

Explaining the Intermodel Spread in CMIP5 Arctic Surface Temperature Projections

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Conclusions

The Barents Sea is an important regulator of Arctic climate change

The role of surface turbulent fluxes and the seasonality in ocean heat storage in the Barents Sea is important to model-simulated Arctic Amplification

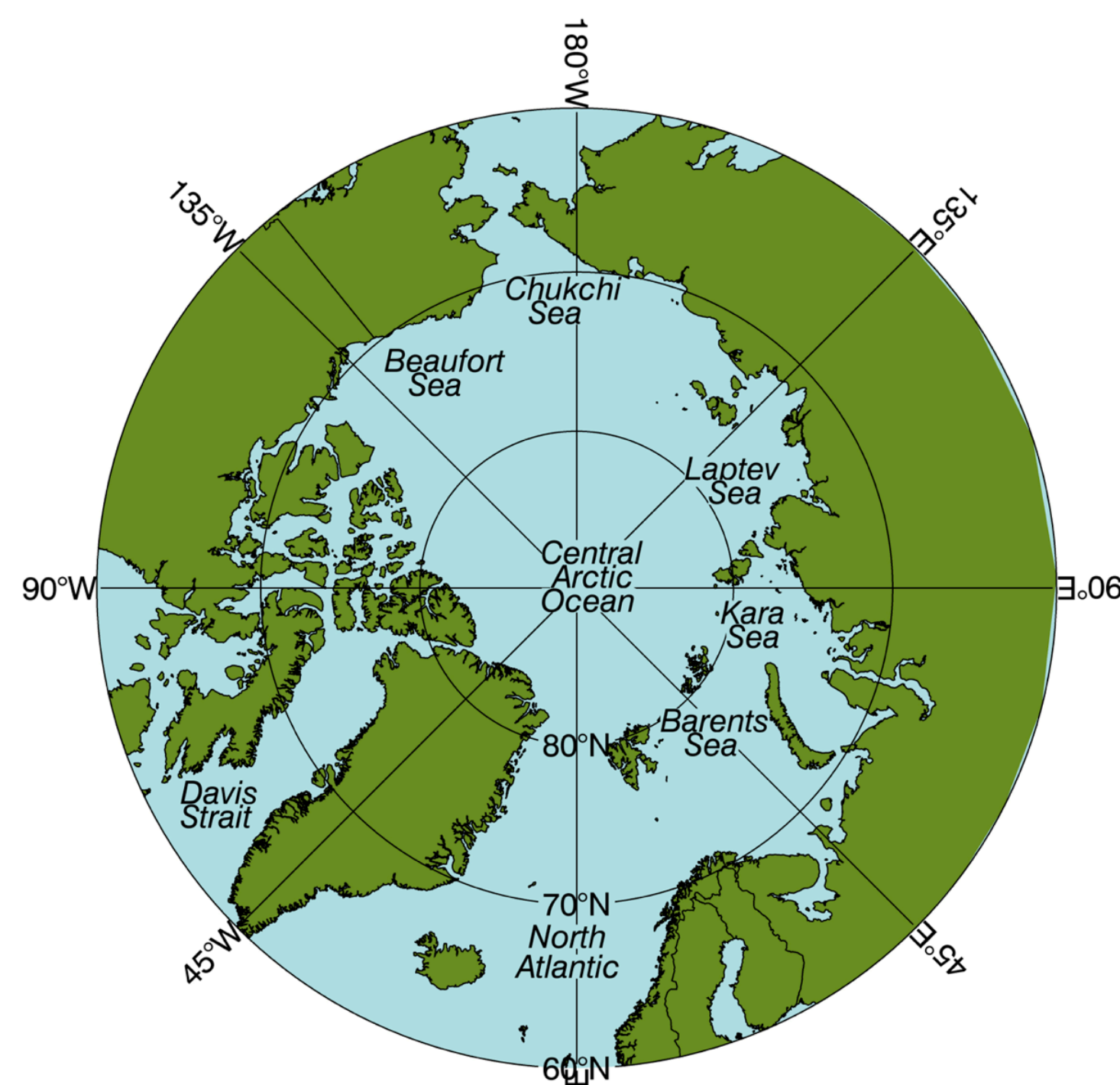
The intermodel spread in Arctic surface temperature projections is more strongly controlled by the cooling of the surface by S+L rather than the surface albedo feedback

