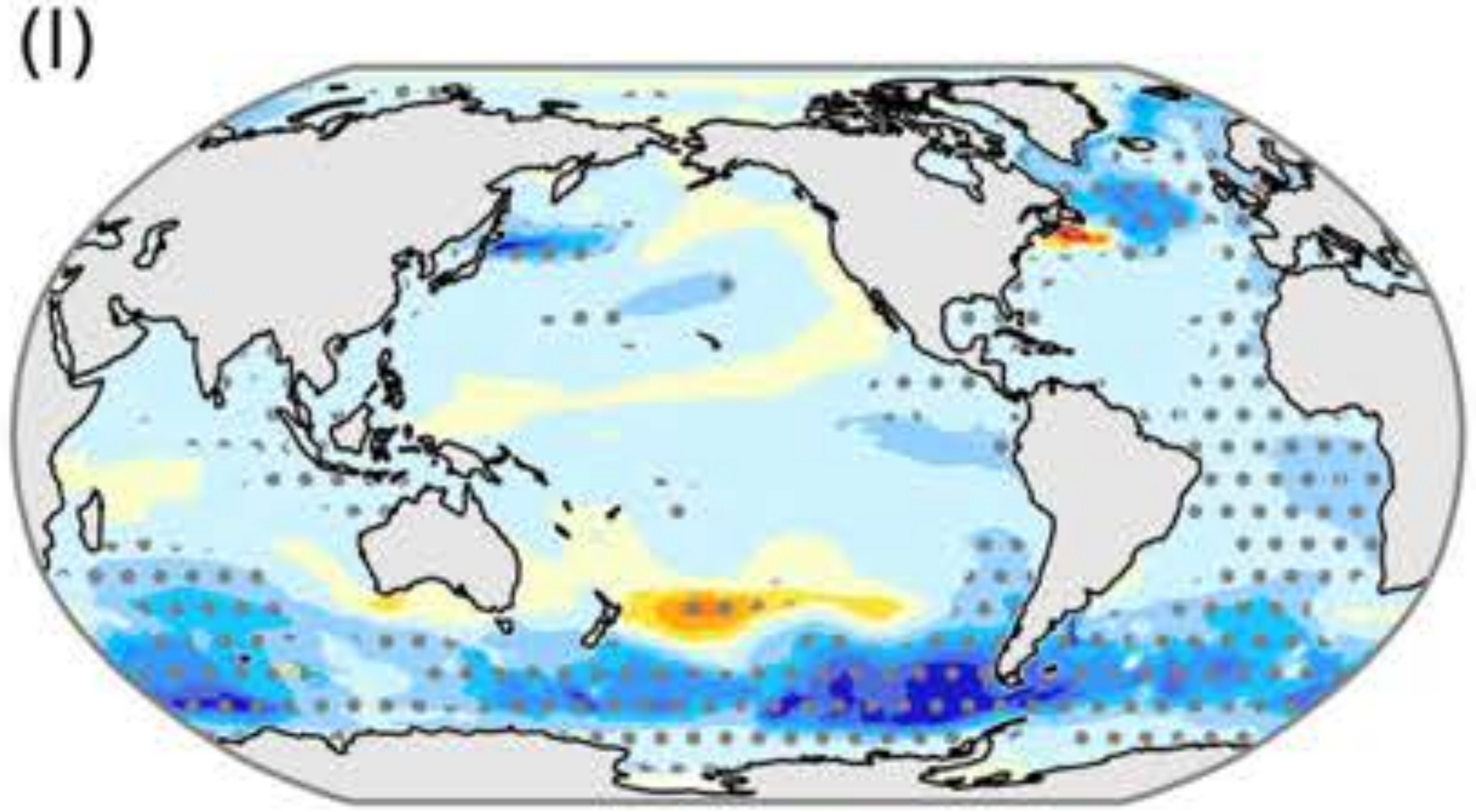
Impacts of observed SO warming



SO warming-driven response

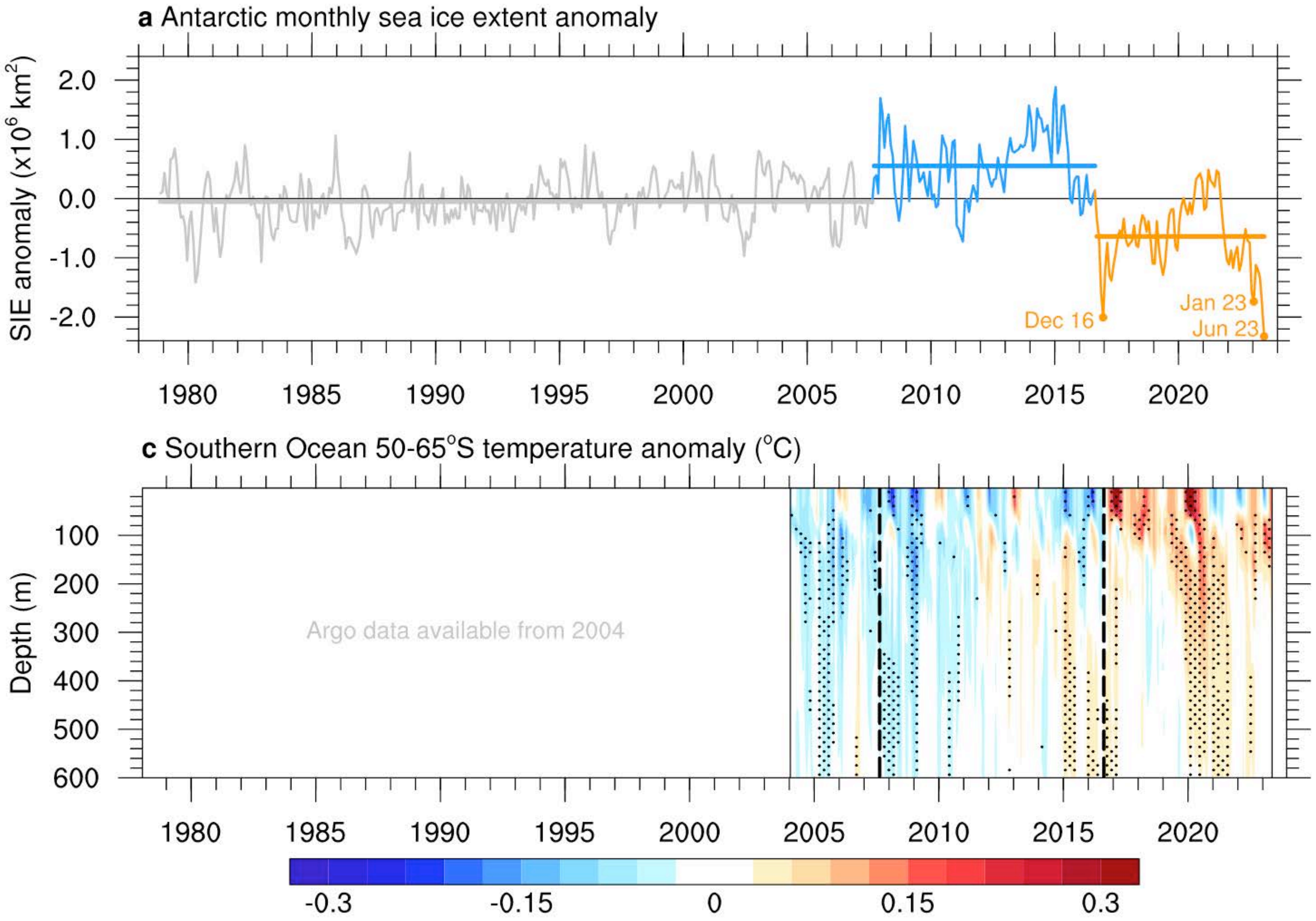


SO cooling-driven response



Zhang et al. (in review)

