Ocean heat transport as a driver of sea ice extent in CMIP6 models

EGU General Assembly

CR4.3 / EGU21-2170

University of Reading

Scenario DOCTORAL TRAINING PARTNERSHIP

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Summary of key points:

1. Sea ice extent is anticorrelated with Ocean Heat Transport (OHT) ⇨
2. **Northern hemisphere:** increased OHT converges mainly near the Atlantic ice edge ⇨
3. **Southern hemisphere:** increased OHT converges uniformly under the Antarctic ice pack ⇨
4. The different hemisphere behaviours are robust across models ⇨
5. Our results suggest ocean biases could contribute substantially to sea ice projection uncertainty ⇨

1. Sea ice decreases with OHT

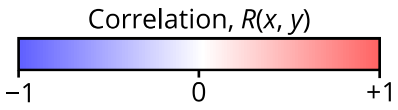
- CMIP6 pre-industrial control simulations
  - → correlations (R) based on **25 year means**
- Quantify sea ice cover with zonal-mean **latitude of the ice edge, ϕ_i**
  - → we verified this is effectively interchangeable with sea ice extent
- Increased OHT ⇔ ϕ_i shifts poleward

  (i.e. sea ice extent decreases)
- Opposite correlation with atmospheric heat transport (AHT)
  - → consequence of Bjerknes compensation
  - → oceanic component more important on these timescales

Table 1: Bold values are significant correlations at 95% confidence.