We speculate that event-driven forcings (e.g. storms tracks, cold-air outbreaks, atmospheric moisture intrusions) will effect the model spread in surface turbulent fluxes and hence Arctic Amplification

Methods

Surface Energy Budget Decomposition

Calculate partial temperature contributions from individual feedbacks by perturbing the surface energy balance equation. Analysis performed seasonally and spatially



We derive the following Partial Temperature Changes (PTCs) for the following feedbacks:

FEEDBACK	PTC (K)	ANNUAL MEAN (K)
Surface Albedo Feedback (SAF)	$\frac{-(\Delta\alpha)(\overline{S} \downarrow + \Delta S \downarrow)}{4\sigma T_s^3}$	1.97 ± 0.79
Cloud Forcing (CRE)	$\frac{(1-\alpha)\Delta S \downarrow_{CLD} + \Delta F \downarrow_{CLD}}{4\sigma T_s^3}$	0.25 ± 0.78
non-SAF shortwave clear-sky feedbacks	$\frac{(1-\alpha)\Delta S \downarrow_{CLR}}{4\sigma T_s^3}$	-0.5 ± 0.28
Longwave clear-sky feedbacks (LWCS)	$\frac{\Delta F \downarrow_{CLR}}{4\sigma T_s^3}$	7.12 ± 1.2
Change in ocean heat storage (HSTOR)	$\frac{-\Delta Q}{4\sigma T_s^3}$	0.32 ± 1.2
Change in latent and sensible heat fluxes (HFLUX)	$\frac{-\Delta(S+L)}{4\sigma T_s^3}$	-1.4 ± 0.71

How to interpret:

PTCs represent the temperature contribution of the corresponding feedback to the total Arctic temperature change from present-day to 2100

Sum of all PTCs is equal to the total Arctic ΔT_s of 7.86 K

LWCS includes the effects of CO₂, temperature, and water vapor feedbacks

HSTOR includes heat storage of ocean and land plus ocean transport

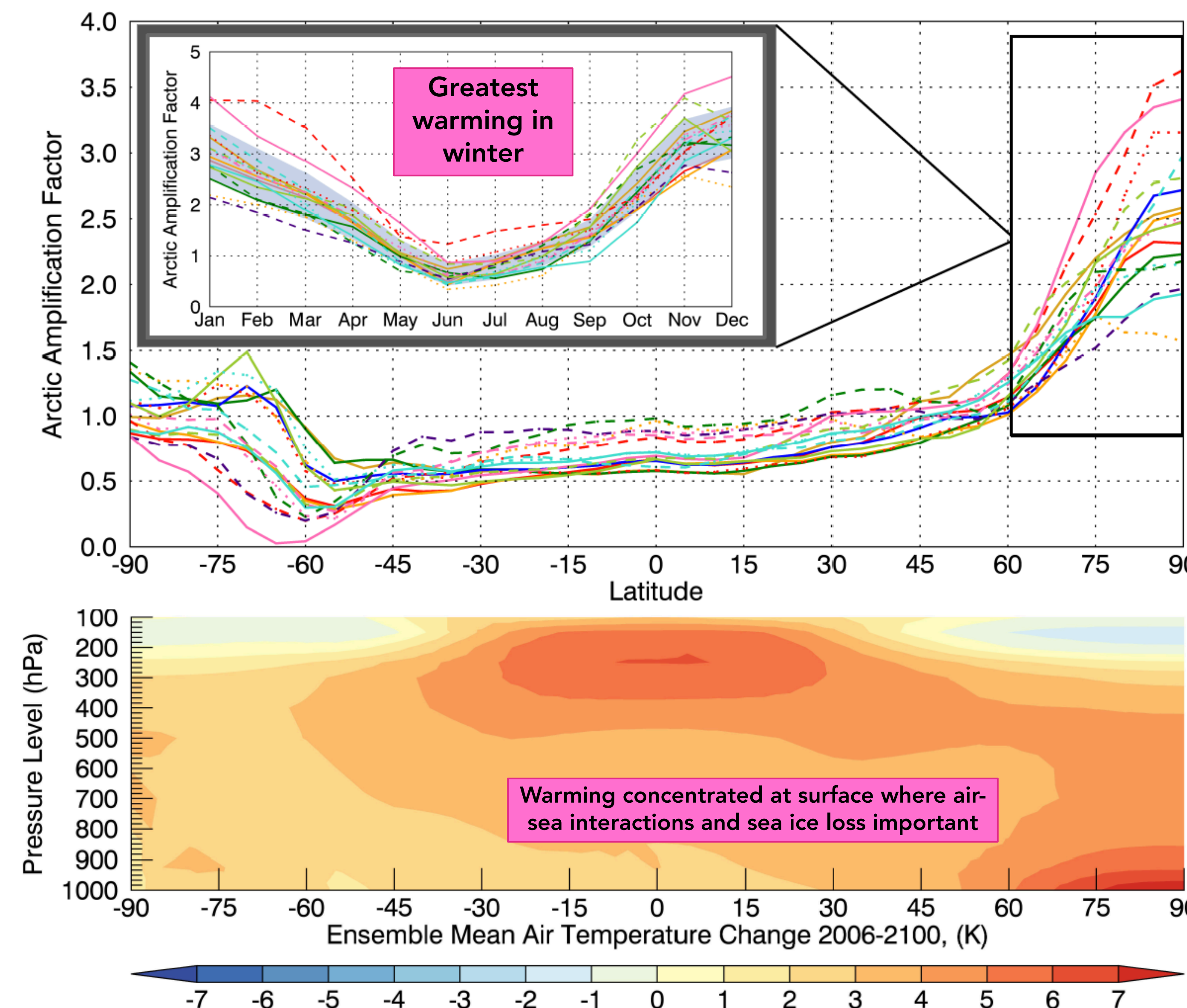
Arctic Amplification Index (AAI)