Recent changes in Antarctic sea ice and SO temperatures


a Antarctic monthly sea ice extent anomaly

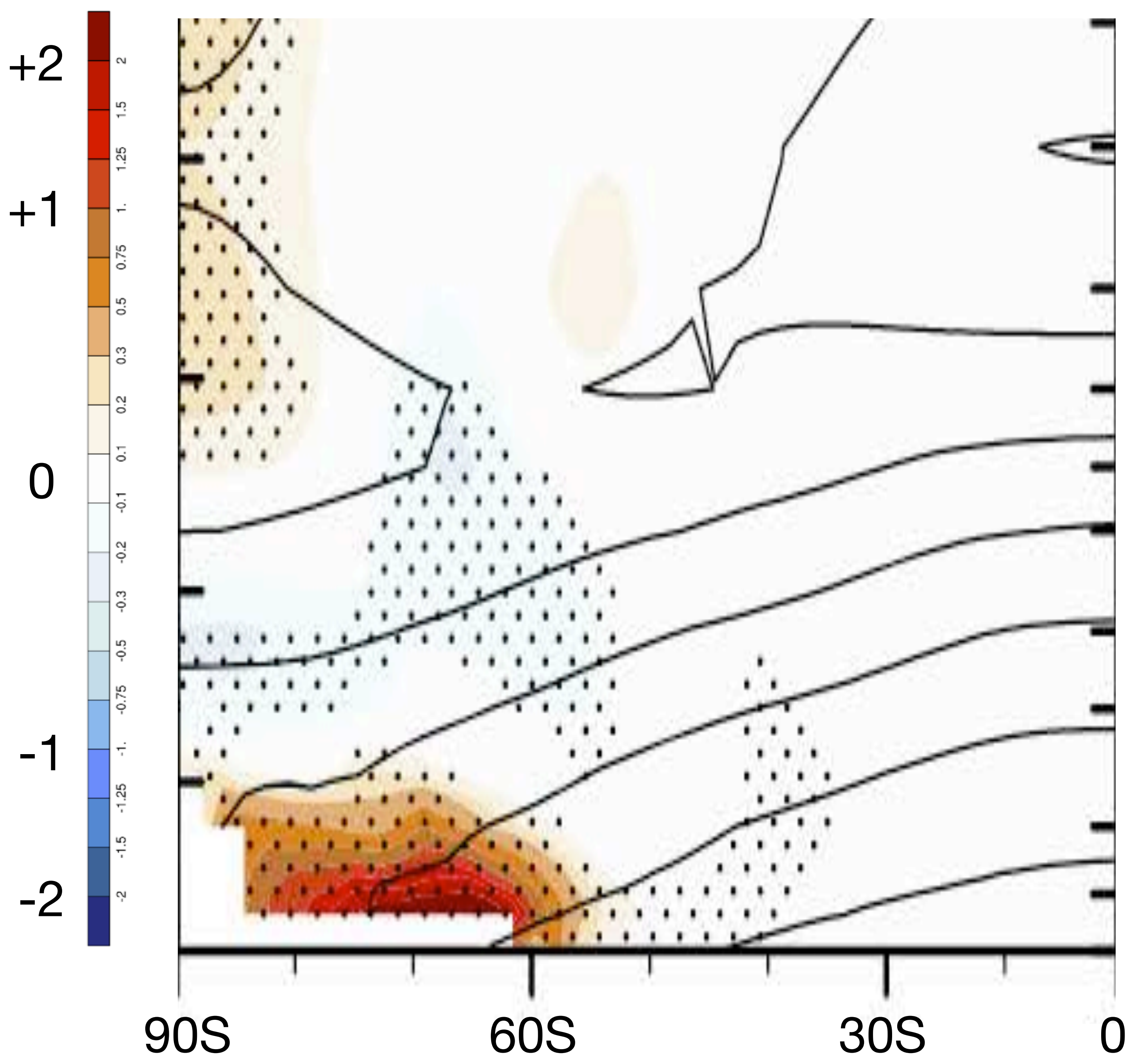
c Southern Ocean 50-65°S temperature anomaly (°C)

There have been 3 record-breaking low sea ice summers in the past 7 years, accompanied by ocean warming

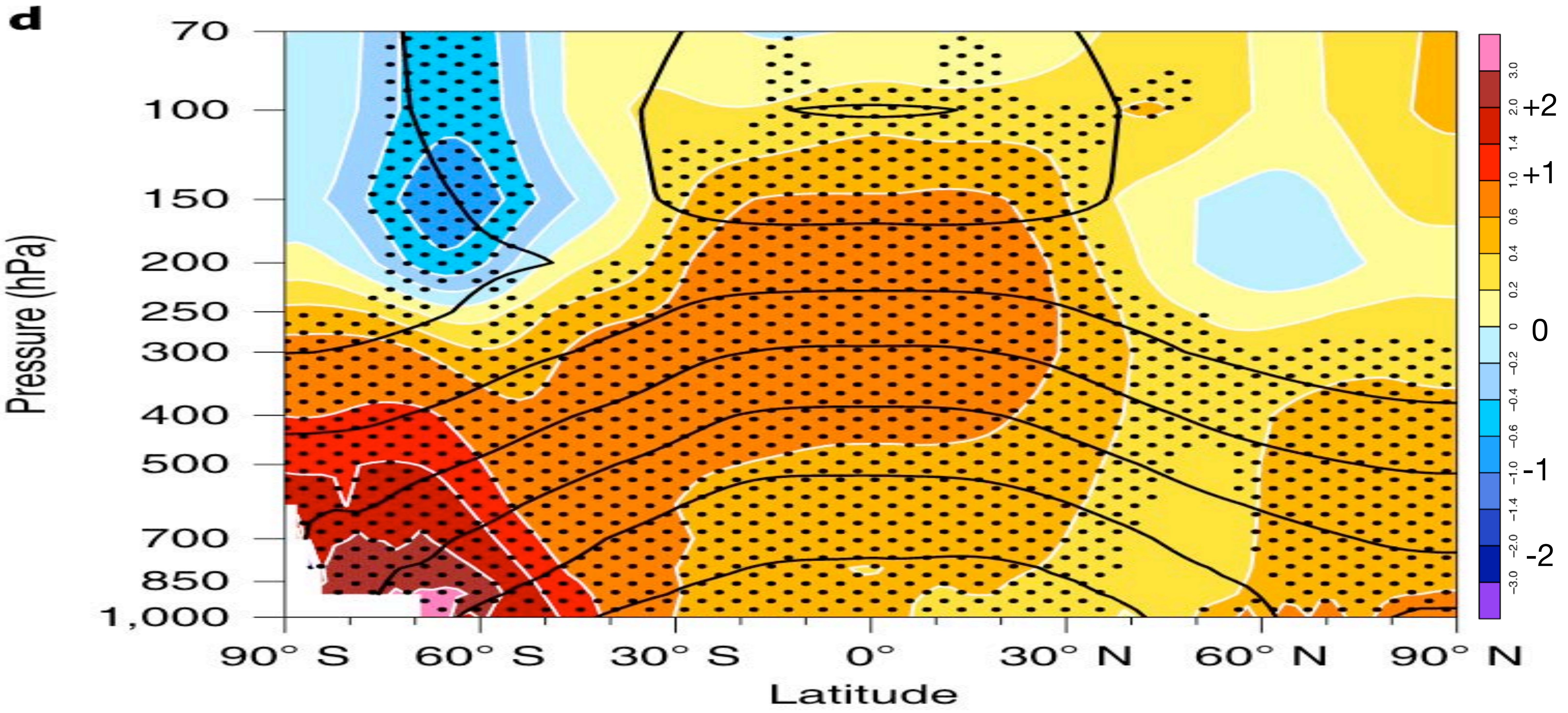
Purich et al. (2023)