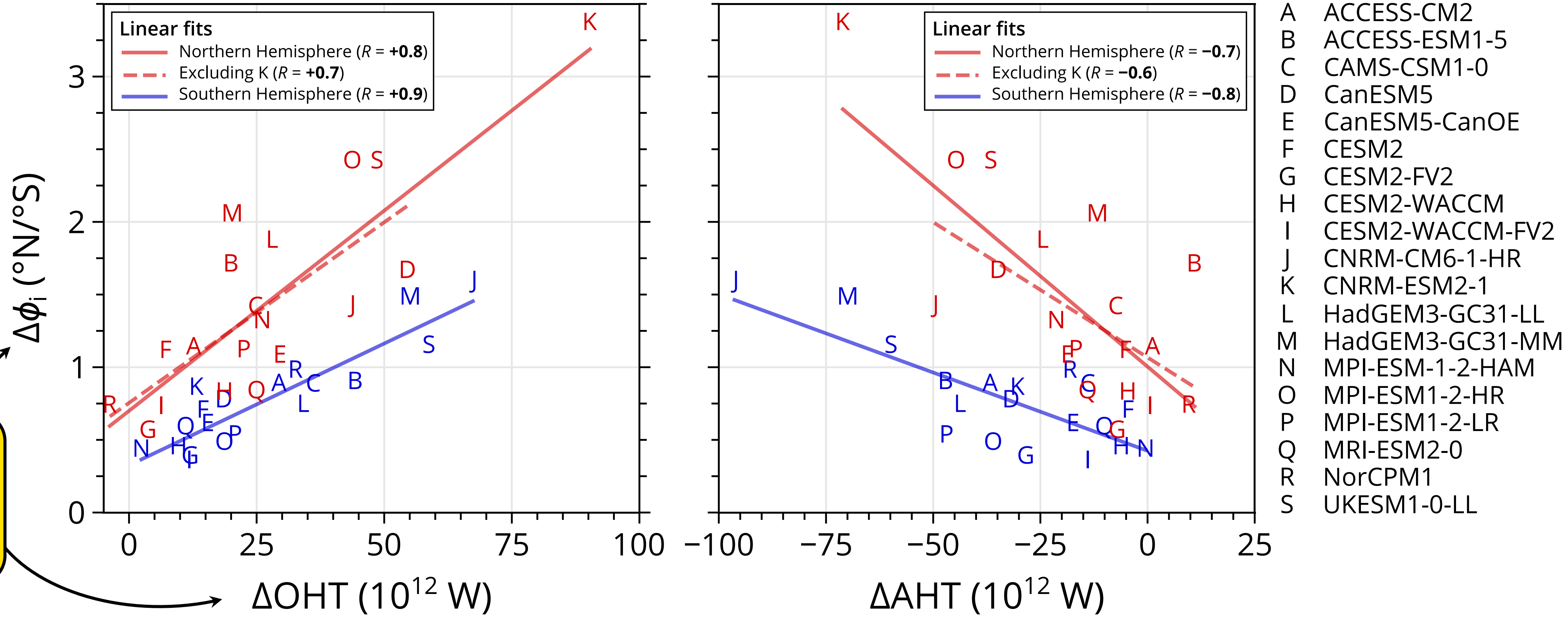
Model	Northern Hemisphere R(OHT, ϕ_i)	Northern Hemisphere R(AHT, ϕ_i)	Southern Hemisphere R(OHT, ϕ_i)	Southern Hemisphere R(AHT, ϕ_i)
ACCESS-CM2	**+0.86**	**−0.75**	**+0.88**	**−0.74**
ACCESS-ESM1-5	**+0.94**	**−0.58**	**+0.84**	**−0.83**
CAMS-CSM1-0	**+0.89**	**−0.49**	**+0.94**	**−0.75**
CanESM5	**+0.88**	**−0.71**	**+0.90**	**−0.93**
CanESM5-CanOE	**+0.91**	**−0.70**	**+0.92**	**−0.95**
CESM2	**+0.73**	**−0.67**	**+0.83**	**−0.54**
CESM2-FV2	**+0.59**	−0.15	**+0.65**	**−0.75**
CESM2-WACCM	**+0.55**	**−0.38**	**+0.90**	**−0.65**
CESM2-WACCM-FV2	**+0.82**	+0.19	**+0.73**	**−0.66**
CNRM-CM6-1-HR	**+0.98**	**−0.83**	**+0.99**	**−0.97**
CNRM-ESM2-1	**+0.98**	**−0.96**	**+0.67**	**−0.71**
HadGEM3-GC31-LL	**+0.84**	**−0.74**	**+0.89**	**−0.80**
HadGEM3-GC31-MM	**+0.94**	**−0.61**	**+0.96**	**−0.96**
MPI-ESM-1-2-HAM	**+0.69**	**−0.56**	**+0.49**	**−0.48**
MPI-ESM1-2-HR	**+0.90**	**−0.84**	**+0.71**	**−0.80**
MPI-ESM1-2-LR	**+0.77**	**−0.58**	**+0.51**	**−0.52**
MRI-ESM2-0	**+0.72**	**−0.32**	**+0.88**	**−0.84**
NorCPM1	**+0.59**	**−0.46**	**+0.96**	**−0.89**
UKESM1-0-LL	**+0.89**	**−0.79**	**+0.88**	**−0.86**

NB: Sign convention
Throughout: OHT/AHT are **poleward** in both hemispheres; and ϕ_i is in **°N** (northern hemisphere) or **°S** (southern hemisphere), so that **each hemisphere may be interpreted symmetrically**



1. Sea ice is strongly correlated with OHT

- Models with greater OHT variations (ΔOHT) have larger sea ice variations ($\Delta\phi_i$):