To assess the degree to which each of these feedbacks amplify Arctic warming, Arctic Amplification Index (AAI) is calculated:

$$AAI_n = \frac{\Delta T_n^{Arctic} - \Delta T_n^{Global}}{\Delta T_{total}^{Global}}$$

Introduction

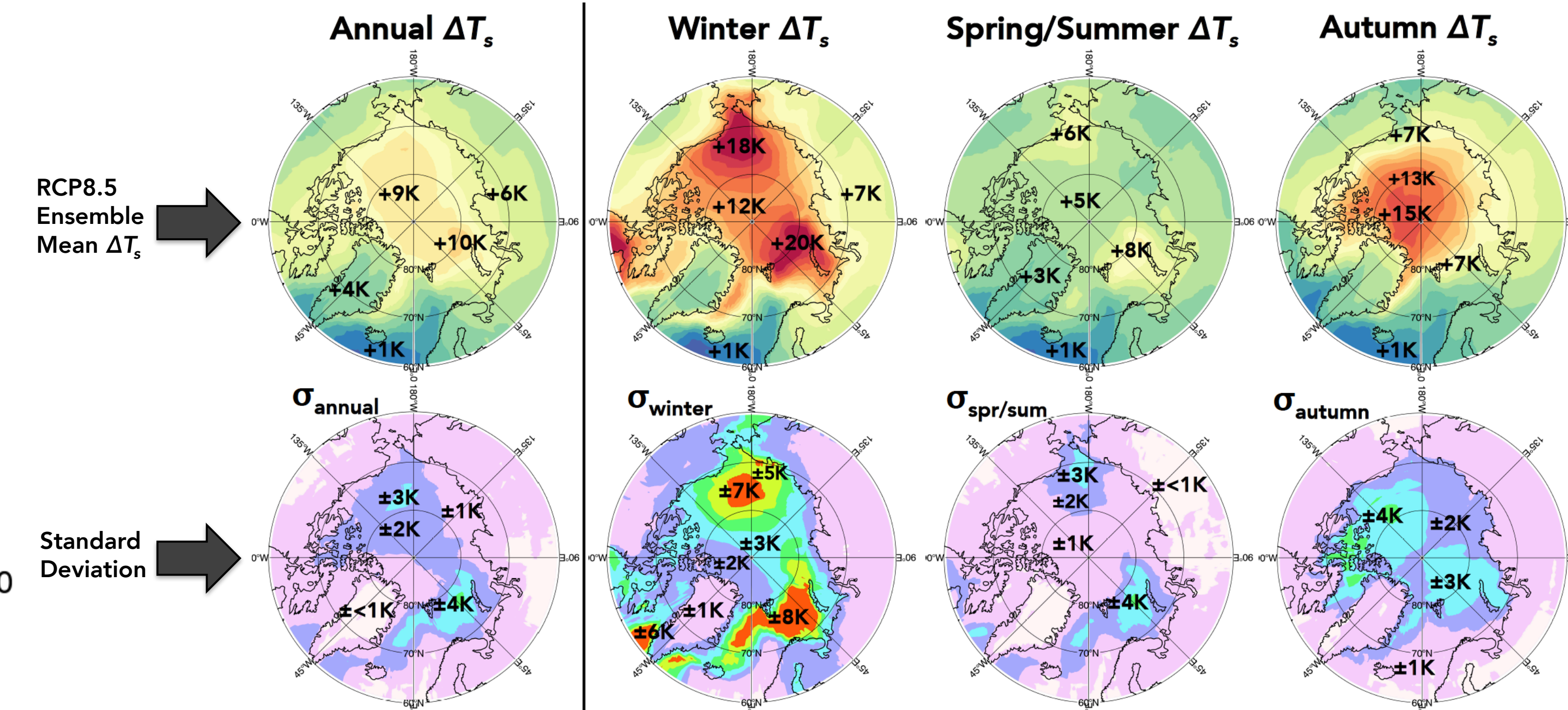
Surface temperature observations over the last century and model simulations show evidence of Arctic Amplification (AA)