Impacts of projected Antarctic sea ice loss

Atmosphere-only



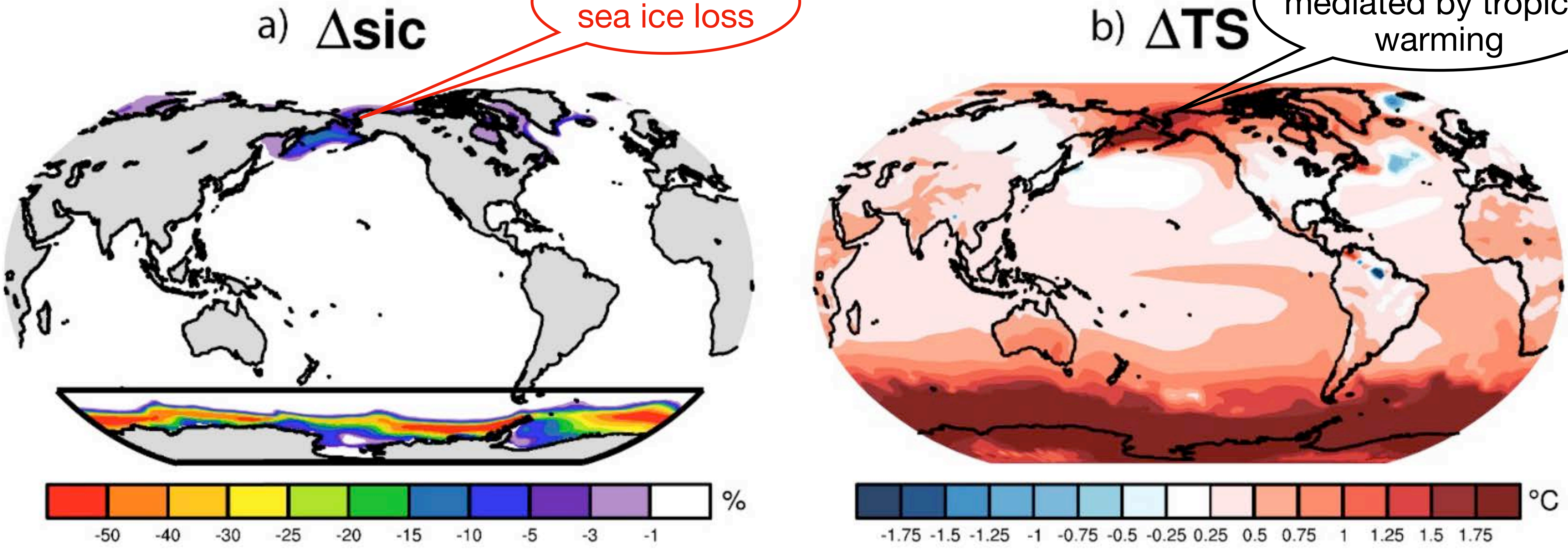
With coupled ocean dynamics



England et al. (2018); England et al. (2021)