$\Delta\phi_i = \max(\phi_i) - \min(\phi_i)$

then ΔOHT is the corresponding change in poleward OHT

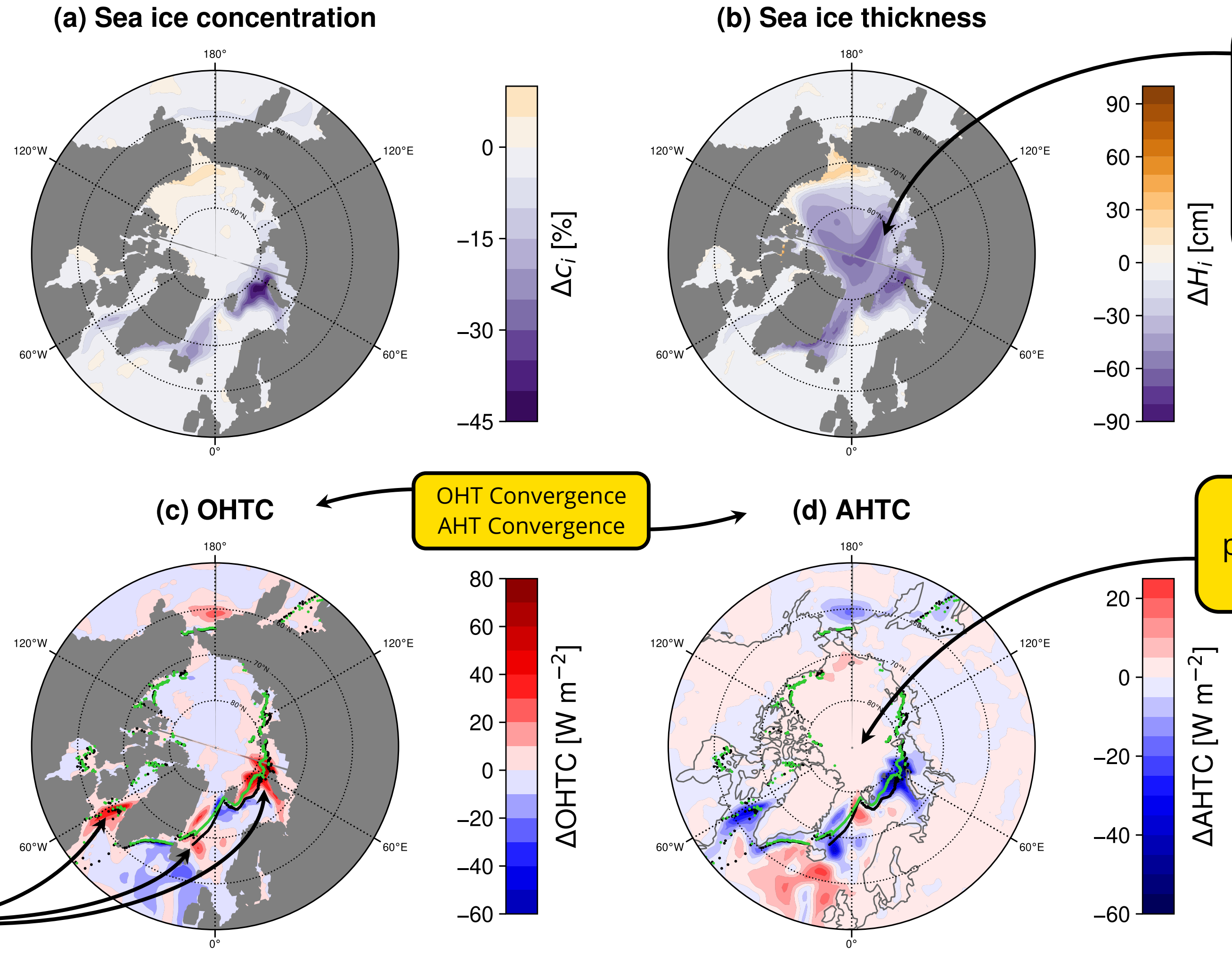
Figure 1

2. What processes underly the Arctic OHT–ϕ_i relationship?

- Difference between maximum and minimum 25 year mean sea ice states

  → HadGEM3-GC31-LL shown here for example

  → Other models behave similarly



Substantial ice thinning, despite ΔOHTC ~ 0 in central Arctic

⇒ ΔH_i driven by increased AHTC

OHT Convergence
AHT Convergence

ΔAHTC weakly positive (~ few W m^{-2}) over central Arctic

Greatest shifts in ice edge where ΔOHTC is largest in the Atlantic sector

- ice edge (maximum extent)
- ice edge (minimum extent)