**Paris Climate Agreement Goal:
Limit ΔT to 2°C**

**2°C global
temperature change
leads to 3°-7°C
change in the Arctic!**

Regions with the most warming have the most intermodel spread



Several processes have been identified as contributors to amplified Arctic warming:

- Surface albedo feedback
- Temperature feedback
- Cloud changes
- Sea Ice Loss
- Poleward heat transport

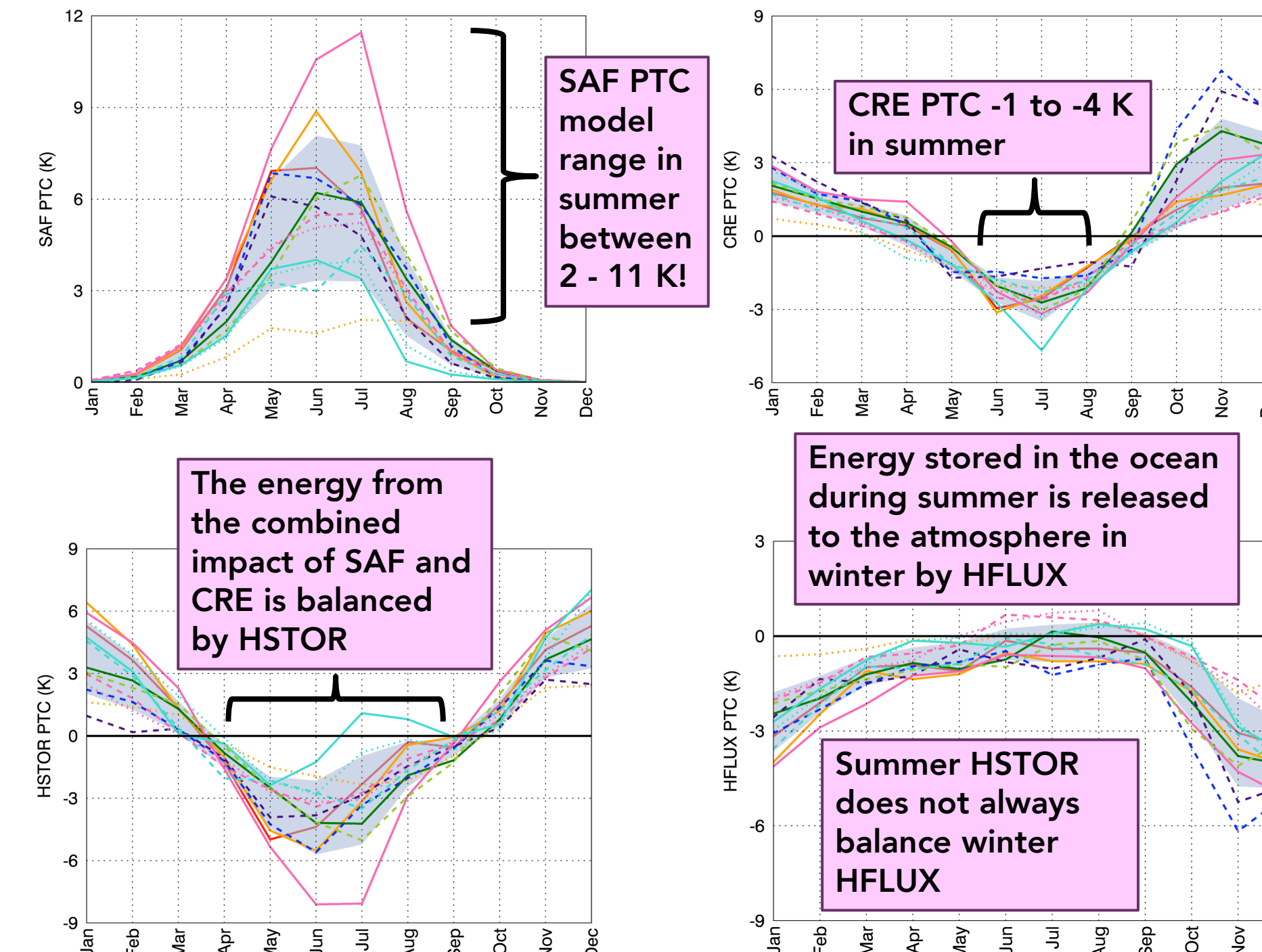
Which of these processes controls the spread of Arctic amplification?