Impacts of projected Antarctic sea ice loss

A coupled model study

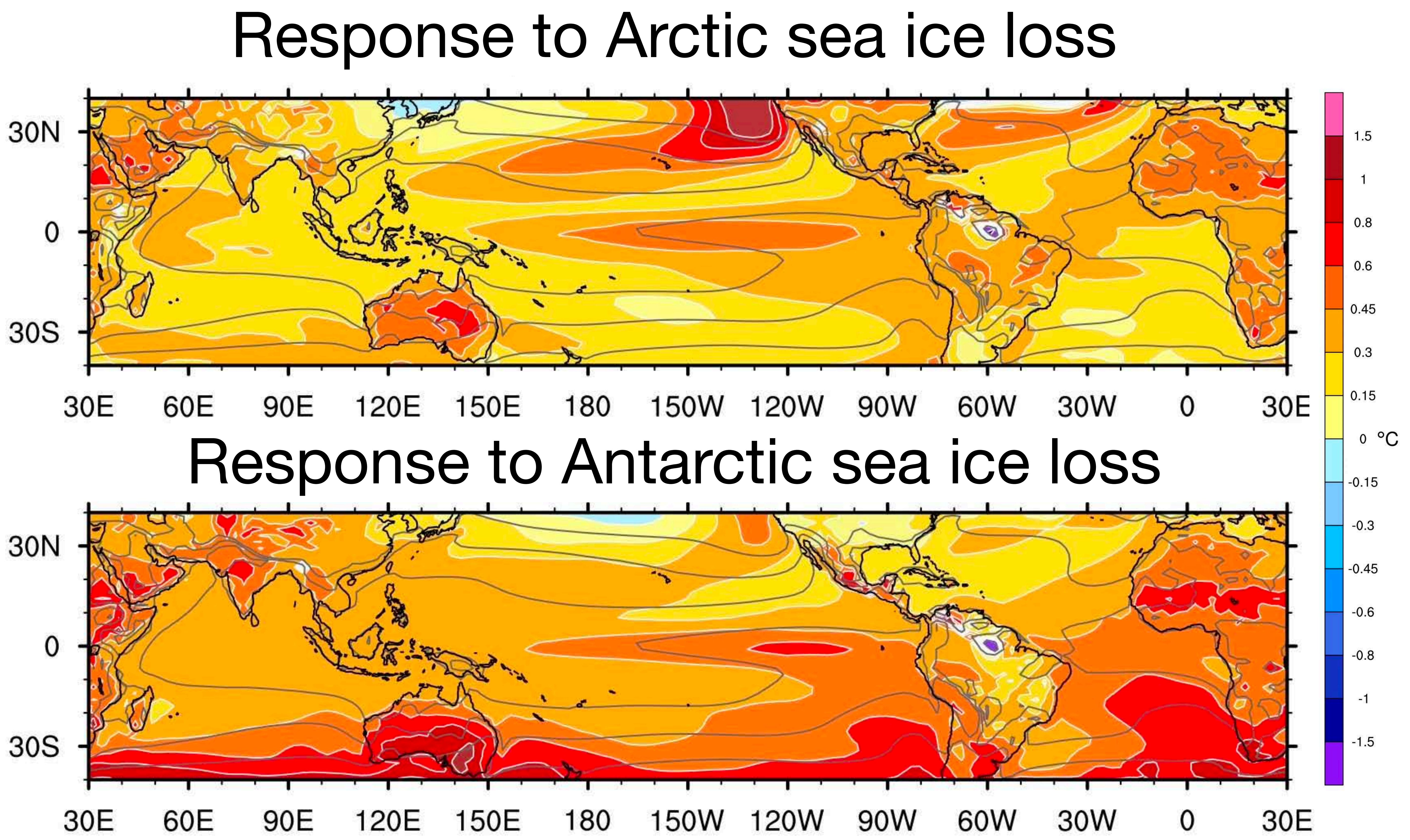


Arctic sea ice loss

Warming mediated by tropical warming

England et al. (2020)

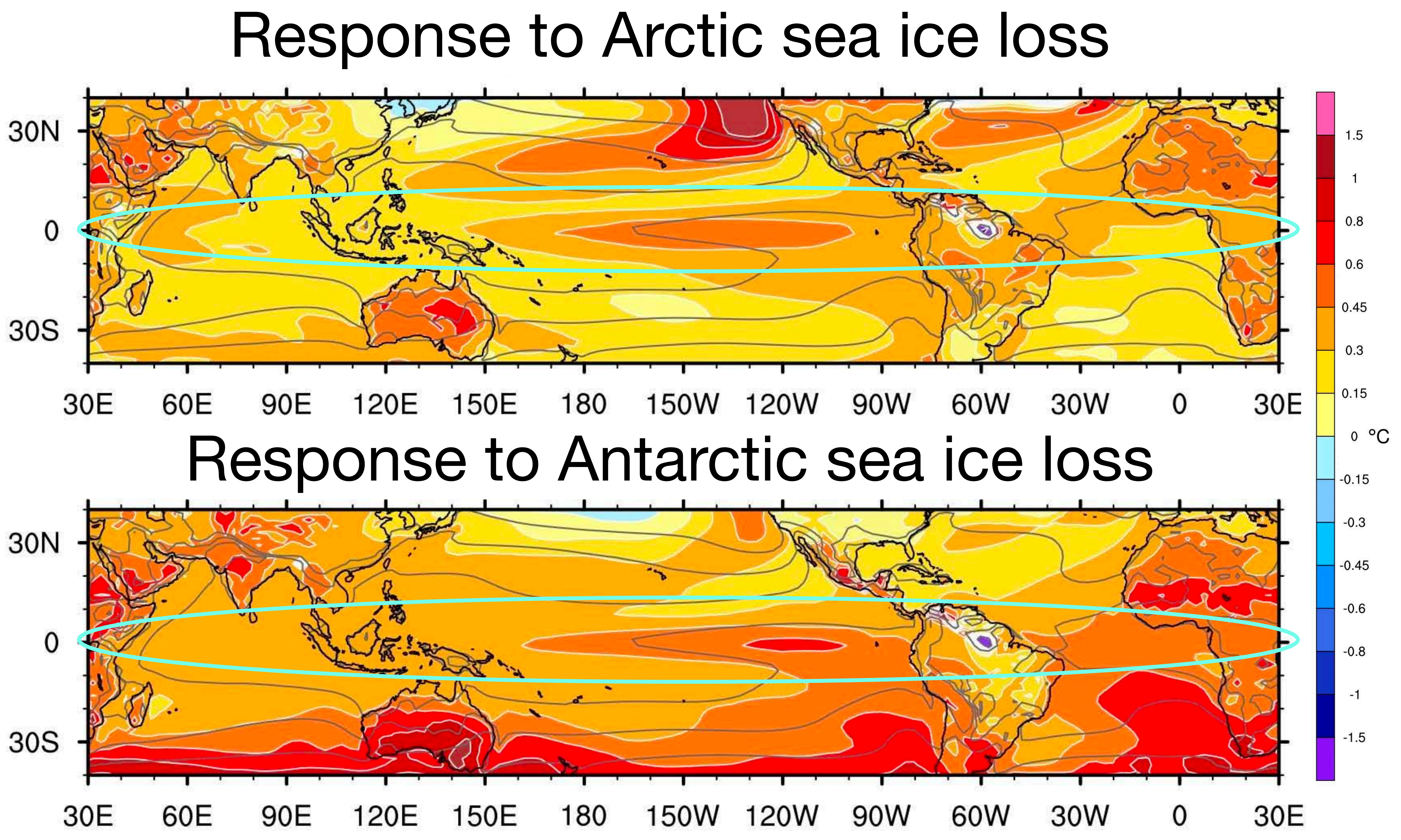
Comparing the impact of projected Arctic and Antarctic sea ice loss


Response to Arctic sea ice loss

Response to Antarctic sea ice loss

England et al. (2021)