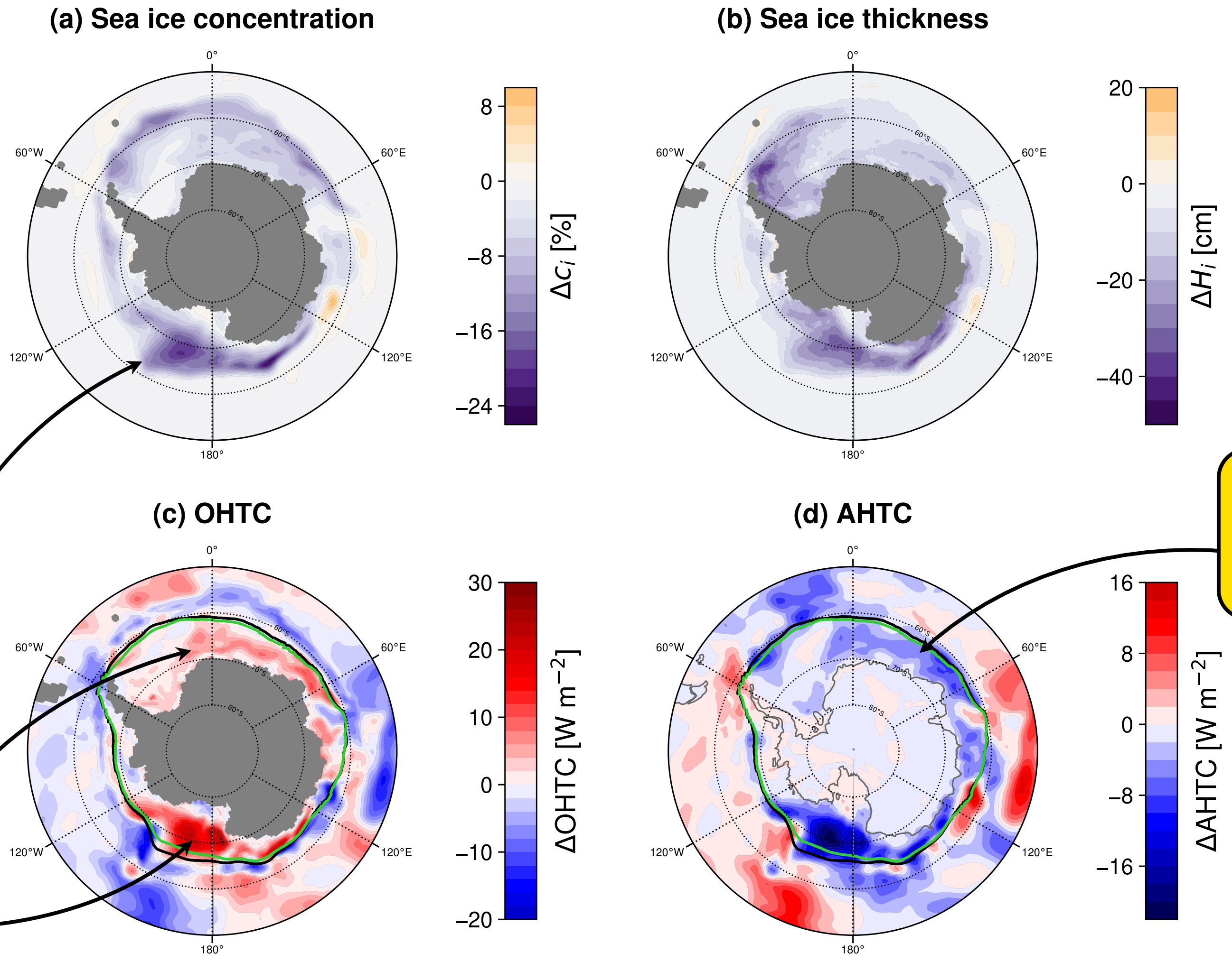
Figure 2

3. What processes underly the Antarctic OHT–ϕ_i relationship?

- Difference between maximum and minimum 25 year mean sea ice states

  → HadGEM3-GC31-LL shown here for example

  → Other models behave similarly



Reduction in concentration roughly follows ΔOHTC

OHTC increases by several W m^{-2} under sea ice, relatively uniformly

AHTC (≈ net downward surface flux) decreases over sea ice

- ice edge (maximum extent)
- ice edge (minimum extent)