To narrow the uncertainty in our projections, there is a need for a process-oriented study of these feedbacks, their regional variation, and their seasonality

- AA is a seasonal phenomenon- strongest in winter, non-existent in summer
- The feedbacks listed above exhibit strong seasonality
- The spatial patterns of sea ice loss affect the warming response, so there is a need to perform the analysis regionally

Results

Partial Temperature Contributions reveal the fate of summer heat:



Think of Arctic surface energy balance as a battery:

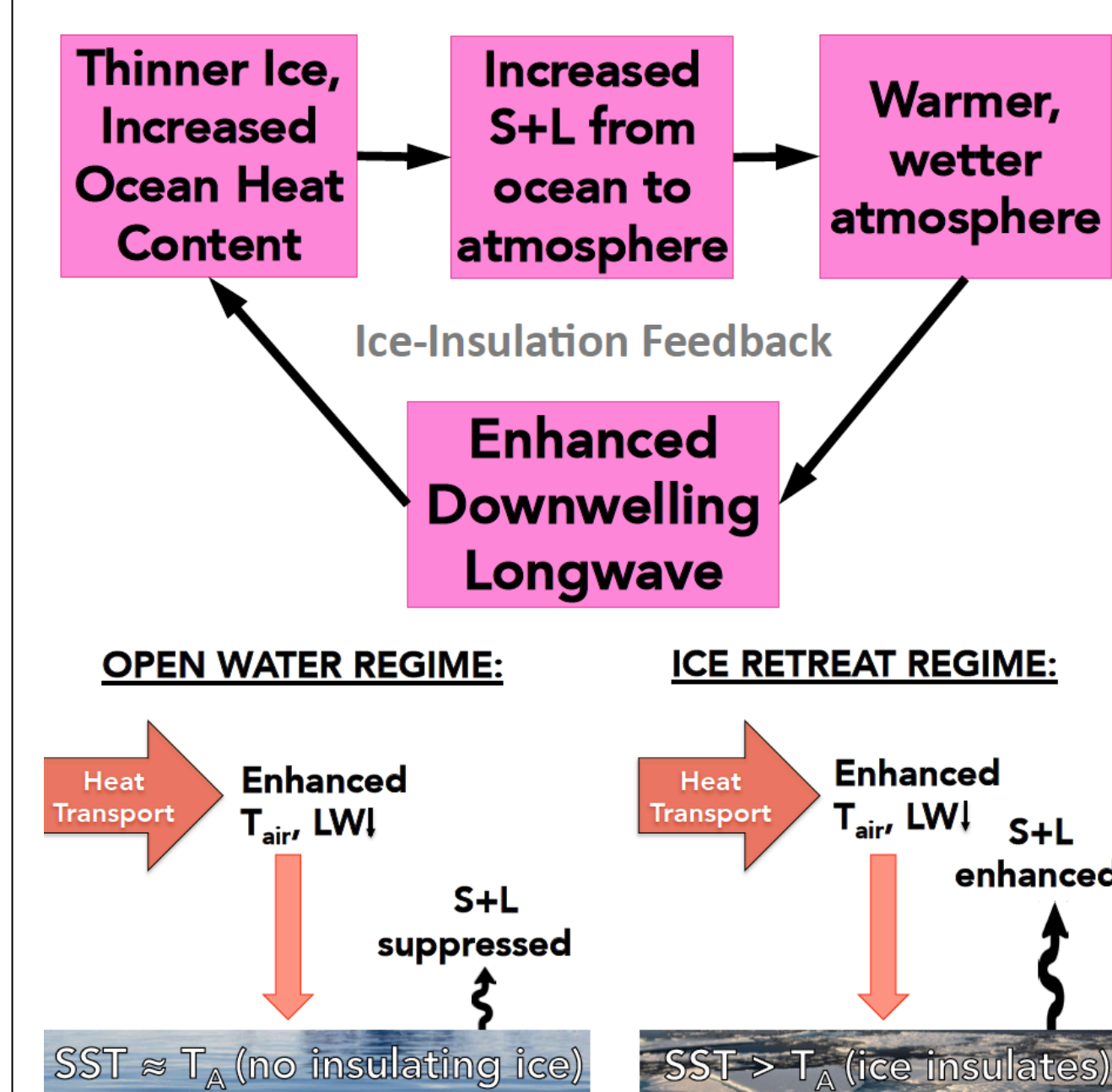
- During summer, the SAF "charges" the battery via ocean storage
- During winter, the battery "discharges" via S+L and LW cooling