Comparing the impact of projected Arctic and Antarctic sea ice loss


Response to Arctic sea ice loss

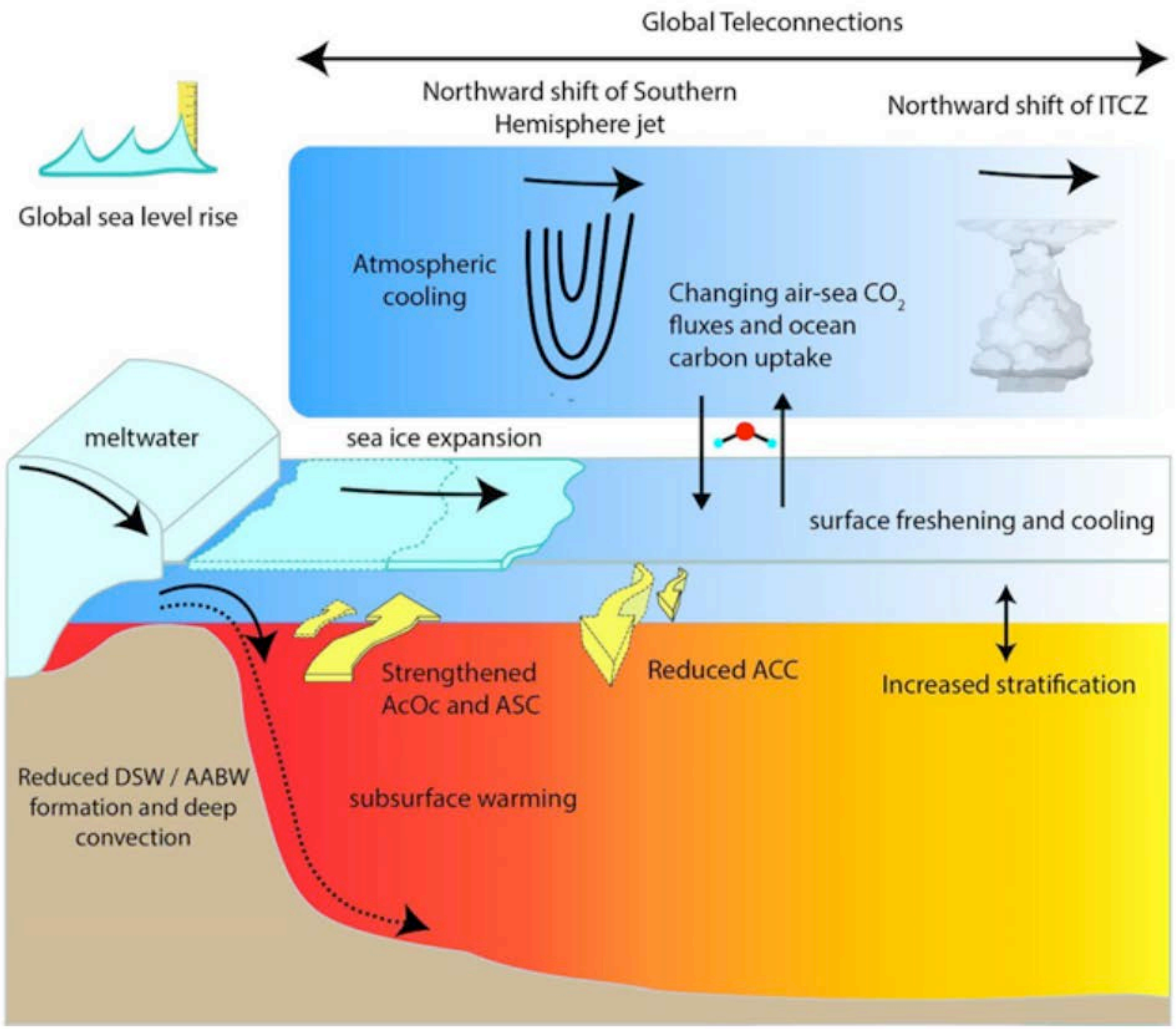
Response to Antarctic sea ice loss

Stronger tropical warming in response to Antarctic sea ice loss

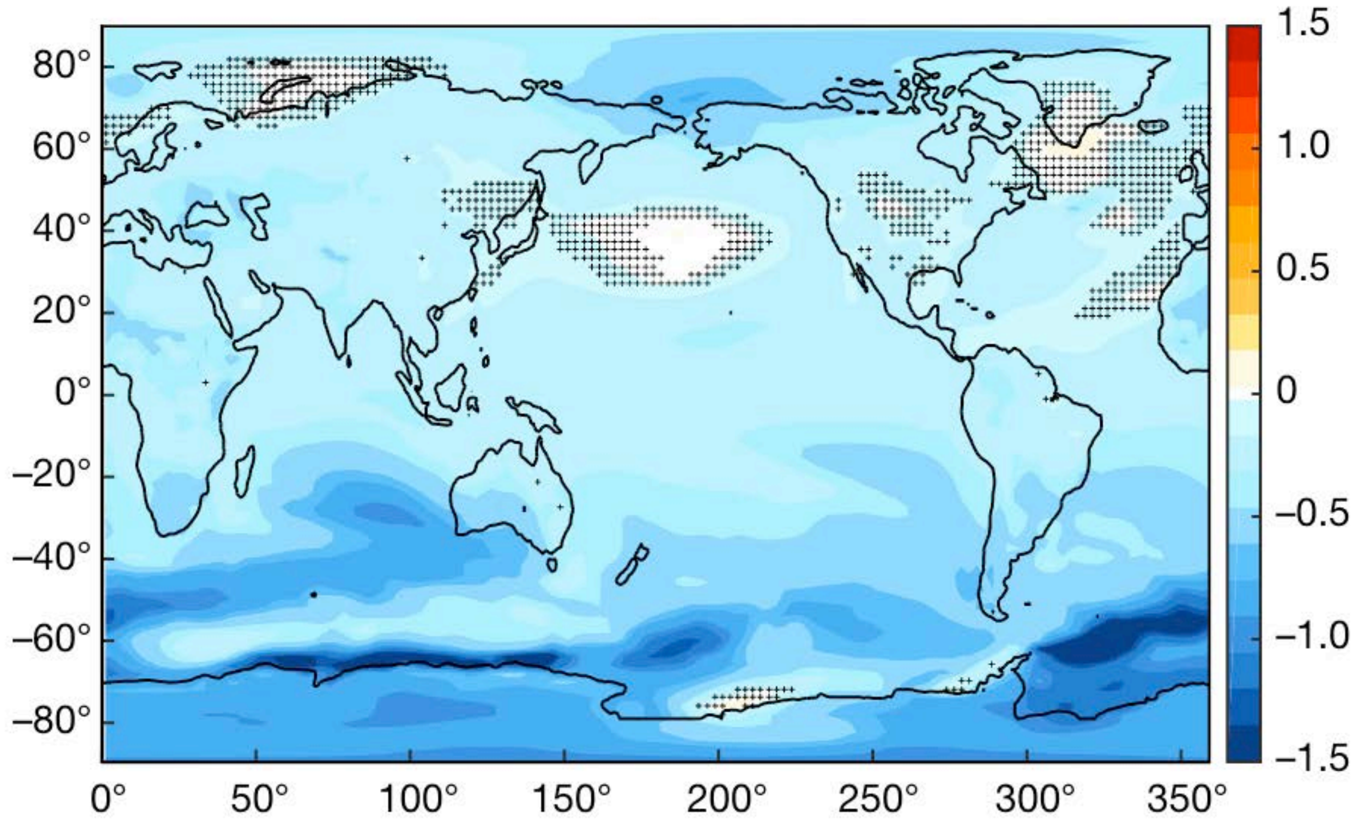
England et al. (2021)