Figure 3

4. Robustness across models

A	ACCESS-CM2	F	CESM2	K	CNRM-ESM2-1	P	MPI-ESM1-2-LR
B	ACCESS-ESM1-5	G	CESM2-FV2	L	HadGEM3-GC31-LL	Q	MRI-ESM2-0
C	CAMS-CSM1-0	H	CESM2-WACCM	M	HadGEM3-GC31-MM	R	NorCPM1
D	CanESM5	I	CESM2-WACCM-FV2	N	MPI-ESM-1-2-HAM	S	UKESM1-0-LL
E	CanESM5-CanOE	J	CNRM-CM6-1-HR	O	MPI-ESM1-2-HR		

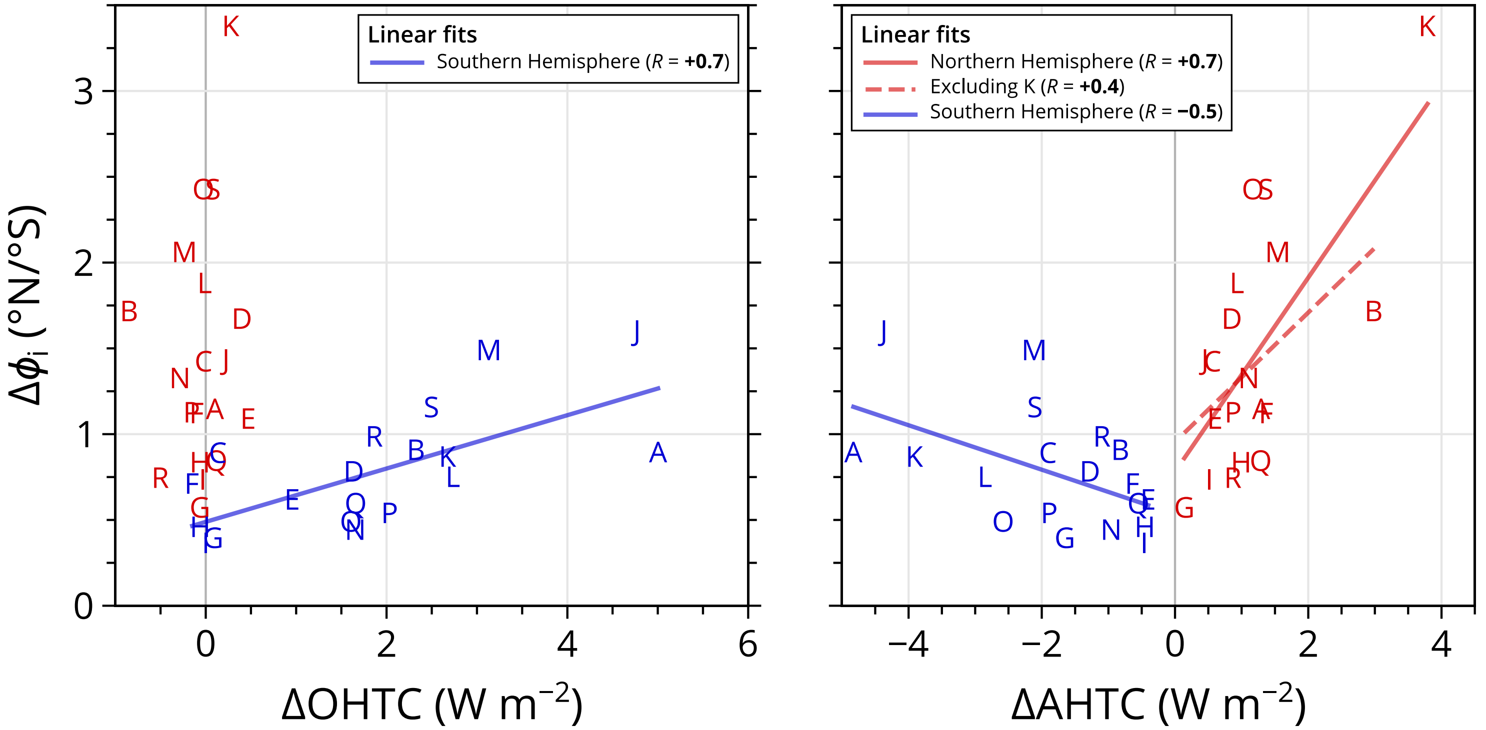


Figure 4

Averaged over sea ice

- **In the Arctic:** increased OHT is mainly lost near the ice edge
  - → OHTC under sea ice does not change much (Fig. 4 left)
  - → Second effect: increased pan-Arctic AHTC and associated thinning

- **In the Antarctic:** increased OHT mainly converges under sea ice and drives basal melt