Intermodel spread can be a result of either the charging or discharging!

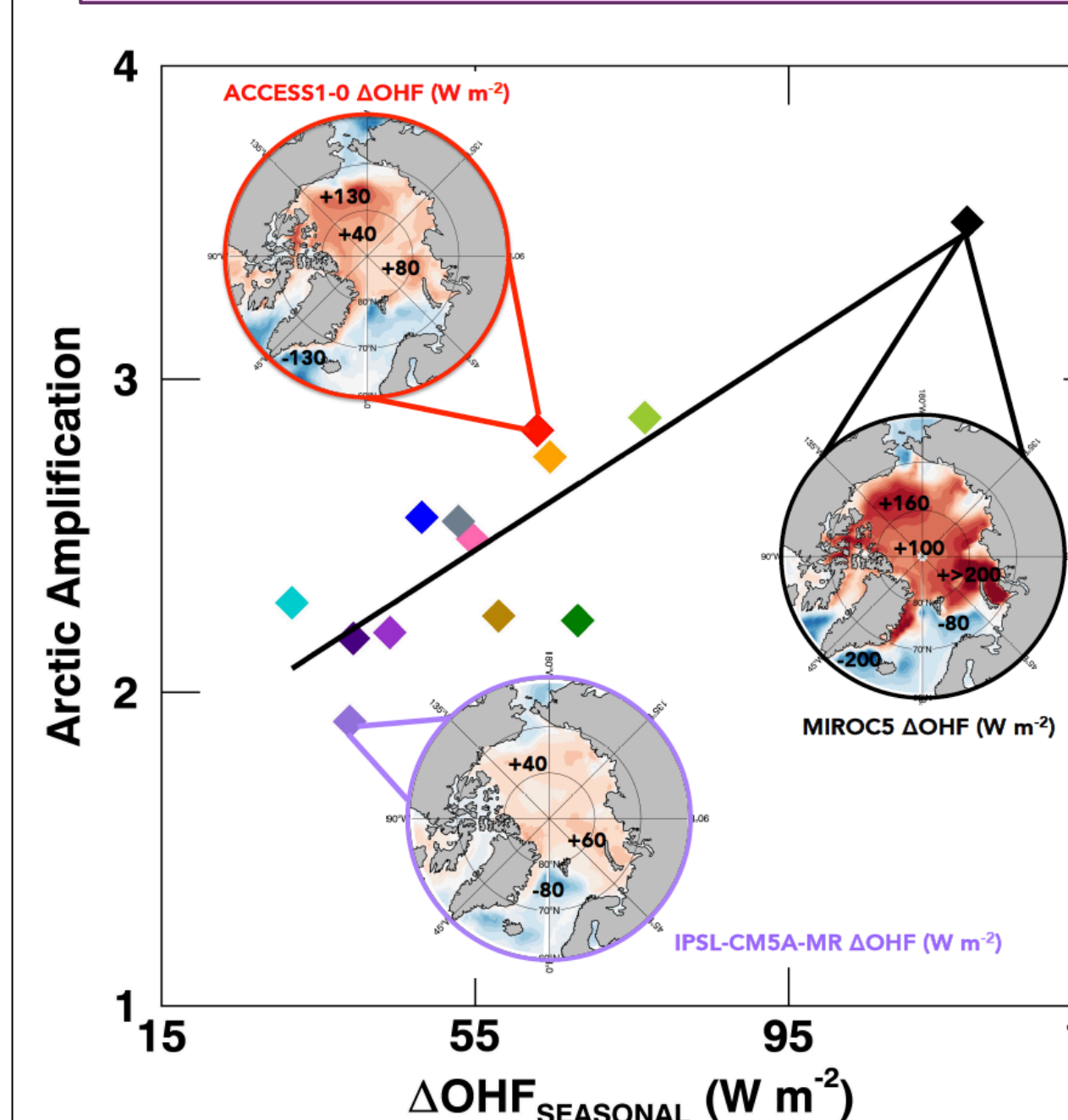
1. While the SAF correlates with AA, its seasonal maximum in summer does not energetically line up with maximum surface warming in winter, therefore cannot directly drive AA
1. While all of the incident summertime radiation is stored in the ocean, this radiation is not completely cooled in fall/winter as surface turbulent fluxes are controlled by the atmospheric conditions and the difference $T_s - T_a$