Impacts of projected Antarctic meltwater input

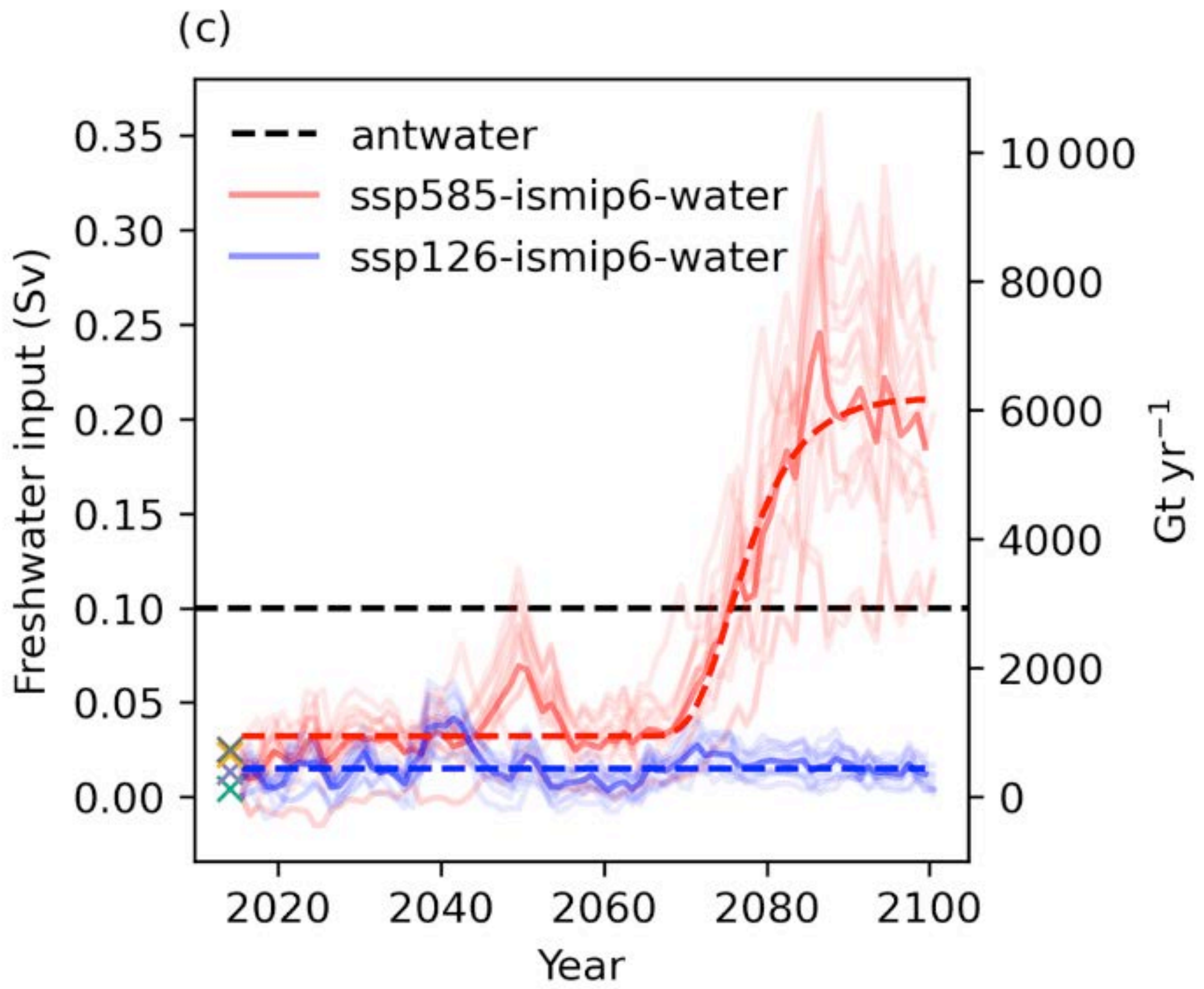
Southern Ocean Freshwater Input from Antarctica (SOFIA)



Meltwater-induced surface temperature anomaly



Bronselaer et al. (2018)



SOFIA forcing scenarios

Swart et al. (2023)

Summary: non-local impacts of SO and Antarctic changes

Observed and projected changes in the SO and Antarctica are weaker than (and sometimes opposite to) Arctic changes

- Southern Ocean surface cooling in recent decades can partially contribute to the observed tropical Pacific cooling
- Antarctic sea ice loss can lead to warming that reaches the Arctic
- Antarctic meltwater can induce extensive cooling and northward circulation shift

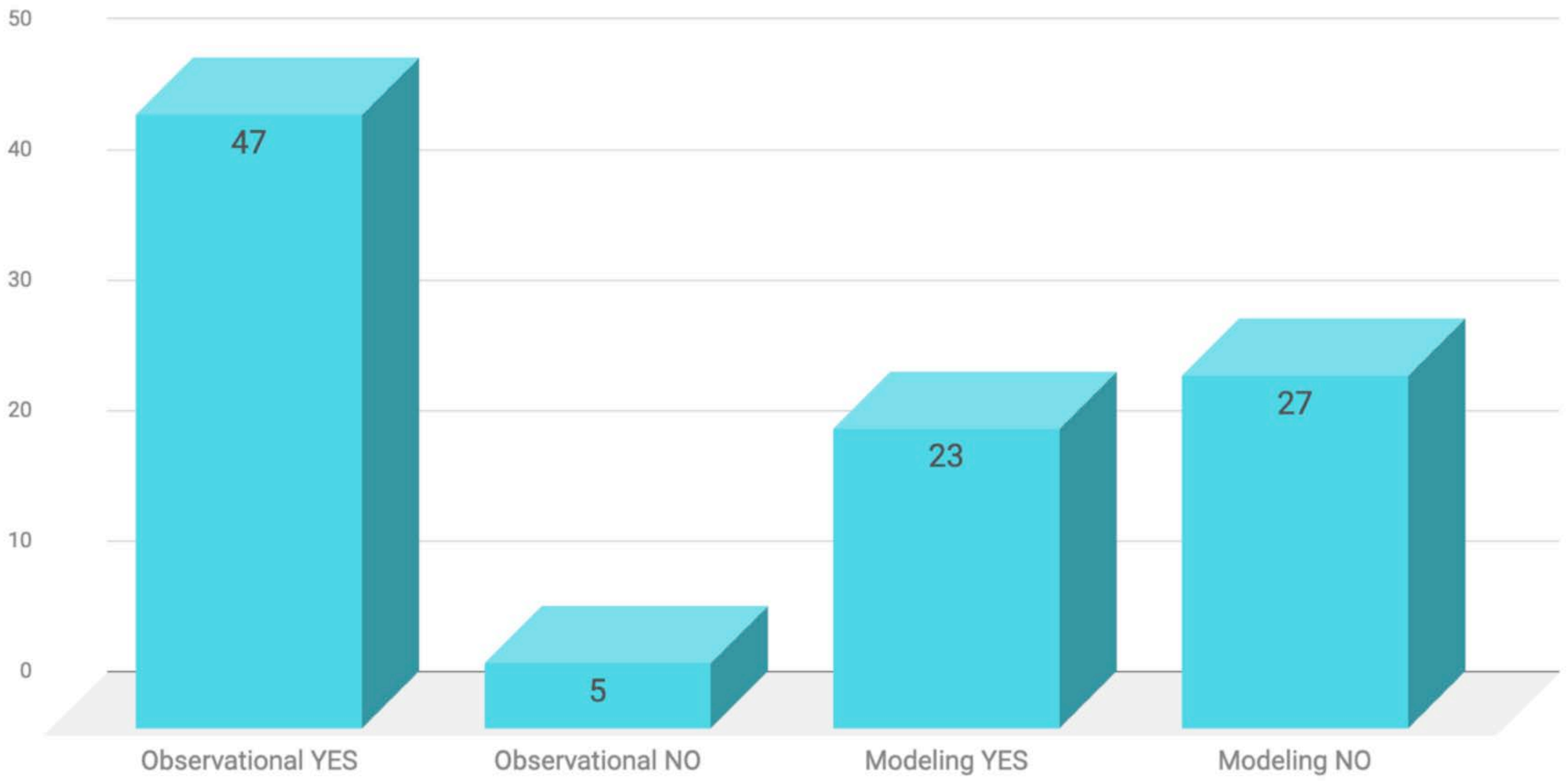
SOFIA
Southern Ocean Freshwater Input from Antarctica
Initiative