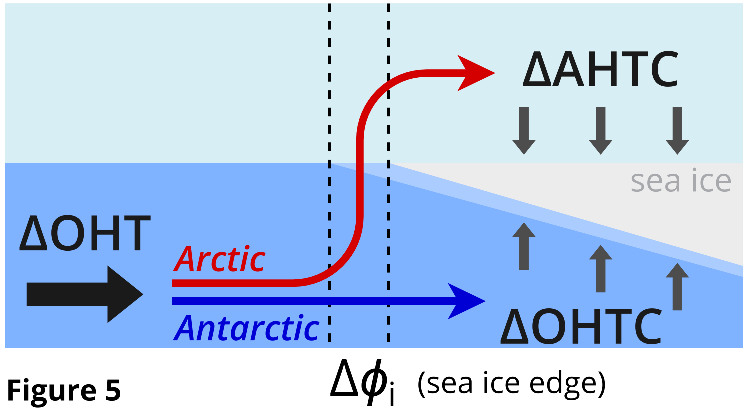


Figure 5

5. Implications for climate projections

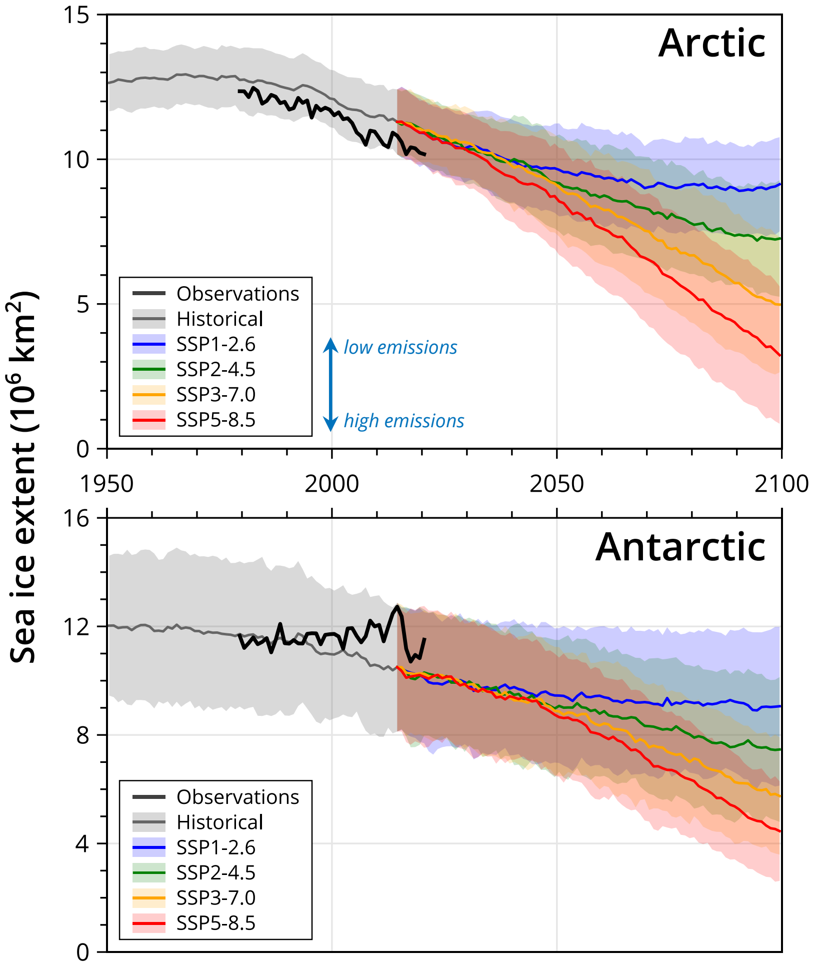


Figure 6: CMIP6 projections of sea ice extent (annual mean) under four emission scenarios (each line: multi-model mean of ensemble means of 15 models; shading indicates one standard deviation). Observations from NSIDC.

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- Latest generation models exhibit intermodel spread in future projections (Fig. 6)