We find that the limitations on winter surface cooling in ice-retreat regions is responsible for the model spread in AA

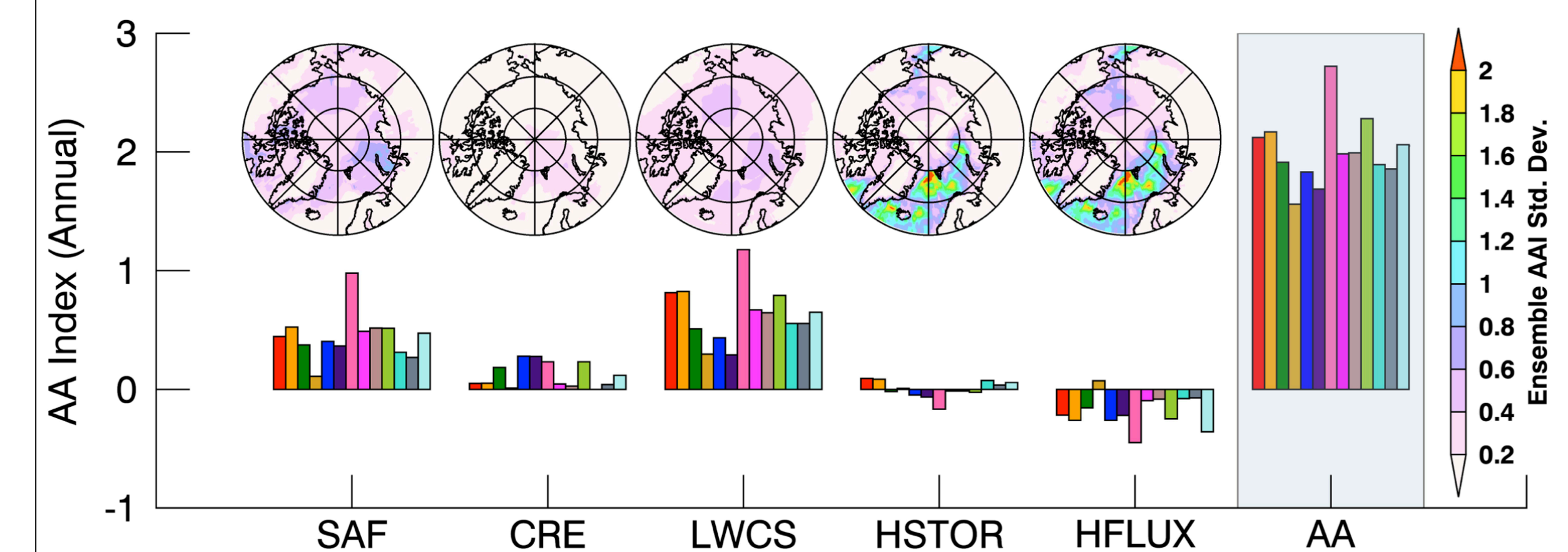
How does the seasonality of ocean heat storage and the S+L response be used to constrain model projections of AA?