Exciting opportunities ahead to quantify the remote impact of Antarctic climate change

Additional slides

Arctic/midlatitude weather linkages

Number of studies on the link between Arctic amplification and increased severe winter weather as of 2020…

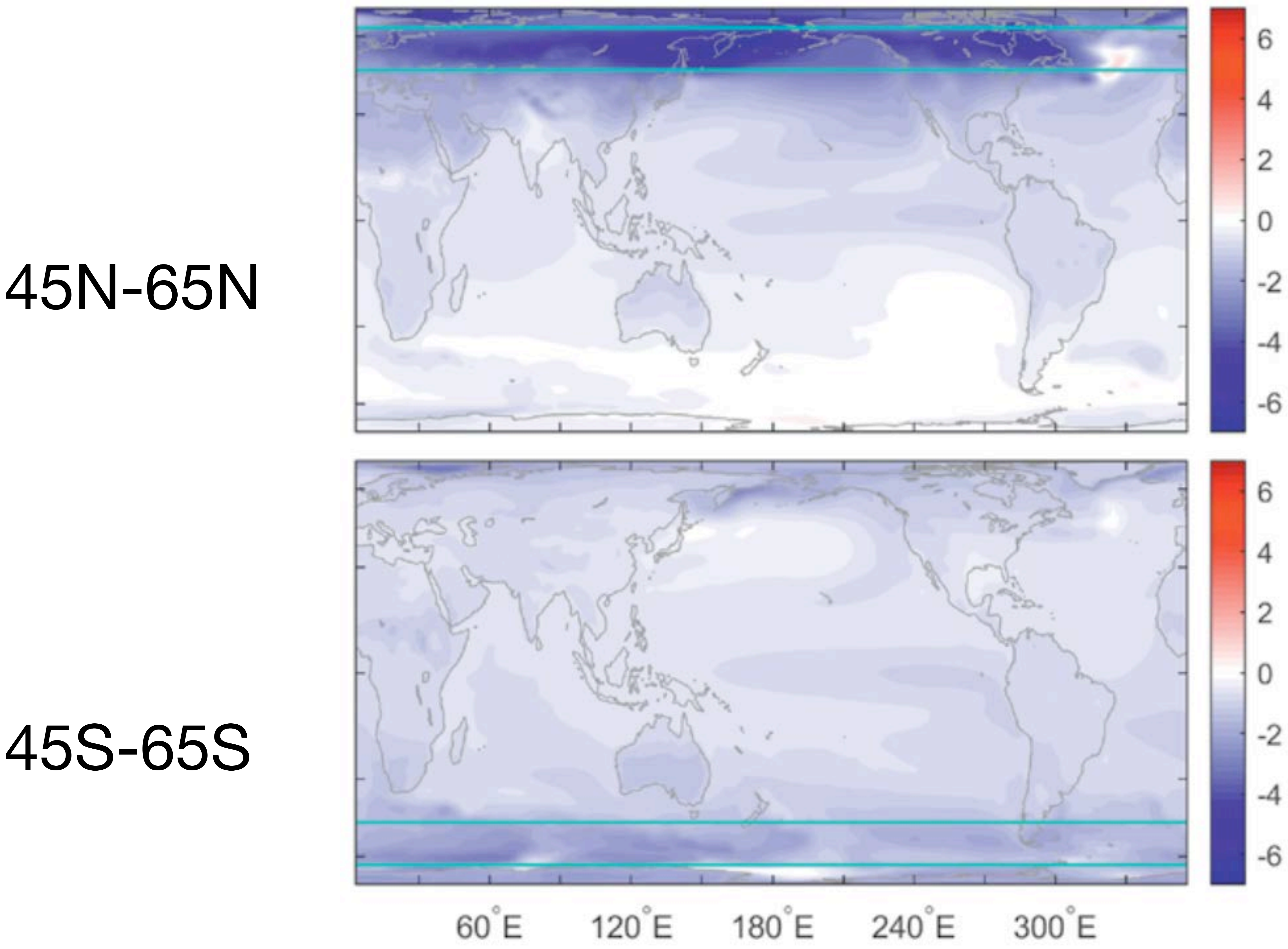


Cohen et al. (2020)

> "…there is *low to medium confidence* in the exact role and quantitative effect of historical Arctic warming and sea ice loss on mid-latitude atmospheric variability."
>
> – IPCC AR6 WG1 Ch10