  - → e.g. size of spread is comparable to differences in emission scenario means
- Our results suggest ocean biases could contribute to sea ice projection uncertainty
  - → future work will investigate links between projected rates of sea ice loss and simulated OHT biases (Fig. 7)

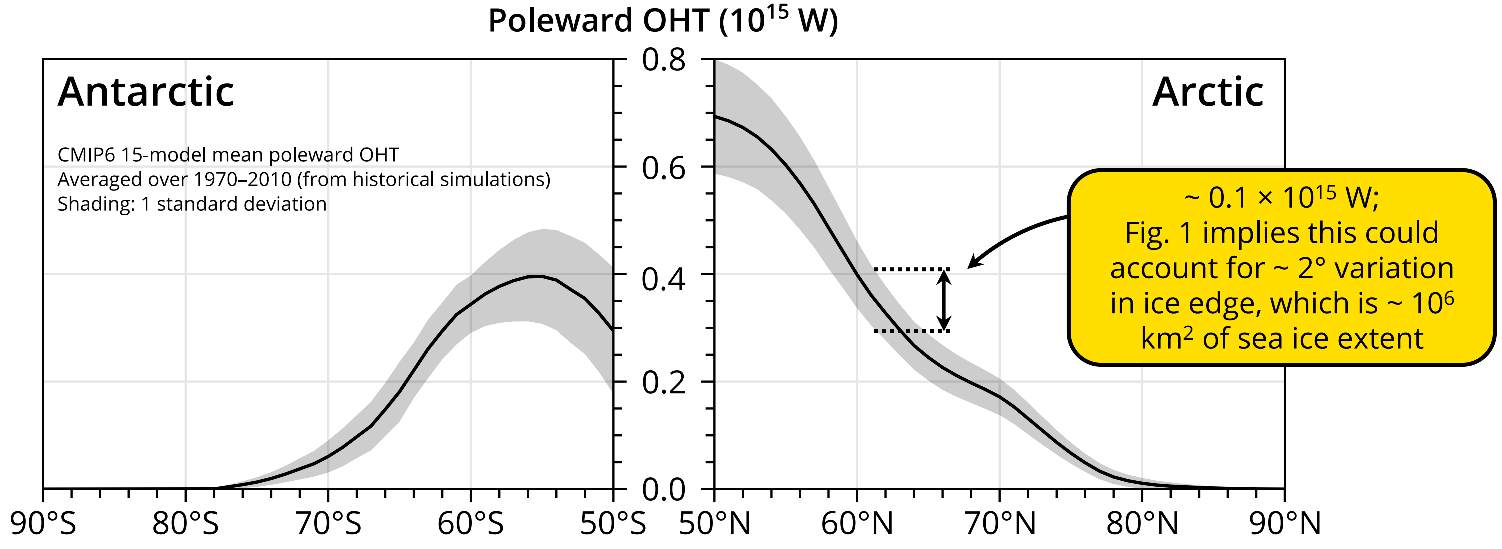

Figure 7: OHT in historical simulations of CMIP6 models (same set as in Fig. 6).