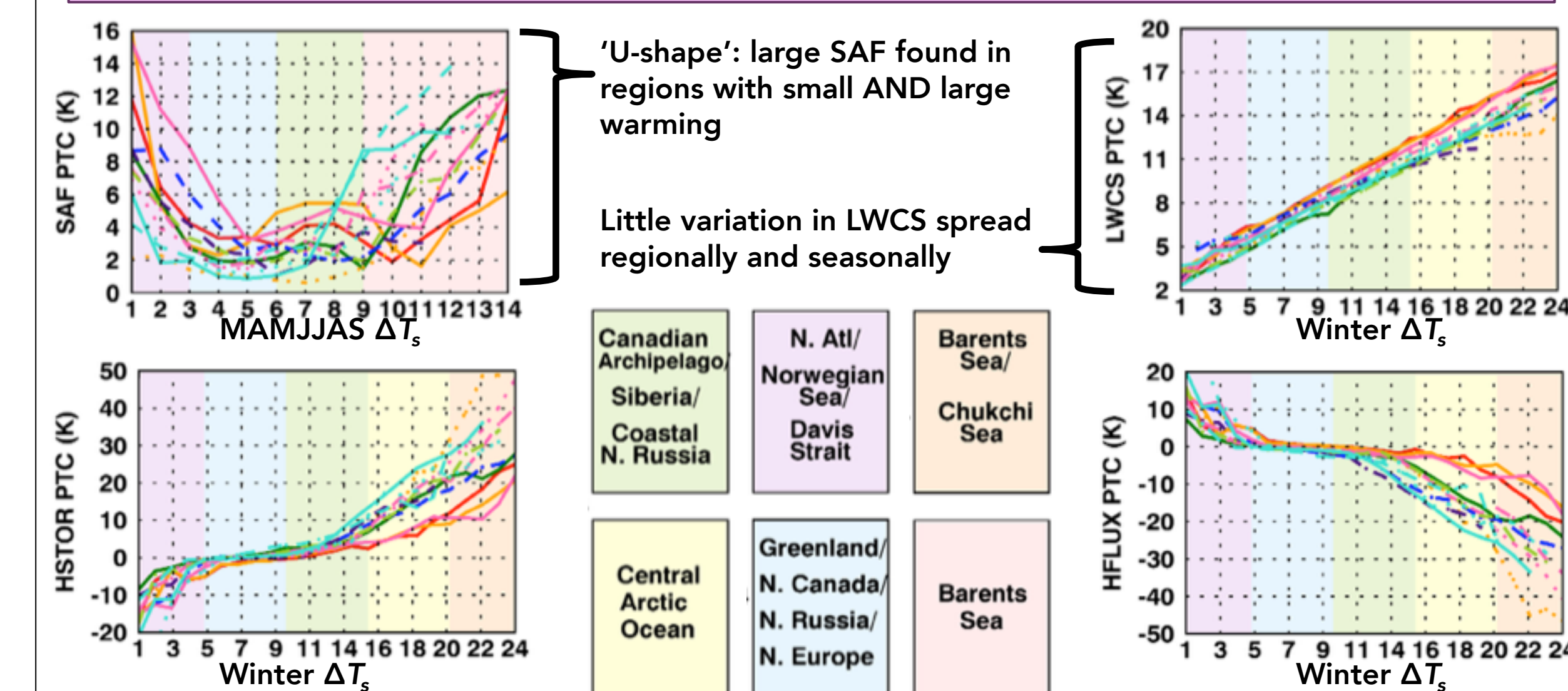
The increase in seasonal ocean heat fluxing (ΔOHF) correlates with model AA ($R = 0.86$)



1. The largest AAI std. dev. found for HSTOR and HFLUX in ice-retreat regions
2. While radiative feedbacks (SAF, CRE, LWCS) heavily influence AA, intermodel spread is controlled by non-radiative feedbacks



HSTOR and HFLUX are better metrics to constrain intermodel spread in Arctic T_e projections than SAF or LWCS



- Increased HFLUX corresponds to more LWCS
- Offsetting behavior between HSTOR and HFLUX- in regions of small ΔT_{sr} , HFLUX cools all heat stored in the ocean. In regions with greater ΔT_{sr} , cooling of the surface by S+L cannot keep up with the increased HSTOR

The largest warming and model spread occurs in HISTOR and HFLUX in the Barents Sea; processes operating in this region that control HISTOR and HFLUX are prime candidates to constrain AA