Asymmetric response to extratropical forcing

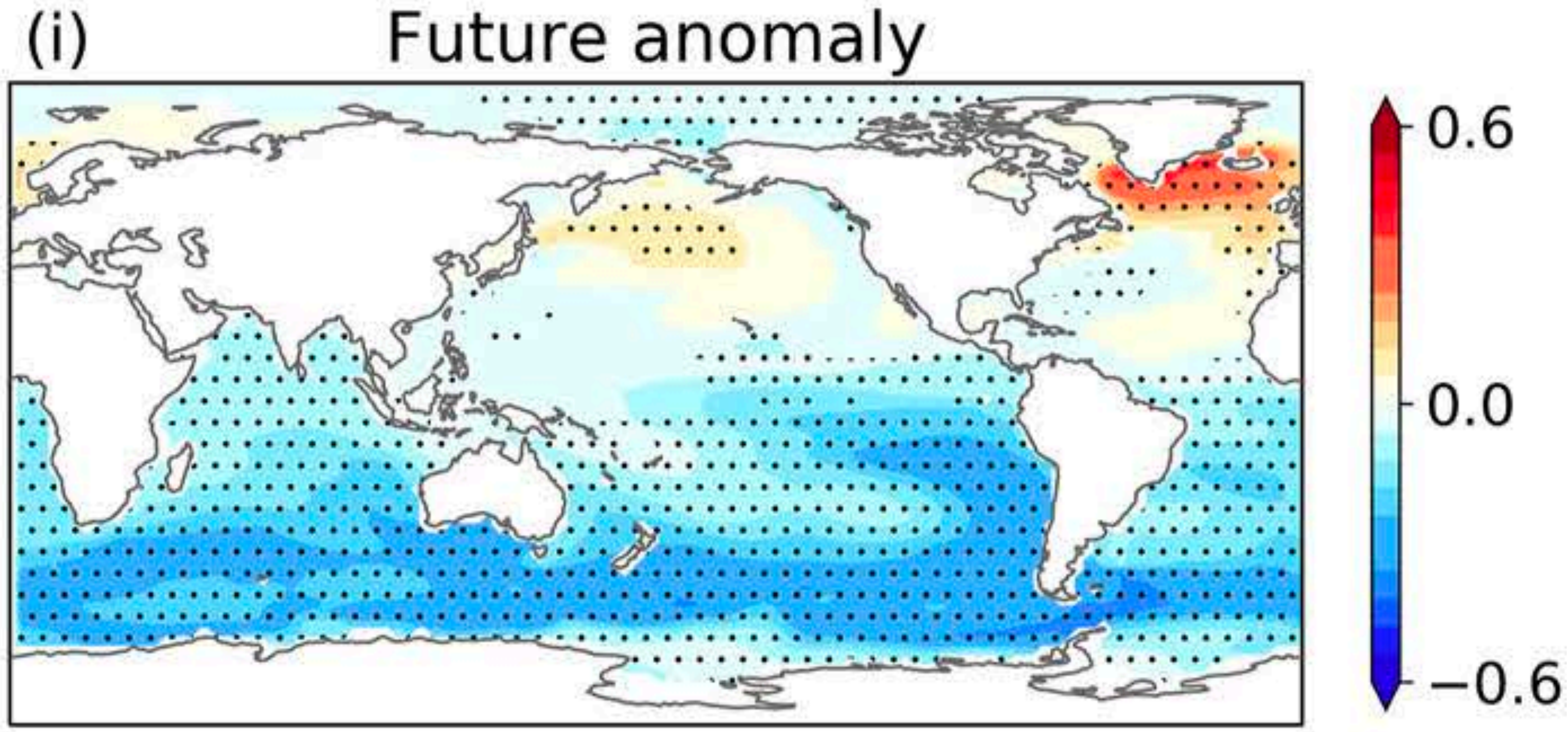
ETIN-MIP idealized experiment

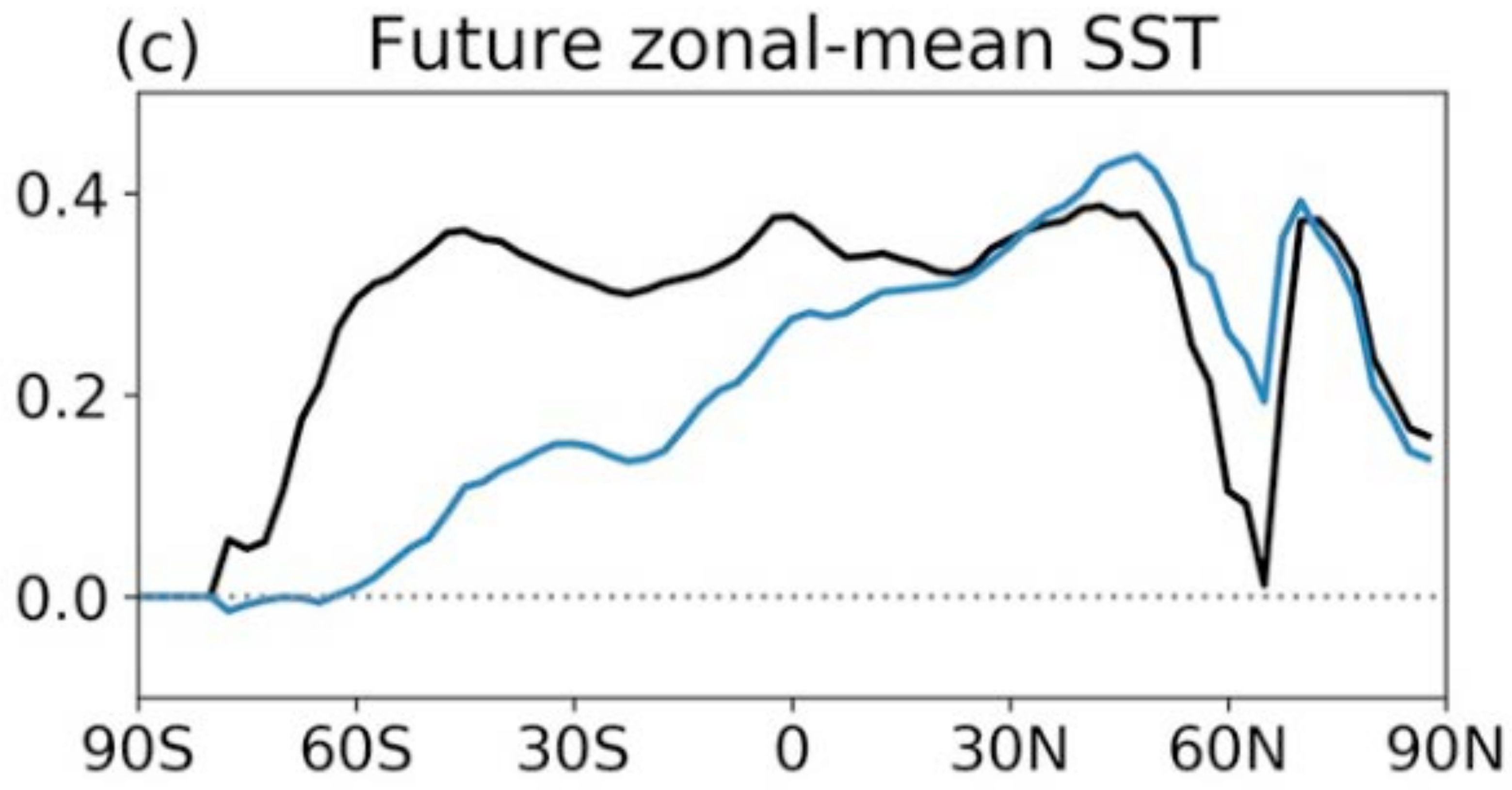


Southern extratropical forcing induces cooling that reaches the Arctic, while the impact of northern extratropical forcing only reaches SH subtropics.

Kang et al. (2019)

Antarctic meltwater leads to cooling in a coupled model





CESM1 shows meltwater-induced cooling trend (2006–2100) throughout SH and slight warming trend in NH midlatitude ocean.

Dong et al. (2022);
see also Bronselaer et al. (2018); Golledge et al. (2019); Sadai et al. (2020);